A Method for Evaluating and Mapping Terrestrial Deposition and Preservation Potential- for Palaeostorm Surge Traces.

Remote Mapping of the Coast of Scania, Blekinge and Halland, in Southern Sweden, with a Field Study at Dalköpinge Ängar, Trelleborg.

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Dissertations in Geology at Lund University,
Master's thesis, no 614
(45 hp/ECTS credits)

Department of Geology

Lund University

2021

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Cover picture: An artistic interpretation of a Storm Surge hitting the church of Skanör, Scania. Figure by Lykke Lundgren Sassner

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Lundgren Sassner, L. 2021: A Method for Evaluating and Mapping Terrestrial Deposition and Preservation Potential- for Palaeostorm Surge Traces. Remote Mapping of the Coast of Scania, Blekinge and Halland, in Southern Sweden, with a Field Study at Dalköpinge Ängar, Trelleborg. *Dissertations in Geology at Lund University, No. 614,* 62 pp. 45 hp (45 ECTS credits) .

Abstract:
Studies of palaeostorm surges provides background into at what frequencies storms of different magnitudes are expected to return and hit different areas. This information can be used when modelling, doing risk assesments and city planing. Using the marine equations of Nittrouer and Sternberg (1981; The formation of sedimentary strata in an allochthonous shelf environment: the Washington continental shelf. Marine Geology 42 : 201-232), a terrestrial model of preservation potential has been made. This has been used along with the important factors, determined by Chaumillon et al. (2017: Storm-induced marine flooding: Lessons from a multidisciplinary approach. Earth-Science Reviews 165. 151-184), for storm surges to remote map areas where there could be palaeostorm surge overwash deposits which should be preserved. The remote mapping was done along the coast of Scania, Blekinge and Halland. During this part of the study 68 locations of sites with potential for preserved palaeostorm surge traces were found. Out of these, 12 areas were further studied to find historical documentation of land use, making sure that the areas have the best possible preservation potential, and to find out the natural conservation status. After the mapping was conducted, Dalköpinge Ängar was chosen as a field study. Here four sediment/peat cores were taken up with a Russian corer and studied. Loss on Ignition was done at the two longest cores; a biological proxy method using the habitat of foraminifers and 14C analysis were done on one core to trace changes in the environment and possible palaeostorm surge overwash deposits. The data from Dalköpinge Ängar showed traces of a storm surge changing the environment dated to sometime prior to 1957-1958 (8% likelihood) or 1990-1993 (92% likelihood). Using documentation in old newspapers, aerial photographs, documentation of old storms in Scania and other documentation available, the deposits could be correlated to a large storm in 1954. The positive result of the field study indicates a good mapping and method of determining areas of well preserved storm surge overwash deposits. This is the first mapping and sedimentary study of palaeostorm surges in Sweden.

Keywords: Storm surge, Storm surge formation, Storm patterns in Baltic Sea, Preservation potential, Terrestrial preservation potential and erosion.

Supervisor(s): Helena Alexanderson (Lund University), Mats Rundgren (Lund University), Anne-Birgitte Nielsen (Lund University) & Bradley Goodfellow (Swedens Geological Survey)

Subject: Quaternary Geology

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En metod för att utvärdera och kartera terrestriell deposition och bevaringspotential- för palaeostormflods sediment.
Fjärrkartering av Skåne, Blekinge och Hallands kust, i södra Sverige, med en fältstudie i Dalköpinge Ängar, Trelleborg

LYKKE LUNDGREN SASSNER

Lundgren Sassner, L., 2019: En metod för att utvärdera och kartera terrestriell deposition och bevaringspotential- för palaeostormflods sediment. Fjärrkartering av Skåne, Blekinge och Hallands kust, i södra Sverige, med en fältstudie i Dalköpinge Ängar, Trelleborg. Ex*amensarbeten i geologi vid Lunds universitet, Nr. 614,* 62 sid. 45 hp.

Abstrakt:
Studier av palaeostormfloder ger bakgrund till inom vilka intevall stormar av olika storlek förväntas återkomma och träffa olika områden. Denna information kan användas vid modellering, riskbedömning och stadsplanering. Genom att använda de marina ekvationerna av Nittrouer och Sternberg (1981; The formation of sedimentary strata in an allochthonous shelf environment: the Washington continental shelf. *Marine Geology 42* : 201-232), har en enkel modell över bevaringspotentialen i terrestra miljöer gjorts. Denna har använts tillsammans med Chaumillon et al. (2017: Storm-induced marine flooding: Lessons from a multidisciplinary approach. *Earth-Science Reviews 165*. 151-184)s definerade faktorer för bildning av stormfloder för att kunna bygga upp en metod över hur man kan fjärrkartera områden där det är gynnsamma förutsättningar för palaeostormstormflodsavlagringar som har bevarats. Fjärrkarteringen har gjorts utmed Skåne, Blekinge och Hallands kust. Under denna studie av Skåne, Blekinge och Halland hittades 68 platser med potential för bevarade spår av palaeostormfloder. Av dessa studerades 12 områden ytterligare för att hitta historisk dokumentation av markanvändning, vilken kan indikera om en mänsklig störning, och för att ta reda på om det finns något naturskydd. Efter att kartläggningen var klar valdes Dalköpinge Ängar för en fältstudie. Här togs fyra borrkärnor med en ryssborr. Dessa studerades, beskrevs och en Loss On Ignition gjordes på de två längsta kärnorna. En biologisk proxy-metod med habitatbestämning av foraminerer och C^{14}-analys gjordes på en kärna, för att spåra förändringar i miljön och möjliga palaeostormflodsavlagringar. Datan från Dalköpinge Ängar visade spår av en stormflod som förändrade miljön daterad till antingen en tid före 1957-1958 (8% sannolikhet) eller 1990-1993 (92% sannolikhet). Med hjälp av dokumentation i gamla tidningar, flygfoton, dokumentation av gamla stormar i Skåne och annan tillgänglig data kunde förändringen som hittats korreleras med en stor storm 1954. Stormflodsfynden i fältstudien indikerar en bra fjärrkartering och metod för att bestämma områden med bevarade stormflodsavlagringar. Detta är den första kartläggningen och sedimentära studien av palaeostormfloder i Sverige.

Nyckelord: Stormflod, Stormflodsbildning, Stormmönster i Östersjön, Bevaringspotential, Bevaringspotential i terrestra miljöer & Erosion

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1. Introduction to subject and Method of Litterature Study

This study is the first mapping and study of palaeostorm surge overwash traces and areas in Sweden. It complements studies of palaeostorms from other parts of the world, including studies of palaeostorm frequencies (Nott et al. 2009; Scheffers et al. 2011), and site-specific studies of palaeostorm surge traces and storm-history (Clemmensen et al. 2014; Swindles et al. 2018; Moskalewicz et al. 2020). Paleostorm surge archives and studies are valuable resources for future predictions of both local and regional sensitivity to coastal flooding and can be used when modelling future storm effects. By using palaeostorm surge overwash data collected from sedimentary archives, it is possible to date the palaeostorm surge events, which can be related to different storm surge heights and storm frequencies in the areas (Chaumillon et al. 2017; Schöld et al. 2017b). Studies of palaeostorm surges becomes increasingly relevant with a rising sea level. The sea level rise provides a higher normal sea level on which the storm surge sea level rise can act, making storm surges reach higher onto land, potentially necessitating the implementation of adaptative measures (Chaumillon et al. 2017). For this reason the study of storm surges and the paleorecord is important thus this report may be a guide for historical storm surge researches.

The aim of this study is to provide a method to evaluate possible occurrences and the preservation potential of palaeostorm surge overwash traces remotely. This is done as a preparation, so that field study can be performed on the most promising areas, making field study more efficient and optimising the probability for positive results and findings of palaeostorm surge traces. The method is based on remote mapping using aerial photographs, soil maps and historical documentation to locate areas with a good potential for palaeostorm surge overwash deposition and preservation along the coast of Scania, Blekinge and Halland. One field site is examined for storm surges to test the accuracy of the mapping.

This report provides a simple method of identifying areas with well-preserved sedimentary traces, here applied for storm surge traces, and ensures a higher probability to find well preserved structures in field. The theories explained in this report can be applied for the determination of preservation potential of any and all deposited material in the terrestrial environment and the method can be used for any terrestrial sedimentary deposit, with some adjustments. For example: *the exposure*, which define the probability of deposition of palaeostorm surge overwash sediments in this method, can be exchanged to *possibility of deposition* which depend on the probability of deposition of the sedimentary trace one looks for.

The questions I wish to answer was:

- How does storm surges form?
- How does it differ along the swedish coast?
- What traces is displayed after the storm surge?
- What determines were we can find old remnants of storm surges?
- How can the terrestrial preservation potential be evaluated?
- Where along the coast of Scania, Blekinge and Halland can palaeostormtraces be found?
- Will there be a trace if one of the localities were visited?

The first step in the palaeostorm evaluation is to define the factors affecting the formation of storm surges and how to find and identify the palaeostorm surge overwash traces (sedimentary and biological) and how they vary in different settings. The preservation potential in different terrestrial settings is evaluated to determine if remnant palaeostorm surge overwash deposits are likely to be detected through field examination. The importance of both deposition and preservation are emphasised in this report, because both factors control the likelihood of remnant palaeostorm surge overwash deposits to be identified.

The second step in the palaeostorm evaluation involves evaluating how human land use and infrastructure have affected and changed the areas and the preservation potential, as well as an evaluation of the natural protection and possibility of sampling.

The need for a broad theoretical background has resulted in an extensive literature review. The literature study started with answering the question of what storm surge is and how it is formed. As the literature study continued, questions about 1) deposition, 2) preservation and 3) identification of storm surge sediments arose. As the different parts of the literature study asked different questions, the key words varied. For the general information about storm surges and palaeostorm surges the key words were: *storm surge, storm surge formation* and *storm patterns in Baltic Sea*. For question one the key words: *storm surge deposition, coastal deposition* and *storm surge deposits,* were used. For the second question, key words such as: *preservation potential, terrestrial preservation potential, wind erosion, water erosion* and *biological mixing soil* were used. To answer the third question key words such as: *storm surge identification, palaeotsunami identification* and *sedimentary structures palaeostorm surge* were used. These were used in the search motor: Google Scholar and Lubsearch.

The results of this is presented in the background "2. Theoretical Background" and it is the basis of the theories the method "3. Method of remote mapping and field study" is built upon. It includes the definition and formation of storm surges (described in "2.1. The Mechanisms Controlling the Formation and Magnitude of Storm Surges"), how storms affect variably along the Swedish coastline and how these effects may change with time ("2.2. Future Predictions and Historically Measured Sea Level Variations in Sweden"), how the palaeostorm surge overwash deposits appear in different environments (described in "2.3.1. Deposition of Storm Surge Sediments" and "2.3.2. Sedimentary Structures of Storm Surge Sediments"), how the preservation potential in terrestrial environments can be evaluated (“2.3.3. Principles of Preservation”), and which methods to use when identifying different palaeostorm surge overwash deposits (“2.4. Methods of Storm Surge identification”).

2.1 Theoretical Background

2.1. Mechanisms Controlling the Formation and Magnitude of Storm Surges

A storm is defined by SMHI (2020a), Sweden’s Meteorological and Hydrological Institute, as wind speeds above 10 on the Beaufort scale, described as the speed at which trees and houses will likely experience substantial damage. Today this correlates to wind speeds of 24.5 m/s to 32.7 m/s, above which the wind speed is defined a hurricane (SMHI 2020a). There are, however, large differences in the wind speed corresponding to 10 Beaufort in the older archives. Historical storms defined using the Beaufort scale are therefore harder to translate into a more quantitative wind speed (Östman 1928).

In addition to wind damage, coastal storms can create storm surges, raising the water level. These surges are explained by the wave interaction with the coastal topography/bathymetry (**Wave Setup**), wind stress (**Ekman Current**), and the air pressure systems (**Barometric Air Pressure**). It is also affected by the tides (**Tidal Effect**) changing the sea level on which the storm surge acts (*Figure 1*; Chaumillon et al. 2017).

2.1.1. Wave Setup

As wind moves across a sea surface, friction creates small ripples which with long fetch, exposure and high wind speeds are strengthened into waves that grow in height and wavelength (Hutchinson 1957). These currents and movements in the water are in the direction of the wind, Stokes drift (Mao & Heron 2008). When the waves start to interact with the seafloor, the process of wave setup will begin thus raising the local sea level (*Figure 1*; Chaumillon et al. 2017). The process is explained by the physics of waves: as the wave base reaches the seafloor the height of the waves will increase, and the wavelength will be smaller (Reading 1996). This increase in the height of the waves will result in a corresponding rise of the local sea level; this is defined by Longuet-Higgins and Stewart (1964) as wave setup.

The effect of the wave setup is dependent on the cross-shore gradient of the coast. In coasts where the gradient is low and displays a constant landwards shallowing of the profile, there will be a constant increase in wave height towards the shore and a corresponding rise in sea level. This is because the wave base continuously reaches the seafloor, pushing the water upwards, losing energy and raising the local sea level (Longuet-Higgins & Stewart 1964). In coasts with steep gradients and a quick transition from deep to shallow water, the wave setup is somewhat more complex as, depending on the gradient, much of the incident wave energy can be reflected. This process counteracts the wave setup and could result in an absence of a sea level rise (Longuet-Higgins & Stewart 1964). In intermediate profiles, where there is a lot of energy close to the coastline, the waves breaks close to the shore, but there is still a constant shallowing which successively pushes the water upwards. This results in a very large wave setup and high local sea level rise within a short interval in towards the coast (Longuet-Higgins & Stewart 1964).

2.1.2. Ekman Setup by the Ekman Current

The strong winds during storms will not only create waves which raise the sea level by wave setup, but can also create movement deeper in the water column, forming currents which force the water onto the coast. At the top of the water column the movement is in the direction of Stokes drift (the motion of the currents and waves in the water is in the same direction as current in the wind) but as the distance to the surface of the water column gets larger the Coriolis drift, as a result of the rotation of the earth, efficiently diverges the orientation of the water particles (*Figure 1*; Hutchinson 1957; Mao & Heron 2008). This results in an Ekman drift, the successive change of water orientation depending on the interaction between the wind setting water into motion and the Coriolis effect diverging the orientation with depth (Hutchinson 1957; Gill 1983). Ideally the deflection of the water movement is 45^{o} (Gill 1983). This will generate a surface current, Ekman current, flowing in the direction of the Coriolis-force: to the right in the Northern Hemisphere and to the left in the Southern Hemisphere and can result in water being pushed up against the shoreline, raising the sea level (Kennedy et al. 2011). The energy of the Ekman current is dependent on the wind stress, the force extracted on the sea surface by the wind current and the density of the air, as well as the density of the water (Mao & Heron 2008; Bryant & Akbar 2016).

The Ekman drift acts in combination with Stokes drift. This means that the surface currents vary with dominance of the different drift patterns depending on fetch. In areas with a longer fetch, the waves can grow longer, with longer wavelength and energy, and shallow surface water currents (in the direction of Stokes drift) result in surface water currents that are strong, both in the direction of the wind (Stokes drift) and the Ekman drift. In areas with shorter fetch, the Ekman currents are stronger than the energy in the shallower currents and waves in the direction of Stokes drift (Mao & Heron 2008). This should mean that in areas with larger fetch, the wave setup is high, since there are larger waves and more energy close to the coast. At the same time the Ekman current is strong, resulting in high storm surges. Where there are shorter fetches, the waves are less mature according to Mao & Heron (2008), which should give a lower wave setup and the Ekman current would be the dominant storm surge-forming process.

The effect of the Ekman currents can be very large and for example Shen and Gong (2009) concluded that the presence of Ekman currents in the Chesapeake Bay, in the United States of America, would increase the sea level from 20% up to 220%, emphasising the importance these currents have for the sea level at the coast.

2.1.3. Barometric Air Pressure

The global and local barometric air pressure have a large effect on both the local sea level, the calm weather sea level and storm surges as it either pushes the water column down or force it to rise (*Figure 1*; Rego & Li 2010; Chaumillon et al. 2017; Schöld et al. 2017). At the average global air pressure, a change of 1 hPa results in a change of sea level with 1 centimetre, with lower pressures resulting in higher water level (Chaumillon et al. 2017). This could have a large effect both directly while the storm passes, forcing the sea level to drastically rise within a shorter time span, and on longer time scales, as it changes the in- and outflow of water to the basin (Schöld et al. 2017b).

2.1.4. Tidal Effect

Although the tides do not form the surges, the magnitude of the storm surges will vary depending on the correlation with the tide. Since the height of the storm surge is superimposed on the normal sea level and tide, a storm surge during low tide has a lower magnitude than during a high tide, as the low tide compensates for some of the sea level rise of the surge. During high tides, the sea level rise from the surge will be added to the naturally higher sea level during high tide and the effects will be more severe (*Figure 1*; Chaumillon et al. 2017). Murty (1984) concluded from their study that the effect of a high tide in combination with storm surges could give a rise in sea level which is more than 500% higher than if it was a low tide. This effect is only applicable in tidal areas and varies a lot depending on the tidal impact and differences between high and low tide (Chaumillon et al. 2017).

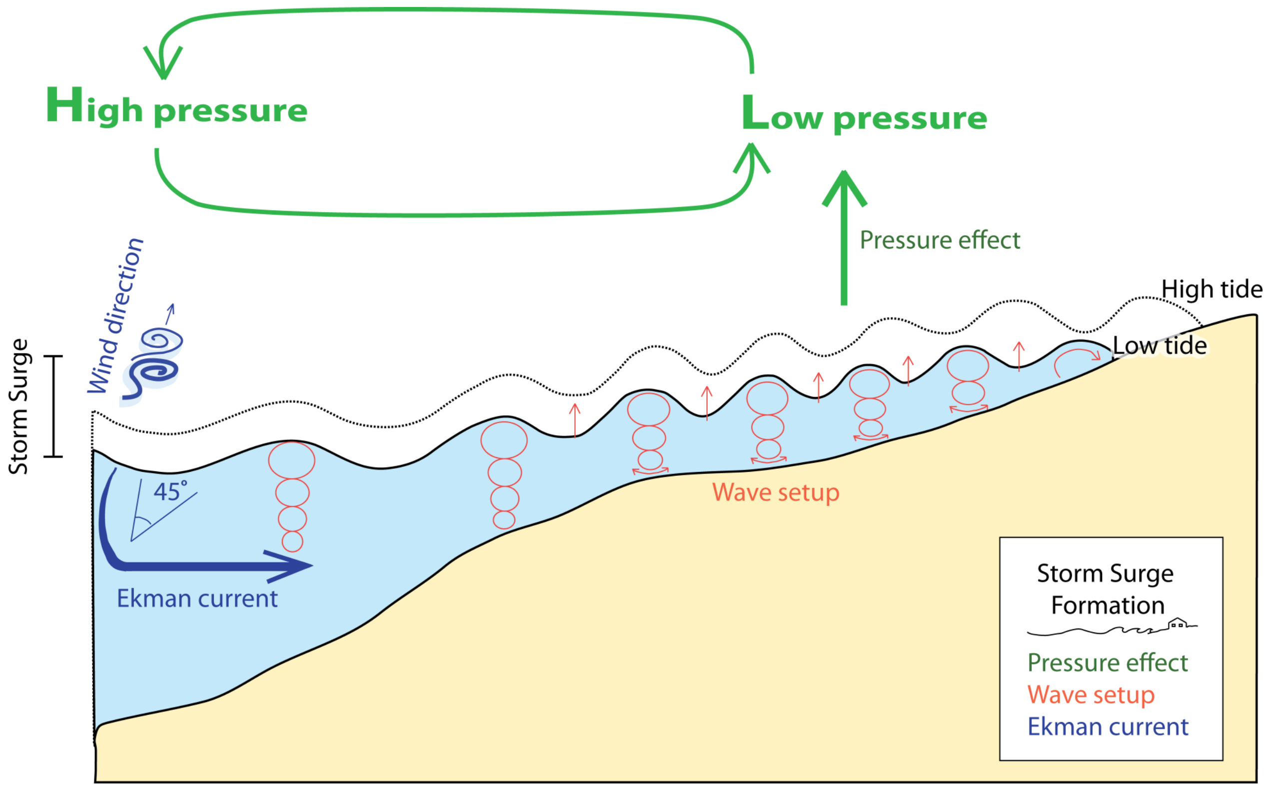


Figure 1, The different factors which result in the sea level changes during storm surges. The pressure effect is the barometric air pressure that that pushes the water column up or down . The wave setup is the increase in height of the waves as the wave base reach the seafloor and forces the coastal sea level to rise. The Ekman current is the current that forms by the Ekman effect, deflation of the current direction with depth during windy conditions. The tidal effect is the natural change of the normal sea level due to tides and can amplify the storm surge. Figure by Lykke Lundgren Sassner.

2.2. Future Predictions and Historically Measured Sea Level Variations in Sweden

Extratropical cyclones are the main storm surge creating storms in the Pärnu bay of Estonia, on the eastern side of the Baltic Sea, a storm pattern which is consistent with the present day Norwegian west coast and is expected to be dominating in Sweden (Haarsma et al. 2013; Mäll et al. 2017). This is important when predicting the frequencies, magnitude and intensity of future storms, as there are variations in the predictions of future tropical and extratropical storms. When it comes to changes in the storm frequency and intensity of extratropical storms, most studies indicate fewer and less intense storms as a result of global warming (Michaelis et al. 2017; Harvey et al. 2014). This is a result of a reduced difference between the polar and equatorial troposphere and barometric systems (Michaelis et al. 2017; Harvey et al. 2014). Therefore, if the trend of mostly extratropical storms forming the large storm surges would prevail, the storminess in Sweden would decrease. There are, however, models that shows a shift from only extratropical to more tropical storms: Haarsma et al. (2013). These show an opposite trend of an increase in frequency and intensity of the storms during the autumns due to global warming (Haarsma et al. 2013). As a result of the different predictions depending on the dominating storm type, extratropical or tropical storms, it is of importance to continuously trace the origin of all and each storm to document changes from a pattern of extratropical dominance to tropical. In addition to possible changes in storminess in Sweden, the sea level will rise, resulting in the storm surges acting on a higher surface and therefore reaching higher onto land than previously (Church & White 2006). Models and documentations of the magnitude and frequency of storms are therefore vital for the preservation of infrastructure and to save lives.

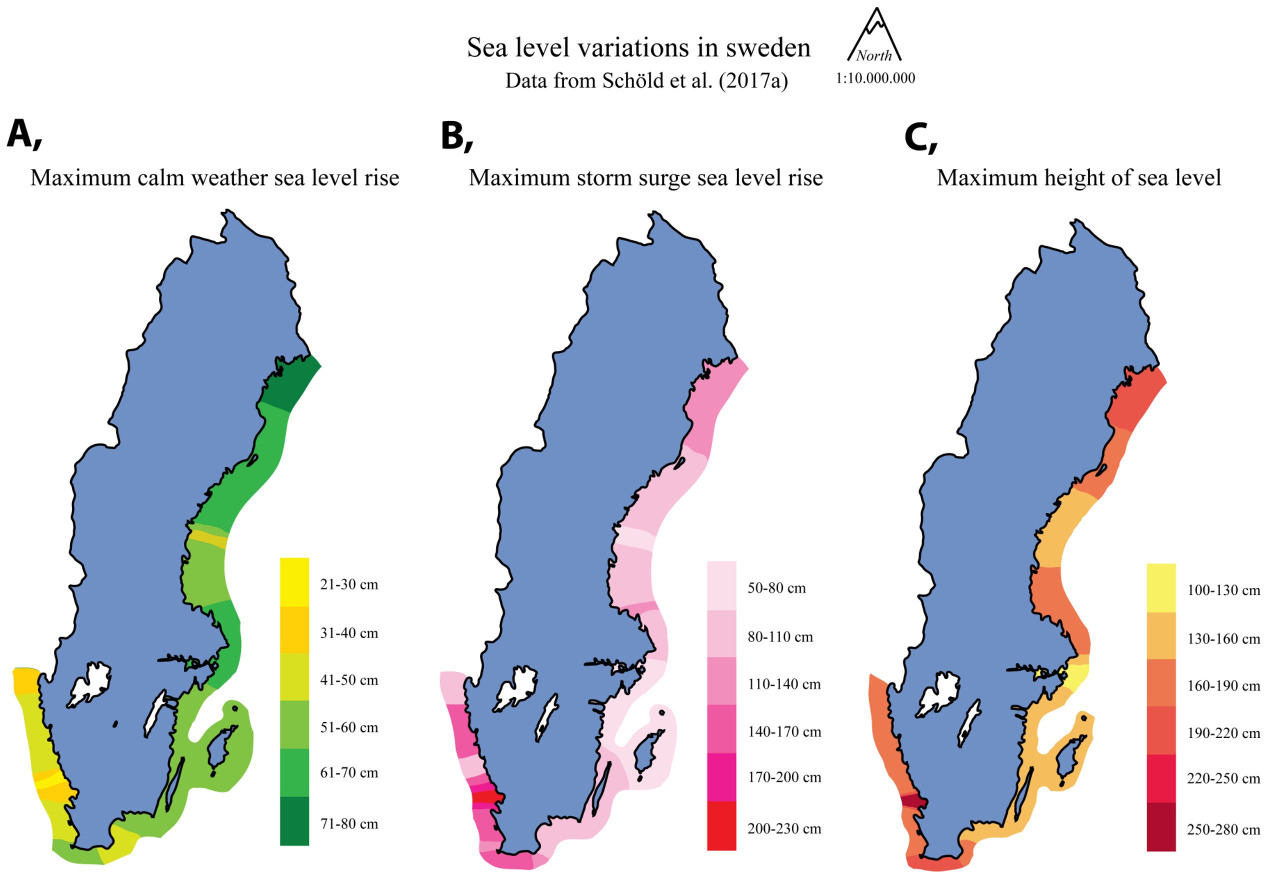


Figure 2, A, interpolated maximum calm weather sea level rise measured along the coast of Sweden based on the data of Schöld et al. (2017a). B, the measured storm surge level along the coast of Sweden from data of Schöld et al. (2017a). C: interpolation of the largest possible sea level rise. This is the sum of the highest measured storm surge sea level rise and the maximum sea level measured. The data is from Figure 14 in Schöld et al. (2017a) and the map is based on a map from @Lantmäteriet. Figure by Lykke Lundgren Sassner.

Historical studies of Sweden's storminess, since 1800, show a consistent storminess (Barring & Von Storch 2004). Using sea level documentation, with between 25-130 years continuity, Schöld et al. (2017a) and Schöld et al. (2017b) could make conclusions about the sea level patterns along the Swedish coast. There are large differences in the height of storm surges and maximum calm weather sea level of the different parts of the Swedish coast, see *Figure 2* (Schöld et al. 2017a; Schöld et al. 2017b).

The data of Schöld et al. (2017a) showed a higher maximum calm weather sea level, indicating more natural variations in sea level, in the Baltic Sea, with a notably high calm weather sea level in the northern parts of the Baltic Sea, opposed to Kattegat (*Figure 2A*). This trend of higher natural sea level variations is explained by periodically long periods of low-pressure systems and south-western winds in the Baltic Sea, forcing water through the restricted inlet and building up a large body of water in the Baltic Sea. In the northern part of the Baltic Sea, the Bothnian Bay, the low-pressure systems force the surface water of the Baltic Sea to accumulate in a very restricted area. This results in an even larger sea level rise due to the air pressure forcing and is the reason for the exceptionally high natural variations in sea level here opposed to elsewhere. On the coast of Kattegat the process of air pressure forcing of water is small, giving smaller natural variations in the maximum calm weather sea level (*Figure 2A*; Schöld et al. 2017).

Schöld et al. (2017a) have also analysed the maximum storm surge height recorded at the stations around the coast of Sweden and the maximum possible height of sea level (the sum of the maximum calm weather sea level rise and storm surge sea level rise), illustrated in *Figure 2B*. The different parts of the Swedish coast are affected differently by the storm surges. In the Baltic Sea, the storm surges are not large, but the magnitude could be amplified when combined with a high calm weather sea level before the storm hits. This means that the calm weather sea level has a large effect on the observed sea level height during a storm and the maximum possible sea level. The sea level could rise to 220-250 centimetres (in the Bothnian Bay) when the highest measured calm weather sea level rise and storm surge sea level rise is combined (*Figure 2C*; Schöld et al. 2017b). On the west coast, the coast of Kattegat, the storm surges are high while the natural calm weather sea level is low *(Figure 2)*. Therefore, it is the storm surge which, to the highest degree, control the maximum possible sea level height and not the calm weather sea level rise here. When the storm surges and the maximum calm weather sea level are combined, the sea level can be as high as between 250-280 centimetres above normal sea level (*Figure 2C*; Schöld et al. 2017b).

2.3. Deposition and Preservation of Storm Surge Sediments

The deposition of storm surge sediments is dynamic and complex, as the storm surge can be both locally erosive and deposit sediment (Clemmensen et al. 2014; Labuz and Kowalewska-Kalkowska 2011). This can be exemplified by Labuz and Kowalewska-Kalkowska´s (2011) study of a storm event in Poland, where 22 m^2 sand per 1 metre length of coast was removed and Clemmensen et al.s (2014) study of storm ridges. Both studies focus on storm surges and the traces thereof but gives completely different results due to the different local dynamic during the storms.

During events with larger erosion than deposition hiatuses are expected as sedimentary traces are removed. Contrary, during events with more deposition, the sedimentary palaeostorm surge overwash deposits could be well preserved in event-layers. When there is high bioturbation, organisms mix the sediment and can destroy the palaeostorm surge overwash traces, structures and event horizons (Hippensteel et al. 2013). To understand the dynamic and complexity of the erosion, deposition and preservation during and after storms, it is important to get a good understanding of the parameters which affect the storm surge traces, both during deposition and through post-depositional preservation processes.

2.3.1. Deposition of Storm Surge Sediments

The deposition of sediments is dependent on the formation of accommodation space, defined by Jervey (1988) as an area with the possibility for deposition. Jervey (1988) focussed on the sediment influx, subsidence of the crust and local sea level changes as triggers for changes in the base level for deposition, creating deeper or shallower water depth, making it possible for different amounts of sediments to get deposited in oceans. This theory is the basis of the present-day sedimentary basin analysis, sequence stratigraphy and the large-scale changes in the sedimentary basins (Miall 2000), but can also be used for shorter time intervals. This theory can explain the temporary accommodation spaces formed when there is a storm surge. During storm surges there is an increase in the relative sea level (Chaumillon et al. 2017). This results in a temporary higher base level of accumulation and the formation of more accommodation space according to Jerveys (1988) theory. This means that when a storm surge hits the coastal areas, there is temporarily an increased accommodation space where sediments can be deposited. However, the storm events are high energy events with strong waves of long wavelength which evens out the topography of the flooded coastal areas, the foredunes, foreshore and shoreface. Consequently it can erode large sediment volumes from steeper coast profiles and the foredunes to deposit the sediment offshore, making the foreshore and shoreface more gradually sloping than before and leaving scars in the foredunes (Wright & Short 1984; Morton & Sallenger 2003).

To deposit storm surge sediments in the terrestrial area, flooding and a trap are required, where the water energy as well as the velocity of the water is lower, resulting in a loss of carrying capacity and potential deposition (Hjulström 1935). This could be backbarriers (with deposition in large and protected areas behind the dunes, such as in lakes and marshes), beach ridges/beach berms (formed as the higher water level builds up ridges that follow the swash-zone, where the waves can reach onto land), or it could be deposition in washover-fans behind the dunes (where the water breaches the dunes, quickly decreases its velocity, and deposits sediments) (Chaumillon et al. 2017).

2.3.2. Sedimentary Structures of Storm Surge Sediments

The traces of the storm surges vary spatially. In areas where the water has been backwashed, there are usually deposition of sediments which display a normal grading (with the largest clasts along the bottom of the event horizon) and planar bedding. The sediment is dominated by sand or silt and it is often interbedded in a clay-dominated environment (*Figure 3*; Chaumillon et al. 2017).

In coastal lakes and marshes, the storm surge sediments can form units of normally graded sand or silt in the muddy environment. In marshes, the storm surge sediments can also consist of a hiatus or a unit of compacted sediment (*Figure 3*; Chaumillon et al. 2017). In these cases, it is possible to identify a storm surge only by analysing fossil remains of macro or micro fossils, such as ostracods, diatoms and foraminiferas (Goff et al. 2012).

In coastal dunes and cheniers (thin dunes associated with muddy marshes) there is usually an erosive surface above which there is normal grading of sand, rich in shells when there has been storm surge sedimentation. The more-gravelly beach ridges have a normal grading and show a landward imbrication, in an orientation consistent with the incident waves (*Figure 3*; Chaumillon et al. 2017). These storm berms are particularly stable and demand strong currents to erode them (Scheffers et al. 2011), making them an important asset for evaluating storm surges.

The washover fan´s sedimentary trace depends on which area of the washover is studied. The proximal area, close to the top of the fan, display an erosive reactivation surface with planar bedded and normally graded sand. In the more distal area there is also an erosive reactivation surface, though the bedding is oblique and there is some shearing in the sediment above the reactivation surface (*Figure 3*; Chaumillon et al. 2017).

A problem when sampling and analysing storm surge sediments often arises when small volumes of marine sediment become intermixed with aeolian, as for example in beach ridges, or the lack of siliciclastic sediments, making it hard to determine the origin of the event/change/unit (Chaumillon et al. 2017). It is possible to analyse sediment origin by studying organisms, such as foraminifera or diatoms interbedded in the sediment. By determining the organism's habitat, it is possible to make conclusions about the ecosystems in which they lived, to trace changes in ecosystem and environment as well as to identify the presence of marine organisms, as a sign of a marine sedimentary origin. There can, however, be problems in that acidic sediments and bioturbation might efficiently dissolve the biological archive. Consequently, the absence of marine fauna might not be a reliable indicator of a non-marine origin (Goff et al. 2012; Hippensteel et al. 2013). Similarly, marine traces and organisms can be redeposited by wind and therefore indicate a marine origin although the most present deposition was wind driven. These marginals of error exist but the method of using biological proxies is both common and relied upon (Goff et al. 2012; Dura et al. 2016).

2.3.3. Principles of Preservation

Although sediments may be deposited on land by storm surges, their preservation potential varies spatially. Here I will try to explain and theorise around the background and principles of terrestrial preservation potential which is applied during the remote mapping for possible storm surge sedimentation. It is extremely important to know the general trends of preservation to make good assessments of areas for possible preserved sediments. Therefore, the following section has a general focus, but the trends can be applied in all terrestrial environments and will in my work be applied to coastal areas and palaeostorm surge overwash deposits.

The different processes which affect and change the preservation potential in the aquatic environment was studied as early as in the 1950s by Moore and Scruton (1957). They did an extensive study of the sediments in the Gulf of Mexico and concluded that the final preserved product was a result of the sediment source, the re-working of sediment and the sedimentation rate. The speed and depth of the different processes was later quantified by the application of radionuclides, where the occurrence and progression of certain radionuclides, for example Pb^{210}, at different depths could be correlated to time intervals since the area had contact with surface water and when comparing larger datasets: the different processes showed distinct pattern (Moore and Scruton 1957; Nittrouer et al. 1979). Nittrouer and Sternberg (1981) used radionuclides and studies of sediment structure and biology to establish two Formulae which can be used for evaluation of the preservation on the seafloor. The first formula explains the effect of the bioturbation on a sea bottom by dividing it into different zones of different intensities until mixing/bioturbation has no effect.

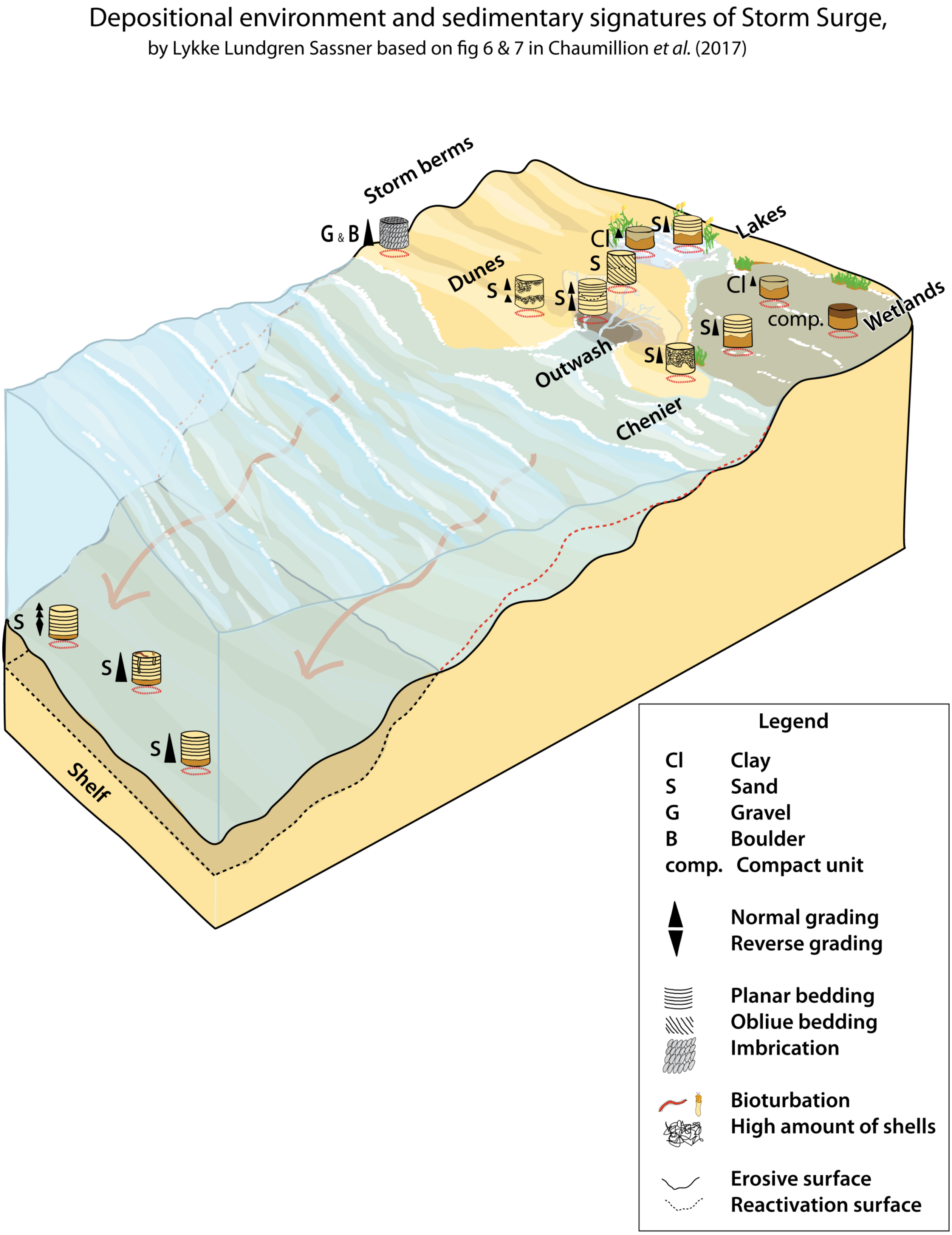


Figure 3, The Figure demonstrates the different kinds of storm surge deposition and their sedimentary records. The depositional environments are based on Chaumillon et al. (2017) Figure 6 and the sedimentary structures are from Chaumillion et al. (2017) Figure 7. Figure by Lykke Lundgren Sassner.

Equation 1, Biological parameter (Nittrouer and Sternberg 1981):

$$G = \frac{\sum_{b=1}^{m}(D_b * L_b)}{A} = \frac{\text{The amount of bioturbation}}{\text{The amount of accumulation}}$$

In the Equation of the biological parameter of preservation, **G** is the amount of biological reworking/bioturbation defined as volume/time: **D** is defined as the biologically processed sediment (volume/time), $\mathbf{D_b}$ is the volume of sediment in a of the zone of the bioturbation (volume), $\mathbf{L_b}$: the extent of bioturbation and **A** is defined as the sediment accumulation-rate (Nittrouer and Sternberg 1981).

The second formula of Nittrouer and Sternberg (1981) explains the effect of erosion and represents the balance between the supply and removal of sediments:

Equation 2, mechanical parameter (Nittrouer and Sternberg 1981):

$$H = \frac{\left(\left|\sum_{p=1}^{n}(F_p * L_p)\right|/n\right)}{A} = \frac{\textit{The amount of erosion and reworking}}{\textit{The amount of accumulation}}$$

H is described by Nittrouer and Sternberg (1981) as a parameter of the mechanical preservation and represents the amount of mechanical reworking (volume/time), $\mathbf{F_P}$ is the depth of the zone of the disturbance, $\mathbf{L_P}$ is the disturbance (volume), **n** is the amount of different zones with different disturbances and **A** is defined as the accumulation-rate of sediments.

In both these equations (*Equation 1; Equation 2*), low values indicate a low amount of reworking in relationship to the deposition and therefore a higher preservation potential. The problem is that these studies and equations are based on aquatic environments but will be used when evaluating the terrestrial preservation potential in this report, because preservation potential in the terrestrial environment is poorly described in the literature. I do this with the theoretical background in that the principles of preservation are expected to be the same in an aquatic and terrestrial environment, though there are different systems and ecosystems that affect the origin of the vertical mixing, erosion, and accumulation. The following sections: "2.3.3.2. Bioturbation dependent Preservation" and "2.3.3.3. Mechanically dependent Preservation" is my interpretation of the theories behind preservation in the aquatic environment and the equations (*Equation 1; Equation 2*) by Nittrouer and Sternberg (1981) to the terrestrial environment. I have additionally included a section about the human impact on preservation potential in the terrestrial environment: "2.3.3.4. Human Impact of Preservation in Terrestrial Environments".

2.3.3.1. Accumulation Rate, A

Both equations (*Equation 1; Equation 2*) give higher values, and therefore higher disturbance of sediments, if an area has lower sedimentation rate/smaller rate of burial. According to Jervey (1988) the deposition/sedimentation is controlled by the formation of accumulation space, being related to the sea level and the base level, under which there is more accumulation of sediments than erosion. This means that there is a constant relocation of terrestrial sediments, above the base level, into the aquatic systems, below the base level, resulting in a generally higher erosion than accumulation in the terrestrial environments, a lower **A** (*Equation 1; Equation 2*), and a poorer preservation potential than in the aquatic environments. Even though this is the general trend, there are variations in sedimentation rate within the terrestrial and marine environments which gives large local variations in the accumulation rate and result in differences in preservation potential.

The preservation potential is higher in areas with constant sedimentation and/or a quick burial (*Equation 1; Equation 2;* Nittrouer and Sternberg 1981; Briggs 2007). A constant sedimentation results in a low overall disturbance of sediments/structures because it takes a short time before the sediments/structures reach a level deep enough for neither biological nor mechanical mixing. A quick burial results in the shortest time of exposure as the top-most soil/sediments before the structures/sediments reach a depth where no disturbance occurs (*Equation 1; Equation 2;* Nittrouer and Sternberg 1981). Quick burial is recognised by the palaeontological society as one of the most efficient ways to preserve sedimentary structures, biological traces and fossils (Briggs 2001).

2.3.3.2. Bioturbation Dependent Preservation, G-value (Equation 1)

As described in “2.3.3. Principles of preservation” the previous studies focus on describing different preservation potentials in the context of aquatic environments. Therefore, the aquatic principles must be translated to the terrestrial environment, based on *Equation 1*.

In marine ecosystems, the local variation in bioturbation result from the different benthic organisms and communities which naturally vary with nutrient and oxygen availability, strata/grain size, ecosystem balance and the ratio of the different functional animal groups (Schaffner et al. 1992; Bernard et al. 2019). This is a trend which has a parallel in the terrestrial ecosystem where mixing and bioturbation will vary depending on the local species’ composition, ecosystem, different functional biological groups, local environment, and chemistry (Bornebusch 1930; Fenton 1947). Similar to the aquatic environments, where bioturbation is caused by the benthic fauna, terrestrial soils exhibit mixing and bioturbation as terrestrial organisms live in and on the ground (Bornebusch 1930; Schaffner et al. 1992), mainly different species of earth worms that dig in and turn around the soil (Bornebusch 1930). Considering these similarities, the same methods of quantifying bioturbation in the aquatic environment should be applicable to terrestrial environments (*Figure 4*).

2.3.3.2.1. Soil as an Indicator

One way of getting a good overview of possible bioturbation in a terrestrial area is to get a general overview of the environment, ecosystem and corresponding soil. Depending on the environment there will be large differences in the ecosystems and the functional groups of the organisms living in the soil, resulting in differences in mixing and soil (Bornebush 1930; Fenton 1947). It is this connection between the soil and the mixing that will be explored further.

Although the soil classification is classically used to describe the soil properties, i.e. its units and thickness, it is possible to use the information to evaluate the biological activity and mixing (Bornebusch 1930; Fenton 1947; Andréasson 2006). This is exemplified by Fenton (1947), who ascribed the species documented by Bornebush (1930) to functional groups and found that different types of soils, i.e. mull and mor, correlated to different ecosystems and mixing properties of the animals. By applying a generalisation of the functional groups and properties of the different soils it is possible to make a general evaluation of bioturbation in larger areas. The most common soil in Sweden is podsol followed by Swedish brown soils, often defined as cambisols in the more modern classification by FAO/UNESCO (Andréasson 2006). These soils are used as a basis and be related to ecosystems and functional biological groups to make a generalisation with the aid of Bornebusch (1930) and Fentons (1947).

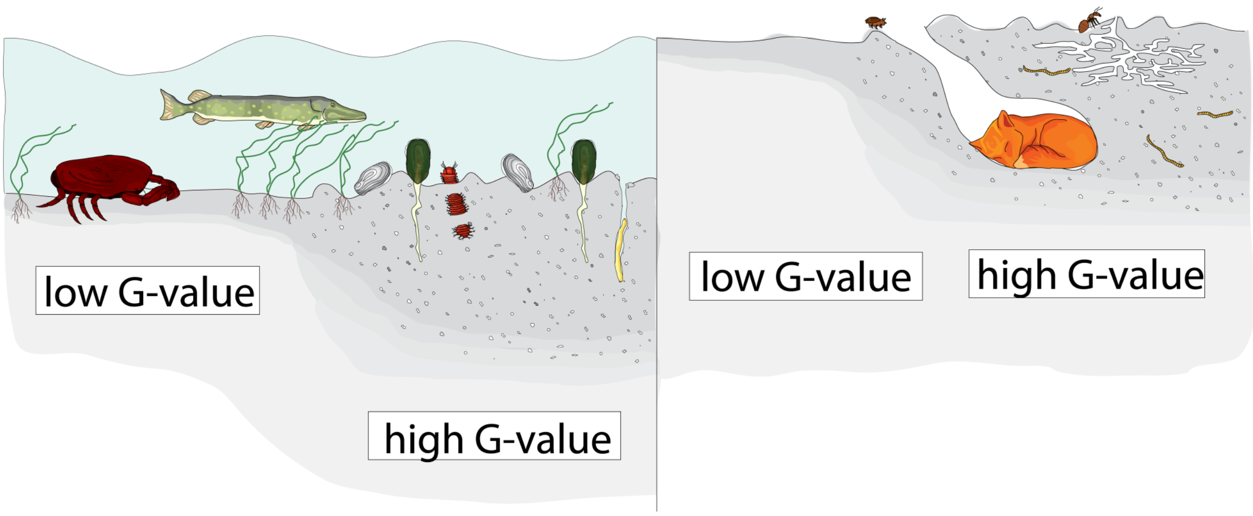


Figure 4, An illustration of the effect of bioturbation on preservation potential. The darker grey is soil that is being disturbed by some kind of biological mixing. A lower G-value (Equation 1) indicates a lower amount of disturbance and a higher preservation potential. Figure by Lykke Lundgren Sassner.

Cambisols are soils that are generally homogenised with gradual transition between the top soil and deeper subzones (IUSS Working Group WRB 2015). According to IUSS Working Group WRB (2015) these are soils which efficiently change the parent material and are characterised by clay formation and brown discolouration. With the help of data from Bornebush (1930), Fenton (1947) could conclude a trend where the brown soil/cambisol had a high amount of digging animals which disturbed the sediments. The high degree of digging organisms results in the cambisols/brown soils having efficient mixing/bioturbation to a large depth (Bornebusch 1930). This results in an efficient relocation of soil and disturbance of structures in the sediment, a high **G**-value from *Equation 1* and a low preservation potential. Consequently, the biological preservation potential for potential storm surge event layers is relatively low in this soil type.

Podsols are soils common in conifer-rich areas and have a different structure, with sharp transitions between clear horisons shaped by the soil chemistry (IUSS Working Group WRB 2015). These soils have a low pH, resulting in the leaching of Al, Fe and nutrients. This gives rise to low amounts of available nutrients and water for the organisms (Fenton 1947; IUSS Working Group WRB 2015). The organic horison in these soils is shallow and according to the faunal function groups that Fenton (1947) summarised from Bornebush (1930) a fauna that is mainly living in or on the top litter and does not penetrate the soil. The mixing is therefore restrained to the top of the soil. This should result in weaker bioturbation in podsols than cambisols and a lower **G**-value from *Equation 1* in podsols. Therefore, podsols generally have a higher biological preservation potential for structures such as storm surge sediments.

When doing these evaluations and comparisons it is important to appreciate the complexity of the ecosystems which shape the soils and it is, for example, easy to confuse efficiency of degradation of organic matter with mixing. Looking at degradation and mixing, there are no large differences in the degradation between podsols and cambisols, meaning that the differences between the different soils is mainly in the bioturbation, where the degradation takes place and by what organisms. There is however a feedback where the degradation is important for the bioturbation as the degradation by organisms in the different soils results in different end products/chemicals, affecting the soil chemistry, organisms and ecosystems that allowed for the bioturbation (Romell 1935; Gast I937). The patterns of how soil can be related to ecosystems, mixing, chemistry and functional groups are complex, which is why every soil type should, to the highest possible degree, be evaluated individually. This also introduces a field of science that could be further explored.

An example of a study that illustrates the different functional groups, and correlated mixing, within different ecosystems in one soil group is that by Fenton (1947), where three different kinds of brown soils/cambisols from oak-, beech- and spruce forests were studied. These showed a lot more species' diversity and digging organisms in the oak than in the beech and spruce mull (Fenton 1947). But, although the biodiversity and degree of mixing might vary with different brown soils/cambisols, the definition of brown soils/cambisols is a homogenised soil type (IUSS Working Group WRB 2015). Therefore all brown soils/cambisols must involve some degree of bioturbation and mixing, resulting in a higher **G**-value (*Equation 1*) amongst these soil types than the podsols.

2.3.3.3. Mechanically Dependent Preservation, H-value (Equation 2)

Just as with bioturbation, the translation of *Equation 2* by Nittrouer and Sternberg (1981) is based on the assumption that the processes of erosion are similar though dominated by different medium: water in the aquatic environment and both wind and water in the terrestrial. *Equation 2* describes the preservation in relation to the frequency of erosion, depth of the effect and the accumulation of sediments (Nittrouer and Sternberg 1981).

The erosion and deposition of sediments are dependent on the weight of the clast which gets carried and the force of the medium which carries it, as is evident in the observations of Hjulström (1935). When comparing wind and water erosion the most important difference lies within the densities, where water has an almost 100 times larger density of 998 kg/m^3 to 1.293 kg/m^3 of air (Ingelstam et al 2014). This large difference in density results in a corresponding difference in mass, the kinetic energy and possibility to exert force on an object and make clasts move. In practice this results in a larger potential for water to carry heavier sediments than that of wind, at the same speed (*Figure 5*). It is important to note that although the density, and therefore capacity, of water might be higher than the wind, the continuity, exposure and speed of the different types of wind and water currents will lead to local variation in the patterns of dominance of wind and/or water erosion, both with space and time (Breshears et al. 2003; Van Pelt and Zobeck 2004; Zhang et al. 2011).

A feature which is important when evaluating the possibility for erosion and the mechanical preservation potential, **H-value** in *Equation 2*, is the soil properties, with the most emphasis on the soil erodibility. The soil erodibility depends on the formation of large structures (aggregates) and making the weight greater (Morgan 2005). This results in the sediments resisting erosion by the wind and water current velocities which could have eroded the clasts if they were alone and lighter. The aggregates can be formed by a high volume of cohesive sediments (clay and silt), a high amount of organic compounds and with water content (the effect varying depending on the soils grain size) (Morgan 2005).

The vegetation also has a large effect on the erodibility. It contributes to the organic content in the soil and holds the sediments to the ground with their root systems, increasing the soils aggregates and stability. Plants also lower the impact of rain and the velocity of the wind, by shielding the ground and increasing the friction at surface level (Morgan 2005).

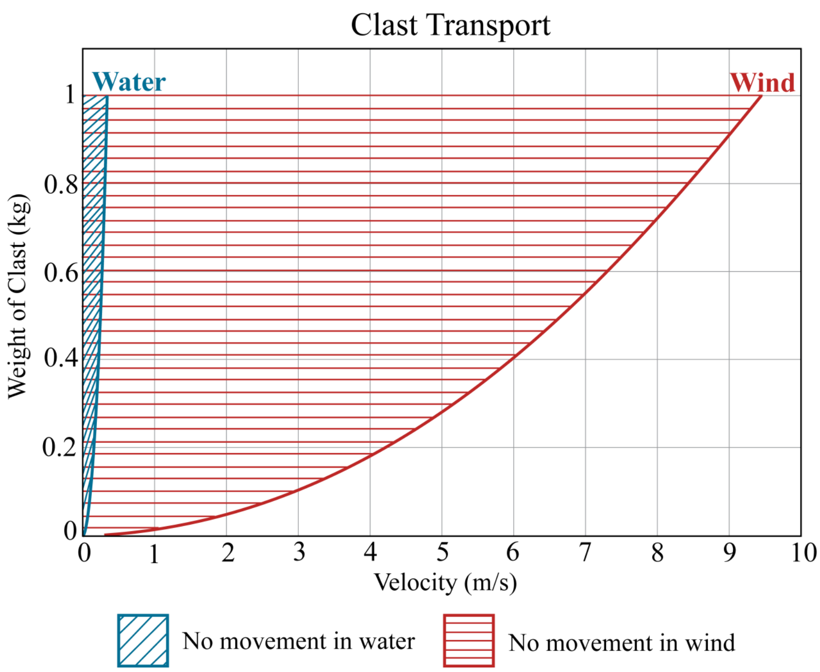


Figure 5, The theoretical differences in erosion-capacity dependent on the weight of the clasts and the different substrates: water and wind. The diagram presents what velocity/flow is needed for 1 m^3 of water respectively air to move clasts of different weights and is calculated for values between 1 gram and 1 kilogram. This has been done in all simplicity with the framework of 1, no acceleration vertically, 2, minimum requirement to set a clast into motion, 3, no experimental testing in field and 4, a static friction which is not measured in field but assumed to be the same as a brick against wood: 0,6 (engineer toolbox n.d.). The mathematical equations as well as density of water and air comes from Ingelstam et al (2014). The equations are explained in further detail in Appendix 1. Figure by Lykke Lundgren Sassner.

2.3.3.3.1. Properties of Wind Erosion

Woodruff and Siddoways' (1965) Equation of **wind erosion** of farmed land, define the erosion to be a result of the erodibility of the soil (I, a result of the amount of aggregates), The roughness of the farmed land (K, the ridges, undulations and variations in topography dependent on geology and geomorphology), climate (C), length of the area in the direction of the wind (L, similar to the fetch this is the length that the wind current act on the field) and the Vegetation cover (V). During a more modern evaluation of the equation, Van Pelt and Zobeck (2004) found that there were some problems and had to modify the different variables. However, as Van Pelt and Zobeck (2004) managed to correct for the error without adding or removing parameters, the key attributes which contributes to the soil erosion by wind, defined by Woodruff and Siddoway (1965), is to be considered correct. Therefore areas with a lower wind erosion and lower **H**-value according to *Equation 2*, should be correlated to lower erodibility of soil, higher roughness of surface, rainier climate, shorter length of field in wind direction and larger vegetation cover (Woodruff and Siddoway 1965).

2.3.3.3.2. Properties of Water Erosion

The water erosion can take different forms: precipitational-, fluvial- and coastal erosion.

The main erosive power of **precipitational erosion** is the impact of the droplet, which can splash away sediments, and the possible surface run-off (Hairsine 1991; Morgan 2005). Depending on the land use, vegetation, slope, impact of the droplets and the erodibility of the soil there will be large differences in the effect of the precipitation and the corresponding erosion. The variables vegetation and gradient have the largest effect when it comes to precipitational erosion, with the lowest erosion, highest mechanical preservation and lowest **H**-value (*Equation 2*) where there are high amounts of vegetation and a low gradient (Panagos et al. 2015). As soon as the water from participation becomes surface run off it follows the rules of the fluvial systems and fluvial erosion.

In the fluvial systems the flow is restricted to channels and the mass of the water is higher than during precipitation, resulting in a higher velocity and therefore the potential erosion (Morgan 2005). The long-term changes of **fluvial erosion** in a stream is a result of the rainfall (providing the influx of water), the vegetation (by changing the impact of rain, the structure of the soil), the soil (by differences in the erodibility, permeability), the erosion threshold (the velocity required for erosion at the bottom of the stream), the topographic features (for example gradients) and the daily variations of flow in the stream, and is also affected by the effect of hydrological changes in the basin. This means that there will be less erosion, more mechanical preservation, and a lower **H**- value (*Equation 2*) when there are low amounts of rainfall, low erodibility of the soil, low gradient, high erosional threshold and large amounts of vegetation (Deal et al. 2018). It is important to be aware of the coupling between this fluvial erosion and the precipitational erosion since the precipitation provides the influx of water and the more precipitation, the more mass and the more power to erode (Deal et al. 2018; Morgan 2005).

Coastal erosion is the form of water erosion in which the largest mass of water is active. This is controlled by the movements of a large body of water, laying in a reservoir such as a lake, a sea or an ocean, resulting in even higher kinetic energy and possibility to erode. The effect of coastal erosion is dependent on the changes in and balance of wind, wave and current patterns and energy over time, as well as the bathymetry, pressure system, Coriolis force, wave setup, exposure, gradients of the coast and sediment properties/ erodibility in the area (Dalrymple & Thompson 1977; Reineck & Singh 1980; Wright & Short 1984; Walker & Guy Plint 1992; Reading 1996; Komar 1978; The Open University 1999; Collinson et al. 2006; Andréasson 2006; Zhang et al. 2004; Malmberg Persson et al. 2016; Chaumillon et al. 2017). Generally, the sediment is transported out to sea and the coast is more gradually shallowing after a storm, due to the long storm waves (Malmberg Persson et al. 2016; Wright & Short 1984). This means that an already shallow beach is going to have less dramatic shifts in morphology and erosion after a storm than if it was steeper.

This erosion can be either acute or chronical. A**cute coastal erosion**, being a fast shift in the sediment balance due to storms and storm surges, result in a fast removal of a lot of sediments, or the coastal erosion could be a chronical process, **chronic coastal erosion**, when the changes in the system are slow, result in a slow shift of the sediment-balance and a slow erosion (Malmberg Persson et al. 2016). An example of acute erosion is shown by Labuz and Kowalewska-Kalkowska´s (2011) study in Poland, the southern part of the Baltic Sea. Here the effect of a storm in November 2004 was recorded and everything below the maximum storm surge height was eroded and lost relief, the surrounding dunes got erosion scars, and Labuz and Kowalewska-Kalkowskas (2011) could quantify the loss of sediments to 22 m^3 sand per 1 metre shoreline length. Although this is a large sediment loss during a short time and therefore has a large effect, it is important to not underestimate the effect of a chronical coastal erosion, as it can erode these amounts of sediments or more but during a longer time span (Wolman and Miller 1960). The effect of the storm surge and the possibility of erosion is dependent on for example the slope of the coast, where a steeper coastal profile (beach, foredunes, foreshore and shoreface) results in a more prominent transport of sediment from the beach and out to sea, resulting in a transition to a more gradual slope in the foreshore and shoreface and an erosion scar in the foredunes. In beaches which already have a gradual profile the change is not as prominent (Wright & Short 1984; Morton & Sallenger 2003)

For coastal erosion it is hard to estimate the mechanical preservation/**H**-value (*Equation 2*). Using pictures, sediment- and LIDAR-data, SMHI has created a map of areas with higher coastal erosion in Sweden (SMHI n.d.a) which can be used as an indication of the erosion in larger areas (SMHI 2020c). Wright and Short (1984) have developed a method of studying morphology to trace changes in the wave patterns and coastal erosion in particular areas. A study, determining the morphology according to the principles of Wright and Short (1984), has been done on one area, Halmstad, and on one occasion by Lundgren Sassner (2019), but these studies need a continuous documentation over time to track the long scale changes in the morphology and coastal erosion pattern of the particular beach (Wright & Short 1984).

2.3.3.3.3. Evaluating the Mechanically Dependent Preservation Potential

Relating the different types of erosion back to **H**-value (*Equation 2*) and mechanical preservation, there are different ways to evaluate the erosion of a terrestrial area: Woodruff and Siddoway (1965), Wright and Short (1984), Panagos et al. (2015); Deal et al. (2018) and SMHI (2020c), but they are often complex and vary depending on the dominant erosional patterns in the individual areas. It is, however, easy to make a more general interpretation of the trends based on the parametres which they define as important and describe in their models: vegetation resulting in a higher mechanical preservation potential, lower **H**-value (*Equation 2*), and protection from both wind and water erosion and the erodibility of a soil as a result of the formation of aggregates that add weight and stabilise, resulting in the need for larger velocities to erode (*Figure 6*; Woodruff and Siddoway 1965; Morgan 2005; Panagos et al. 2015; Deal et al. 2018). This means that, to some degree, the erosion can be estimated with the help of satellite images of the area, to see the vegetation cover, the maps of grain size, soil and Quaternary deposits.

These methods, important variables and theories of evaluating the mechanical preservation, **H**-value (*Equation 2*), is as relevant for storm surge deposits as any other terrestrial deposit with the main difference being the proximity to the sea and the large risk of coastal erosion removing the palaeostorm surge overwash sediments. The balance between deposition and erosion is a complex pattern as the flooding from the sea being necessary for the storm surge deposition, but also a risk, as it easily could erode some of the traces and large volumes of sediments.

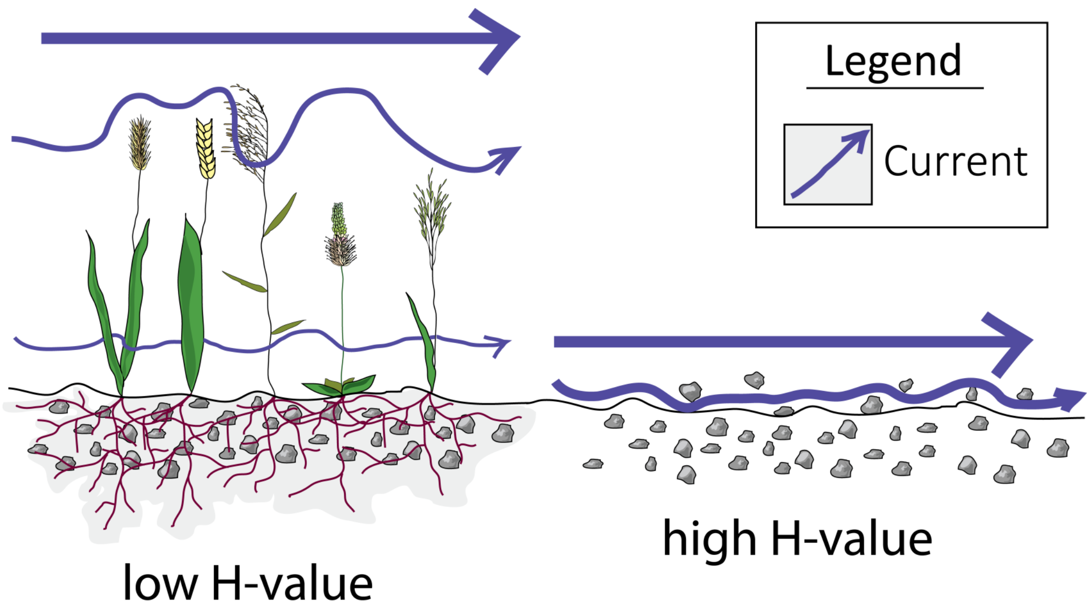


Figure 6, Illustration of how the vegetation forms aggregates and lower the velocity of the currents, resulting in less erosion and a higher mechanically dependent preservation and lower **H**-value (equation 2). Higher H-value indicates higher erosion and a lower G-value indicates less. The thickness of the current arrow is representative of the velocity. Figure by Lykke Lundgren Sassner.

2.3.3.4. Human Impact on Preservation

The human effect on the preservation in the terrestrial environment is not to be underestimated. The agricultural society affects both large scale morphology, the ecosystems, soil profiles and the erosion rate (Trimble & Lund 1982; Andréasson 2006; Hooke 2000). Because of this the human impact and historical agricultural practices and usage must be taken into account when evaluating the preservation potential.

Large differences are expected regarding both the erosion and the mixing of the sediments depending on if an area is actively farmed, grazed or left alone. There are documented enhanced erosion rates through human activity that can be related to two main factors: the clearing of vegetation to make farmlands and the management and agricultural practises in the areas (Hooke 2000). A historical and local example of this is the farming of the nutrient poor, unconsolidated and sand rich areas of Kristianstadslätten, Scania. Here some of the farming led to the removal of vegetation and aggregates thus resulting in relocation of the sand, a high local erosion and deposition in the surrounding fields (Campbell 1928; Kärrstedt & Rydiander 2018). Another example of the effect of historical practices is the ditching that occurred from the 1700s in Sweden, which negatively affected the preservation potential. This is both because previously undisturbed areas could be farmed, resulting in a mechanical mixing and erosion of previously undisturbed areas, and the lowering of the water level/Table resulting in more oxygenation, opening the possibility for more mixing species (Andréasson 2006). There is a trend of a steady increase in erosion with human population growth, until dependence on pastures decreased and the modern management practices were established (Trimble and Lunds 1982; Hooke 2000). The expectance of a higher mixing in areas that are being used and farmed is due to the turning of the soil and digging that is done for example in crop-lands or when infrastructure is established (*Figure 7*).

The effect of the historical usage and management on preservation potential can be large (Trimble & Lund 1982; Andréasson 2006; Hooke 2000). Therefore it is important to understand and examine the local historical traces, such as patterns in the landscape indicating land use, and background, to estimate the human effect on preservation potential and find areas of good preservation potential. By determining how practices have varied through time it is possible to determine within which time frame there is likely to have been more, or less, disturbances (*Figure 7*). The most disturbances are expected in areas with a lot of infrastructure and a long history of farming. Optimal conditions are expected in areas that are used as natural grazeland and left alone without impact during long periods (*Figure 7*).

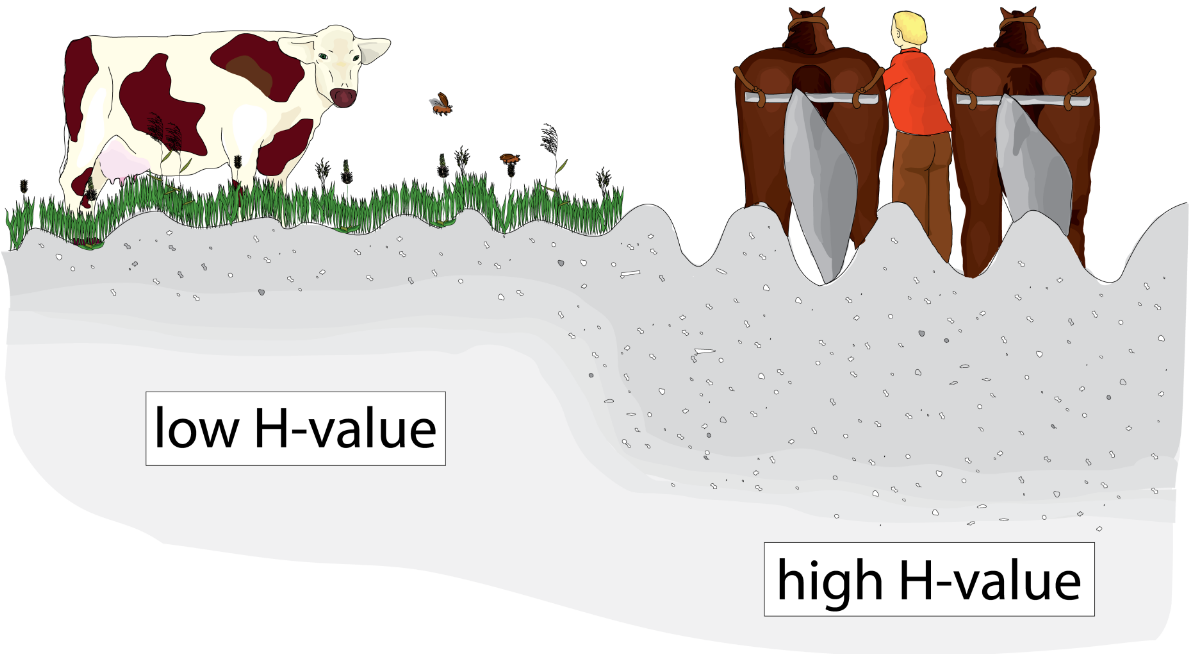


Figure 7, The differences in the estimated preservation potential-factors depending on the human disturbance and agricultural practices. The darker grey is soil that is being disturbed by mixing. A low H-value denotes good preservation, while a high H-value means poor preservation (see 1.3.3). Figure by Lykke Lundgren Sassner.

2.4. Methods of Storm Surge Identification

The study of palaeostorm surge traces is dependent on the deposition of sediments and traces and the local preservation potential, but it is also dependent on the identification and methods thereof. Studies of palaeostorms and the palaeostorm record includes studies of historical storm frequencies and flooding by the dating of storm ridges. For example, by documenting the age of different ridges in larger ridge plains, Scheffers et al (2011) showed it to be possible to observe large storms and the frequencies of these. By correlating the time interval of different ridges globally, Scheffers et al (2011) manage to make assumptions about the general periodicity of large storms. These showed variations depending on storm patterns, with a periodicity of 150-300 years in tropical storm-dominating areas and intervals from decades to somewhat over 100 years periodicity in the extratropical-dominating and high latitude areas, such as Sweden, though some caution of the results of these studies should be taken. As older and younger material gets mixed in the ridges it gives some marginals of error regarding the ages, and there is a risk of underestimating the frequency, as the archive is poor or lacking smaller storms or traces of storms whose landforms has later been eroded by larger storms (Scheffers et al 2011). Similar studies with the same methodology have been conducted earlier by, for example, Nott et al. (2009), who evaluated frequency of palaeostorms by dating and evaluating a series of storm berms along the coast of Australia and found evidence for the continuity of strong cyclones back to 6 000 years BP.

A more local study of storm ridges is the experimental study by Clemmensen et al. (2014) along the eastern coast of Denmark. Here they studied historical maps to trace the progradation of the coastline as well as documented changes to it and analysed ridge morphology to locate good sampling areas. On these they used a ground-penetrating radar (GPR), to trace the large structural changes in the coast, took sediment samples and did an OSL-analysis to correlate the formation of particular storm berms and washover fans to a specific storm event (Clemmensen et al. 2014). Using this methodology Clemmensen et al (2014) managed to correlate the formation of the sampled wash over fan and storm berms to an 1872 storm surge.

Another method of analysing storm surge sediments and traces is by looking at differences in clast-sizes and geochemical traces (Swindles et al. 2018). Swindles et al. (2018) studied the palaeostorm effect in a salt marsh in Holkham, UK, and could find a clear layer, where the fine marsh sediments were abruptly cut by deposition of coarser sand sizes. This unit also showed an abrupt change in the geochemistry, with a high increase of silica. They could relate this unit to deposition of sand from a storm surge, and by isotope dating with ^{137}Cs determine it to a storm event 1953. A similar study was later done in the Baltic Sea by Moskalewicz et al. (2020) in Gdansk bay, Poland, where extensive field examination was followed by the collection of three sediment cores on which a grain size, isotope and diatom-analyses was done. By doing this they managed to identify storm surge sedimentations, small units of high siliciclastic sandy content and sometimes an erosive lower boundary which they dated with the isotopes. The diatoms were in this study used to indicate changes in the ecosystem and corresponding environment (Moskalewicz et al. 2020).

Goff et al. (2012) provides a good summary of the different methods of identifying palaeotsunamis. As these are similar to palaeostorm traces it is possible to use the same methods of detecting these sediments many include the methods described from the aforementioned studies. The methods of determination of storm surge sediment are for example: geological (grain sizes, magnetic susceptibility and magnetic properties), chemical (trace element and biomarkers), geomorphological or biological (micro- and macrofossils). Depending on the location and sediments, different proxies must be applied. In areas where no sediment is deposited the biological and chemical traces can be invaluable but in areas of more sedimentary deposition the geological and geomorphological proxies may have the most importance (Goff et al. 2012). Although other proxies are used the study of fossils, such as diatoms, foraminiferas and ostracods, can be beneficial. They provide information about the environment in which they grow and can therefore allude to the origin of certain units and changes in the environment of the sampled area (Goff et al. 2012; Dura et al. 2016).

3. Method of remote mapping and field study

3.1. Remote Mapping

3.1.1. Part 1, Locating Possible Areas

The conclusions and theories from the literature study ("2. Theoretical background") were used to map the locations of possibly preserved palaeostorm surge sediments. For the remote mapping, publicly accessible datasets in the computer program Google Earth Pro, the search motor Google maps and the Quaternary deposits maps from SGUs, Sweden's Geological Surveys (2016) were used.

The conclusions from the literature study were used to map the locations of possibly preserved palaeostorm surge sediments. For the remote mapping, publicly accessible datasets in the computer program Google Earth Pro, the search motor Google maps and SGUs, the Geological Survey of Sweden (2016) quaternary deposits maps were used.

The whole coastline of Scania, Blekinge and Halland was remotely mapped, for possible palaeostorm surge traces that could be preserved, in Google Earth Pro and during this process the most promising areas regarding exposure to the sea and occurrences of peat was graded in a Microsoft Excel sheet according to *Table 1*, from 1 (very bad) to 5(excellent) on the defined requirements, which are:

- **Contact/exposure to the sea**: This was evaluated in the computer program Google Earth Pro and is defined by the possibility for sediments, in this case the palaeostorm surge overwash sediment, to be deposited. In areas where there are poor exposure to open water such as areas protected by islands, embayments or long fjords, some of the surge forming processes, the Ekman currents and the wave setup will be more limited. This is because the wind has lower fetch, resulting in less wave energy close to the coast and therefore lower possibility for a local sea level rise due to wave setup, as discussed in "2.1.1. Wave Setup" (Mao & Heron 2008). The Ekman current will vary mostly depending on the density of the water and air as well as the wind current acting on the sea surface as discussed in "2.1.2. Ekman Current". This means that a smaller fetch, by for examples islands and embayments, will mostly affect the wave setup and not the Ekman current (see "2.1.2. Ekman Current"; Mao & Heron 2008). It could, however, have an effect on the Ekman current too, as the velocity of the wind current will become lowers because of the resistance of the obstacle, such as an island, using the same principles as when the vegetation lower the wind speed (see "2.3.3.3. Mechanically dependent Preservation"). The lower velocity of the wind will give a lower wind stress and weaker Ekman current. By giving the locations a value of the exposure to open water it should, according to these principles, be possible to determine the probability for both strong a wave setup and Ekman current that give a large storm surge. The values have been given according to:
    1. A confined embayment, long fjord or/and directly behind an island
    2. Somewhat behind an island or in a long but open embayment
    3. Some distance from/behind an island or in a semi -open embayment
    4. In an open embayment or far from the island and
    5. Completely unprotected from the sea/ocean.

- **Impact by infrastructure**: this was evaluated using Google Earth Pro and is a measurement of the possible human impact on preservation potential. As described in "2.3.3.4. Human Impact on Preservation Potential" infrastructures can be seen as an indication of a human induced mixing by for example digging and farming. This is also graded from 1 to 5 where:
    1. No impact of infrastructure
    2. Some smaller roads close to the area
    3. Larger roads close to the area and some houses
    4. Proximity to a village or industry (such as harbour)
    5. In close proximity to a town or large industry (such as harbour).

- **Historical remains/ traces**: this was evaluated using Google Earth Pro and is a first evaluation of the human impact on preservation in a more historical sense (as described in "2.3.3.4. Human Impact on Preservation Potential"). This includes historical remains such as houses as well as the parcels and ditches seen on the satellite documentation.

- **Sediment/Soil type:** a general interpretation of the soil along the coast was done based on SLU (2020) and a site-specific evaluation of quaternary deposits was done with the help of the SGUs (2016) quaternary deposits map. The site-specific quaternary deposits evaluation was documented in a Microsoft excel sheet, *Table 1*, and the preservation potential of both the quaternary deposits and soil was evaluated according to “2.3.3.2.1. Soil as an Indicator” and “2.3.3.3. Mechanically dependent preservation”. SGUs (2016) quaternary deposits map was also used in order to locate peat lands, where the preservation potential is expected to be high (“2.3.3.2.1. Soil as an Indicator”; “2.3.3.3. Mechanically dependent Preservation”.)

- **Vegetation:** was evaluated using Google Earth Pro. In this section the absence and the presence of vegetation should be noted as well as if it is higher vegetation (trees), intermediate (bushes) or lower vegetation (grasses). The presence of vegetation gives higher resilience to erosion as described in “2.3.3.3. Mechanically dependent Preservation”, but the presence of trees might also indicate that the area is or has recently been used for forestry. This is something to bear in mind during the evaluation.

- **Gradient of the slope/ topographic cross-profile:** this has an effect both in regard to if there might be a catchment area, such as lake, terrace or other depression, and to how the waves interact with the coast and form the storm surge, as described in “2.1.1. Wave setup”, and the probability for erosion, as described in “2.3.3.3. Mechanically dependent Preservation”. The topographic cross-profile was checked in the computer program: Google Earth Pros transect tool, the precision of which is unknown, and a gradient was calculated using the equation:

$$\frac{Height\ differance\ in\ transect}{Width\ of\ transect} * 100$$

Other than the evaluation explained , the site’s position in WGS84dec with a metre precision, was determined in Google Maps. This was then transformed to the Swedish standard coordinate system SWEREF99TM using Lantmäteriet (n.d.a,). All the data was entered in a Microsoft Excel sheet, *Table 1*.

Table 1, The excel-sheet which was used when determining the deposition and preservation possibilities for the sediment and what to enter in each slot. For the once graded between 1 and 5, 5 is the best and 1 is the worst. Table by Lykke Lundgren Sassner.

Part 1, remote mapping										
	Location	**Coordinate**	**Exposure to Sea**	**Impact of Infrastructure**	**Historical remains**	**Sediment type**	**Vegetation**	**Gradient (%)**	**Other information**	**Number in map**
COUNTY	*Name of location*		1 to 5	1 to 5	Any finds?	what type of sediment?	Any vegetation? High or low?	The slope of the coast	Anything els worth noting?	A number on a larger map.

3.1.2. Part 2, Historical Background and Protection of Localised Areas

The historical background of the areas was based on historical documentation such as: "*Ekonomiska kartan"* and *"Häradsekonomiska kartan"*, maps of economic interests, *"Generalstaabens karta"*-maps, showing the larger morphologies of the areas, along with *"Laga Skifte*"-documents, "*Vattenåtgärd*"-documents, "*Geometrisk avmätning*"-documents, "*Mätning*"-documents and "*Utstakning av gräns*"-documents, informing about ownership and historical man-made changes to the environment. All these maps and documents came from Lantmäteriets (n.d.b,) databases. A full inventory of the maps used can be found at the end of the reference section.

The purpose of the historical documentation is to evaluate the human impact on preservation. By looking at what the area has been used for (farming, grazing, settlements, forestry, etc.) during different intervals, it is possible to estimate which periods should have been disturbed by the human induced mixing and erosion, explained in "2.3.3.4. Human Impact on Preservation". If there are documentation of farming, old settlements and a lot of human-introduced changes within a certain interval, the probability for disturbance within these intervals, as well as some time before, is high. In the same way, periods of grazing or when the area has been left alone with little or no human introduced changes, result in less disturbance and a higher preservation potential (see "2.3.3.4. Human Impact on Preservation").

LIDAR data was collected from ©Lantmäteriet and processed in Arcmap 10.5.1 to further study the topography and structures of the areas. This was done as a complement to part 1, with the gradient and the topographic cross-profile from Google Earth Pro and as an aid in finding the best areas of possible catchments for palaeostorm surge overwash sediments.

Lastly, the natural conservation protection had to be established to know what kind of permits would be needed for sampling. This was done with the help of Naturvårdsverkets (n.d.) web map of natural conservation protection. In the cases when this map was not enough detailed the location was searched for on the search engine: www.google.com with the key words "*naturskydd*", "*naturreservat*", "*Natura2000*" and "*regler*". The extra literature included: Ahnlund & Mascher (2017), Länsstyrelsen Halland (2020a), Länsstyrelsen Halland (n.d), Länsstyrelsen Skåne (n.d.), Länsstyrelsen Halland (2020b) and Naturvårdsverket (n.d.).

All the data of the second part of the remote mapping was summarised in a Microsoft excel-sheet according to *Table 2*. The final evaluation was done based on the evaluation of part 1, *Table 1*, and part 2, *Table 2*. The purpose of this summarised evaluation was to locate where the deposition, as well as preservation potential, and therefore possibility of preserved palaeostrom surge overwash traces, was the highest. The area/areas that showed the most promising potential for preserved surge sediment preservation and sampling was chosen and one of them was studied in the field study.

Table 2, The Microsoft Excel-sheet and what to enter in the different columns/what to answer for part 2 of the remote mapping and the final evaluation. Table by Lykke Lundgren Sassner.

Part 2, remote mapping							
Location		**Coordinate**	**Historical documentation**	**LIDAR observations and historical Generalstaabens maps**	**Nature conservation protection**	**Final evaluation**	**Number in map**
C O U N T Y	*The name of location*		Any historical land uses documented? Human changes? Any digging and infrastructural traces that are documented?	Anything new found in the LIDAR and the Generalstaabens maps? Any chatchment areas? What is the character of the landscape?	Is the area protected by any legislation? Is a permit needed for sampling?	What is the final evaluation of the area? Is there a possibility for palaeostorm surge overwash deposition? Should there be a good preservation considering the observations here and in part 1?	A number on a larger map.

3.2. Field Study

Skummeslöv strand, N6261212 E372373 (SWEREF99TM) with metre precision, was the first choice, as the human impact is estimated to be low and there is evidence of a deposition in a washover fan from the satellite pictures of Google Earth Pro. Due to travel restrictions because of COVID-19 and bad weather conditions, an area closer to the department had to be chosen. Dalköpinge Ängar, N6136373 E387216 (SWEREF99TM) with metre precision, was the final choice for the field study. This area is a wetland and should therefore have a good preservation potential according to the discussion in "2.3.3. Principles of Preservation" and as the other areas identified in Scania are protected by Natura2000-legislation, see *Appendix 2*, Dalköpinge Ängar was the only possible locality were a permit could be given within the time frame of the thesis. The area is protected as a nature reserve but after contact with Länsstyrelsen, a permit was given.

After the area had been chosen it was visited on January 22, 2021, and four cores were taken with a Russian corer, 10 centimetres in diameter and 1 metre long, and brought back to the department. Their coordinates were marked out with a Garmin GPS eTrex Vista C and about 3 metres precision. These cores were taken along two transects of around 5 meters, one in a north/north-eastern and one in an east/north-eastern direction, in different parts of the coastal wetland. The areas were chosen in field with the criteria of sampling in a wetland, where preservation should be good, and different parts of the wetland, to trace if there is a general trend and variations within the area.

The cores were described both briefly in field and in more detail in the laboratory. During the descriptive study of the cores the composition, minerogenic content, form of gyttja and organic content, was described as well as the occurrences of shells, colours of the core and transitions between units. Distinctive attributes, such as sulphur smell or an uneven transition to the upper unit, was also noted in this descriptive study. These were used to differentiate the cores into separate units with different composition, shell content and colour. The different units of the cores were correlated within the transects to estimate how they could be traced laterally.

Since there was no unit of higher minerogenic/sand content visible, a more biological proxy dependent method was applied. As a part of the first biological overview, larger shells were collected within different intervals and identified to species using Gärdenfors et al. (2004) and Artfakta (n.d.a). This was done to determine which core should be further studied.

After the initial description and correlation, one core was chosen (T1B1) as it contained a find of a bristle worm (Polychaeta), a possibly brackish/marine find, as the majority of polychaeta is marine (Glasby & Timm 2008). The core was 80 centimetres and a loss on ignition (LOI) analysis was performed at every 5 centimetres, in accordance with Heck and Rogers (2013) and Heiri et al. (2001), to see if any unit with more sand was missed and to trace compositional trends. A problem with operating the oven occurred during the first heating to 105°C, as the oven reached 380°C. The problem was, however, spotted early, and the oven was switched off. When comparing the LOI results with the weight changes during the heating during the sample preparation for foram sampling (see below), no difference could be observed. Therefore, the oven incident is concluded to have had only a marginal influence on the LOI data.

Foraminifera samples were taken at every 5 centimetres and analysed for shells and foraminifers. The samples were first dried at 105°C over night after which they were heated to 450°C for 4 hours in order to remove organic matter and make it easier to see and determine the shells and foraminifers. The samples were studied in a stereo microscope and the shells were defined to species using Gärdenfors et al. (2004) and Artfakta (n.d.a). No foraminifers could be found. The habitat restraints with regard to salinity for the organisms identified were taken from the Artfakta (n.d.a) database. As there were no foraminifers, four diatom samples were taken at intervals of 2.5 centimetres in and around the area of large LOI change 35-40 centimetres from the bottom. Because no quantitative analysis was attempted, and due to time constraints, the samples were not treated chemically but only dispersed in de-ionised water and studied under a microscope at a magnification of up to 400 magnification. This procedure hampered species identification, and therefore the results should be interpreted with caution. Nilsson (1968a), Nilsson (1968b) and National History Museum Wales (n.d.) were used to determine the species of the diatoms and the names were checked in algaebase (n.d.) to get updated species groups and names. The salinity requirements of the identified bivalves, gastropods, diatoms, stoneworts (*Chara*) and waterflees (Cladocera) were taken from Nilsson (1968a), Nilsson (1968b) along with Glasby and Timm (2008) and the Artfakta (n.d.a) database.

After these procedures were conducted for core T1B1, a LOI analysis was done on the long core of the other transect, i.e. core T1B4. This core was 78 centimetres and sampled every 5th centimetre, in the same way as for core T1B1, using Heck and Rogers. (2013) and Heiri et al. (2001), to trace if the patterns were similar.

At 27-38 centimetres from the surface in core T1B1, a prominent change in ecosystem and content could be seen and a sample for ^{14}C dating was taken at this depth 1. To avoid any contribution of dissolved C taken up from the water, terrestrial plant remains (one *Carex* seed, unidentified seeds, and moss stems) were identified under a stereo microscope and submitted to Lund University Radiocarbon Dating Laboratory. The reported ^{14}C date was calibrated with the CALIBomb software (Reimer et al. 2004), using the NHZ1 post-bomb calibration data set (Hua et al., 2013), as it showed a ^{14}C activity above the level in 1950, when atmospheric nuclear bomb tests started. In order to find documentation of storms occurring at the time indicated by the radiocarbon dating result, searches were made with the search engine Svenska dagstidningar (n.d.).

Sediment samples were taken at different depth intervals, 38-53 and 70-82 centimetres, on a coast parallel ridge at the beach. The grain size analysis was done according to Delteus and Kristianssons (2000) second alternative, with a 15-minute washing of the sediment with 0.05 Mol $Na_4P_2O_7$ followed by sieving with a 0.063 µm sieve before drying overnight in a 105°C oven and sieved with the increments: 22.4, 16.0, 11.2, 8.0, 5.6, 4.0, 2.8, 2.0, 1.4, 1.0, 0.710, 0.500, 0.355, 0.250, 0.180, 0.125, 0.090 and 0.063 mm.

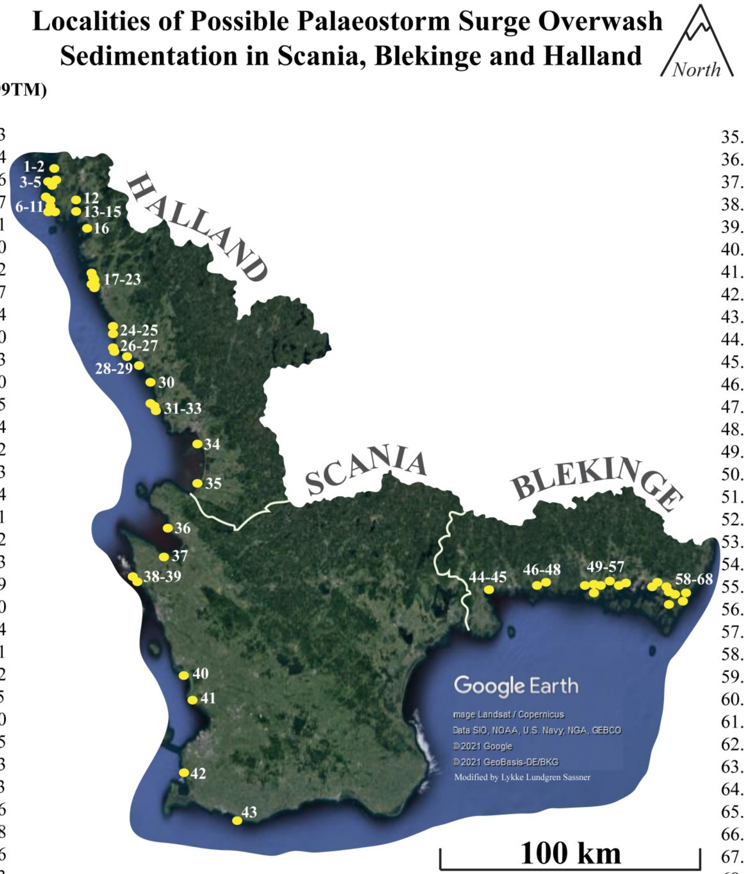
4. Results

4.1. Areas of Possible Storm Surge Traces

On the coast of Scania, Blekinge and Halland, 68 different locations partly or fully met the requirements set for storm surge preservation (*Figure 8*). Most of the locations were in Halland (34), followed by Blekinge (24), and the least number of locations were found in Scania (9).

Localities of Possible Palaeostorm Surge Overwash Sedimentation in Scania, Blekinge and Halland

Location	Coodinate (SWEREF99TM)
1. Hagen by Malevik, Northern	N6380893 E316573
2. Hagen by Malevik, Southern	N6380361 E316824
3. Stora Klev	N6377294 E317596
4. Vallda/Sandö badplats	N6375367 E315217
5. Vallda	N6374943 E316471
6. North of Gate Klova	N6370723 E314650
7. Västra Hagen	N6369274 E315482
8. South of Västra Hagen	N6368515 E315527
9. 3 km south of Västra Hagen	N6366250 E315354
10. By Onsala Rymdobervatorium	N6365424 E315240
11. 2 km North West of Runsås	N6364663 E317423
12. Torkelstorp by Hanhals	N6369344 E326620
13. Tjolöholms slott, Northern	N6365828 E326795
14. Tjolöholms slott, Southern	N6365016 E327444
15. North of Ölmanäs	N6364237 E327232
16. Between Byendal and Vassbäck	N6357780 E328773
17. South of Kärradal	N6340909 E331684
18. South of Kråkeberg, Northern	N6339398 E331881
19. South of Kråkeberg, Southern	N6339190 E332242
20. Northern of Lindhov	N6337824 E332253
21. Northern of Trönningenäs	N6337280 E331359
22. Gätteröns naturreservat, North of Varberg	N6335854 E332450
23. The coast between Björkäng and Morup, Sik	N6320236 E339564
24. The coast between Björkäng and Morup, Morup	N6317969 E339671
25. Southern of Glommen	N6312455 E339412
26. North of Olofsbo	N6311658 E340115
27. North of Falkenberg	N6308864 E345020
28. South of Falkenberg	N6305953 E349075
29. Ugglarps havsbad by Småris	N6300121 E354123
30. East of Särdal	N6291098 E355113
31. North of Haverdal	N6290133 E355946
32. South of Haverdal	N6289032 E356908
33. South of Halmstad	N6276047 E372146
34. Skummelövs strand	N6261212 E372373



Location	Coodinate (SWEREF99TM)
35. Stora Hult strand	N6244075 E361530
36. Between Farhult and Utvälinge	N6233506 E360555
37. Viken	N6225958 E348893
38. Domsten/Viken naturreservat	N6223739 E350187
39. South of Landskrona	N6190072 E369189
40. South of Saxtorps-skogen	N6188688 E369669
41. South of Barsebäck	N6179180 E372061
42. Gessie villastad strand	N6151695 E369897
43. Dalköpinge Ängar	N6136373 E387216
44. East of Pukavik, Magleholmar	N6223664 E480846
45. East of Pukavik, Nissabacken	N6224420 E481093
46. Eriksbergs naturreservat by Eriksberg	N6225508 E499885
47. Köpegårda, Gåsaviken	N6226806 E502384
48. Köpegårda, Köpegårdaviken	N6227334 E502052
49. South of Ronneby	N6225148 E517580
50. East of Ronneby hamn	N6225831 E520056
51. South of Aspan	N6223843 E520335
52. Lake by Ronneby, Bakarebodaviken	N6222796 E521002
53. Lake by Ronneby, Bredasund	N6222519 E520313
54. Sörekåsa	N6224961 E523391
55. Saltäng, by Östranäs	N6226535 E526363
56. Tromtesunda	N6224880 E529914
57. Skillingenäs	N6225995 E532629
58. Framnäs, Torpaviken	N6226758 E541867
59. Säljö	N6224813 E542559
60. Knipehall, Öljersjövikenorm surges.	N6226894 E543460
61. Färjös Eastern side	N6226037 E543018
62. Coast of Torsnäs	N6226064 E543471
63. East of Gängletorp	N6224359 E547199
64. Lillö, by Möcklö	N6222944 E548519
65. Flagen, by Stora Roms naturreservat	N6221926 E550639
66. West of Brunnsvik	N6218815 E548892
67. North of Svanhalla	N6219709 E555100
68. North of Sibbeboda	N6221819 E555816

Figure 8, The identified locations of possible storm surge sediments and traces with the names and the coordinates, unknown precision, along the sides of the map. The yellow dots are the areas that could be localised with the method. Map the map is from Google Earth Pro:Image Landsat/Copernicus, Data SIO, NOAA, U.S. Navy, NGA, GEBCO. ©2021 Google, ©2021 Geo-Basis-DE/BKG. Modifications by Lykke Lundgren Sassner.

In Blekinge, most of the locations are peatlands and often within bays and hidden behind islands or bedrock outcrops, making the exposure to the sea poor. In Scania, the locations are wetlands or sandy areas with a generally good exposure to the sea, the problem being mainly that the areas show traces of historical agriculture. The most promising areas in Scania are also protected by Nature2000-legislation or are natural reserves, making field study permits necessary to get. In Halland, the locations are dominantly sandy and, in some places, intermixed with some peat formation. The exposure to the sea as well as the impact of infrastructure vary between the different locations found in Halland. *Table 3* demonstrates how the Microsoft Excel work sheet for the first part of the remote mapping the Table being filled in for some of the more promising localities of the different counties. The coordinates are in SWEREF99TM with metre precision. For a more in-depth result, or information about all sites: see *Appendix 2*.

The second part of the remote mapping, focusing on the natural protection, historical background and finding historical data, was performed on the most promising localities. This resulted in a study of 12 areas: three in Scania and nine in Halland. During this part, the study was focused on Halland and Scania, as the exposure in the localities in Blekinge was low. There are a lot of areas with a reasonable to good probability of finding storm surge sediments, such as Skummeslövs strand, though some localities had to be re-evaluated because historical disturbance was found, such as Viken. The results are presented as short texts of interpretations under the different headings explained in "3.1.2. Part 2, Remote Mapping" and *Table 4*. *Table 4* contains a selection of three areas which turned out to be better or poorer locations for possible palaeostorm surge overwash deposition and preservation after the second part of the remote mapping according to the final evaluation. The coordinates are presented in SWEREF99TM with metre precision. For the full Table of all locations, see *Appendix 3*.

Table 3, Some of the more promising areas from the different counties, where there is a possible deposition of palaeostorm surge overwash sediments and traces which could have been preserved. The coordinates are in SWEREF99TM, with meter precision. The full Table can be seen in Appendix 2. The number in map is referencing Figure 8.

Location			Coordinate, SWEREF99TM	Exposure to Sea	Impact of Infrastructure	Historical remains	Sediment type	Vegetation	Gradient (%)	Other information	Number in map
HALLAND	*The coast between Björkäng and Morup*	*Sik*	N6320236 E339564	5	2	traces of fences, probably from farming	sand intermixed with peat	low	0.6	Permanent to semi-permanent lakes in the area	23
		Morup	N6317969 E339671	5	2	traces of fences, probably from farming	sand intermixed with peat	low	0.2	Permanent to semi-permanent lakes in the area	24
	Skummelövs strand		N6261212 E372373	5	3		sand	low	2.1	Evidence of breaching of dunes and deposition in washover fans evident on Google Earth Pro	34
SCANIA	*South of Saxtorps-skogen*		N6188688 E369669	5	2		sand	low	1.9		40
	Dalköpinge ängar		N6136373 E387216	5	4		sand and fen-peat	low	to the ramp- 12 on ramp- 0.0		43
BLEKINGE	*North of Sibbeboda*		N6221819 E555816	3	2		gyttja	low	1.3		68
	East of Pukavik	*Nissabacken*	N6224420 E481093	3	2	historical remains	fen peat	low	1.9		45

**5 is high and 1 is low*

Table 4. The final evaluation of three selected sites, one in Halland and two in Scania. The first site, Skummelöv, is the best regarding possible findings of palaeostorm surge overwash deposits, the third site, Dalköpinge Ängar, has some indication of humans changing the environment and the second site, Viken, has the worst chances of finding traces of storm surge sediments, as there has been extraction of sand and gravel. The number in the map refers to the map in Figure 8. The coordinates are in SWEREF99TM with meter precision. The full Table is attached in Appendix 3.

Part 2, remote mapping							
	Location	**Coordinate SWEREF99TM**	**Historical documentation**	**LIDAR observations and historical Generalstaabens maps**	**Nature conservation protection**	**Final evaluation**	**Number in map**
HALLAND	*Skummelövs strand*	N6261212 E372373	The old documentation from the map: *Häradsekonomiska kartan, 1919-25, Skottorp J112-2-72*, show that: at the beginning of 1900, most of the present day town was farmed land and some of the more coastal parts of the present day town as well as the beach was unaffected by farming. During the mid-1900: the map: *Ekonomiska kartan, 1968, Skummeslöv J133-4C2e70*, demonstrates that there was small houses being built along the coastal road onto the previously untouched beach.	On the LIDAR there are three clear ridges following the coast, behind which there are irregular mounds. These show patterns similar to those presented in *Clemmensen et al. (2014)* and where they found paleostormsurge sediments. Further inland there are planar and undulating features. The map: *Generalstabskartan, 1867, Halmstad J243-13-1*, from 1867 only show the land as low lying with no clear topography	This area has no natural protection though the more northern part of the beach is protected by a "Natural reserve" and the more southern areas has "Plant and animal-protection" (Naturvårdsverket, n.d.).	*This area seems to be largely unaffected historically and today from human disturbances. There could be problems in that te area with similar washover fan-shapes as other studies have infrastructure on it and only the very closest area to the sea is free to sample and free from disturbance. There should be good archives of palaeostorm surges. <u>A very good potential!</u>*	34
SCANIA	*Viken*	N6225958 E348893	From documents dating back to 1737: *Geometrisk avmätning, 1737, Vikens socken Viken nr 1-94*, there are information of the area being part of the outmark and therefore grazed. The soil was described as sandy and rich in boulders. From the early 1800 the document: *Mätning, 1800, 12-VIK-266*, show that the area weren't farmed during this period. During the late 1800 there is documentation: *Utstakning av gräns, 1899, 12-VIK-64*, of the coast being used as a gravel pit and an area to collect sea weed and sand. The documentation from the beginning of the 1900: *Häradsekonomiska kartan, 1910-15, Kulla gunnarstorp J112-1-6 1*, demonstrates that the area wasn't farmed but there was small roads passing in the close surrounding. The maps from the mid-1900: *Ekonomiska kartan, 1969, Viken J133-3B5j71* and *Ekonomiska kartan, 1969, Lerberget J133-3B6j72* also demonstrates that the area has never been used for farming.	The LIDAR show that the landscape has two large terraces, the first along the coast and the second some hundred of meters inland. These are very flat and on the most landward one there are clear squares and rectangular fields. There is a coast parallel ridge and depression. The general map: *Generalstabskartan, 1861, Ängelholm J243-8-1*, show the landscape as flat.	There is no natural protection of the area according to Naturvårdsverket (n.d.)	*The gravel and sand extraction during the late 1800 would result in a very high disturbance of the sedimentary structures and inability to find older preserved storm surge sediments. More modern storm surges could be found here. It is <u>a poor area.</u>*	37
	Dalköpinge Ängar	N6136373 E387216	The documentation from 1910-1915: *Häradsekonomiska kartan, 1910-15, Trälleborg J112-1-69*, show that the area was divided into parcels but not farmed. On the Economic map from 1968-1969: *Ekonomiska kartan, 1968,69, Gislövs läge J133-1C7h70*, the area is marked as a shooting range as well as a wetland. According to Länsstyrelsen Skåne (n.d.) the area has been grazed for hundreds of years and possibly not ever been farmed, though this theory don't explain the straight ditches and squares/rectangles that is visible through LIDAR.	The LIDAR show that there are some coast parallel ridges but the most dominant feature is the strait ditches that form rectangles and squares in the landscape. The landscape is flat, as is evident from older documentation too: *Generalstabskartan, 1864, Ystad J243-2-1.*	The area is part of the natural reserve: Dalköpinge Ängars Naturreservat (Naturvårdsverket, n.d.).	*This area is probably more disturbed than Länsstyrelsen Skåne (n.d.) writes as there are clear strait structures on the LIDAR, resulting in a poor archive for longer period. Although that this is <u>a possible area</u>.*	43

4.2. Theoretical Differences in Preservation Potential Along the Coast of Scania, Blekinge and Halland

The climatic variations between Scania, Blekinge and Halland are mostly precipitation-related, with more rain in Halland than Scania and Blekinge (SMHI 2020b). This should, as discussed in "2.3.3.3. Mechanically dependent Preservation", result in larger erosion through precipitational and fluvial erosion (Panagos et al. 2015; Deal et al. 2018). The roughness as well as the wetness and vegetation will vary depending on the local environment and it is hard to determine a general trend. Therefore, it needs to be determined individually for all locations.

It is possible to make assumptions about the general preservation potential, based on section "2.3.3. Principles of Preservation", on the soils along the Swedish coast which are described by SLU (2020). When looking at the documentation of the soils along the coast of Halland there is a general trend, where the northern areas are lentosols, middle are arenosols and the most southern areas are regosols (SLU 2020). In Scania, the regosols of Halland continue to Laholmsbukten after which they are followed by a small area of Cambisols until the northern part of the Hallandsås horst. From the horst to around Kivik, there is no documentation of soils. The rest of the coast, from around Kivik to the border of Blekinge, consists of arenosols (SLU 2020). In Blekinge, the trend of arenosols continue almost all the way to Karlskrona, with a small inclusions of histosols around Pukavik. To the east of Karlskrona there are mostly regosols with some smaller areas of arenosols (SLU 2020).

According to IUSS Working Group WRB (2015) the **leptosols** are shallow soils, rich in gravel and coarse clasts, with only 20% finer material. This soil is common in mountainous areas with a lot of bedrock outcrops and the organic zone is defined as very limited (IUSS Working Group WRB 2015). As these soils are immature with a shallow organic zone, the biological activity should be low, minimizing the depth and intensity of the bioturbation. In that aspect these soils have a good bioturbation dependent preservation potential for possible storm surge sediments and a low **G-**value (*Equation 1*). There are problems in that the sediments are prone to erosion when they are not bound up by vegetation according to IUSS Working Group WRB (2015), resulting in a high risk for the possible storm surge sediments to erode, a lower mechanical preservation potential and higher **H-**value (*Equation 2*).

Arenosols are a sandy soil, commonly found in sandy deposits of all ages, such as dunes. They are fairly homogenous or have deep horizons (IUSS Working Group WRB 2015). From the description of IUSS Working Group WRB (2015) it appears that the vegetation and organic matter is very limited, resulting in a good bioturbation dependent preservation potential and a low **G**-value (*Equation 1*). The properties of the soil, with unconsolidated sand, is at high risk of erosion both from the sea and wind unless there are vegetation that holds the unconsolidated sediment down and forms aggregates (IUSS Working Group WRB 2015) making the mechanical preservation potential low, with a high **H-**value (*Equation 2*).

Regosol is a homogenous soil, with poorly developed zonation. The parent material is often fine grained and unconsolidated, and it is common in areas of active erosion and accumulation (IUSS Working Group WRB 2015). As this is a soil with poor zone formation the vegetation should be limited, resulting in very limited biological mixing to disturb the sediments and high bioturbation dependent preservation potential, low **G**-value (*Equation 1*). The problems in this soil is rather that it indicates some sort of sediment movement and it is at risk of erosion depending on the sedimentation-pattern (IUSS Working Group WRB 2015), making the mechanical preservation potential and **H-**value (*Equation 2*) either high or poor, depending on the local accumulation/erosion pattern.

The **cambisols** have, as described in "2.3.3.2. Bioturbation dependent Preservation", a generally high degree of mixing (Bornebusch, C. H. 1930; Fenton 1947) and a low bioturbation dependent preservation potential, high **G**-value (*Equation 1*). The sediments have a high organic content (Bornebush 1930), which indicate a large number of aggregates (Morgan 2005) and resistance towards erosion, resulting in a high mechanical preservation potential and low **H-**value (*Equation 2*).

The **histosol** is a soil built up of organic matter and is often related to wetlands with growth of peat: fens, bogs, mires and mangroves (IUSS Working Group WRB 2015). As the peat grows with a steady rate, the area has a constant sediment accumulation. The soil, though with some lateral and vertical variations, is known to have a high water column and acidity as well as being low in nutrient content, making it unhostile for many organisms and peatlands famous for the good biological preservation potential, low **G**-value (*Equation 1;* Painter T.J. 2001; Bragazza & Gerdol 2002; Scott 2003; Minayeva et al. 2008). The high organic content forms large aggregates which protect against erosion, making the mechanical preservation potential high and gives a low **H-**value (*Equation 2*; Morgan 2005). This results in a high preservation potential regarding both bioturbation and mechanical preservation potential and an optimal preservation area for storm surge sediments.

4.3. The Dalköpinge Ängar, Field Study.

The study site at Dalköpinge Ängar, N6136373 E387216 (SWEREF99TM) with metre precision, is a flat wetland area to the east of Trelleborg on the south coast of Scania. It is located behind the beach, around 50-100 metres from the present-day coastline, on top of a ramp approximately 1,5-2 metres above the sea level according to the Lidar data from ©Lantmäteriet and Google Earth Pros Transect tool.

The area is characterised by coast parallel ridges of sorted sand which are crossed by an old, abandoned, stream channel. The wetlands between the ridges are dominated by sedges (*Carex*), while grasses (*Poaceae*) dominate on top of the ridges. In some of the wettest areas there are standing water with reed *(Phragmites)* and reedmace *(Typha)*. The vegetation is generally low except for some smaller bushes (*Figure 9*).

The cores of the two transects were very different. The first transect, including core T1B1 and T1B2, contained numerous shells, while the second transect, including core T1B3 and T1B4, had no finds of calcareous shells (*Table 5; Figure 10*). The different units of the cores were correlated hypothetically within the transects, depending on the descriptions (*Table 5*) and is presented in *Figure 10*.

The grain size analysis preformed on the sediments from different depths in a coast parallel ridge (N 613630 & E 387073 in SWEREF99TM with three metre precision) and along the beach (N613661 E387024 in SWEREF99TM with three metre precision) show that the dominant grainsize in all samples is sand. At the beach it is well sorted and at the ridge the sediments are moderately well sorted within both depth intervals. The full results can be seen in *Appendix 4*.

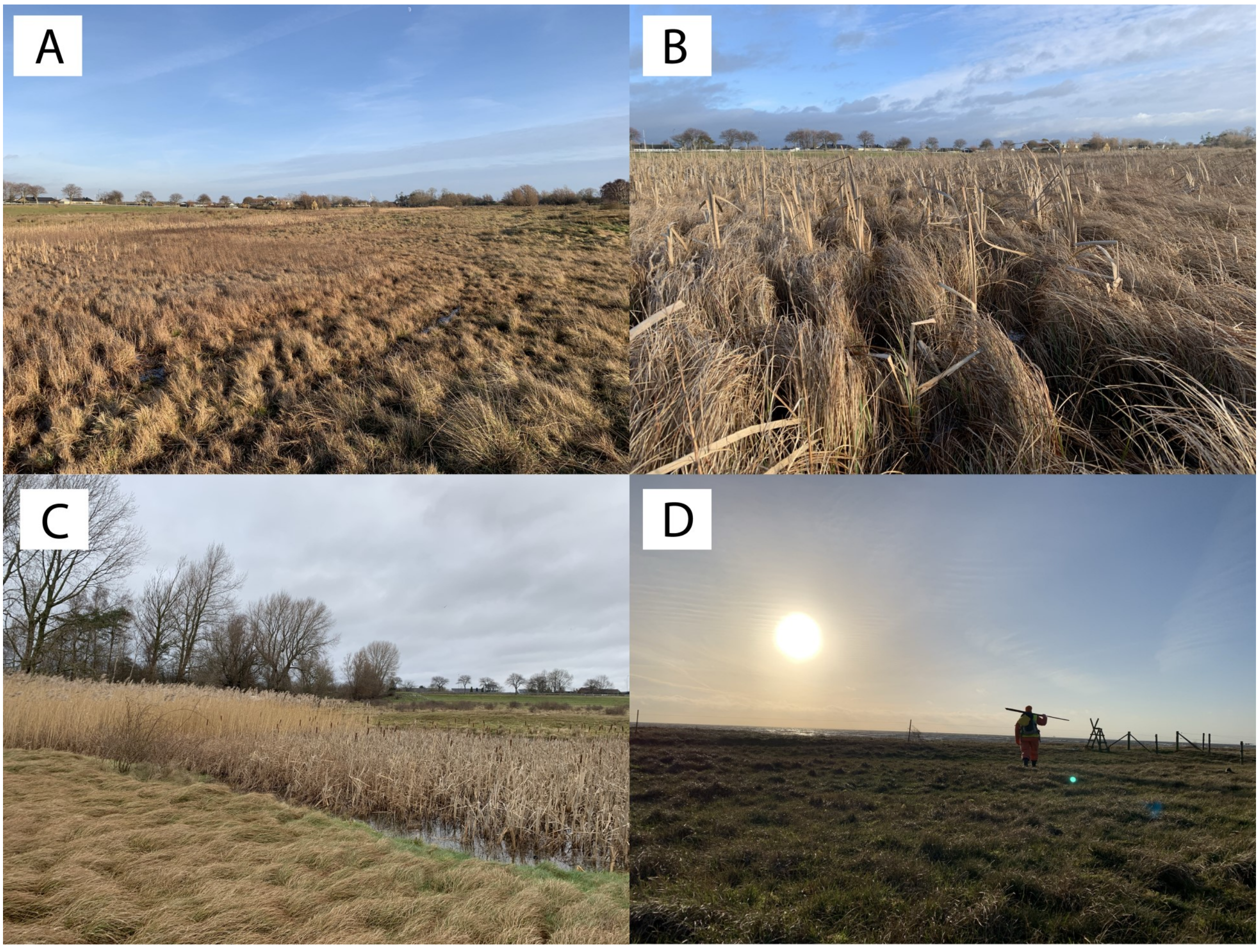


Figure 9, Demonstration of the nature at Dalköpinge ängar, from the field work 22/1, 2021. A, the open grassland, with mostly Poaceae, on the coast parallel ridges at the study area. B, the wetter areas between the ridges at the study area with more Carex and less Poaceae. C, the areas of open water in-between the coast parallel ridges, with populations of Phragmites and Typha. D, the view towards the sea as seen from the sample areas. Photos by Lykke Lundgren Sassner.

Table 5, Unit descriptions from core T1B1, T1B2, T1B3 and T1B4.

Transect 1							
T1B1				T1B2			
Unit	**cm from surface**	**field description**	**Summary**	**Unit**	**cm from surface**	**field description**	**Summary**
1	*0-21*	Phragmites-gyttja & rich in shells	*SpoFrShr*	8	*0-13*	Lose gyttja, modern plant fossils (grass, moss and roots) & rich in shells	*SpoFrShr*
2	*21-38*	Light brown/orange colour, rich in shells, rich in organic fossils (root strands & leafs). Gradual transition to upper unit.	*SpoFrShr*	9	*13-25.5*	Brown gyttja, larger organic fossils (mostly large/long roots and Phragmites) & rich in shells. Gradual transition to upper unit.	*SpoFrShr*
3	*38-49*	Dark brown sediment, rich in organic fossils (rootstrands & leafs), only a little sand, lamination around 32 cm & a litte shells. Sharp transition to upper unit.	*SpoFrShp*	10	*25.5-26.5*	Light brown gyttja, little sediment, rich in organic fossils (root strands & leaf fragment), shells present but low amount. Sharp contact with upper unit.	*SpoFrShp*
4	*49-50*	A clear gray band/lamination. Gradual transition to upper unit.	*SpoFrShpo*	11	*26.5-34*	Dark brown gyttja, low amount of sand, rich in organic fossils (root stands and moss) & one shell found. Sharp transition to upper unit.	*SpoFrShpo*
5	*50-53*	Darker brown sediment, rich in organic fossils (root strands & leafs), a little sand & sharp transition to upper unit	*SpoFrShpo*	12	*34-45*	Brown gyttja, little sediment, rich in plant fossils (root strands, Equisetum-fossil and leaf fragment). Gradual transition to upper unit.	*SpoFrShpo*
6	*53-69*	Lighter to gray/green/brown sediment, rich in organic fossils (root strands & leafs) & sediment poor. Gradual transition to upper unit.	*SpoFrShpo*	13	*45-53*	Brown gyttja, sediment rich & rich in plant fossils (fine rootstrands and leafs). Sharp uneven contact with upper unit.	*SrFrShpo*
7	*69-80*	Dark brown colour, massive structure, high sand content with more in the bottom and less in the top & larger clasts present. Sharp transition to upper unit.	*mSrFpShpo*				

Transect 2							
T1B4				T1B3			
Unit	**cm from surface**	**field description**	**Summary**	**Unit**	**cm from surface**	**field description**	**Summary**
14	*0-8.5/11.5*	Brown gyttja, rich in modern roots and grass, distict sulphursmell & little to no sand.	*SpoFrShpo*	21	*0-9*	Dark gyttja, large and non-degraded plant fossils (root strands & grass). Massive structure, only a little sediment & un-compact unit.	*mSpoFrShpo*
15	*8.5/11.5-20.5*	Orange gyttja, laminated (two bigger: 0.3 cm thick at 17 cm from the surface & 0.4 cm thick at 11.5 cm from the surface), a little sand, rich in plant fossils (root strands & leafs) & distinct sulphursmell. Sharp transition to upper unit.	*lSpoFrShpo*	22	*9-18.5*	Brown gyttja, laminated, only a little sand, rich in plant fossils (root strands, grass and Phragmites). Gradual transition to upper unit.	*lSpoFrShpo*
16	*20,5-36,5*	Lighter/orange gyttja, a little sand, laminated (darker band at 33-31), rich in larger plant fossils (root strands, grass & leafs). Sharp contact to unit above.	*lSpoFrShpo*	23	*18.5-32.5*	Darker gyttja, laminated (around 0.3 cm thick in the intervall around 21-18.5 cm from the surface), rich in plant fossils (root strands, leafs, grass and Phragmites) more sand in the bottom of this unit than the top. Gradual transition to upper unit.	*lSpFrShpo*
17	*36,5-51*	Light/orange gyttja, less sand, rich in plant fossils (root strands), lamination at 49-44 cm from the surface. Contact to upper unit is gradual.	*lSpoFrShpo*	24	*32.5-34*	Grayish gyttja, more clay rich and less sandy sediment & plant fossil present (root strands). Sharp contact to the unit above.	*SpFrShpo*
18	*51-67*	Brown gyttja, sand present, some larger clasts (0.5*0.5*0.1 cm). A dark disturbance along half of the core (around 63-56 cm from surface) rich in plant fossils (root strands). Gradual transition to upper unit.	*SpFrShpo*	25	*34-39*	Light brown gyttja, massive structure, rich in plant fossil (root strands), sediments present and some larger clasts. Sharp contact with unit above.	*mSpFrShpo*
19	*67-68*	Light sediment rich gyttja, laminated & plant fossils present (root strands, grass & Phragmites). Gradual transition to unit above.	*SrFrShpo*	26	*39-46*	Sediment rich gyttja, plantfossil present (root strands & leafs) & larger clats (0.5*0.5*0.5 cm) present. Gradual transition to unit above.	*SrFpShpo*
20	*68-78*	sand-rich gyttja, large clasts present (0.5*0.5*0.5 cm), plant fossils present (root strands, grass & Phragmites), somewhat laminated unit. Sharp contact to the upper unit.	*lSrFpShpo*				
Description for summaries: l: laminated, m: massive, Sr: sand rich, Sp: sand present, Spo: sand poor, Fr: plant fossil rich, Fp: plant fossil present, Fpo: plant fossil poor, Shr: shell rich, Shp: shell present & Shp: shell poor							

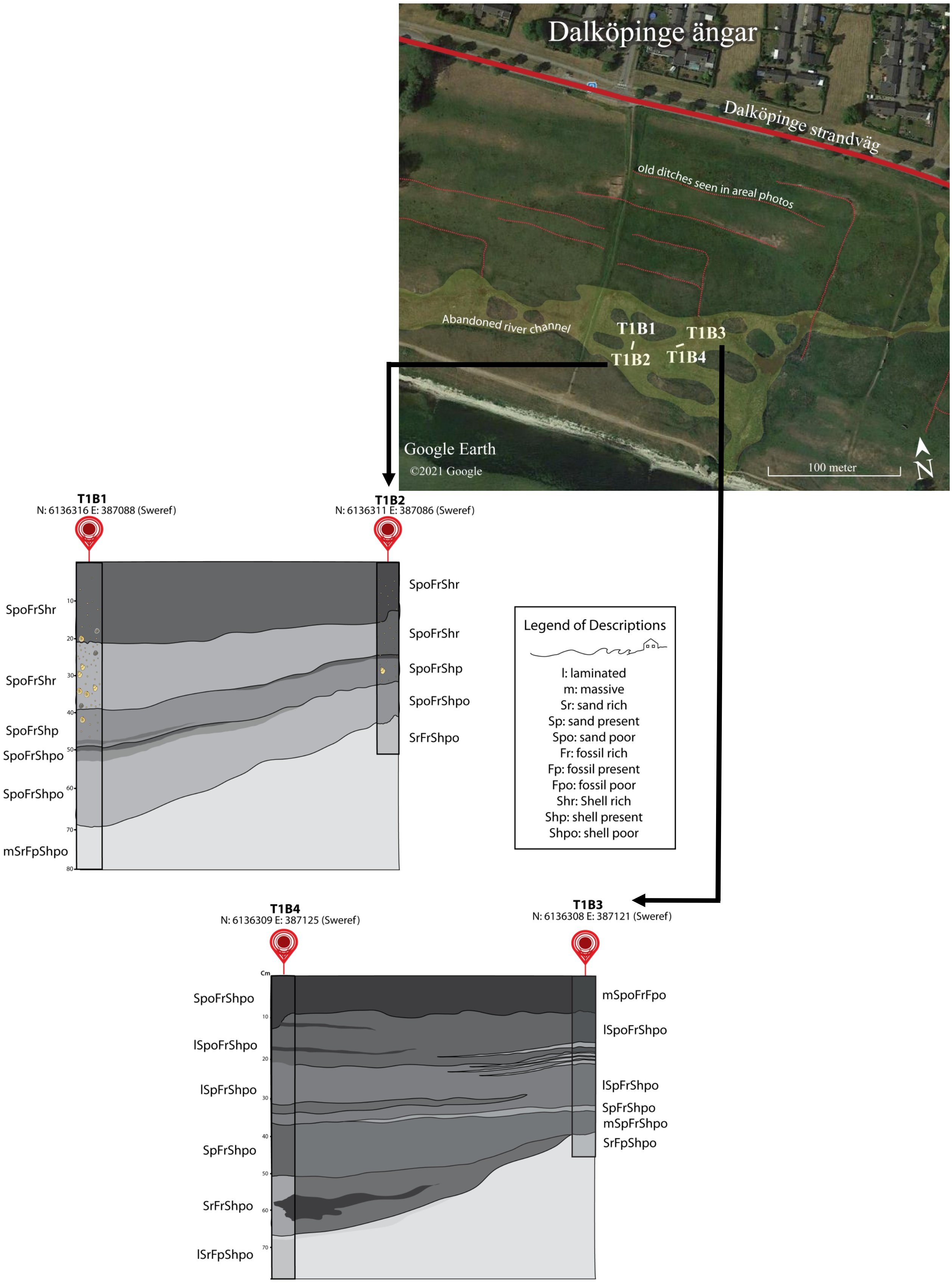


Figure 11. The composition of the deposits in core T1B1 and T1B4 as shown by LOI data. The location of the ^{14}C sample and the calibrated dating result is also presented. Figure by Lykke Lundgren Sassner.

The Loss on Ignition (LOI) data showed a large difference in the composition of the different cores, with core T1B4 having a generally larger minerogenic content than core T1B1. In core T1B1, there was a larger carbonate content, rising quickly between 40 and 35 centimetres from the surface, and with a gradual increase in the organic content from around the same interval (*Figure 11*). In core T1B4 there were only small amounts of carbonates, a few percent, but there was a quick increase in the organic content at the interval 35 to 30 centimetres from the surface and then a final increase between 10 and 0 centimetres from the surface (*Figure 11*).

The ^{14}C analysis of the sediment at 36-37 centimetres from the surface in core T1B1 gave a radiocarbon age of 1.142±0.005 fM (LuS 16760). Calibration results in two possible ages, one on each side of the bomb pulse peak, and the calibrated age is either AD 1957-1958 or AD 1990-1993 (*Appendix 5*). The age interval in the 1950s, however, only represents a minor part (8%) of the probability distribution of the calibrated age at the 95% probability level and is therefore less likely to represent the true age of the event.

The first study of the macro species, which were found during the initial description of all cores, showed that the same species of bivalves and gastropods occur in T1B1 and T1B2 (*Figure 12*), with the exception of a singular find of a Polychaeta jaw in the T1B1 core.

The result of the calcareous macrofossil study and study of calcareous organisms > 63µm of the T1B1 core is presented in *Figure 12*. There are occurrences of gastropod species with habitats ranging from brackish to freshwater as well as species which live only in freshwater environments (Artfakta n.d.c; Artfakta n.d.d; Artfakta n.d.e; Artfakta n.d.f; Artfakta n.d.g; Artfakta n.d.h; Artfakta n.d.i; Artfakta n.d.j; Artfakta n.d.k). The species which are defined to have brackish to freshwater habitats, i.e. *Bathyomphalus contortus, Gyraulus crista*, *Stagnicola palustris, Bithynia sp.,* and *Radix sp*., are marked as a combination of fresh and brackish environments since they, although they are common in the freshwater system, to some degree are tolerant to salinities which can occur in the Baltic Sea. *B. contortus* and *G. crista* can be found at up to 3‰ salinity, *S. palustris* can be found at up to 6‰, *Bithynia tectaculata* tolerates up to 12‰ and *Radix balthica* can be found at up to 14‰ (Artfakta n.d.c; Artfakta n.d.d; Artfakta n.d.e; Artfakta n.d.f; Artfakta n.d.h; Artfakta n.d.i; Artfakta n.d.j; Artfakta n.d.k). The species *Planorbis planorbis* is the only species which lives only in freshwater, of the ones found in the core (Artfakta n.d.g). Polychaetas live in environments varying from marine to freshwater, though they are primarily in the marine environment according to Glasby and Timm (2008). Ostracods as well as *Chara* can also be found in marine to freshwater environments (Artfakta n.d.l; Artfakta n.d.m). The *Pisidium* genus only includes freshwater species (Artfakta n.d.b). The list of species and intervals of occurrence is shown in *Figure 12*.

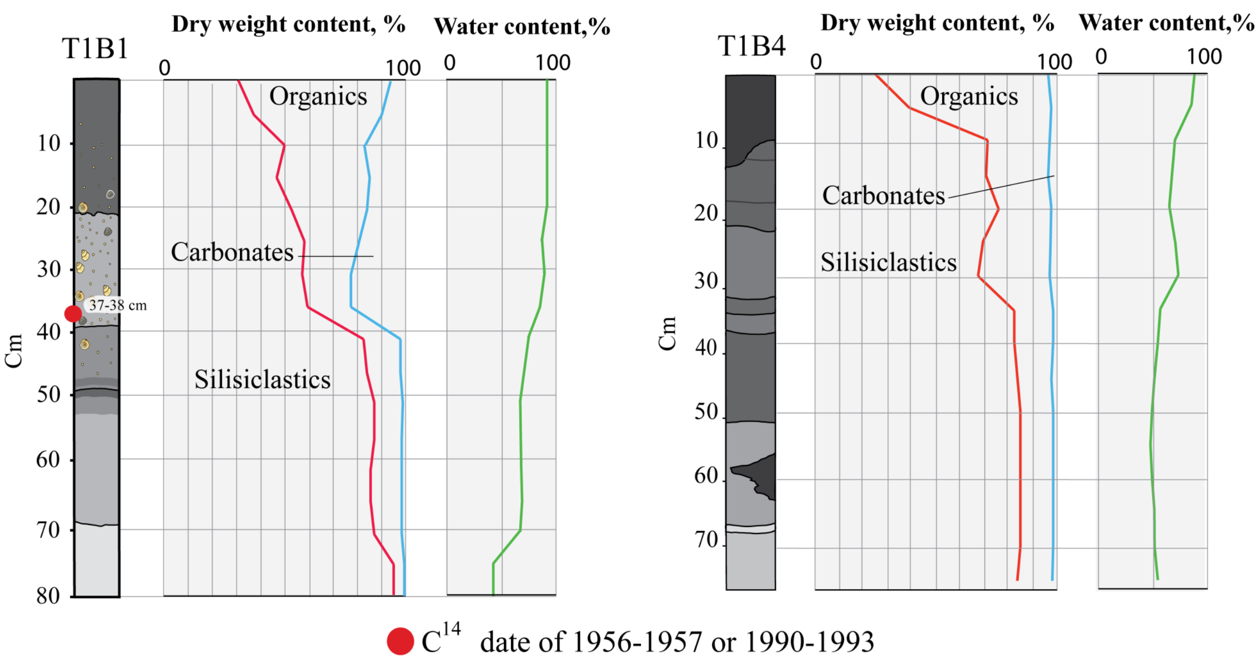


Figure 10. In the top photo the transects and the abandoned stream channel is marked out along with other observations . In the bottom figures, the locations of the transects and sample points, their coordinates with about 3 metres precision, are decribed along with a description of the cores and a possible correlation between the units in the transects. Top Figure comes from Google Earth Pro (©2021 Google) and is modified by Lykke Lundgren Sassner. The bottom Figure is done by Lykke Lundgren Sassner.

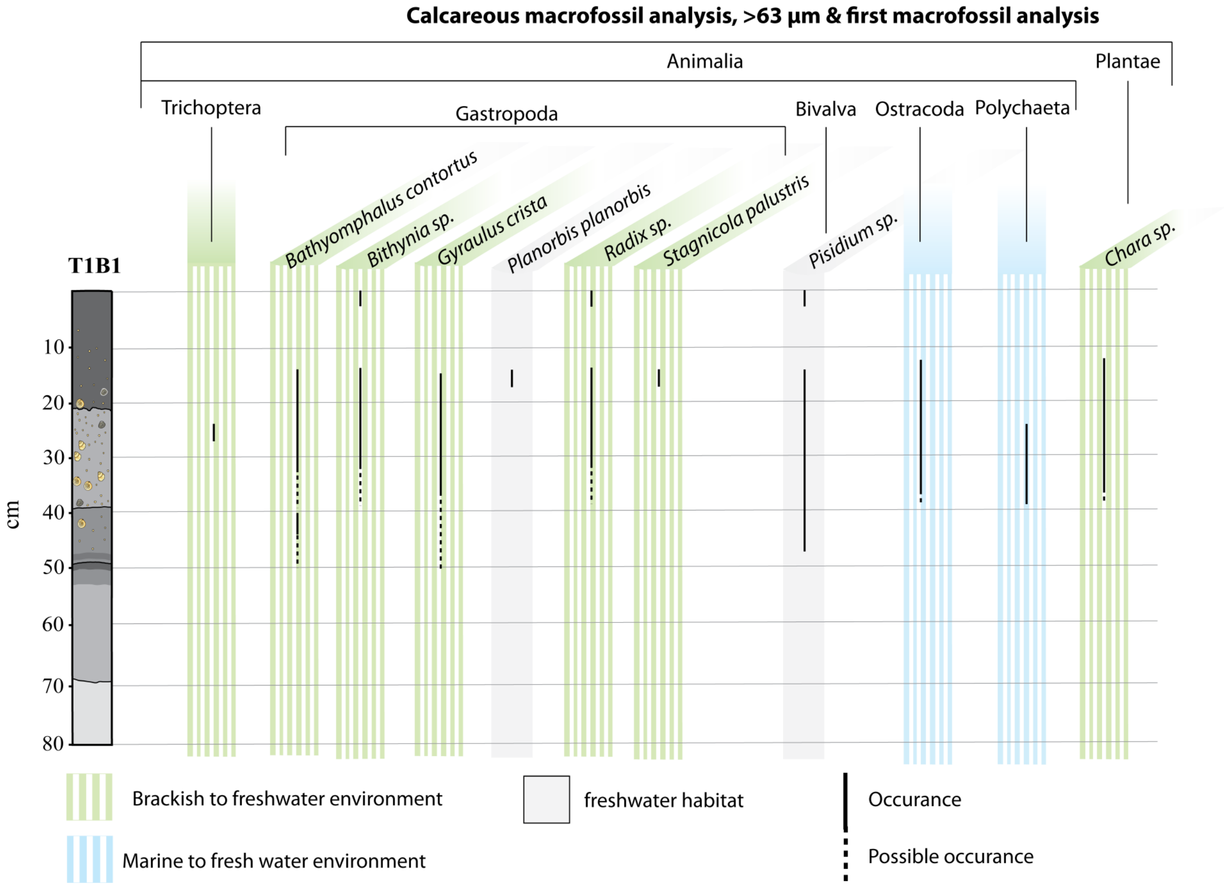


Figure 12. Results of the calcareous macrofossil analysis of core T1B1. The occurrences are marked with an interval in which the species are present. The possible occurrences is when the species is determine within a longer interval and therefore could occur anywhere within the depth but there is less certainty. The environments of the species are marked as colours and colour combinations and the habitats are taken from Glasby and Timm (2008) and the Artfakta (n.d.a) database (Artfakta n.d.b; Artfakta n.d.l; Artfakta n.d.m; Artfakta n.d.c; Artfakta n.d.d; Artfakta n.d.e; Artfakta n.d.f, Artfakta n.d.g, Artfakta n.d.h; Artfakta n.d.i; Artfakta n.d.j; Artfakta n.d.k). The species of Bivalvia and Gastropoda are presented as belonging to brackish to freshwater habitats but they are dominatingly in the fresh water systems, with the exception of some more tolerant species in some of the identified groups, for example Radix balthica which can be found at 14‰ or Bithynia tentaculata which tolerates 12‰ salinity (Artfakta n.d.c; Artfakta n.d.d; Artfakta n.d.e; Artfakta n.d.f; Artfakta n.d.g; Artfakta n.d.h.; Artfakta n.d.i.; Artfakta n.d.j; Artfakta n.d.k). Figure by Lykke Lundgren Sassner

A large find of a Trichoptera sp. larva nest was found at 24 centimetres from the surface (*Figure 13*). This was built solely out of shells of *B. contortus, G. crista, Radix sp.* and *Bithynia sp.*

Figure 13. The Trichoptera sp. larva nest built out of gastropods. The scale bar at the top shows graduations of millimetres. Photo by Lykke Lundgren Sassner.

The diatom analysis showed more marine species below 40 centimetres according to their habitats defined by Nilsson (1968a), Nilsson (1968b), Artfakta (n.d.n), Artfakta (n.d.o) Artfakta (n.d.m) and Artfakta (n.d.p), see *Figure 14*. There was no information found about specific salinities and tolerance for the diatoms other than for the ones defined by Nilsson (1968a) and Nilsson (1968b), where the freshwater is defined by 0-5‰ salinity, brackish 5-20‰ and marine 30-40‰ salinity. Nilsson (1968a) is lacking information about the definition if the species tolerates the span 20-30‰ salinity. The species which live in a transition between the salinities of different environments is defined as both. The Cladocera can be found in both marine and freshwater systems (Artfakta n.d.p,)

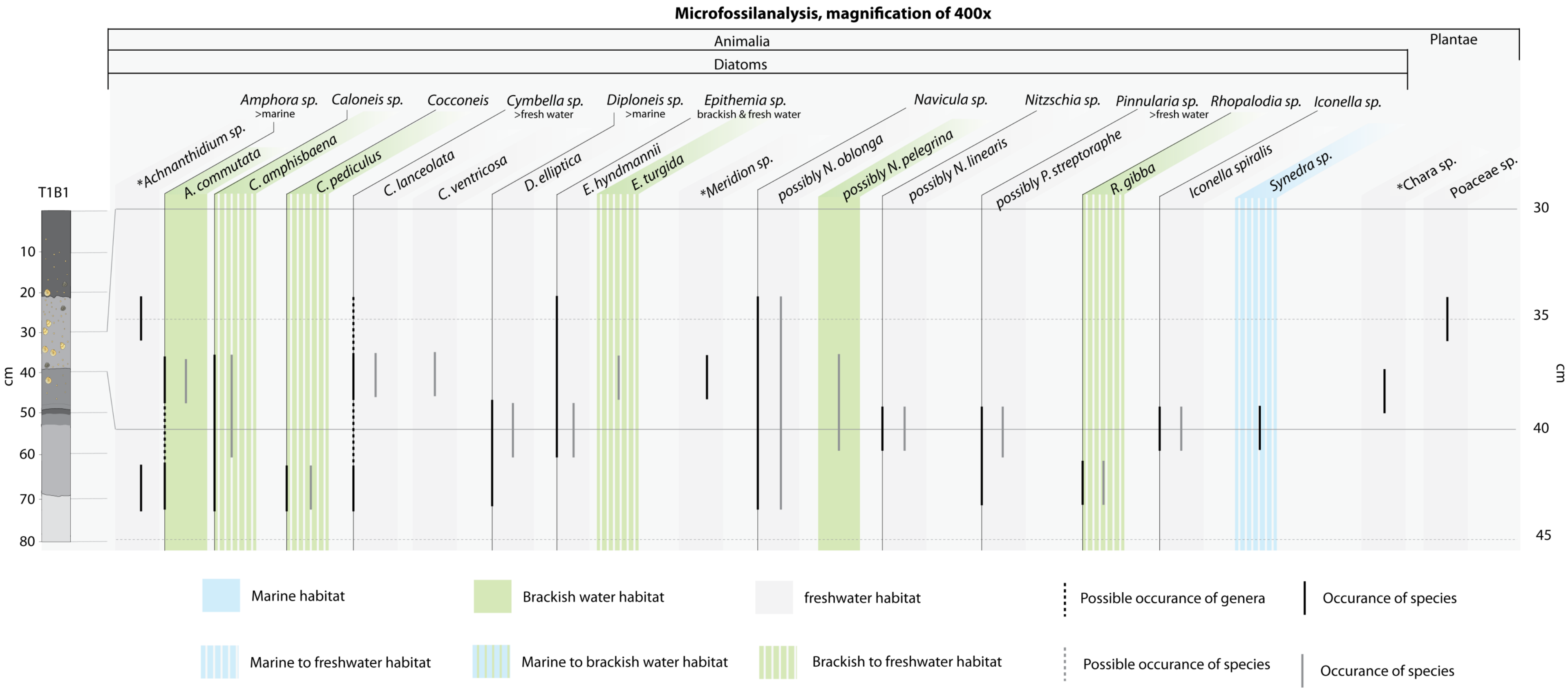


Figure 14. a display of the diatom taxa found in core T1B1, with the environment of the taxa shown as colours and the data for these collected from Nilsson (1968a), Nilsson (1968b) , Artfakta (n.d.n), Artfakta (n.d.o) and Artfakta (n.d.m). If a certain habitat is the most common in the genuses it is shown by ">" and if only one or two habitats are present in a group they are written out underneath. If no information is found, there is no note under the family. For the species described by Nilsson (1968a), Nilsson (1968b) fresh water is defined by 0-5‰ salinity, brackish 5-20‰ and marine 30-40‰. All species where the habitat is not from Nilsson (1968a), Nilsson (1968b) are marked with *. The possible occurrences is when the species is determine within a longer interval and therefore could occur anywhere within the depth but there is less certainty. Figure by Lykke Lundgren Sassner

5. Discussion

5.1. Differences between Scania, Blekinge and Halland

The general character of the determined localities varies between the three counties. Most localities in Halland are defined, from the remote mapping, *Appendix 2*, as sandy and at some places the sand is intermixed with a thin layer of peat. In Blekinge, the locations with gyttja and fen peat well outweigh the sandy ones, *Appendix 2*, as is expected from the observation of SLU (2020). In Scania there are too few locations to make good assumptions about the general character of the areas.

As explained in "2.3. Deposition and Preservation of Storm Surge Sediments", a more constant sedimentation results in a higher preservation potential, and lower **G-** and **H-**values from *Equation 1* and *Equation 2.* In "4.2. Theoretical differences in preservation potential along the coast of Scania, Blekinge and Halland", it is described that the constant growth of the vegetation and acidity of the peat in histosols results in a high bioturbation dependent preservation potential, low **G-**value (*Equation 1*), and a high mechanically dependent preservation, low **H-**value (*Equation 2*). This means that the histosols and bogs/fens which were observed as well as documented in Blekinge by SLU (2020) have a generally good preservation potential. The sandier soils, such as lentosols, arenosols and regosols, which are the soils of Halland according to SLU (2020) and have been observed during the remote mapping, have a poorer preservation potential with a high bioturbation dependent preservation, low **G-**value (*Equation 1*) and a low mechanically dependent preservation, high **H-**value (*Equation 2*), according to the discussions in the section "4.2. Theoretical differences in preservation potential along the coast of Scania, Blekinge and Halland". In practice this should mean that the preservation potential is higher for the locations found in Blekinge, and therefor chances to find undisturbed palaeostorm surge overwash traces should be higher in Blekinge than in Halland. For Scania it is harder to make more general assumptions as there are very few localities and only a little data from SLU (2020), but, for the reasons as explained above, the locations with peat sedimentation should be expected to have a higher probability of finding well preserved units and event-layers, such as palaeostorm surge overwash deposits, than the sandier ones.

Another important difference to be aware of is the surface salinity, which is a lot higher on the west coast, Halland, than on the east coast, Blekinge, of Sweden (Winsor et al. 2001). This higher salinity should result in the occurrence of more marine and brackish water organisms in the sea and a more pronounced difference between the marine/brackish ecosystems of the sea and the limnic/freshwater ecosystems in the coastal wetlands and lakes. This is important because the biological proxy method relies on the occurrence of marine and brackish organisms in the sediments to identify a marine/brackish origin and a possible palaeostorm surge overwash deposits (Goff et al. 2012; Chaumillon et al. 2017). It should therefore be easier to identify palaeostorm surges by biological proxies at the coast of Halland than in Blekinge.

There is also a trend of less exposure and more protection from storm waves of the locations found in Blekinge, because of the numerous islands protecting the mainland shore and the many sheltered embayment's of the coast. In contrast, Halland has more small, exposed bays. This should mean that the storm surge effects would be lower along the coast of Blekinge than Halland. The reasoning behind this is that the wave setup in Blekinge is limited as a result of the smaller fetch, because of the blocking from the islands and embayments, resulting in smaller waves and less energetic waves hitting the coast than if it was in direct exposure to the sea, such as on most of the coast in Halland (Hutchinson 1957; Longuet-Higgins & Stewart 1964). Looking at *Figure 2* the measured data of Schöld et al. (2017a) supports the statement of higher storm surges in Halland and the Eastern part of Scania than in Blekinge though they do not explain this blocking to be the reason.

Looking at the maximum calm weather sea level rise, *Figure 2A*, the localities in Blekinge show a higher maximum calm weather sea level than Halland (Schöld et al. 2017a). As the measuring of palaeostorm surge overwash deposits in practice is the measurement of times and events where the sea has flooded terrestrial areas, it is important to remember that the sea level is known to fluctuate a lot in the Baltic Sea and not just depending on storm surges, but the balance between in - and out flow of water through the Danish strait and Öresund (Schöld et al. 2017a; Schöld et al. 2017b). This means that sediments and traces, identified to be from a flooding of the sea, in the areas around the Baltic Sea do not necessarily have to be correlated to storm surges, but could also be correlated to a longer period of south western winds and low-pressure systems pushing water into the Baltic Sea, raising the sea level, or this in combination with storms. The natural variations in calm weather sea level can largely be disregarded along the west coast, because the maximum calm weather sea level is low in relation to the maximum storm surge sea level (Schöld et al. 2017a; Schöld et al. 2017b). When selecting an area for sampling it is therefore important to know that when sampling in Halland the result is more likely to be indicative of a storm surge while a sample in Blekinge may be indicative of a storm surge and/or a high calm weather sea level.

Generally, Scania should be seen as a transition from the Baltic Sea to Kattegat and the eastern area is expected to be more similar to Blekinge, whereas the western part more similar to Halland, as seem to be the trend of *Figure 2* (Schöld et al. 2017a; Schöld et al. 2017b). The southern part of Scania has both high values for maximum storm surge sea level rise and for maximum calm weather sea level rise (*Figure 2*; Schöld et al. 2017a; Schöld et al. 2017b). Therefore, the effect of both should be events of coastal flooding by sea water and traces of flooding/storm surge overwash traces can, like Blekinge, be a result of both a high calm weather sea level, a large storm surge and/or a combination.

In the study area of Scania, Blekinge and Halland there is documentation of historically large storms in 1872 and 1904 (Fredriksson et al. 2017) but there are also other large storms that can reasonably be expected to have left storm surge overwash traces along the studied coastlines. For example: in Blekinge there is documentation from Sölvesborgs-tidningen (1954) and Expressen (1954) regarding a storm in 1954, where Listerlandet was inundated by about 1 metre of water and there were large floods in Karlskrona. This should mean that at least some of the documented peatlands in Blekinge, especially around Pukavik, Karlshamn and Karlskrona, should have traces of this palaeostorm surge.

5.2. Interpretation of a Possible Palaeostorm Surge at Dalköpinge Ängar

5.2.1. Loss On Ignition

The LOI of the different cores show, despite their differences in overall composition, a clear shift at around the same depth: 40-35 centimetres from the surface for T1B1 and 35-30 centimetres from the surface for T1B4. At these depths, the deposition changed from mainly minerogenic sediment to a deposition of more organic matter and carbonates. This suggests a large change in the depositional environment and, based on the fossils of freshwater gastropods and the *Trichoptera sp*., the area became limnic and therefore must have been dammed. The differences in the carbonate content of the area as well as the slight difference in the depth at which the change occur, is probably just a result of local variations.

5.2.2. Biological Proxies:

As there were no visible siliciclastic rich units and no indications of minerogenic peaks in the LOI data, indicating a palaeostorm surge, the main focus had to be on the biological proxies and determining the habitats of the identified species in order to trace any influence of sea water in the area (palaeostorm surge evidence), and this with a focus on the interval 35 to 40 centimetres from the surface in core T1B1, where the LOI showed a large change in environment.

It is impossible to determine the salinity from the polychaeta, ostracods and *Chara* without knowing the species, as these are very large groups with marine to freshwater habitats (Glasby and Timm 2008; Artfakta n.d.l; Artfakta n.d.m). The *Pisidium sp.* and *P. planorbis* are halophobic freshwater species and are therefore indicative of a freshwater environment (Artfakta n.d.b; Artfakta n.d.g).

Trichoptera sp. larvae live in both brackish and freshwater environments. but only the tubes inhabited by larvae were found, no remains of the larvae themselves. However, these tubes were constructed of shells of *B. contortus, G. crista, Radix sp.* and *Bithynia sp*. (*Figure 13*) of which *B. contortus* and *G. crista* have a low salt tolerance. Therefore, the environment should have been freshwater to slightly saline when the *Trichoptera sp* tubes were deposited at 24 centimetres from the surface in core T1B1 (Artfakta n.d.c; Artfakta n.d.f; Artfakta, n.d.q).

All the gastropods found in T1B1 and defined to have brackish to freshwater habitats, could have lived in the same freshwater environment as *Pisidium sp.* and *P. planorbis*, but they do not have to. The tolerance to salinity is very different between the different taxa, making the possibility of them originating from the Baltic Sea very different (*Figure 12*; Artfakta n.d.c; Artfakta n.d.d; Artfakta n.d.e; Artfakta n.d.f; Artfakta n.d.h; Artfakta n.d.i; Artfakta n.d.j; Artfakta n.d.k). Today there is a zonation of the surface water in the Baltic Sea, where the most saline water comes from the inlets from the Nordic Sea/Kattegat, i.e. the Danish Straits and the Öresund area, in the southern part of the Baltic Sea and the least saline water is in the northern part of the Baltic Sea, the Bothnia bay (Winsor et al. 2001). This means that the species which can handle some, but not a lot, of salt will be found in the most northern part of the Baltic Sea, the Bothnia bay, and the more tolerant species can be found further south (*Figure 15*). The mean salinity in the sea off Dalköpinge Ängar in 2001 was between 8 and 10‰, making it unlikely that some of the encountered gastropods assigned to brackish to freshwater habitats originate in the Baltic Sea (Winsor et al. 2001). At least *B. contortus* and *G. crista* should not have come from the sea, as they only tolerate salinities up to 3 ‰ (Artfakta n.d.c; Artfakta n.d.f). Also, the probability of *S. palustris* to originate in the sea is low, as it has only been found in salinities up to 6‰ (Artfakta n.d.k). The species *B. tectaculata* and *R. balthica* of the fount genera *Bithynia* and *Radix* could survive and thrive in the Baltic Sea surface salinities which occur at the investigated site and could therefore originate from the sea, although they do not necessarily have to (*Figure 15*; Winsor et al. 2001; Artfakta n.d.e; Artfakta n.d.i).

However, the above statements about the possible Baltic Sea origin of these taxa are based on the assumption of a stable salinity over time, but there are documented changes in the salinity of the Baltic Sea over time (Winsor et al. 2001). Winsor et. al. (2001) have demonstrated changes in salinity over time scales as short as decades, and historically, on the timescale of the last 15,000 years (Andréasson 2006). The area has

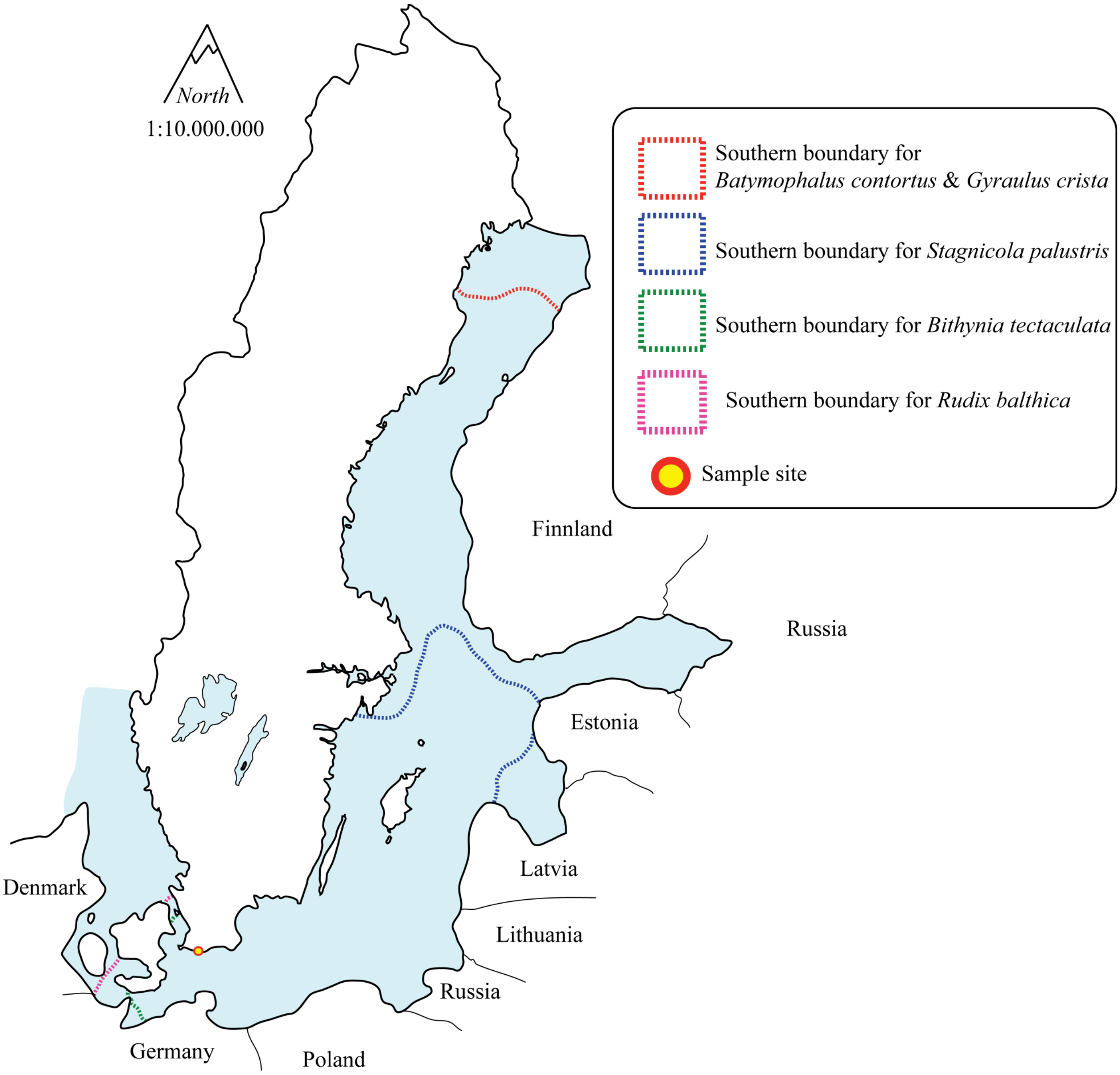


Figure 15. Distribution limits for the brackish to fresh water gastropods identified in the T1B1 core from Dalköpinge Ängar based on the salinity of Winsor et al. (2001) and documented salinity-tolerance (Artfakta n.d.c,; Artfakta n.d.e,; Artfakta n.d.f,; Artfakta n.d.i,; Artfakta n.d.k,). The background is simplified and based on the lakes and land masses collected from @Lantmäteriet and Google Earth Pro. Figure by Lykke Lundgren Sassner.

been everything from a freshwater lake to a brackish sea in different intervals of time, making the salinity and therefore probable origin for the species found in an area very different depending on the time interval (Andréasson 2006).

As the sediments at 43-44 centimetres depth were deposited during 1957-1958 or 1990-1993, we have an indication of the salinity of the water. According to Winsor et al. (2001) the Baltic Sea was more saline in the 1950s. This should result in lower probability for the more halophobic organisms to originate from the Baltic Sea if the deposition occurred during this time. During the 1990s the salinity was lower, and there was a larger influx of freshwater to the Baltic Sea (Winsor et al. 2001). This makes the probability to find more halophobic species in the more southern parts of the Baltic Sea higher during the 1990s. Although there are measurable variations in the salinity within the determined time frame, 1950s and 1990s, the salinity is still close to today's values, as is demonstrated by the general sea surface trends from Kniebusch et al. (2019), which show a variation of a maximum of 0.5 ‰ of the surface water within the time frame of 1920-2004.

Looking at the species of diatoms there has been a shift from brackish to freshwater environment at the transition from unit 3 to unit 2, at 38 centimetres depth in core T1B1 (*Table 5; Figure 14*). Below 40 centimetres there are two identified taxa of diatoms which have a brackish habitat and four species of with brackish to freshwater habitats. This could be seen as an indication of a more brackish environment. Above 40 centimetres only one species that definitely belongs to freshwater environments was identified. Other than that, only taxa could be identified, but what is worth noting is that the taxa found contain species which live mostly in freshwater (*Figure 14*). This is an indication of a change at the transition between unit 3 and 2, where the environment changed from brackish to more fresh water. Some caution regarding the determination of diatoms should be taken as it was done without preparing the samples and therefore the resolution was not optimal (see "3.2. Field Study"). There is, however, other evidence: the occurrence of gastropods common in the freshwater environment and, if these are deposits from the 1950s as was one of the s suggestions by the C^{14}-analysis, the changes of coastal morphology seen in the photographs collected from Center for Geographical Information Systems, Lund University (2021) and presented in *Figure 16,* which would support the general trends of the diatoms and the determined species/taxa of the found organisms.

The brackish diatoms continue down some centimetres into the unit 3 sediments which could either be a result of vertical mixing, through bioturbation (see "2.3.3.2. Bioturbation dependent Preservation") or a large deposition during the storm surge-event, depositing either the whole unit 3 or the upper part of it and giving the sediment the brackish traces.

5.2.3. Evaluation of Change in Environment at Dalköpinge Ängar

One of the reasons for the change at the transition of unit 3 and unit 2, being indicative of a flooding is that the diatom data which showed mostly marine taxa in the transition between unit 3 and 2 (*Table 5*). The brackish diatoms in unit 3, below 38 centimetres under the surface (*Figure 14*), indicate that the change in environment was brought on by storm surge, flooding the area, changing the morphology and possibly damming it by the formation of a coastal ridge or blocking of the old stream outlet. A storm surge origin can be supported by aerial photographs between 1940 and 1960, *Figure 16*. During the period between 1940 and 1960 (*Figure 16A; Figure 16B*) there is a change in the coastal profile of the area. There are signs of erosion scars along parts of the beach, around where the bunkers are, red circles in *Figure 16B*, which indicate a coastal erosion and the coast seems broader and more gradually shallowing in the foreshore area in 1960. These are trends that would be expected after a large storm, as the sediments from the steeper coast and foredune are expected to be transported out to sea forming a more shallow and constantly sloping foreshore, and erosion scars would be formed along the foredune, where the sediments are lost (Wright & Short 1984; Morton & Sallenger 2003). If the sediment is from the 1990s, there are is no photographic indicative evidence of a storm surge from aerial and satellite photographs or satellite photographs (at Google Earth Pro)

The amount of carbonate and bivalves/gastropods increases at the same point as there is a change in the diatom community, in T1B1 at 38 centimetres below surface and in the transition between unit 3 and 2. The large and fast change in carbonate content, as seen in the Loss on Ignition, suggest a fast immigration of the gastropods. The occurrences of fresh water- and more halophobic brackish water gastropods (*Figure 12*), as well as the fact that all of the found species of gastropods are being common in freshwater environments (Artfakta n.d.a; Artfakta n.d.b; Artfakta n.d.l; Artfakta n.d.m; Artfakta n.d.c; Artfakta n.d.d; Artfakta n.d.e; Artfakta n.d.f, Artfakta n.d.g, Artfakta n.d.h; Artfakta n.d.i; Artfakta n.d.j; Artfakta n.d.k), indicates an almost completely freshwater environment. Since the transition is sharp, the shift into a freshwater environment is quick. Subsequently, water supply from the small streams feeding the area and surface runoff are expected to have been efficient and filled the dammed area.

Looking at old photographs of the area from 1940, 1960, 1975 and the present day coast, it is clear that the environment has shifted from drier conditions in 1940 (Figure 16A) to wetter in 1960 (Figure 16B) and then successively drier in 1970 (Figure 16C) and in 2021 (Figure 16D). This documented change during the 1960, supports the theory of a damming resulting in the change in carbonate content and the occurrences of the freshwater and halophobic species if the age of the sediment is 1957-1958, as defined by the C^{14}-analysis. If the event occurred during 1990-1993, there is no photographic documentation to support the evaluation but the evidence is still strong for this damming.

5.2.4. Origin of the Storm Surge

The changes in the environment which are documented at 38 centimetres below surface in T1B1 were dated by a sample 1 centimetres above the transition and gave an age of 1957-1958 or 1990-1993. This means that the flooding, recorded by the LOI and biological traces, should have occurred soon before the measured time intervals: 1957-1958 or 1990-1993. The changes seen in the aerial photographs between 1940 and 1960, *Figure 16*, explain the changes in the ecosystems which are seen in the biological proxies well. This can be seen as a good indication of the C^{14} age of 1957-1958 being more probable for the change than the 1990-1993, although the probability from the C^{14}-analysis was lower, 8% likelihood. However, because aerial photographs from 1990-1993 are unavailable, the probability for both ages cannot be excluded. A change similar to that 1940-1960 could have happened at 1990-1993, though it is undocumented. For this reason both C^{14}-ages, 1957-1958 and 1990-1993, will be evaluated in regard to the probability for the change to be man-made, section "5.3.4.1. Possible man-made Changes during the 1950 and 1990s", and storm related, section "5.3.4.2. Possible storm induced Changes during the 1950 and 1990s", below.

5.2.4.1. Possible Man-made Changes during the 1950s and 1990s

The possibility for the change seen in the LOI and the biological traces to be man-made is small as there are indications of a brackish origin but still not negligible. There are no records of historical changes in the area within the time interval 1990-1993, defined by the ^{14}C analysis. The area has been a natural reserve since 1975 and has a long history of being a grazing land (Ek 2010). The natural protection would ensure that no large man-made change was made to the environment, meaning that if the sediments are from 1990-1993, the only cause for changes in the core and ecosystem/organism groups would be natural changes and events, such as a storm surge.

During the 1950s there is some archaeological documentation of old graves being removed in the nearby area (Riksantikvarieämbetet 2007). The effect of this removal on the study area and the possibility for this to result in the change in the environment which is seen in core T1B1, by digging and damming is unknown. However, although these could explain a change in environment they can not, at least alone, explain the documented change from brackish to freshwater diatoms in the transition between unit 2 and 3 in core T1B1. The change must be, at least in part, caused by a brackish water body: the Baltic Sea. Other than the removed graves there are no documentation of human changes to the area during the interval of the 1950s.

5.2.4.2 Possible Storm Induced Changes during the 1950s and 1990s

According to Nordlöf and Theland (2020) a 1.85 metre rise of the sea level (today) would result in flooding of the sampled area at Dalköpinge Ängar, as the water would breach the old stream channel which was abandoned in 1850 (Ek 2010). This means that if the change in environment was a result of a storm surge, this should be the minimum sea level that should affect the area.

Looking at SMHI (2020d) there are only a few storms which would fit the time frame of the ^{14}C date: 1957-1958 or 1990-1993. These are Ölandsstormen, 1985, or Snöstormen, 1954. When analysing SMHI´s data, provided by SMHI (n.d.b), of historical sea level measurements from Ystad, a town around 40 km to the east of Dalköpinge Ängar, it is evident that only the storm of 1954 showed a large increase in sea level. The storm of 1954 had a highest recorded sea level of 120 centimetres at the measuring station on 4 January 1954, while the storm of 1985 had almost no surge with a maximum sea level rise of below 30 centimetres (SMHI n.d.b). Focusing on the storm 1954, there is some documentation from SMHI (2014) of large numbers of fallen trees and the stormy January but the newspapers give more information of the surge and height of the sea level.

The storm surge sea level rise in 1954 was the greatest in the eastern parts of Scania where, according to Svenska Dagbladet (1954), there is documentation of flooding as far as 400 metres inland at Kivik with similar floodings in Åhus, Simrishamn and Kåseberga. From Trelleborgstidningen (1954), there is documentation of the coastal road in Abbekås, a town some 25 km east of Dalköpinge Ängar, having substantial damages. Looking at Google Earth Pro, this coastal road lay approximately 3 metres above sea level, indicating that a breaching of the 1.85 metre threshold value at Dalköpinge Ängar, identified by Nordlöf and Theland (2020), is possible as well as probable. The flooding and reshaping, by a build-up of some form of ridge that later dammed up the area, by this event would also support the findings of brackish water diatoms in the transition between unit 3 and 2.

From the aerial photographs (*Figure 16*) a change in the coast between 1940 (*Figure 16A*) and 1960 (*Figure 16B)* is clear. During this interval, 1940-1960, I would interpret large degrees of erosion to have occurred, as the coast show erosion scars and the coast seem to be broader, a trend which is expected as the long storm waves hit a steeper slope (Wright & Short 1984; Morton & Sallenger 2003). These trends could also be from a more chronical erosion, but then the patterns would be expected to continue in the interval 1960-1975.

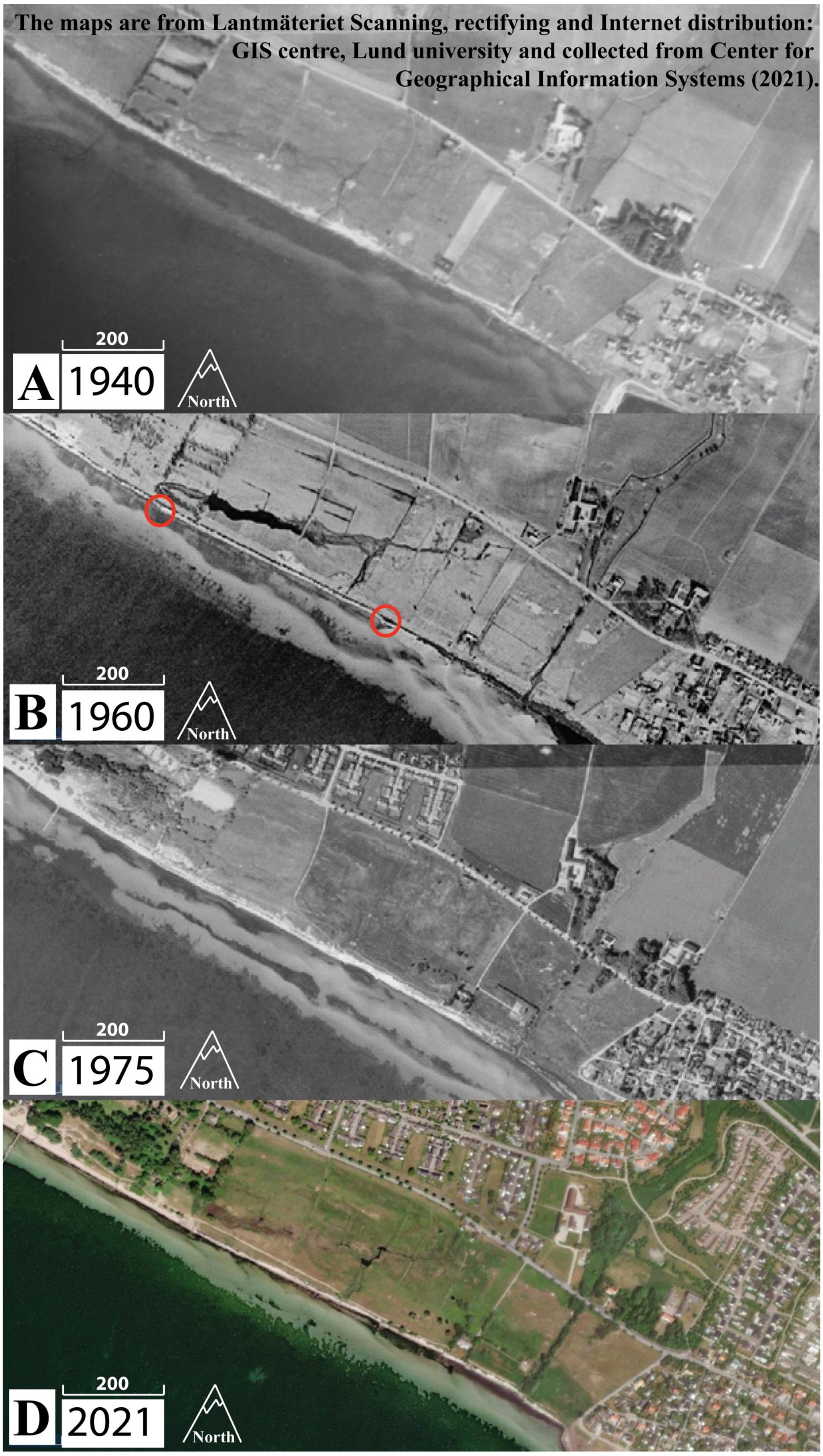


Figure 16, Aerial photographs of Dalköpinge Ängar during A, 1940, B, 1960, C, 1975 and D, 2021. These show changes both in the patterns of the dunes and foreshore, with a thin foreshore in 1920 and what seems to be a broader foreshore in 1960. From 1975 to the present day (2021) the beach seems to go back and return to a thinner form. The wetness of the area is also clear, with the area being drier 1940, very wet in 1960 and then drying up in the 1970 and in 2021 being somewhat wetter again. The Map from 1970 also show traces of erosion with erosion scars along the coast and where the bunkers should be (see red circle). The maps are from Lantmäteriet Scanning, rectifying and Internet distribution: GIS centre, Lund university and collected from Center for Geographical Information Systems (2021).

The change in environment (documented by the biological proxies "5.3.2. Biological Proxies"), the coastal change seen in *Figure 16*, the C^{14}-ages and the historical research of the 1950s ("5.2.3.1. possible man-made changes during the 1950s and 1990s"), all explain and support each other and give a uniform picture of the change seen in the transition between unit 3 and 2, being a storm surge in the 1950s, probably 1954, resulting in damming and a new environment.

5.3. Conclusion about the Method and Possible Storm Surge at Dalköpinge Ängar

The remote mapping of areas with possible palaeostorm surge overwash deposits is to be seen as successful, since the one locality determined and visited showed a palaeostorm surge trace and could even be restricted to one probable event. Therefore, the demands set on the environment in this study should be relevant to the deposition, preservation and identification of storm surge sediments, as expected. This study is intended to be used as a guide to areas of possible storm surge preservation in Scania, Blekinge and Halland, as well as act as an example of how to remotely map possible areas with, as was shown by the positive result in the field study, high probability of palaeostorm surge overwash traces. It would be optimal to visit more localities and make field studies, to quality-check, but there is no reason to doubt the accuracy of the mapping after this study.

With all the evidence of a change from more brackish to a more limnic environment, demonstrated by the biological traces, core stratigraphy, LOI, ^{14}C-dating and documentation of palaeostorms, the aerial photographs and possible man made changes in the area, I conclude that the change in environment is most likely the result of the large storm in 1954. Although the 1957-1958-time interval has the lower likelihood of the two (1957-1958 and 1990-1993) it is the only one which gives a full and comprehensive explanation to all the traces that was found and I therefore choose to trust this as the correct date. As both cores, on which a LOI was made, showed a change in content and therefore environment at around the same depth, it indicates a larger event occurring at or around the same time that has affected the entire or a large proportion of the study area, as should be the case if the change was triggered by a storm surge. The differences between the two transects is likely the result of local variations but it would be beneficial to examine the diatoms in core T1B4.

5.4. Evaluation of Study

The search engines and databases: Google Earth Pro, Google maps, SGU and Sweden's Geological Surveys, (2016) Quaternary deposits maps were used because of their accessibility, their tools and and their free open access. The computer program Google Earth Pro contains both tools to mark the localised areas, remote map their coastal profiles and satellite documentation over time which makes it possible to track the progression of the coast with time and changes. These functions were invaluable during the remotely mapping process. There are some problems in that there is no documentation of the precision of the data of the coastal profiles. This could be avoided if another site or database is used. For the Google Maps search engine, it provided an easy tool to get the coordinates, but similar to Google Earth Pro no precision is known. I would however recommend using another tool for the coordinates as both the precision is unknown and the coordinate system used in Google Maps had to be transformed to SWEREF99TM with the help of Lantmäteriet (n.d.a,). The SGU, Sweden's Geological Surveys, (2016) Quaternary deposits maps provided a good background into what deposits was to be expected in field and an estimate of the preservation potential. The map of soil types from SLU (2020) lacked 1/3 of the study areas, Scania, and had another alternative been available, I would recommend a change.

The LIDAR data from @Lantmäteriet and Generalstaabens maps did not give much more information than the Google Earth Pro satellite pictures but made it easier to see the structures, such as ditches, on the different localities. Therefore, this step could be skipped if there is a lack of time. The search engine Naturvårdsverket (n.d.) is free and provided an exceptional resource in finding information about the natural conservation protection.

This method of identification of areas with storm surge deposition and preservation is done with tools which are free and easy to use and the results are positive. Therefore, I would say that I have identified, at least in parts, the key factors for preservation and deposition of palaeostorm surge sediments and found a good way to apply them when remote mapping. The problem with the method is time. As the whole coast and all areas are examined separately for all the different aspects affecting deposition and preservation, described in "3.1. Remote Mapping" and not automatically in a program, the remote mapping is time consuming. However, as this report contain the framework of how and where the deposition and preservation should be better it is possible to make a GIS-map and models which selects areas that fulfil some of the requirements explained, such as the exposure, the gradient, the presence of peat, the nature conservation protection and the identification of soil and quaternary deposits. Some parts of the study, such as the identification of historical remains and the historical background, would still need to be examined for all localities separately by an expert even if the other parts of the method can be more automated.

The methods used for identification of palaeostorm surge sediments will look very different depending on sediment-type and experience (Goff et al. 2012).

In this study I can conclude that the Loss on Ignition was one of the most useful tools as it provided a good background into where and how the environment changed. In the case of my samples there was no sedimentary structures present, so I had to take a more biological approach. Although having a short master's in biology, I still had a hard time with the identification of the different species of diatoms and gastropods. For this reason, I would recommend specialised help from either biologists or experts within the different organism groups. I was also in luck, as the dating of the sediments gave reliable results that could be followed up. The study of palaeostorm traces is a cross-disciplinary field and therefore demands broad knowledge, both in landscape history, geology and biology and, from my experience, the expert knowledge of each field could be invaluable.

6. Future Studies

Because this was a master thesis (45 ECTS) and done during the COVID-19 pandemic, there was a lack of time as well as some problems with administration of the field study and programs. If anyone wishes to continue in this field, these are the changes and studies I would recommend and observations I made along the way:

- The section "2.3.3.2. Bioturbation dependent Preservation" introduces a field of science: soils as an aid in determining the biological preservation potential (**G-value** in *Equation 1*). This field of study which could be further explored, and which could aid in the determination of terrestrial preservation potential as it would give more insight into how soil can be related to vertical biological mixing.

- A GIS-model which includes the determined variables of the different types of erosion in section "2.3.3.3. Mechanical dependent Preservation" could be a valuable tool when determining the mechanically dependent preservation potential and aid in locating areas of good terrestrial mechanically dependent preservation potential (low **H-value** in *Equation 2*). It was not done in this report due to lack of time.

- Skummelöv strand, is a good locality to study the traces of a washover fan of known age. This would be a scientifically interesting study both in regard to how it looks today and how it changes with time.

- It would be beneficial to examine the diatoms in core T1B4 in order to see if the brackish traces can be found in this core too.

- It would be preferable to evaluate all the localities that were identified in the first part of the remote mapping further, into stage 2, and to find out the historical background to locate the absolutely best localities.

- Had I done this study again I would include localities in Blekinge in the second evaluation as, although the areas are protected from the wind and does not historically have the highest storm surges, there is still knowledge to be found of the frequency of the flooding from the high calm weather sea levels alone or in combination with storm surges.

- This study shows promising result from one of the selected sites, Dalköpinge Ängar, but as this is only one locality out of the 68 possible areas of storm surge traces, it would be beneficial to make more field studies on the areas identified as ***good*** by the remote mapping, to further quality check the method of identification of the possible palaeostorm surge areas.

- A large scale mapping of the coast of Sweden should be done. As the study of paleostorms, the frequency and height of the storm surges, is of importance when estimating future storms and their impact on both lives and infrastructure, the study of this paleorecord should be a priority.

7. Acknowledgement

I want to thank my internal supervisors: *Helena Alexanderson*, *Anne-Birgitte Nielsen* and *Mats Rundgren* as well as my external supervisor: *Bradley Goodfellow*, from SGU, for all the encouragement, ideas, helps and remarks. I also wish to thank *Mikael Sassner* for the help with reading the historical documents, understanding some of the maps and finding newspapers. I want to thank *Marie Sassner* and *Margareta Sassner* for reading the work and commenting the language. A BIG thank you to *Elise Moat* who, though she was sick in covid-19, gave me help and good advice regarding the text and a boost of confidence. I also wish to thank *Svante*, for tolerating that there was a lot less time for him during this period. Other people who have helped along the way is *Per Wahlquist*, who lent me the key to the core-fridge, *Anders Johansson*, who works at Länsstyrelsen and quickly gave me permission to drill at Dalköpinge Ängar, *Britta Smångs*, who helped me with my references, and *Karl Ljung*, who is my examiner but also has given me helpful pointers and helped me in the organic lab during my laboratory work. Lastly, I would like to thank *Emmy Molin, Ida Bonnevier Wallstedt* and *Anna Sartell*. During this very trying time, with the global pandemic and strict regulations at the department, you have kept me sane. THANK YOU.

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Appendix 1, The equations of wind and water erosion

Equations from Ingelstam et al (2014)

$$Since\ the\ object\ isn't\ moving\ vertically\ the\ accelleration\ is\ defined\ to\ 0, the\ normal\ force:$$

$$n = \mu_s mg$$

$$Since\ we\ need\ to\ know\ the\ amount\ of\ force\ to\ start\ object\ to\ move, acceleration\ is\ defined\ to\ 0\ and:$$

$$F = n$$

In order to estimate the velocity of the wind and water to move a grain:

$$v = \sqrt{\frac{Ke * 2}{m}}$$

Wind mass		
Density (kg/m3) from Ingelstam et al (2014)	Volume (m3)	Mass (kg)
1.293	1.000	1.293

Water mass		
Density (kg/m3) from *Ingelstam et al (2014)*	Volume (m3)	Mass (kg)
999.00	1.000	999

Friction is assumed to be the same as brick against wood and: 0,6 (engineer toolbox n.d.).

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Appendix 2

Region	Location		Coordinate SWEREF99TM	Exposure to Sea	Impact of Infrastructure	Historical remains	Soil type	Vegetation	Gradient (%)	Other information	Number in map
Halland	*Hagen by Malevik:*	*Northern*	N6380893 E316573	4	4		sand	low	0.7		1
		Southern	N6380361 E316824	4	3	parcels from farming	sand	low	0.9	A ridge some 150 meter inland. It can be man-made but has shape of natural dune	2
	Stora Klev		N6377294 E317596	4	2		sand	low	2.1		3
	Vallda/Sandö badplats		N6375367 E315217	5	2		sand	low	1.7	Sign of old storm erosion scar	4
	Vallda		N6374943 E316471	2	2	ditching from draining of water & fences from farming	sand	low	0.8		5
	North of Gate Klova		N6370723 E314650	2	2	ditching from draining	sand	low	2.5		6
	Västra Hagen		N6369274 E315482	2	3		sand	low	1.9	Flooded with some regularity	7
	South of Västra Hagen		N6368515 E315527	2	2	ditching from draining & fences from farming	sand	low	1.1	Bedrock outcrops could indicate small sample depth	8
	3 km south of Västra Hagen		N6366250 E315354	2	3		sand	low	0.8	Small size but a storm surge could be documented in the near by lake & surrounding bedrock could indicate small sample depth	9
	By Onsala Rymdobervatorium		N6365424 E315240	2	2	fences, probably from farming	sand	low	0.3	Lobal structures incidcating storm surge flooding found & a lake nearby that could be good for sampling	10
	2 km North West of Runsås		N6364663 E317423	3	2	fences, probably from farming	clay	low	1.3		11
	Torkelstorp by Hanhals		N6369344 E326620	2	2		sand	low	1.0		12
	Tjolöholms slott	*Northern*	N6365828 E326795	3	2	ditching from draining of water & fences from farming	sand	low	0.0	Small lake inland	13
		Southern	N6365016 E327444	3	2	ditching from draining of water & fences from farming	sand	low	0.2		14
	North of Ölmanäs		N6364237 E327232	3	2	ditching from draining of water & parcels from farming	sand	low	0.5	Signs of temporary flooding and a lake	15
	Between Byendal and Vassbäck		N6357780 E328773	4	4		sand	low	2.5	A large road in close proximity & changes to coastline in a near area	16
	South of Kärradal		N6340909 E331684	3	3	fences from farming	sand	low	0.8	Bedrock outcrops could indicate small sample depth	17
	South of Kråkeberg	*Northern*	N6339398 E331881	2	3	fences, probably from farming	sand intermixed with peat	low	0.5		18
		Southern	N6339190 E332242	2	3	fences, probably from farming	sand intermixed with peat	low	0.3		19
	Northern of Lindhov		N6337824 E332253	4	2	fences, probably from farming	sand/clay intermixed with peat	low	1.0		20
	Northern of Trönningenäs		N6337280 E331359	4	2		sand intermixed with peat	low	2.2		21
	Gätteröns naturreservat, North of Varberg		N6335854 E332450	2	3	fences, probably from farming & parcels from farming	sand intermixed with peat	low	0.1		22
	The coast between Björkäng c	*Sik*	N6320236 E339564	5	2	traces of fences, probably from farming	sand intermixed with peat	low	0.6	Permanent to semi-permanent lakes in the area	23
		Morup	N6317969 E339671	5	2	traces of fences, probably from farming	sand intermixed with peat	low	0.2	Permanent to semi-permanent lakes in the area	24
	Southern of Glommen		N6312455 E339412	4	2	fences & parcels from farming and possibly grazing	sand intermixed with peat	low	1.2		25
	North of Olofsbo		N6311658 E340115	4	2	ditching from draining of nearby fieds	sand	low	0.3	Small lakes further inland	26
	North of Falkenberg		N6308864 E345020	4	3		sand	low	1.6		27
	South of Falkenberg		N6305953 E349075	4	3		sand	low	2.0		28
	Ugglarps havsbad by Smäris		N6300121 E354123	5	3		sand	close the sea- high & inland- low	3.0	Bedrock outcrops could indicate small sample depth	29
	East of Särdal		N6291098 E355113	5	3	ditching	sand intermixed with peat	low	1.5		30
	North of Haverdal		N6290133 E355946	5	2		sand	low	to the ramp- 8 after ramp- 2.7	There is a high gradient up to 4-5 meters where there is a ramp with a lake. Could be used for superstorms.	31
	South of Haverdal		N6289032 E356908	5	3		sand	low	1.7	Evidence of breaching of dunes and deposition in washover fans evident on Google Earth	32
	South of Halmstad		N6276047 E372146	4	3	traces of fences, probably from farming	sand intermixed with peat	low	1.3		33
	Skummelövs strand		N6261212 E372373	5	3		sand	low	2.1	Evidence of breaching of dunes and deposition in washover fans evident on Google Earth	34
Scania	*Stora Hult strand*		N6244075 E361530	4	3		sand	low	2.5		35
	Between Farhult and Utvälinge		N6233506 E360555	4	2		sand and fen-peat	low	0.5	Area is semi-perminently flooded and should have good resolution.	36
	Viken		N6225958 E348893	5	4		sand	low	2.8		37
	Domsten/Viken naturreservat		N6223739 E350187	5	3		sand	low	3.6		38
	South of Landskrona		N6190072 E369189	4	4	fences from farming	sand and fen-peat	low	0.0	The harbour of Landskrona is 3.5 km away and could have affected the area	39
	South of Saxtorps-skogen		N6188688 E369669	5	2		sand	low	1.9		40
	South of Barsebäck		N6179180 E372061	4	4	photo-documentation (Google Earth) of previous farming and parcels from farming	sand	low	0.0		41
	Gessie villastad strand		N6151695 E369897	4	3	parcels from farming	gyttja	low	to the ramp- 20 on ramp- 0.5		42
	Dalköpinge Ängar		N6136373 E387216	5	4		sand and fen-peat	low	to the ramp- 12 on ramp- 0.0		43
Blekinge	*East of Pukavik*	*Magleholmar*	N6223664 E480846	3	2	historical remains	fen peat	low	1.3 to 2.3	This is an island	44
		Nissabacken	N6224420 E481093	3	2	historical remains	fen peat	low	1.9		45
	Eriksbergs naturreservat by Eriksberg		N6225508 E499885	1	2		fen peat	low	3.4	Bedrock outcrops could indicate small sample depth	46
	Köpegårda	*Gåsaviken*	N6226806 E502384	2	2	parcels from farming	fen peat	low	1.6	Bedrock outcrops could indicate small sample depth	47
		Köpegårdaviken	N6227334 E502052	2	2	parcels from farming	fen peat	low	1.2	Bedrock outcrops could indicate small sample depth	48
	South of Ronneby		N6225148 E517580	1	5		gyttja	low	0.6	Looks like an overgrown peatland	49
	East of Ronneby hamn		N6225831 E520056	1	2		gyttja	low	0.0		50
	South of Aspan		N6223843 E520335	2	4	ditching from draining	gyttja	low	0.0		51
	Lake by Ronneby	*Bakarebodaviken*	N6222796 E521002	1	2		gyttja	low	0.0		52
		Bredasund	N6222519 E520313	1	2		gyttja	low	0.0	Lake with a small passage to the sea, but this should show storm surges during larger storms.	53
	Sörekåsa		N6224961 E523391	1	2		gyttja	low	0.2	Partly flooded by the sea.	54
	Saltäng, by Östranäs		N6226535 E526363	2	2	fences, probably from farming	gyttja	low	0.4	Partly flooded by the sea.	55
	Tromtesunda		N6224880 E529914	2	3		gyttja	low	1.2		56
	Skillingenäs		N6225995 E532629	2	4		gyttja	low	2.7		57
	Framnäs, Torpaviken		N6226758 E541867	2	2		gyttja	low	2.7	Partly flooded by the sea.	58
	Säljö		N6224813 E542559	2	2		gyttja	low	0.8		59
	Knipehall, Öljersjövikenorm surges.		N6226894 E543460	2	2		gyttja	low	2.8		60
	Färjös Eastern side		N6226037 E543018	2	2		gyttja	low	1.9	The gyttja follows the passage between an island and the mainland	61
	Coast of Torsnäs		N6226064 E543471	2	2		gyttja	low	0.7	The gyttja follows the passage between an island and the mainland	62
	East of Gängletorp		N6224359 E547199	2	2		sand	low	2.7		63
	Lillö, by Möcklö		N6222944 E548519	2	2		gyttja	low	5.7		64
	Flagen, by Stora Roms naturreservat		N6221926 E550639	1	2		gyttja	low	0.8		65
	West of Brunnsvik		N6218815 E548892	2	2		gyttja	low	0.4		66
	North of Svanhalla		N6219709 E555100	2	3		gyttja	low	1.3		67
	North of Sibbeboda		N6221819 E555816	3	2		gyttja	low	1.3		68

**5 is high and 1 is low*

Targeted study of history, structure and protection, with help of *Lantmäteriets maps*, © *Lantmäteriets* and ©*SGU*s data handled in *ArcMap 10.5.1.* & *Naturvårdsverkets map* of protected nature

Location			Coordinate	Historical documentation	LIDAR observations and historical Generalgrabens maps	Nature protection	Final evaluation	Number in map
Halland	*South of Kärradal*		N6340909 E331684	The first documentation found was from 1919-1925: *Häradsekonomiska kartan, 1919-25, Åskloster J112-2-21*, and demonstrated farmed lands in the localised area within some tens of meters from the sea. The later documentation from 1965: *Ekonomiska kartan, 1965, Årnäs J133-5B9g67*, show how some of the farmed lands the closest to the coast was left behind and no longer used. The areas the closest to the sea should therefore have the longest archive.	The LIDAR show lines/hills in the beach of the area, indicating former shorelines. The surrounding bedrock outcrops as well as the sediment on top of it are streamlined shaped. The map: *Generalgrabenkarta, 1872, Varberg J243-18-1,* from 1872 support the observations of the LIDAR and indicate that the located area during this time was low and surrounded by areas of higher altitudes.	There is no natural protection of the area according to Naturvårdsverket (n.d.).	*This is a possible area though only the areas the closest to the coast would have completely undisturbed sediments.*	17
	South of Kråkeberg	*Southern part*	N6339190 E332242	The map: *Häradsekonomiska kartan, 1919-25, Varberg J112-2-2,* demonstrates how the area hasn´t been farmed but the nearby areas had some famed field. Comparing to the economic map from 1965 (*Ekonomiska kartan, 1965, Trönningenäs J133-5B8g66*) it is evident that there was somewhat more faming in the areas close by during 1965. Ahnlund, B. and Mascher, C. (2017) had, through their research, found that the area has had a long history of grazing. Until 150 years ago the lands of the area were outmark, before the parts that lay more inland were being farmed.	The LIDAR show clear signs of both meandering streams and strait ditches. The diching goes from fields far inland, so it´s probably rather an outlet from the framed areas inland rather than a lowering of the sea level in the area. The area is low with the bedrock outcrops sticking up as heights. These observations are also supported by *Generalstabenskarta, 1872, Varberg J243-18-1.*	. The Bedrock outcrop to the south of the area is protected by the habitat directive 92/43/EEG as well as a nature reserve but the area itself has no natural protection according to Naturvårdsverket (n.d.).	*This area is very promising. There is historical documentation of long usage as grazeland meaning that the effect of agriculture and infrastructure on this particular area is low. There was not found any natural protection of this area.*	19
	The coast between Björkäng and Morup	*Sik*	N6320236 E339564	Documentation from 1828: *Laga skifte, 1828, Tvååkers socken Sik nr 1-3* as well as 1913: *Vattenåtgärd, 1913, 13-TVÅ-308*, describes different ditches being made as soon as in the early 1800. Laga skifte from 1828 also marks out the coastal area as utmark, meaning it was probably used as graze lands at this time. According to Länsstyrelsen Halland (2020), the coastal areas have, from around 1700 b.c., been used as graze land as well as to collect seaweed. The maps from 1919-1925: *Häradsekonomiska kartan, 1919-25, Glommen J112-2-40* and *Häradsekonomiska kartan, 1919-25, Spannarp J112-2-34* show an undisturbed coast line maked as tångallmäning (seaweed collection) and farmlands from some tens of meters from the coast to further inland. The younger map: *Ekonomiska kartan, 1966, Morup J133-5B4i68*, show that the coastline during the mid-1900s was even more undisturbed as some of the previously farmed lands had been left. Looking at the fences and ditches on Google Earth Pro, they seem to follow the pattern of the maps from 1919-1925.	The LIDAR show irregular meandering patterns along the whole shore. The ground seems to have smaller hills that are cut by these irregular channels. This is a pattern that can be traced all along the beach. Further inland it is clear rectangular patches and strait lines. These can be traced into the shore but the structures are unclear. The faint structures indicate that the area could have been farmed but it was some time ago. Generally, there seem to be a low human impact along the shore and a higher inland. The whole area is generally low and shows no larger changes in topography which is also confirmed by the *Generalstabskartan, 1872, Varberg J243-18-1.*	The area is a part of the Nature2000 areas and protected by the bird directive 79/409/EEG as well as protected from disturbing of the area between 1/3 and the 31/10 (Naturvårdsverket, n.d.). Sik is also protected as a Natural Reserve that forbids any disturbance to the vegetation according to the decision of Länsstyrelsen (2020) though this is uncertain as it seems to be appealed according to Naturvårsdverket (n.d.)	*This is an optimal sampling site if one looks at the requirement for storm surge sedimentation BUT it is so highly protected nature that there are problems when it comes to sampling: a promising area that would need time to get the permission to sample.*	23
		Morup	N6317969 E339671	The early documentation from *Häradsekonomiska kartan, 1919-25, Glommen J112-2-40* and later from *Ekonomiska kartan, 1966, Morup J133-5B4i68* show little difference in the distribution of the farmed land, with farming almost all the way out to the sea. The area the closest to the sea is not marked out as farmed land in any of the maps and was probably used for grazing, such as in the nearby area: Sik (Länsstyrelsen Halland, 2020).	The LIDAR show a similar pattern as with Sik: meandering ditches and higher areas in-between that hasn't been cut by the natural streams. There are more and clearer signs of agriculture here as the fences goes all the way to the coast at some parts of the area. The general surrounding area is flat as is confirmed by the *Generalstabskartan, 1872, Varberg J243-18-1*.	The area is a part of the Nature2000 areas and protected by the bird directive 79/409/EEG (Naturvårdsverket, n.d.).	*The history of agriculture so close to the sea could result in a high disturbance and problems. This in combination with the natural protection makes this a less suitable area.*	24
	Ugglarps havsbad by Smäris		N6300121 E354123	The map from 1919-1925: *Häradsekonomiska kartan, 1919-25, Steninge J112-2-52*, show that in the beginning of the 1900-century there was just some spread out farmed lands but nothing that would affect the area. In the mid-1900 the"*Ekonomiska kartan, 1966, Fågelholmen J133-5C0a68*"-map show how the identified locality was farmed all the way until the sea.	. On the LIDAR, coast parallel ridges are visible. Other than that, there are no clear patterns. The area is low and surrounded by streamline shaped bedrock outcrops.	There is no natural protection of the area according to Naturvårdsverket (n.d.).	*The effect of agriculture on preservation should be big in this area, as the location where the sediments would be preserved is the one where there has been "recent" farming. Therefore, this area is not suitable.*	29
	East of Särdal		N6291098 E355113	Häradsekonomiska kartan, 1919-25, Haverdal J112-2-57, show that the area was only affected by some gardens and small paths in the early 1900. The "*Ekonomiska kartan, 1966, Steninge J133-4C9b68* "-map and "*Ekonomiska kartan, 1966, Haverdal J133-4C8b69*"- map from 1966 demonstrates that this trend continued in the mid-1900 and the area was not affected by any farming. The area was probably grazed as the nearby natural protection area: Särdals naturreservat, according to Länsstyrelsen Halland (n.d.), has been grazed as far back as the bronze age.	The LIDAR show that the area is part of a large low laying coastal ramp that some kilometres inland rise to a larger height. On the older *Generalstabskartan, 1867, Halmstad J243-13-1* this pattern is not visible, and area looks generally low. This could be as the older map cover a larger area and lacks some details.	There is no natural protection of the area according to Naturvårdsverket (n.d.)	*This is a promising area.*	30
	North of Haverdal		N6289032 E356908	Both the older map from the early 1900: *Häradsekonomiska kartan, 1919-25, Haverdal J112-2-57*, and the somewhat older from the mid 1900: *Ekonomiska kartan, 1966, Haverdal J133-4C8b69* show how the area has never been farmed. There are some limited areas that is marked as gardens. It is also worth noticing that the lake that is evident from the satellite pictures today is also documented in the map from 1919-1925 (*Häradsekonomiska kartan, 1919-25, Haverdal J112-2-57*). The natural protection area: Särdals naturreservat has documentation of grazing back to the bronze age (Länsstyrelsen Halland, n.d.) and it is likely that this area has the same history.	The LIDAR-data demonstrates how there are a somewhat of a steep gradient from directly behind the sea to a flat terrace. On this terrace there are strait ridges going in North/South direction to somewhat North East. The ground surface is fluctuating slightly with small mounds.	The area is on the edge of the natural reserve of Särdals Naturreservat, and the large bay to the south is protected as a natural reserve as well as by nature2000s habitat directive 92/43/EEG, but the area itself is not protected (Naturvårdsverket, n.d.).	*The area is promising in that there is a lake that seem to have a long continuity and in which there could be well preserved storm surge sediment. The area lay on the edge of a reserve so it should be possible to sample.*	31
	South of Halmstad		N6276047 E372146	The farmland patterns that are presented in the "*Häradsekonomiska kartan, 1919-25, Trönninge J112-2-63*"-map from 1919-1925 are still somewhat visible on satellite and show that most of the coastal areas are unaffected by farming. The 1919-1925-map also show that most, if not all, of the present-day wetlands weren't present in the beginning of the 1900-century. The map from 1965: *Ekonomiska kartan, 1967, Påarp J133-4C5e69*, show that the farmed lands was split up by a road. The coastal areas were left behind while the inland areas to the east of the road was being used for farming. There are no signs of wetlands and water bodies on this map either.	The LIDAR show the area as low lying. There are some smaller ridges that follow the coast and in the surrounding, there are some higher areas close to bedrock outcrops. The LIDAR also demonstrates a clear depression following the motorway and where there today is a small lake. The depression is not visible in the *Generalstabskartan, 1867, Halmstad J243-13-1* from 1867, but the heights to the south and in connection to the bedrock outcrops is the same as with the LIDAR data from ©Lantmäteriet	There are no natural protection here according to Naturvårdsverket (n.d.). The island to the south of the area is a bird protection area, where access is prohibited between 2020-04-01 and 2020-07-15 (Naturvårdsverket n.d.).	*This area could have good archives closer to the sea, but it shouldn't have any older storm surges preserved in the lakes as these are modern. The area is not protected, and it would be possible to sample from it.*	33
	Skummelövs strand		N6261212 E372373	The old documentation from the map: *Häradsekonomiska kartan, 1919-25, Skottorp J112-2-72*, show that: at the beginning of 1900, most of the present day town was farmed land and some of the more coastal parts of the present day town as well as the beach was unaffected by farming. During the mid-1900: the map: *Ekonomiska kartan, 1968, Skummeslöv J133-4C2e70*, demonstrates that there was small houses being built along the coastal road onto the previously untouched beach.	On the LIDAR there are three clear ridges following the coast, behind which there are irregular mounds. These show patterns similar to those presented in *Clemmensen et al. (2014)* and where they found paleostormsurge sediments. Further inland there are planar and undulating features. The map: *Generalstabskartan, 1867, Halmstad J243-13-1,* from 1867 only show the land as low lying with no clear topography	This area has no natural protection though the more northern part of the beach is protected by a "Natural reserve" and the more southern areas has "Plant and animal-protection" (Naturvårdsverket, n.d.).	*This area seems to be largely unaffected historically and today from human disturbances. There could be problems in that te area with similar washover fan-shapes as other studies have infrastructure on it and only the very closest area to the sea is free to sample and free from disturbance. There should be good archives of palaeostorm surges. A very good potential!*	34
Scania	*Viken*		N6225958 E348893	: From documents dating back to 1737: *Geometrisk avmätning, 1737, Vikens socken Viken nr 1-94*, there are information of the area being part of the outmark and therefore grazed. The soil was described as sandy and rich in boulders. From the early 1800 the document: *Mätning, 1800, 12-VIK-266*, show that the area weren't farmed during this period. During the late 1800 there is documentation: *Utstakning av gräns, 1899, 12-VIK-64*, of the coast being used as a gravel pit and an area to collect sea weed and sand. The documentation from the beginning of the 1900: *Häradsekonomiska kartan, 1910-15, Kulla gunnarstorp J112-1-6 1*, demonstrates that the area wasn't farmed but there was small roads passing in the close surrounding. The maps from the mid-1900: *Ekonomiska kartan, 1969, Viken J133-3B5j71* and *Ekonomiska kartan, 1969, Lerberget J133-3B6j72* also demonstrates that the area has never been used for farming.	The LIDAR show that the landscape has two large terraces, the first along the coast and the second some hundred of meters inland. These are very flat and on the most landward one there are clear squares and rectangular fields. There is a coast parallel ridge and depression. The general map: *Generalstabskartan, 1861, Ängelholm J243-8-1*, show the landscape as flat.	There is no natural protection of the area according to Naturvårdsverket (n.d.)	*The gravel and sand extraction during the late 1800 would result in a very high disturbance of the sedimentary structures and inability to find older preserved storm surge sediments. More modern storm surges could be found here. It is a poor area.*	37
	South of Barsebäck		N6179180 E372061	The map: *Häradsekonomiska kartan, 1910-15, Bjärred J112-1-39,* from 1910-1915, show that the area was a wetland with farmlands close to the coast. The later documentation from 1968-1969: *Ekonomiska kartan, 1968-69, Löddesborg J133-2C6e70*, show that they left some of the more coastal farmland.	The LIDAR show that the area is a lowland and some hundred meters to a kilometre inland, there is a ramp to a higher terrace. There are a lot of small coast parallel ridges following the lowland all the way up to the ramp. There can also be seen some clear ditches. The map: *Generalstabskartan, 1860, Landskrona J243-4-1,* just show that the area is low.	This area is not just protected by the Nature2000 bird directive 79/409/EEG , but is also a natural reserve (Naturvårdsverket, n.d.).	*The area closest to the sea should have a very good archive of palaeostorm surges but as the area is well protected there will be problem with permission to sample. It is a promising area that needs time to get permission to sample.*	41
	Dalköpinge Ängar		N6136373 E387216	The documentation from 1910-1915: *Häradsekonomiska kartan, 1910-15, Trälleborg J112-1-69,* show that the area was divided into parcels but not farmed. On the Economic map from 1968-1969: *Ekonomiska kartan, 1968,69, Gislövs läge J133-1C7h70,* the area is marked as a shooting range as well as a wetland. According to Länsstyrelsen Skåne (n.d.) the area has been grazed for hundreds of years and possibly not ever been farmed, though this theory don't explain the strait ditches and squares/rectangles that is visible through LIDAR.	The LIDAR show that there are some coast parallel ridges but the most dominant feature is the strait ditches that form rectangles and squares in the landscape. The landscape is flat, as is evident from older documentation too: *Generalstabskartan, 1864, Ystad J243-2-1.*	The area is part of the natural reserve: Dalköpinge Ängars Naturreservat (Naturvårdsverket, n.d.).	*This area is probably more disturbed than Länsstyrelsen Skåne (n.d.) writes as there are clear strait structures on the LIDAR, resulting in a poor archive for longer period. Although that this is a possible area.*	43

Ekonomiska kartan, Häradsekonomiska kartan, Generalgrabens maps, Laga Skifte as well as Vattenåtgärd of the areas was collected from Lantmäteriet and retrieved 2020-11-29 from httpshistoriskakartor.lantmateriet.sehistoriskakartorsearch.html

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Appendix 4, Grain-size analysis

Along one of the ridges at 38-53 centimetres depth (coordinate: N613630 & E387073 in SWEREF99TM with three metre precision)

SAMPLE STATISTICS

SIEVING ERROR:	0,1%		
SAMPLE IDENTITY:	**T1B5A**	ANALYST & DATE:	Lykke Lundgren Sassner, 12/2-2021
SAMPLE TYPE:	Unimodal, Moderately Sorted	TEXTURAL GROUP:	Slightly Gravelly Sand
SEDIMENT NAME:	Slightly Very Fine Gravelly Medium Sand		

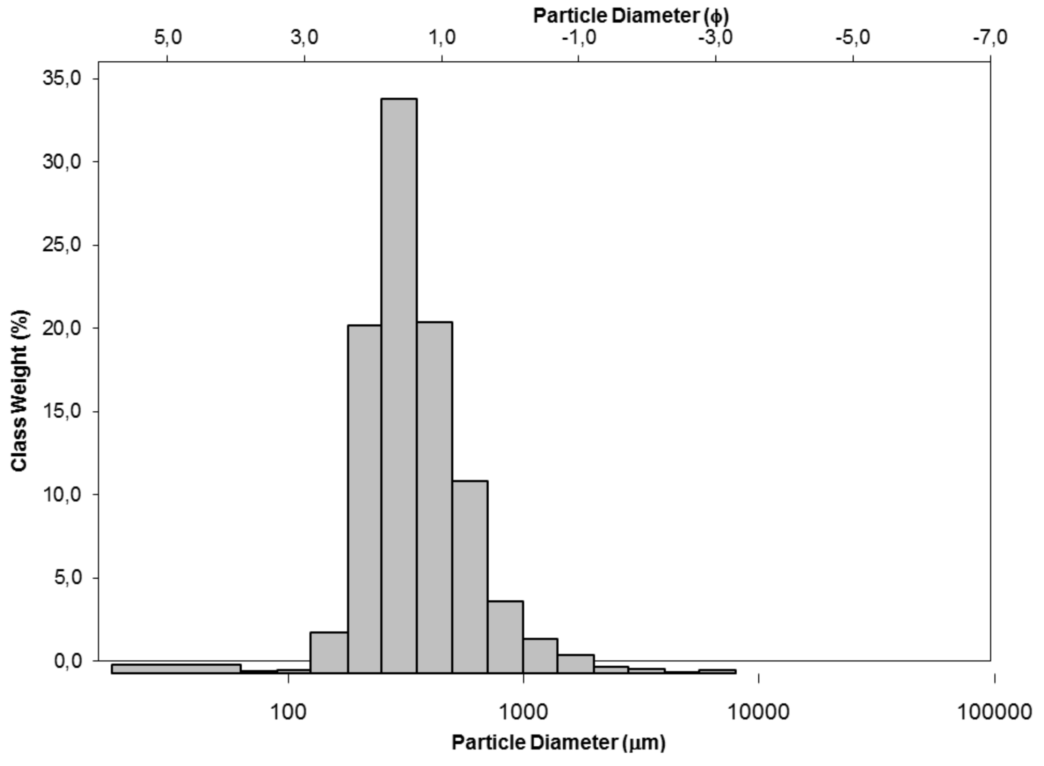
	μm	ϕ
MODE 1:	302,5	1,747
MODE 2:		
MODE 3:		
D_{10}:	195,7	0,566
MEDIAN or D_{50}:	323,1	1,630
D_{90}:	675,7	2,353
(D_{90} / D_{10}):	3,452	4,160
(D_{90} - D_{10}):	480,0	1,788
(D_{75} / D_{25}):	1,834	1,781
(D_{75} - D_{25}):	209,2	0,875

GRAIN SIZE DISTRIBUTION

GRAVEL:	1,0%	COARSE SAND:	15,8%
SAND:	97,0%	MEDIUM SAND:	55,4%
MUD:	2,0%	FINE SAND:	22,2%
		V FINE SAND:	0,4%
V COARSE GRAVEL:	0,0%	V COARSE SILT:	1,1%
COARSE GRAVEL:	0,0%	COARSE SILT:	0,9%
MEDIUM GRAVEL:	0,0%	MEDIUM SILT:	0,0%
FINE GRAVEL:	0,3%	FINE SILT:	0,0%
V FINE GRAVEL:	0,7%	V FINE SILT:	0,0%
V COARSE SAND:	3,2%	CLAY:	0,0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	428,8	340,8	1,553	340,3	1,555	Medium Sand
SORTING (σ):	456,9	1,849	0,887	1,630	0,705	Moderately Sorted
SKEWNESS (Sk):	8,290	-0,095	0,095	0,226	-0,226	Coarse Skewed
KURTOSIS (K):	100,4	7,857	7,857	1,111	1,111	Leptokurtic

GRAIN SIZE DISTRIBUTION



Along the same ridge at 70-82 *depth (coordinate: N613630 & E387073 in SWEREF99TM with three metre precision)*

SIEVING ERROR: 0,1%

SAMPLE STATISTICS

SAMPLE IDENTITY: **T1B5B** ANALYST & DATE: Lykke Lundgren Sassner, 12/2-2021

SAMPLE TYPE: Unimodal, Moderately Well Sorted TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Medium Sand

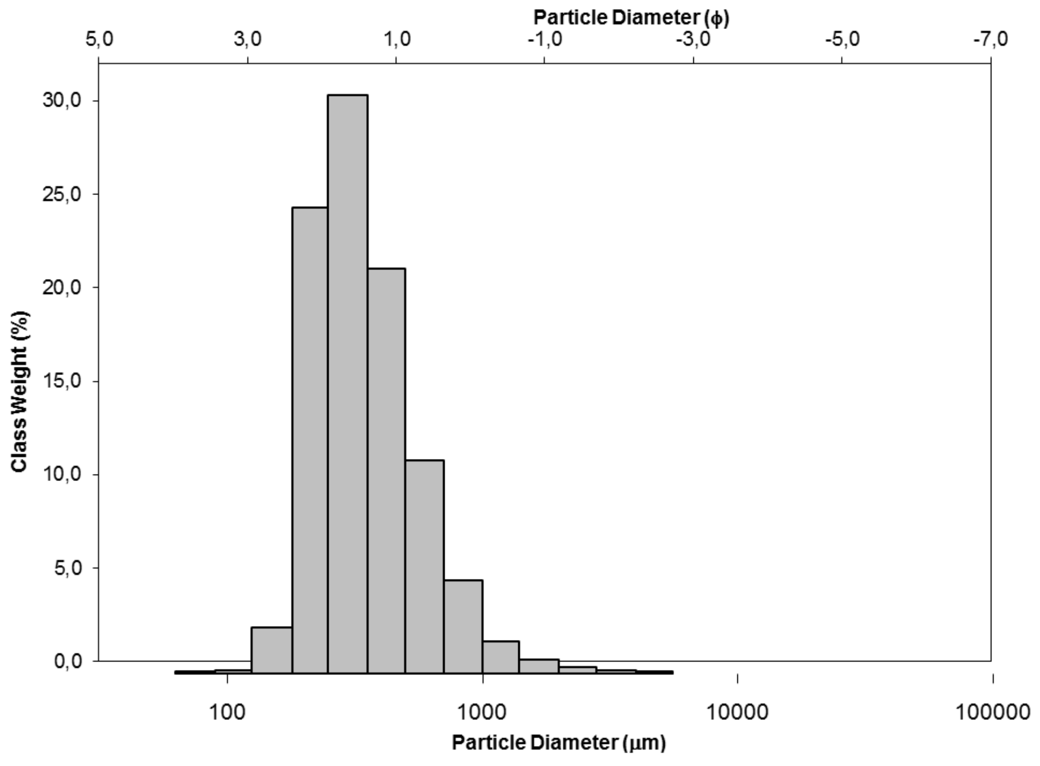
	μm	ϕ
MODE 1:	302,5	1,747
MODE 2:		
MODE 3:		
D_{10}:	194,1	0,579
MEDIAN or D_{50}:	320,0	1,644
D_{90}:	669,5	2,365
(D_{90} / D_{10}):	3,450	4,086
$(D_{90} - D_{10})$:	475,4	1,786
(D_{75} / D_{25}):	1,913	1,830
$(D_{75} - D_{25})$:	218,5	0,935

GRAIN SIZE DISTRIBUTION

GRAVEL:	0,7%	COARSE SAND:	16,3%
SAND:	97,6%	MEDIUM SAND:	52,4%
MUD:	1,7%	FINE SAND:	26,0%
		V FINE SAND:	0,3%
V COARSE GRAVEL:	0,0%	V COARSE SILT:	0,3%
COARSE GRAVEL:	0,0%	COARSE SILT:	0,3%
MEDIUM GRAVEL:	0,0%	MEDIUM SILT:	0,3%
FINE GRAVEL:	0,2%	FINE SILT:	0,3%
V FINE GRAVEL:	0,6%	V FINE SILT:	0,3%
V COARSE SAND:	2,5%	CLAY:	0,3%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	407,8	326,9	1,613	335,1	1,577	Medium Sand
SORTING (σ):	341,9	2,019	1,014	1,620	0,696	Moderately Well Sorted
SKEWNESS (Sk):	6,032	-2,079	2,079	0,211	-0,211	Coarse Skewed
KURTOSIS (K):	60,48	15,41	15,41	1,000	1,000	Mesokurtic

GRAIN SIZE DISTRIBUTION



At the beach (coordinate: N613661 E387024)

SAMPLE STATISTICS

SIEVING ERROR: 0,1%

SAMPLE IDENTITY: **T1B6**

ANALYST & DATE: Lykke Lundgren Sassner, 12/2-2021

SAMPLE TYPE: Unimodal, Well Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Medium Sand

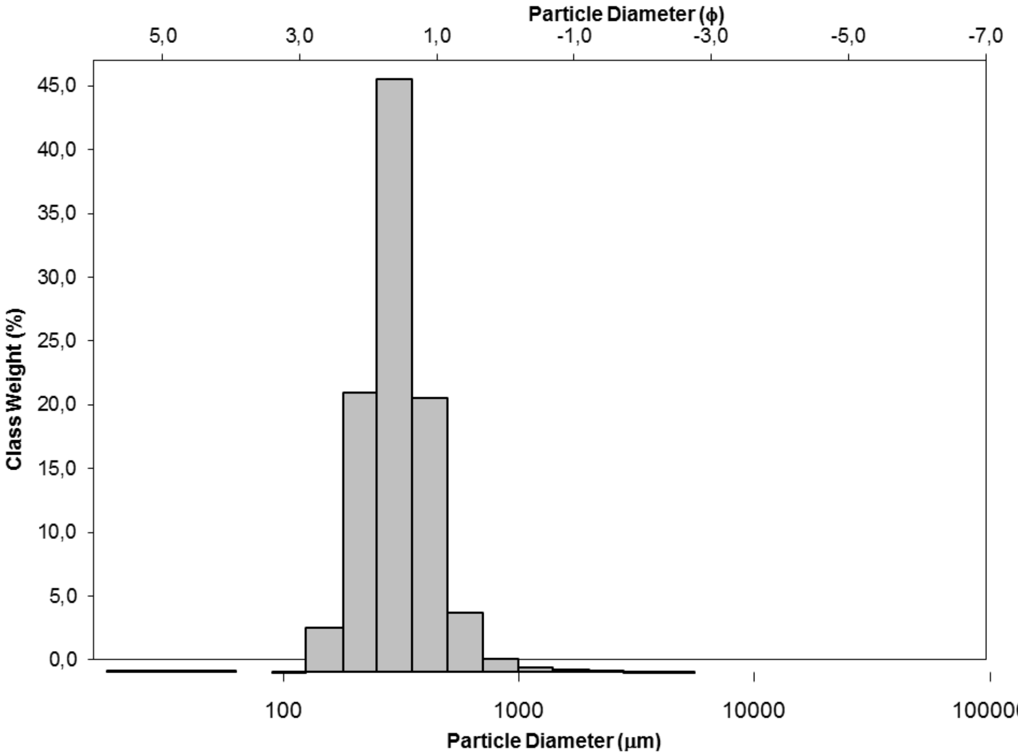
	μm	ϕ
MODE 1:	302,5	1,747
MODE 2:		
MODE 3:		
D_{10}:	197,1	1,082
MEDIAN or D_{50}:	300,9	1,733
D_{90}:	472,4	2,343
(D_{90} / D_{10}):	2,397	2,166
(D_{90} - D_{10}):	275,3	1,261
(D_{75} / D_{25}):	1,487	1,400
(D_{75} - D_{25}):	121,5	0,572

GRAIN SIZE DISTRIBUTION

GRAVEL:	0,1%	COARSE SAND:	5,8%
SAND:	99,3%	MEDIUM SAND:	68,4%
MUD:	0,5%	FINE SAND:	24,5%
		V FINE SAND:	0,1%
V COARSE GRAVEL:	0,0%	V COARSE SILT:	0,3%
COARSE GRAVEL:	0,0%	COARSE SILT:	0,2%
MEDIUM GRAVEL:	0,0%	MEDIUM SILT:	0,0%
FINE GRAVEL:	0,0%	FINE SILT:	0,0%
V FINE GRAVEL:	0,1%	V FINE SILT:	0,0%
V COARSE SAND:	0,6%	CLAY:	0,0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	333,1	304,0	1,718	303,5	1,720	Medium Sand
SORTING (σ):	167,6	1,465	0,551	1,405	0,491	Well Sorted
SKEWNESS (Sk):	7,496	-0,298	0,298	0,070	-0,070	Symmetrical
KURTOSIS (K):	125,6	10,53	10,53	1,155	1,155	Leptokurtic

GRAIN SIZE DISTRIBUTION



Appendix 5, C^{14} analysis results

LUNDS UNIVERSITET

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Helena Alexanderson
KvgA
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Dateringsattest

Provets benämning	Lab no	^{14}C-ålder BP	Provmgd (mg C)	Förbehandling
Dalköpinge ängar, Trelleborg T1B1 43-44	LuS 16760	1.142 ± 0.005 fM	0,9	HCl, NaOH

Beräkningen av 14C-åldern är baserad på halveringstiden 5568 år. Resultaten är givna i antal år före 1950 (14C-ålder BP). I osäkerhetsangivelsen (+/- 1 SD) innefattas statistiskt åtkomliga bidrag från mätningen av prov, standard och bakgrund. Enligt internationell överenskommelse baseras åldersberäkningen på 95% av aktiviteten hos NBS oxalsyre-standard. Alla 14C-åldrar är 13C-korrigerade för avvikelsen från överenskommet standardvärde på 13C/12C-förhållandet. 14C-åldern måste översättas till kalibrerade 14C-år (kalenderår) genom att använda en lämplig kalibreringskurva: IntCal20 (terrestra prover från norra halvklotet), SHCal20 (terrestra prover från södra halvklotet) eller Marine20 (marina prover).

Lund 2021-04-01

Anne Birgitte Nielsen Mats Rundgren

Calibrate

intcal13 pre-Bomb Calibration data set

NHZ1 post-Bomb Calibration data set

1.142 $F^{14}C$

.005 $F^{14}C$ Uncertainty

1.0 Smoothing in Years

☑ AD/BC output

LuS 16760 Description

☑ Enable Help

Calculate F14C

Radiocarbon Age

Radiocarbon Uncertainty

Calculate F14C

$D^{14}C$

$D^{14}C$ Uncertainty

Advanced...

Calibration of 1.142000±0.005000 with NHZ1, intcal13.f14c,

Smoothing: 1.000000

```
# Northern Hemisphere Zone 1 compilation
#
#
# Quan Hua,Mike Barbetti,Andrzej Z Rakowski
# "ATMOSPHERIC RADIOCARBON FOR THE PERIOD 1950-2010",
# Radiocarbon, 55(4), 2013
#
#
#

##Atmospheric data from Reimer et al (2013);
# Reimer et al. 2013
# Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Buck CE
# Cheng H, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Haflidason H,
# Hajdas I, Hatté C, Heaton TJ, Hogg AG, Hughen KA, Kaiser KF, Kromer B,
# Manning SW, Niu M, Reimer RW, Richards DA, Scott EM, Southon JR, Turney CSM,
# van der Plicht J.
# IntCal13 and MARINE13 radiocarbon age calibration curves 0-50000 years calBP
# Radiocarbon 55(4). DOI: 10.2458/azu_js_rc.55.16947
```

OneSigma
[cal AD 1991.24 :cal AD 1993.10]1.000

TwoSigma
[cal AD 1957.63 :cal AD 1958.41]0.079
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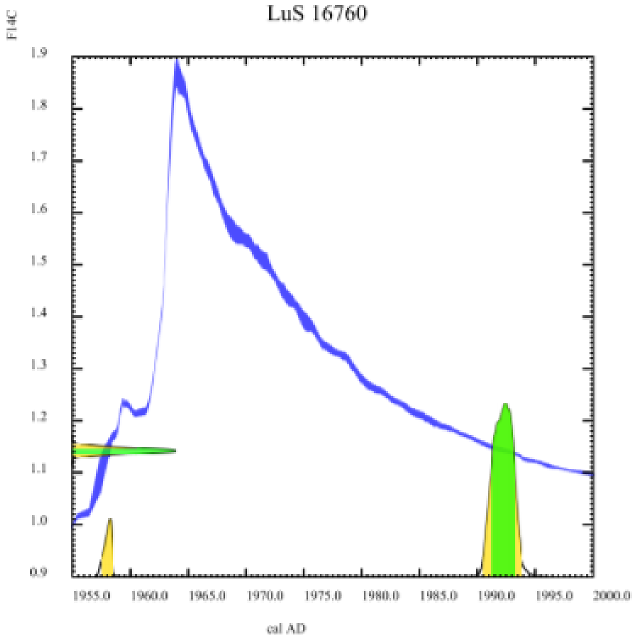

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