Relation between sediment flux variation and land use patterns along the Swedish Baltic Sea coast

Mansoor Khan

Dissertations in Geology at Lund University,
Master's thesis, no 331
(45 hp/ECTS credits)

Department of Geology
Lund University
2013

Relation between sediment flux variation and land use patterns along the Swedish Baltic Sea coast

Master's thesis
Mansoor Khan

Department of Geology
Lund University
2013

Contents

Cover picture: The Baltic Sea coast south of Västervik, Sweden.

Relation between sediment flux variation and land use patterns along the Swedish Baltic Sea coast

MANSOOR KHAN

Khan, M., 2013: Relation between sediment flux variation and land use patterns along the Swedish Baltic Sea coast. *Dissertations in Geology at Lund University*, No. 331, 25 pp., 45 hp (45 ECTS credits).

Abstract: The Baltic Sea is one of the most studied seas in the world and has been in the spotlight due to its wide range of environmental problems. Human impact and climate influence on the Baltic Sea is of major concerns. This study aims to reconstruct the environment of the south east coast of the Baltic Sea and also analyze the human impact and climate influence in changing the landscape and its impact on sedimentation pattern of the marine coastal sediments over time through high resolution particle size analysis using the Sedigraph method. Two stations were selected from the southeastern coast of the Baltic Sea: Gåsfjärden, Västervik and Yttre Redden, Karlskrona. Five cores were collected from Gåsfjärden, one 5.58 m core and four shorter Gemini cores (~0.5m) and similarly five cores were collected from Karlskrona, one 5.20 m and 4 shorter Gemini cores (~0.4m). The age model for both of the cores are based on AMS ^{14}C dates. The Gåsfjärden core shows the last 6000 years and Karlskrona extends to the last 7000 years. The Gåsfjärden core has laminations in the whole core, which imply continuous low oxygen conditions in the area. The up-core decrease in the finer fraction is observed more or less throughout the Gåsfjärden core data which is attributed to deforestation, expansion of agriculture, erosion, and also the hydrographic conditions of the Baltic Sea. In the Karlskrona core there are large variations observed in the lower part of the core with little variability at the upper part. The large variability at the lower part is possibly linked to Littorina transgression and the small variability at upper part could be due to agricultural activities and climate changes. Natural drainage of the wetlands and ditching of fields are observed in the Gemini cores of both of the stations.

Keywords: Baltic Sea, landscape, coastal sediments, sedigraph, Gåsfjärden, Karlskrona, gemini cores

Supervisors: Helena Filipsson and Anupam Ghosh

Mansoor Khan, Department of Geology, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden.
E-mail: mansoorswati@yahoo.com

1 Introduction

Baltic Sea is a relatively young and dynamic sea and is one of the world's largest brackish water bodies. The Baltic Sea has transformed several times since the Last Ice Age (Ruskule et al., 2009). Today, the region has been in the spotlight due to its wide range of environmental problems. The influence of human impact and climate has varied greatly on for instance vegetation, landscape history, land use patterns and hydrology. The most debated argument goes with the role of human activity and its effects on vegetation, land use, and eutrophication. Lots of research has been done to understand its geological and environmental history; however, fewer studies focus on the coastal zones of the Baltic Sea.

One important environmental factor also affecting coastal zone is land use and changes in land use. It includes modification of natural land which can also have a serious impact on natural resources like soil, nutrient, plants, water and animals (Hart, 1996). In the coming decades land use is one of the important challenges to deal with; to provide food, shelter and also raise the standard of living for the world's population and also at the same time sustain ecosystem of living species and humans. In the future urban growth, cropland expansion and other land use changes should be planned keeping in mind the increasing population of the world and its outcome. The information on the pattern of existing and past land use changes are very important and necessary for the betterment of the use of land in future. This study focus on marine sediments covering the Littorina time into the present day from the Baltic coastal zone. The Littorina Transgression was the result of sea level rise in the Baltic, which was caused by melting of global ice and Scandinavian land uplift in the Mid Holocene. This transgression was not consistent. Instead, it is composed of different transgression waves (Berglund, 1971) which led to different sedimentation patterns from 7500 BP to present.

The main aim of the study involves environmental reconstructions covering the last five millennia of the Baltic coastal zone and aims to better understand the variation in nutrient distribution and terrigenous sediment transport from land to the coastal zone. I want to analyze possible human impact on changes in land use through detailed particle size analysis of marine sediments and I aim to examine the accumulated sedimentation and match these to land use changes within the contributing catchment.

1.1 General Baltic Sea setting

The Baltic Sea is characterized generally as a semi enclosed sea having an open boundary towards Skagerrak and the North Sea, located between central and northern Europe having 53° and 66°N latitude with area of 412569 km^2 and volume of 21631km^3,

Figure 1. Map of the Baltic Sea showing the major basins with its surrounding countries (HELCOM,2008)

Figure 1 (Seifert and Kayser, 1995). It has series of basins and the main water masses include Bothnian Sea and Bothnian Bay along with Kattegat. The central part Baltic Proper is subdivided into Northern and Southern Proper and the Eastern and Western Gotland Basins. In the east of Baltic Proper there is Gulf of Riga and in the South there is Gulf of Gdansk (Ruskule et al., 2009) shown in Figure 1. The deepest part of the Baltic Sea is about 459m situated SSE of Stockholm. In the south the water depth is between 25m to 75m, in the center it vary between 100-200m and 100-50m in the north

1.1.1 Present day Hydrography

The brackish water in the Baltic Sea is a result of inflow from saline water of Atlantic and fresh water input from precipitation and river runoff (Döös et al, 2004) from more than 250 rivers (Ruskule et al., 2009). Baltic Sea has an annual fresh water input of 660 km^3 from rivers and precipitation, the annual discharge of saline water is 950 km^3, whereas the annual inflow of bottom brackish water is 475 km^3 (Björck, 1995). For the water balance evaporation is important as well. The average evaporation annually is approximately 493 mm, which reduces the average freshwater input to about 1900 $m^3 \cdot s^{-1}$ which is 14% of the total freshwater water input (Stigebrandt, 2001). The salinity of the Baltic Sea varies greatly in time due to in and outflows and wind induced mixing with saline Skagerrak waters (Stigebrandt, 2001). The inflow of saline water is through the Öresund and Danish Belt which are shallow and narrow, therefore the inflow of saline water are confined. As the saline water is denser it fills the deeper part of the Baltic Sea (Ruskule et al., 2009). The surface water salinity varies between 1 psu in north and between 6-8 psu in the central part. The salinity of deep waters of the central Baltic lies between 15-20 psu (Björck, 1995).

1.1.2 Geology

The oldest bed rock in the Baltic is the crystalline Precambrian basement in the Northern Baltic Sea sloping towards SSE below the sedimentary rocks of the Paleozoic and Mesozoic forming the bed rock in the south-eastern Baltic Sea (Winterhalter, 2001). The crystalline Precambrian basement rock has an irregular topography caused by glacial scouring while the sedimentary exhibits gentle topography (Winterhalter, 2001). The bedrock is covered by fine grained sediments from silt and clay to gyttja clay. From the isostatic uplift and deglaciation the shallow area of the sea is eroded by waves and currents and fine grained sediments are redeposited in the deeper part. The coarse material consisting of silt, sand and gravel is left as a lag deposit (Winterhalter, 2001).

1.2 Late Quaternary History of Baltic Sea

The focus of this study is the last 5000 years; however in order to further understand the environmental changes it is necessary to understand how the Baltic Sea has developed into its modern settings.

The Baltic Sea has undergone through different stages during and after the last deglaciation from 17,000-15,000 cal. BP to 11,000-10,000 cal. BP (Björck, 1995). The decay of the Scandinavian Ice Sheet led to sea level rise and glacio-isostatic uplift, which resulted into many different alteration of marine conditions within the Baltic Basin (Björck, 1995). From the bio and lithostratigraphic records four phases of Baltic Sea development have been identified.

1.2.1 Baltic Ice Lake (12,600-10,300 BP)

The first phase in the Baltic Sea as a result of receding ice sheet is the Baltic Ice Lake (Figure 2) (Björck, 1995), which led to large sedimentation rates due to glacial deposits and erosion in the east of Baltic Sea. Varved glaciolacustrine clay was deposited as a result of ice sheet retreat (Björck, 2008). The damming of the glacial lake started due to the threshold uplift (Andrén et al 2011). The maximum size of the lake was thought to be in the Younger Dryas (Olausson, 1982). The large drainage of the lake started from westward as result of ice retreat to the northern end of the Billingen (Björck, 2008). The final drainage of the Baltic Ice Lake from different evidences was dated to ca 11.7 Ka (Andrén et al., 2011).

Figure 2 The configuration of the Baltic Ice lake prior to final drainage (12,600-10,300 BP) (Andrén, 2003a)

1.2.2 Yoldia Sea (10,300-9500 BP)

After 300 years of the final drainage of the Baltic Ice Lake, sea water enter the Baltic Basin through the narrow straits of the south-central Swedish lowlands as a result of sea level rise (Andrén et al., 2011). From high uplift the straits got shallower which became an obstacle for the saline water to enter into the Baltic (Andrén et al., 2011). It took almost 250 years for the straits to open and weak brackish conditions took place for around 150 years shown in figure 3 (Björck, 2008) and again the brackish phase ended. Most of the sedimentation during this time was of organic material (Björck, 2008). Most part of the Baltic Sea Basin was deglaciated at the end of this stage which led to sedimentation in Baltic Sea Basin. In the Bothnian Bay varved glacial clay was deposited and during the same time in the central and southern part of basin postglacial sediments were deposited (Ignatius et al 1981).

Figure 3. The configuration of the Yoldia Sea stage, the start of short saline phase (10,300- 9500 BP) (Andrén, 2003b)

1.2.3 Ancylus Lake (9500-8000 BP)

During the early Holocene there was more ice retreating due to the warmer climate which led to a distinct isostactic uplift in the central Sweden threshold areas (Steinselva channel and Göta Älv River) (Björck, 1995 and Yu, 2003). Therefore, the Baltic Basin again became a fresh water lake as a result of separation from the ocean as shown in figure 4. The transgression of this lake was started earlier around 10,700 cal. BP which is marked by evidences from the well preserved pine stumps and elevated beach ridges in the south of the Baltic (Persson, 1978 and Björck, 2008). In 10,000 cal. BP the sea level reached Darss Sill (Björck, 1995) and the erosion started which led to the initial drainage of the Ancylus Lake through the Dara rive (Figure 4). However recent studies suggested that the drainage pathway was the Great Belt Channel. (Bennike et al., 1998, Jensen et al., 1999 and Björck, 2008). During the Ancylus lake phase the sedimentation was also of weak organic material and glacially influenced in the north (Björck, 2008).

Figure 4. The culmination of the Ancylus Lake Stage (9500-8000 BP)(Andrén, 2003c)

1.2.4 Littorina Sea (7500-4000 BP)

The transition period of the Ancylus Lake to the brackish marine Littorina Sea is also a weak brackish phase between 9800-8500 cal. BP called as Initial Littorina Sea or Early Littorina Sea (Figure 5) (Berglund et al., 2005). The initial signs of the brackish water in the Baltic basin are dated to 9800 cal. BP (Andrén et al 2011). The salinity was around 0.8 psu in the northern part of Gulf of Bothnia and 1.3 psu in central Baltic (Taipale and Saarnisto, 1991). The transition phase was later named as Mastogloia Sea. Although, the saline influence at that time was very weak probably because of weak connection between the Baltic basin with the North Sea.

The next brackish marine phase, the Littorina Sea, is marked by increased sea water influx (Hyvärinen et al., 1988), lithogical changes (Andrén et al., 2011) as well as by the opening of the Öresund strait around 8500 cal. BP (Björck, 1995). The melting of the Laurentide and Antarctic ice sheet caused sea level rise up to 30m (Lambeck and Chappell, 2011) which led to the Littorina Transgression in the Baltic Sea around 7500 cal. BP (Berglund et al., 2005). There was a notable increase in water depth during the first three Littorina transgressions (Berglund et al., 2005) from Öresund and Great Belt. There was also a considerable increase in the inflowing saline water into the Baltic as an important outcome (Björck, 2008). The mid Holocene warmer climate and increasing salinity gave rise to a suitable aquatic environment in relation to the life diversity in the Baltic Sea. But higher primary productivity and stronger stratification caused by salinity in bottom water also resulted in anoxic conditions (Björck, 2008). The increase in the salinity and primary production in the Littorina sea stage also changed the character of the sediments to more muddy sediments (Winterhalter, 2001). Due to less cohesion of sediments and high water content, the gyttja clay was easily redeposited even by weak bottom currents.

After 6000 cal. BP when the transgression started to slow down, this was the turning point in the development of the Baltic. The sea level ceased to rise,

Figure 5. Start of Littorina Sea stage (7500-4000 BP) (Andrén, 2004)

the uplift pattern became complicated and as a result the magnitude of transgression became less (Björck, 2008). But there was still uplift continued in Sweden and northwards which caused regression. Due to the regression the influx of the saline water became more limited (Zillén et al., 2008). My study focus on sediments covering the Littorina period into the present day.

1.3 Present day environmental problems in the Baltic Sea

The Baltic Sea has borders with nine highly industrial countries and lies close to the air pollution main center in central Europe. Having small mean depth and narrow connections to the sea makes Baltic more vulnerable to anthropogenic influences (Wulff et al., 1990). A large amount of nutrients in the Baltic Sea is coming from anthropogenic sources (Heinkanen, 1998).

1.3.1 Salinity

In the history of the Baltic Sea the variation in the salinity have been caused by changes in the overall freshwater supply (Gustafsson and Westman, 2002). Most of the runoff and inflows are influenced by the climate conditions like Northern Atlantic Oscillation (Hänninen et al., 2000) The inflow of marine water from the North sea due to current and winds also regulate the mean salinity in the Baltic Sea (Lundberg, 2005). The strongest recorded inflows during the 20th century were in 1913, 1921, 1951 and 1975-76 (Matthäus and Franck, 1992). In January 2003, the first larger inflow since 1993 entered through the Danish Straits (Nausch et al., 2003).

1.3.2 Oxygen

Hypoxia, defined as <2 ml l^{-1} dissolved oxygen in aquatic conditions, below which the benthic organisms are negatively affected. Human and climate both played an important role for the present hypoxic conditions in the Baltic Sea. Hypoxia in the Baltic Sea was recorded from its formation (Conley et al., 2002). The Baltic Sea today has high conditions of hypoxia in the bottom waters which reduces the habitat for the living species as well as resources (Conley et al., 2009a). Hypoxia also influenced the biochemical process that ensures the nutrient (nitrogen and phosphorous) in water column (Conley et al., 2002) which results in eutrophication. Due to eutrophication, phytoplankton increases in the water body. When large numbers of phytoplankton dies and fall to the sea floor, the decomposition processes in the bottom consumes oxygen resulting in the low oxygen conditions. Hypoxia can also occur due to vertical stratification of water column causing a strong halocline that reduces the exchange of oxygen from surface to the bottom waters resulting in less supply of oxygen to the bottom waters. The average area affected by the hypoxia in the Baltic Sea is 42,000 km^2 and over the past years hypoxia affected areas recorded is 60,000 km^2 in the Baltic (Conley et al., 2009a).

The oxygen concentration is partly impacted by the saltwater inflow and partly by the eutrophication. The nutrient rich bottom waters are pushed by saline inflows further north from the deep basin in the central Baltic (Cederwall and Sjöberg, 1995), without pushing the anoxic old water to north of Fårö Island as the volume of Eastern Gotland Basin is very large (Cederwall and Sjöberg, 1995). Due to increase in algal production following by the organic material transport to bottom, the sedimentation increases. The organic material decays and consumes oxygen which causes anoxia and hypoxia on a large scale (Karlson et al., 2002).

From 1970-2000, about 12,000 km^2 to 70,000 km^2 of the bottom surface area of the Baltic had oxygen concentration of 2 ml l^{-1} (Conley et al., 2002). In summers 2002 the concentration of oxygen at the Darss Sill was 1-4 ml l^{-1}. In 2003 winter-spring there was no anoxia recorded in Bornholm Basin (Lundberg, 2005). In the Gdansk Deep the mean concentration is about 2ml l^{-1} and in the deep waters of central Baltic Sea it varies from approximately 8ml l^{-1} (fully oxygenated) to anoxia (HELCOM 1996).

1.3.3 Nutrients

There has been an increase nutrient load and a large scale eutrophication noted in the present century (Wulff et al., 1990). Since 1960 the trend of inorganic nitrate and phosphate has been increased in the central Baltic, both in the bottom water and in the whole water column (Conley et al., 2009b). From the late 1980s to the beginning of the 1990s the concentration of total phosphorous decreased in the surface layer with 20% in the central Baltic. The concentration of total nitrogen also increased at the same time but again decreases to the same level as it was in the 1980s. (Larsson and Anderson, 1999). Since 2000 the amount of total nitrogen in the entire water column has been consistent in all the water basins, while the amount of phosphorous has decreased in the Eastern Gotland Basin, Bornholm and Gdansk and increased in the Western Gotland Basin and Northern Baltic Proper (SMHI, 2004).

1.4 Land use changes

During the last 6000 years the relationship between the land use and the natural resources has varied greatly the composition of the landscape (Ihse, 1995). Landscape is generally a synthesis of geomorphology, soil, plants, bedrock and animals, where topography, vegetation and hydrology formed the structures (Berglund et al., 1991). The influence of humans and climate has a great impact on these structures, more in regional vegetation and hydrology as compared to topography, mostly in urban areas (Berglund et al., 1991, Koff and Punning, 2002). The most notable impact of human on nature has been deforestation and expansion of agricultural land (Kaplan et al., 2009). The human impact was high in the lowlands as compared to uplands of Sweden and grazing was dominant in the agriculture land use during the last 6000 years (Berglund et al., 2002). One field farming system was dominating throughout the history of agriculture but around 1000 AD two field farming system was introduced in Sweden (Myrdal, 1997). In the shifting to the two field farming, the arable land for cultivation involved clearing of forests and grasslands during the Medieval expansion known from the palaeoecologcal studies (Berglund et al., 1991, Myrdal, 1997). The notable agricultural activity is dated to 1050-1250 AD, from the conversion of forests into cultivation fields (Stanèikaite et al., 2009).

The land use expansion is recorded during the Medieval Warm period (900-1200 AD) in Sweden. This activity came to a halt due to the Black Death and the agrarian crises in the Late Medieval (Myrdal & Morell, 2011). The cultivation in the arable land in Sweden again started in 16th century when the population started to increase and also when the industrial revolution begins in the 18th and 19th century, the area of cultivation increases with 60% in Sweden (Lagerås, 2007). When the Swedish population reached 6 million in 1920 AD, the cultivation area expanded to 3.8 million ha which is the greatest arable land area recorded in Sweden, which largely declines after 1960 due to the introduction of synthetic fertilizers (Morell, 2001). In the last century modern land use takes place instead of small scale agriculture which includes commercial forestry and crop cultivation (Antonsson and Jansson, 2011).

In this study I want to study the anthropogenic impact on the land use and how it has changed through time covering the last five thousand years from Littorina Transgression into the present day in the south east Swedish Baltic coast.

1.5 Grain-size analysis

Grain-size analysis gives information about the sedimentary environments and paleoenvironmental processes. It has long been used as an excellent tool to provide information about sediment provenance, depositional condition and sediment transport history (Friedman, 1979). Grain size data also gives interpretation of characteristics of the whole particle size distribution which offers information about changing environment conditions and depositional processes. It is also very useful for distinguishing between multiple sedimentary processes (Beierle, 2002). There are different techniques to determine the grain size which include dry and wet sieving, measurement by laser granumeter, X-ray sedigraph, coulter counter and direct measurement. These methods give information about different aspects of size of grain (Blott and Pye, 2001).

2 Study area

Two stations were selected from the south eastern coast of Sweden in the Baltic Sea. The first location, Gåsfjärden, is located south of the town Västervik, Småland shown in figure 6, which is a more remote location compared to the other station. The town of Västervik was moved to its current location in 1433 AD, before that it was located at Gamleby (north of Västervik). The population of Västervik was 21,140 in 2010. The surface salinity in Gåsfjärden varies between 3.5 to 6psu and the bottom water salinity varies between 6.4 to 6.7 psu based on monthly average of 16 years (1995-2010) and surface water temperature varies between 3 to 7°C also from the year

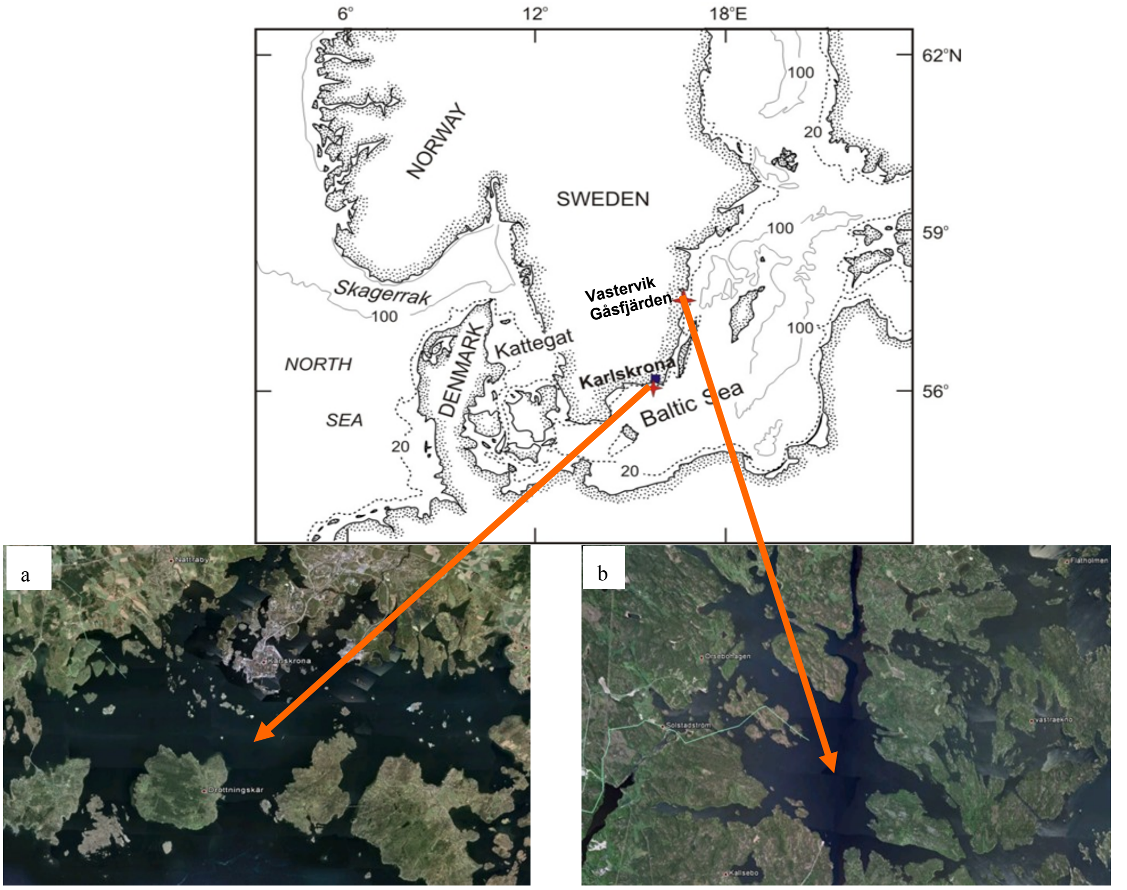

Figure 6: Map of the study area, 6a showing the Karlskrona area and the core location, 6b showing the Gåsfjärden basin and the location of the core (pictures 6a and 6b are taken from Google maps)

1995-2010 (SMHI data base SHARK). The second station is located close to Karlskrona, Blekinge Archipelago shown in figure 6, south Sweden and is more affected by anthropogenic impact as compared to Västervik. Karlskrona is a locality with population of 35,000 in 2010. It is founded in 1680 and grew very quickly by 1750 it had a population of 10,000. It is also known for the only remaining Swedish naval base and the headquarter of Swedish Coast Guard. It was also one of the largest industrial workplaces in Sweden in late the 18th century (Hilson, 2001). The surface salinity varies between 6.8 to 7.2psu and the bottom water salinity varies between 7 to 7.7psu from monthly average of 13 years (1998-2010) and average surface water temperature varies between 2 to 18°C and bottom water temperature varies between 2 to 11°C also from the year 1998-2010 (SMHI data base SHARK).

3 Method

3.1 Core collection and subsampling

The sediment cores were collected during a research cruise *r/v Ocean surveyor* in the summer of 2011 from two different sites, the first station is Gåsfjärden Västervik, (57°34'23"N, 16°35'26"E). The Gåsfjärden core was collected at 31m water depth and is dominated by gyttja clay as well as distinct laminations all throughout shown in figure 7. The other core is close to Karlskrona (56°7'53"N, 15° 32'55"E). The Karlskrona core was collected at 10m water depth and is dominated by homogeneous gyttja, clay with less lamination shown in (Figure 8). A piston corer was used to collect the long cores and Gemini corer was used to collect the short cores from both of the sites. After collecting the cores, they were visually inspected to identify the laminations, colors and shells.

Five cores were sampled at Västervik Gåsfjärden, one 5.78 m core and four shorter gemini cores (~0.5m). Similarly five cores were sampled at Karlskrona one 5.20 m and four Gemini cores (~0.4m). The cores were sliced at Lund University lab at 1 cm intervals and put into marked plastic boxes.

Figure 7: Photo of Gåsfjärden sediment core showing the lamination throughout the core length

Figure 8: Photo of Karlskrona core showing the brownish homogeneous gyttja.

3.2 Sediment geochronology

The age models for both of the cores are based on AMS ^{14}C measurements. ^{14}C measurement was done at the AMS Laboratory at Lund University. ^{14}C measurement is a (radiocarbon) dating method to calculate the age of carbon bearing material up to 58 000 to 62 000 years (Plastino et al., 2001). ^{14}C in the atmosphere can be fixed into plants by photosynthesis. The resulting of this isotope in the plant matches atmospheric isotope fraction. When the plants are consumed by organisms or they die, the organic material of ^{14}C fraction declines due to radioactive decay of ^{14}C at a constant rate. From the remaining fraction of a sample of ^{14}C to ^{14}C expected from atmosphere gives the age of the sample (Lowe and Walker, 1997). In this study, the radiocarbon ages were measured on four mollusk shell and five terrest-rial plant fragments from Västervik and twelve mollusk shell fragments from Karlskrona were radiocarbon dated at the Radio Carbon Dating Laboratory of Lund University using Accelerator Mass Spectrometer (AMS).

The Västervik core extends from 4086 BC to 1896 AD and the Karlskrona core extends from 5216 BC to 1478 AD. The age model gives an average sedimentation rate which is approximately 10cm/100 years but change in sedimentation rate was observed in the Karlskrona core from 1561 BC to 1478 AD. The dates were calibrated using the Ox Cal v 4.1.7. The marine ages were corrected for the marine reservoir effects i.e. age of 300 years.

The chronologies for the Gemini cores for both of the sites are not established yet. The length of the Gåsfjärden is around 50 cm and Karlskrona is 40cm. The assumed chronology for the Gemini cores is taken as 1mm/year sedimentation rate by taking the long core from each site as reference then the gemini cores extend from 2011 AD to 500 years AD for Gåsfjärden and 400 years AD for Karlskrona.

3.3 X-ray fluorescence (XRF) methods

I had also access to the X-ray Fluorescence (XRF) data, done previously by Anupam Ghosh and Wenxin Ning, researchers at Lund University working on the same cores. I used that XRF data to support my particle size interpretation. XRF is an analytical technique used to estimate the composition of sediments and rocks (De Vries and Vrebos, 2002). XRF is also widely used for chemical analysis, elemental analysis and for research in geochemistry, archaeology and forensic science. The basic principle of XRF analysis is the excitation of electrons by incident X-radiation (Weltje & Tjallingii, 2008). When the electrons are ejected from the inner atomic shells and create an empty space which is filled by outer shells electrons, because of which the extra energy is emitted. Wavelength spectra and emitted fluorescence energy helps to identify the atoms of particular elements that allows estimation of relative abundances (Weltje et al., 2008).

3.4 Particle Size analyses

The particle size analysis was done following Hengstum et al (2006). To analyze the grain size distribution of the sediment cores, all the organic, carbonate and silica material must be removed from the samples. 63 samples were analyzed from Gåsfjärden (57 from long core and 6 from gemini core) and 53 samples were analyzed from the Karlskrona (48 from long core and 5 from gemini core)

As there was much organic material in the sediments, several experiments were done; finally 5 – 6 cm sediment intervals were necessary to combine to get enough material (for the pretreatments). To remove the organic matter from a sample in a mixture of 100 ml de -ionized water, 15 ml of hydrogen peroxide H_2O_2 (33%) was added to approximately 13 g of sediment from the Karlskrona core sample and 11 g from Gåsfjärden core samples in a beaker. For making the reaction fast the beaker was heated on a hot plate until the reaction ceases and it was allowed to cool to 40°C. 15 ml of Hydrochloric acid (HCl) of 10% concentration was then added to sample to remove of carbonate material and again heated for about one minute. After heating, 100 ml de-ionized water was added to dilute the HCl from the sample. Then we centrifuge down the whole sample, filled the centrifuge tubes with de-ionized water and shook the sample in the vortex (mixer) to mix with water. The centrifuging and decantation was repeated until to get neutral pH.

To remove biogenic silica opal from the sample, the sample was boiled in 100 ml solution of 2.0 M concentration of Sodium Hydroxide NaOH (8%) until the reaction ceased. Then 100 ml de-ionized water was added to the beaker and we then repeated the dilution and centrifuging step until neutral pH was reached. Then we checked through the microscope that 100 ml NaOH is enough to take away all the opal material, if they are still there the process with NaOH was repeated.

We then filled the centrifuge tubes with Calgon (Sodium pyrophosphate) and shook the tubes in the vortex so that the sample was mixed in the Calgon. We put the samples into the beaker and added more Calgon up to 100 ml. In order to disperse the grains we put the beakers on the shaking table overnight. Once the grains had dispersed we sieved the samples with 63 µm sieve. The amount of sand consists of >63µm from the total amount of each sample is also analyzed. The material >63 µm was transfered to a weighed boat and then we put them into the oven to dry overnight and then weighed again. The <63 samples were used in the Micromeritic Sedigraph III 5120 for the particle size analysis.

The sedigraph method for particle size analysis is based on Stoke's Law when a particle falls in a liquid it has a velocity which depends on the size and density of the particle material and density and viscosity of the liquid, as large particles settle quicker than small particles. To detect the changes and size in the suspended sediment the sedigraph uses parallel X-ray beam at different vertical distances when the particle is settling.

4 Results

The results of the particles size analysis are shown in figures 9-14, together with the XRF data shown in figures 15 and 16. There are two main standardized grain size scales Udden-Wentworth (1922) and Friendman & Sanders (1978) shown in Table 1, the result present here are according to the Udden-Wentworth (1922) standardized particle size scale. In order to describe the sediment composition the fractions are divided into clay (<4 µm), very fine to fine silt (4-16 µm) and medium to coarse silt (16-63 µm). The concentration of sand is very low in both of the cores whereas silt and clay are dominating.

Grain size mm/ µm	Size Descriptive Terminologies	
	Udden-Wentworth (1922)	Friedman & Sanders (1978)
32-63	Coarse silt	Very coarse silt
16-32	Medium silt	Coarse Silt
8-16	Fine silt	Medium Silt
4-8	Very fine Silt	Fine Silt
1-4	Clay	Very Fine Silt
<1		Clay

Table 1: Size scale of the grains fraction used by Udden-Wentworth (1922) & Friedman & Sanders (1978)

4.1 Gåsfjärden Västervik

The cores sampled in Gåsfjärden have laminations almost throughout the core length. The long core is 578 cm long and represents the time between 4086 BC to 1896 AD and the Gemini core is 50 cm and represents the time between ~1500 to 2011. The laminations were very distinctive in the lower part of the core and gradually decreased in distinctness the upper part. The analyzed samples in Gåsfjärden mainly consisted of unconsolidated grey to dark grey gyttja clay. The sediment nature was dominantly clay (85-90 %) with clayey silt and silt fractions. The sand fraction was very low with only 0.5% of the total weight of the sample. Generally, there is an overall increasing trend in the clay content and decreasing trend in the silt fraction upwards along the long core length (older to younger horizons) shown in figure 9.

Overall the mean particle size has a trend towards finer particles from 4000BC to 1000 BC, large variability is observed during Holocene Thermal Maximum/Littorina Transgression 4000 BC to 3500 BC and then from 1000 BC mean has increasing trend from 2.7 to 4.5 µm to the top with again large variability (figure 10). In the clay fractions during the period of Holocene Thermal Maximum/Littorina Transgression 4000 BC-2000 BC there are relatively small changes seen in the grain size plot, figure 10. The mean values were constant between 3.5-4.5 µm in this time period without any distinct trend, a small decrease in the coarser fraction (16-63 µm) can be noticed until 3000 BC. Then there is an increase in the clay fractions profile which can be seen from 3000 BC i.e. the end of the Holocene Thermal Maximum to 1000 BC. From 1000 BC to the start of the Medieval Warm Period (MWP: 950-1250AD) around 1000 AD there is a distinct increase from 85% to 89% seen in the clay fraction which can also be seen in mean. In the larger particle fraction (4-16 µm) there is a decrease from around 1000 BC (Late Bronze Age) to 1000 AD from 10% to 8%. In the last 1000 years there is a sudden change in very fine to fine silt towards larger values around 1000 AD, then the profile stays constant towards the upper most part of the core in both clay and coarse fractions.

Sand only consists of 0.5% from the total weight of the sample which is very low. There is an overall decreasing trend in sand from older to younger horizons shown in figure 9. Large variability is seen in Holocene Thermal Maximum/Littorina Transgression 4000 BC to 35000 BC in sand fraction then from 2000 BC to 1000 BC the variability decrease and then again from 1000 BC to top there is large variability seen in the sand fractions.

The sediment has a mode (dominant particle size) that varies between 1-1.8 µm with an increasing shift in 200 AD. The average modal value is 1.3 µm. The standard deviation (degree of sediment sorting), indicates that both the fine and coarse interbeds were

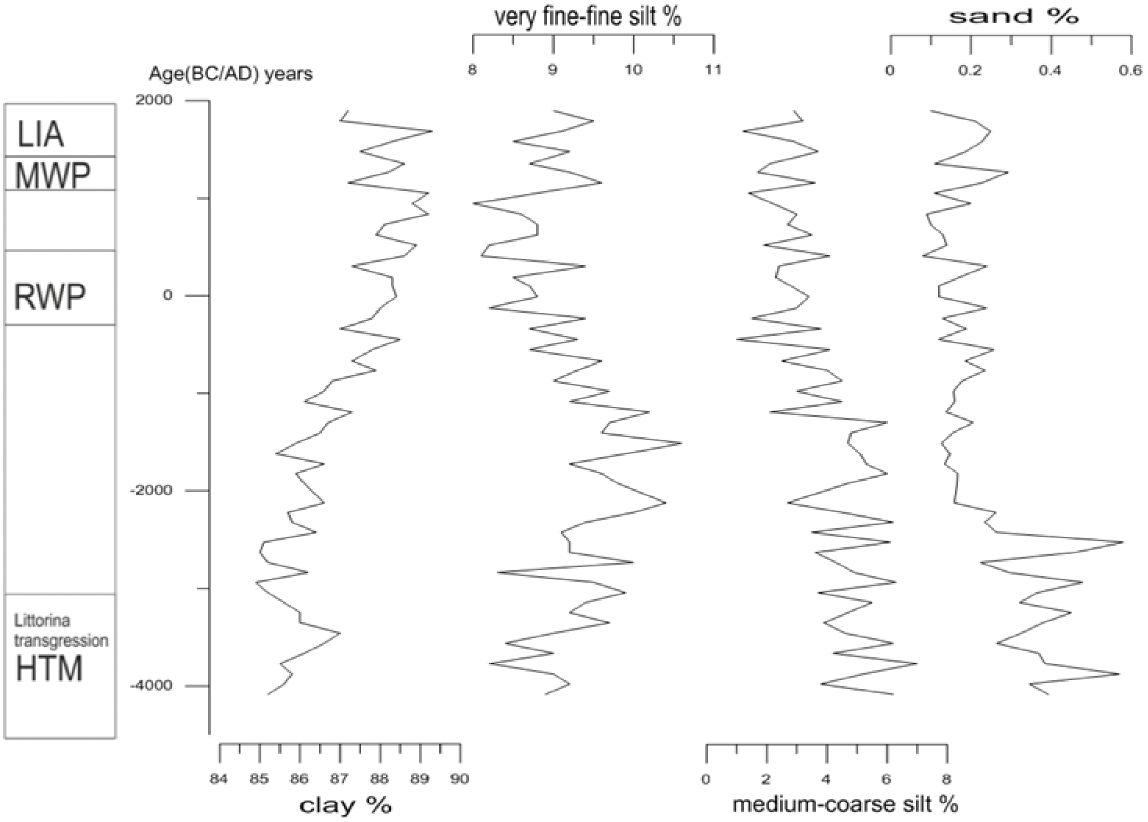

Figure 9: Particle size parameters of Gåsfjärden core (clay, very fine-fine silt, medium-coarse silt and sand). HTM=Holocene Thermal Maximum, RWP=Roman Warm Period, MWP=Medieval Warm Period, LIA= Little Ice Age

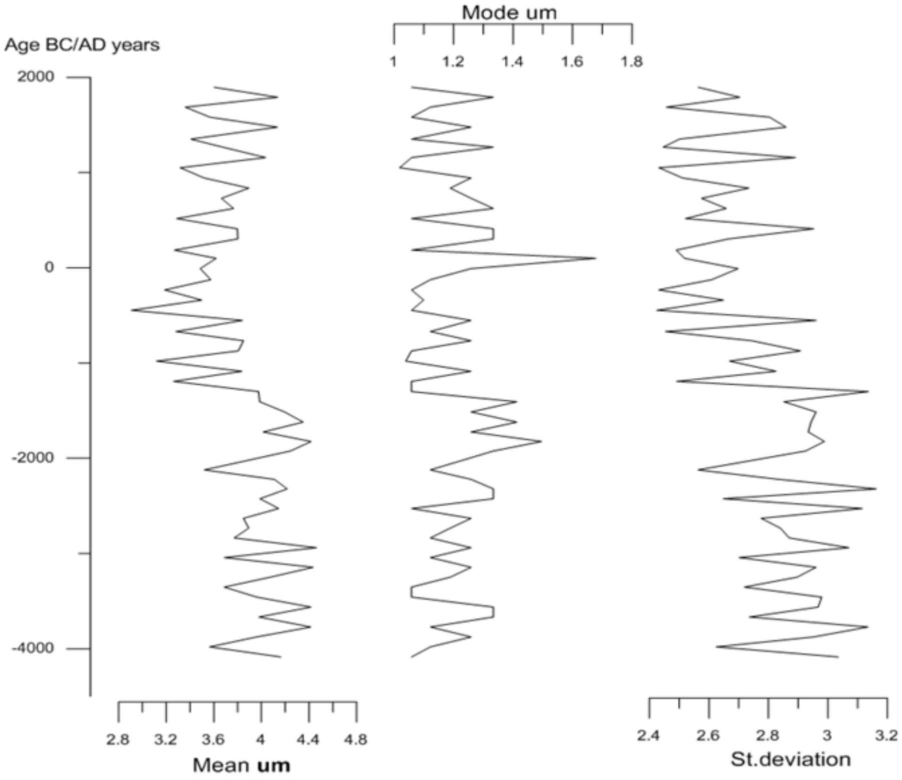

Figure 10: Particle size statistics of Gåsfjärden core (mean, mode and standard deviation)

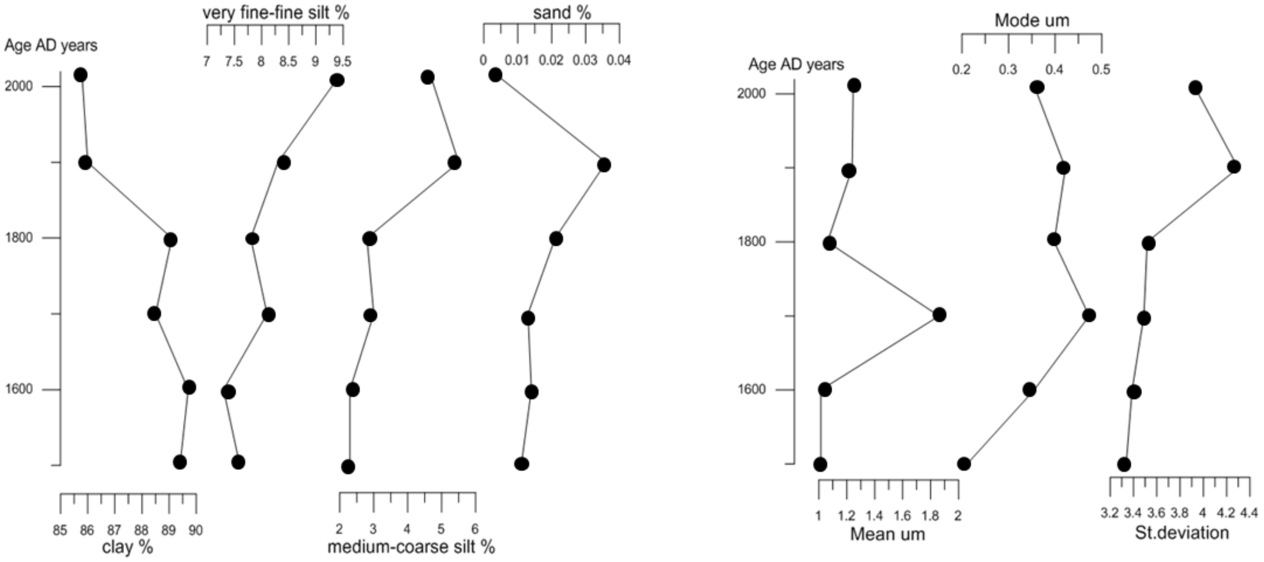

Figure 11: Particle size results and statistics of Gåsfjärden gemini core (clay, very fine-fine silt, medium-coarse silt, sand, mean, mode and standard deviation)

fairly sorted, figure 11.

The Gemini core shows the last 500 years BP which extends from ~1500 AD to 2011 AD. There is about 4% decrease in the clay fraction but increase in all silt fractions. There is significant increase in the coarser fraction (16-63µm) from 2% to 6% and decrease in the clay from 90% to 85% seen in the last 100-150 years shown in figure 11. There are no such changes seen in the very fine to fine fraction (4-16 µm). The concentration of sand in the Gemini core is also very low about 0.04% of the total sample weight and remains more or less constant throughout the core. There are no large changes in the mode and in the standard deviation large spread of sediments are seen from the last century.

4.2 Yttre Redden, Karlskrona

The samples analyzed from the long core sampled in Karlskrona archipelago also consist of unconsolidated brownish homogeneous gyttja. The upper most few cm of the core were lost during the sampling. The long core is 515cm long and represents the time between 5216 BC to 1478 AD and the Gemini core is 40cm and represents the time between ~1600 to 2011. The long core and the Gemini core might not overlap completely. The sediment nature is dominantly clay (~70%) with clayey silt and silt fraction. An overall increase in the in clay fraction and decrease in silt fraction is observed in the Karlskrona area (older to younger horizons), shown in Figure 12.

There is a significant variation seen during the Littorina Transgression (~4000 years BC) / Holocene Thermal Maximum where there is a substantial increase in the clay fraction from 64% to 75% and decrease in the medium to coarse silt fractions from 16% to 8%, figure 12, similarly decreasing trend is also observed in the mean values of particles shown in figure 13. In the Littorina transgression around 4000 BC there is a slightly decrease in the clay fraction from 75% to 68% until 3000 BC. From 3000 BC to 1000 BC there is large variability in the mean and other size fractions but without any major trend. The profile has minor fluctuations from Roman Warm Period (RWP) to the start of the Little Ice age (LIA) without any changes in the mean of the grain size, however there are changes in the different size fractions. Then again there is a decrease in the coarser fractions (16-63 µm) at around 1000 BC till 200 AD, then from 200 AD there is a sudden increase seen in medium to coarse silt and decrease in clay fraction and after that again a decrease in medium to coarse is observed.

The concentration of sand is low i.e. 1.5 % of the total weight of the sample in the Karlskrona core. Overall there is also a decreasing trend in sand from older to younger horizons of the core shown in figure 12. These is large variability and decreasing trend in the profile at the lower part of the core and little variability at the upper part without any large trend.

The Gemini core for Karlskrona represents last ~400 years i.e ~1600 to 2011 AD. There is a significant increase in the coarser silt fraction (16-63µm) from 11% to 19% seen from the last 300 years to present as well as a decrease in the clay fraction from 70% to 57% at the from 1700 AD to 1800 AD and opposite trend is observed in very fine to fine silt (4-16 µm) profile during this part of time, figure 14. The mean particle size shows increasing trend in the Gemini core from old to younger horizons with substantial increase in the last 200-250 years. The mode varied between 0.2-0.5 µm. The standard deviation has lower value in the lower part and deviates to higher values from 1700 AD onwards.

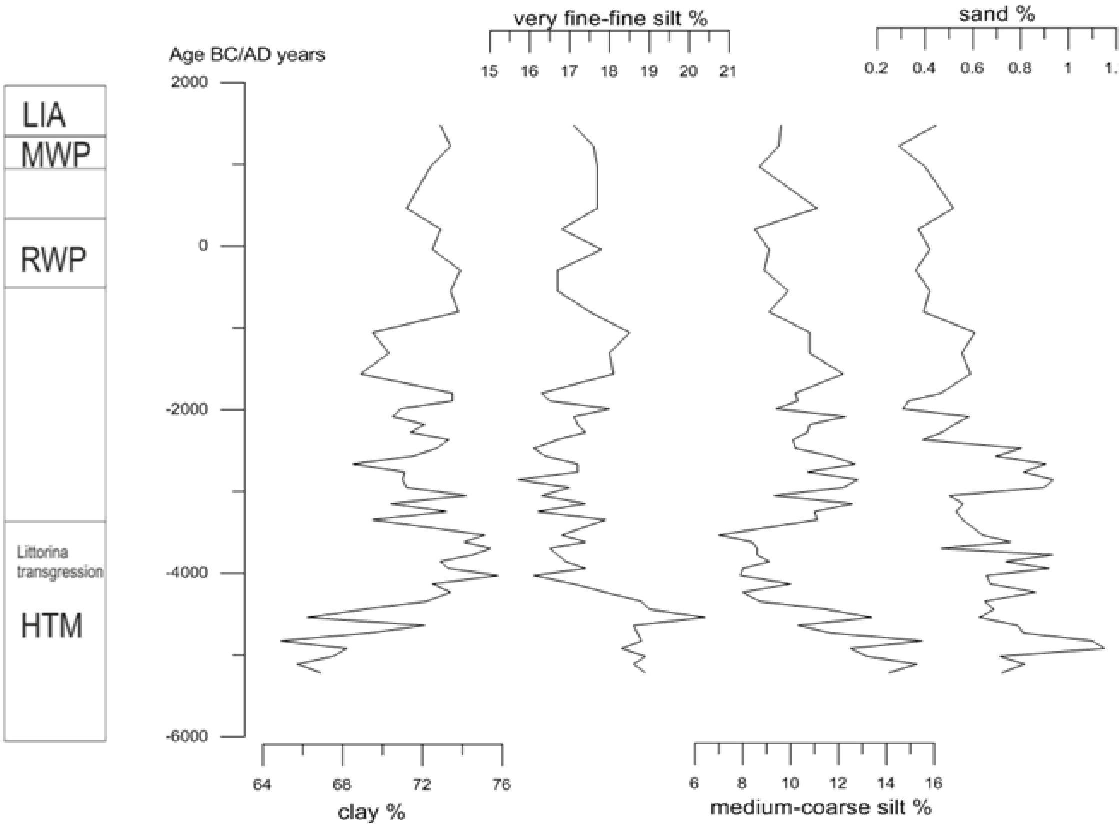

Figure 12: Particle size parameters of Karlskrona (clay, very fine-fine silt, medium-coarse silt and sand). HTM=Holocene Thermal Maximum, RWP=Roman Warm Period, MWP=Medieval Warm Period, LIA= Little Ice Age.

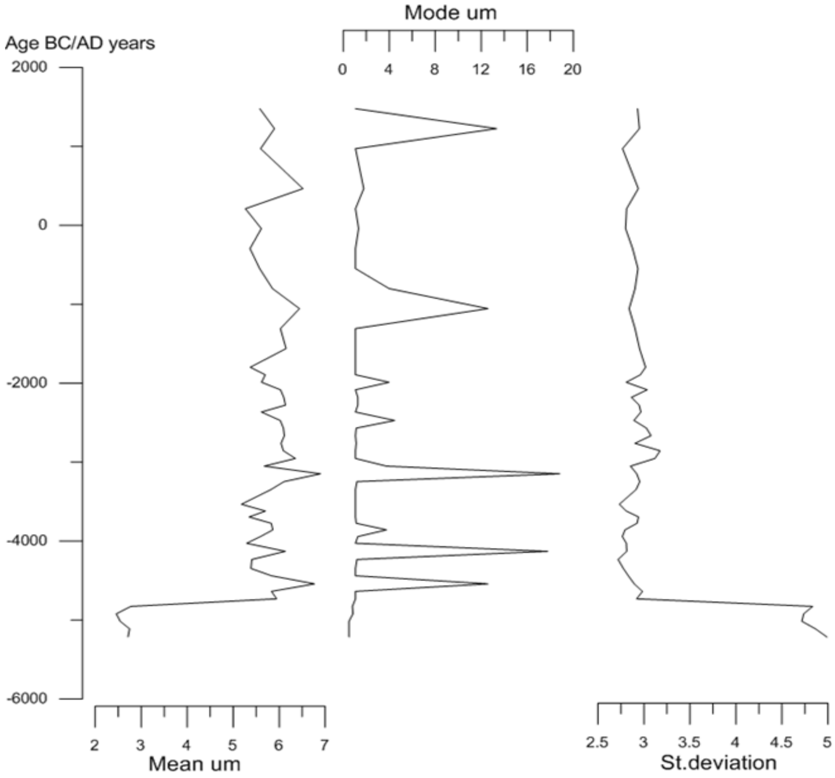

Figure 13: Particle size statistics of Karlskrona core (mean, mode and standard deviation)

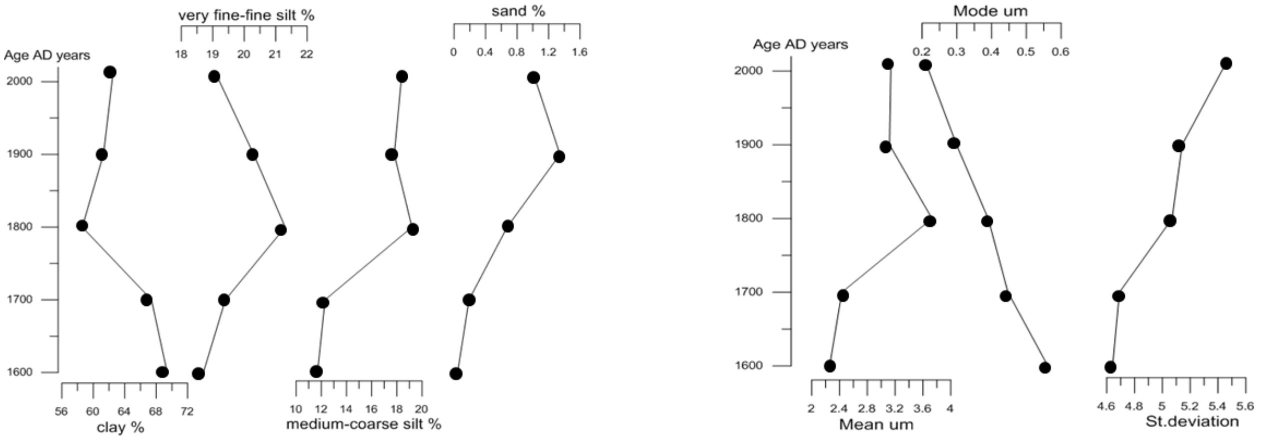

Figure 14: Particle size results and statistics of Karlskrona gemini core (clay, very fine-fine silt, medium-coarse silt, sand, mean, mode and standard deviation)

4.3 XRF

4.3.1 Gåsfjärden, Västervik

In ratio Zr/Ti there is decreasing trend in the HTM/ Littorina Transgression. From 3000 BC to 200 AD Zr/ Ti ratio fluctuates without any trend and then from 200 AD (mid of RWP) there is an increase in Zr/Ti and it continues to the top of the core. In K/Ti ratios there is an overall decreasing trend for most of the core. The K/Rb ratio stays constant in the lower part of the core and is similar to that of K/Ti with decreasing trend from 500 AD to top. Bromine Br stays constant till 3000 BC and then starts to decrease towards the upper part of the core (figure 15).

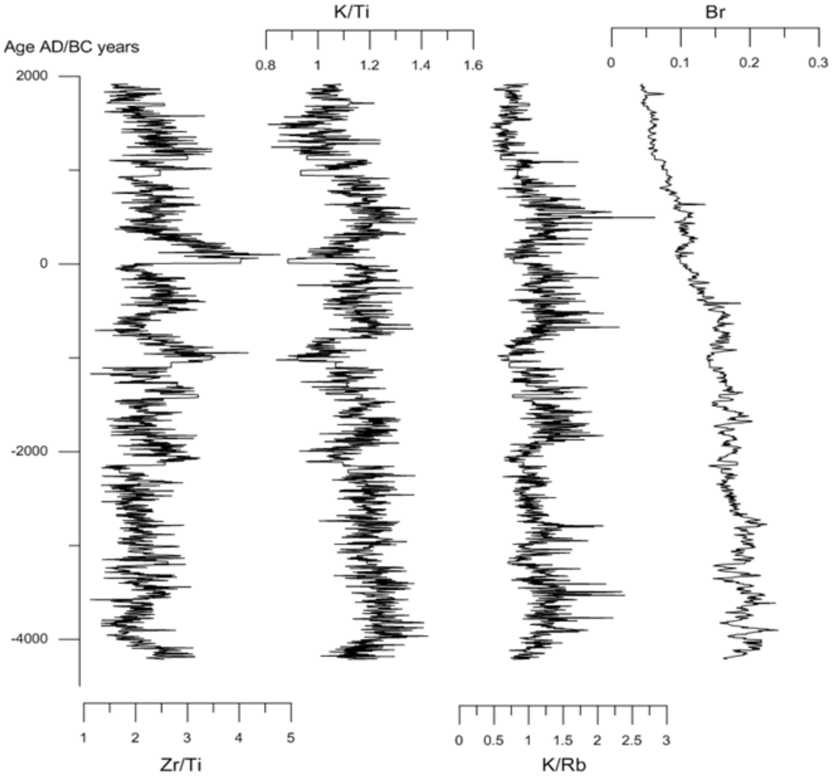

Figure 15: XRF elemental data of the Gåsfjärden core for the ratios (Zr/Ti, K/Ti, K/Rb and Br)

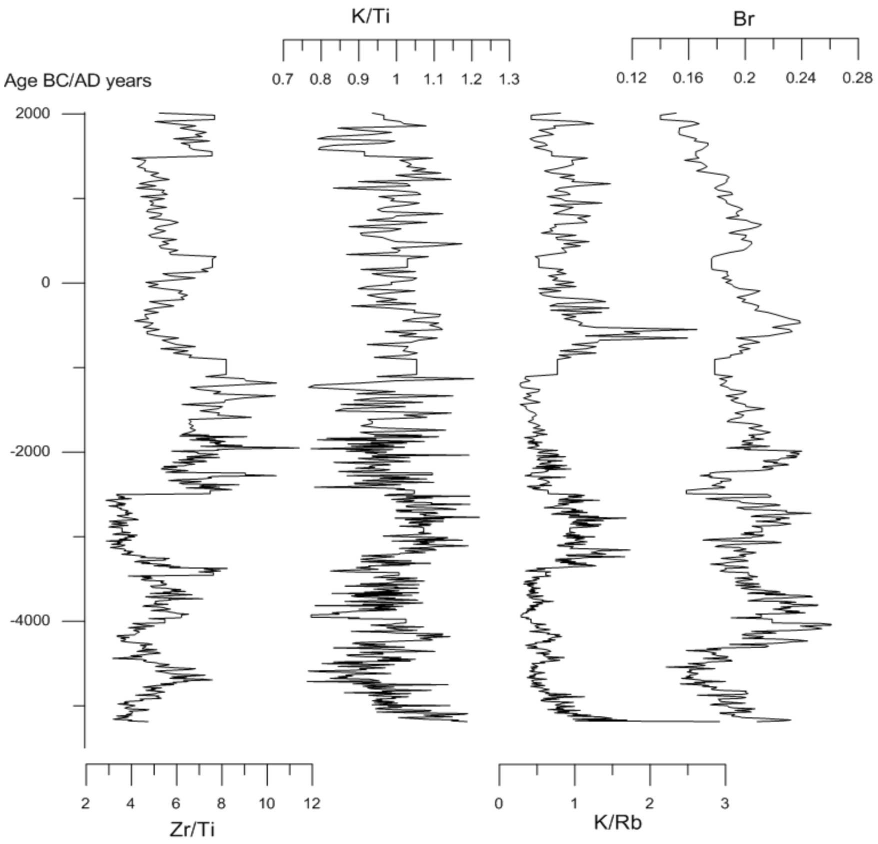

Figure 16: XRF elemental data of the Karlskrona core for the ratios (Zr/Ti, K/Ti, K/Rb and Br)

4.3.2 Karlskrona

At the end of Littorina transgression (4700 BC – 4000 BC), there is an increase in Zr/Ti and decrease in K/Ti and K/Rb ratios. In the remaining portion there are fluctuations but not such distinctable change and are almost constant towards the upper part of the core. The profile of Bromine is fluctuating at the lower part of the core. From 500 AD there is a decreasing trend towards upward in the profile (figure 16).

5 Discussion

Since the coastal marine sediments presented here are very fine-grained fractions, the chances of modification during transport are large because of the selective sorting as fine grained sediments are efficiently mixed (Kairyte et al., 2005). In addition, fine grained particles can also represent remote sources as they could be transported in suspension from over a large distance (Blashchishin, 1976).

Down core intensities for Zr, Ti, K, Rb and Br were measured on both long cores and in general they support the variation of the grain size data. Chemical elements like Zirconium (Zr) and Titanium (Ti) are mostly found in weathering resistant silicate minerals (Brady, 1990). Zr is enriched in coarser fraction i.e. medium to coarser silt and Ti is usually enriched in fine fractions (Taboada et al., 2006) which give indication of change in size of sediment grains. More coarser fraction like sand is enriched in Potassium (K). Bromine (Br) tells about the organic carbon content and its relation with the marine core.

5.1 Gåsfjärden, Västervik

The lamination in this core indicates low oxygen conditions in the bottom water. During the Holocene Thermal Maximum/ Littorina Transgression period there are very small changes seen in the grain size particles that show little influence of human on the landscape and difficult to detect any significant changes seen in the grain size, as this is the period when the transgression ended in 4000 BC and the regression occurred due to uplift that decreased the saline inflow as well (Zillén et al., 2008). The uplift resulted in decreasing surface area in the Baltic and enhances coastal processes which may lead to erosion of the sediments and redeposition of clay.

The bay from where the core is collected is also affected by the Littronia transgression. The Gåsfjärden basin is more or less isolated from the main Baltic because of the narrow and shallower sills. The depth of the bay is not very large but still there are laminated sediments found that indicates less oxygen conditions during the time of the Littorina transgression when the sea level was higher and the water could easily enter the study area and high rate of sedimentation took place. The narrow sills might be the result of the regression after the land uplift and make it difficult for bottom waters to exchange with the main Baltic Basin. The less exchange of bottom water and also the high river inflow from two rivers are likely the cause of the preservation of the laminated sediments.

The slight increase in the finer fraction (<4µm) from 3000 BC to 1000 BC could be the result of seasonal river runoff due to the seasonal ice melting and precipitation or it can also be the indication of the starting of the agricultural activities in this period and due to the expansion of cultivated and grazed areas the topsoil erosion increased. At this time the large ecological changes and opening of the landscape at smaller areas occurred (Berglund, 1991). The local expansion of agriculture activities during this time were more dominant in the southern Sweden (Myrdal & Morell, 2011) and agrarian activities are also more concentrated towards the coasts of southern Sweden (Berglund, 1991).

The substantial change seen in grain size around 800 BC with a shift towards more finer particles (Figure 9) which is also supported by the XRF data (K/Ti, K/Rb, Zr/Ti), could potentially be an indication of early signs of land-use changes in the Gåsfjärden region and shows the expansion of agriculture from local to regional level and deforestation. This is the time when evidence of soil erosion appeared in southern Sweden and also for the first time evidence of lake eutrophication is seen as a result of transport of nearby soils mineral nutrients (Berglund, 1991). The increasing amount of clay particles noted in the Roman Warm Period could be because of the intense deforestation mostly in the coastal areas. This increase of fine fraction in the RWP can also be seen in the XRF data of Zr/Ti ratio that indicates the sedimentation upward is towards the fine fractions, more clay or less silt. There is also a decreasing trend in Br seen at the same time that extends to the upper most part of the core which perhaps shows increase of terrestrial organic carbon input from RWP to present (Ziegler et al., 2008). In the coarser fractions (4-16 µm) of Gåsfjärden from 0-500 AD slightly decreasing trend is noted which can be interpreted as reforestation in the nearby areas. In this time period the landscape was more stable with very low soil erosion (Berglund, 1991).

There is again increase seen in both fine fractions (clay and fine silt) untill around 1000 AD which is also supported by XRF data. In this time period two-field agrarian system was introduced from one-field system (Mydral, 1997). This shifting requires clearance of forests and grassland. Also in this time period hypoxia was recorded in the Baltic Sea (Baltic Proper) which overlaps the MWP and correlates with increase in population and regional changes in land use mostly in the Baltic catchment (Zillèn et al., 2008). It is known from the studies that nutrient loading is increased due to cutting of forests (Likens et al., 1970). In Gåsfjärden since it is stagnant basin it was continuously low oxygen conditions.

In the last 1000 years, finer fractions dominates over coarser fractions, could perhaps relate to the plague, Black Death. The Black Death occurred after the early medieval expansion, in the 14th century. The Swedish population declines from 1100,000 to 347,000 (Andersson Palm, 2001). This decline is called late Medieval Crisis due to decrease in abundance and total productions of farms (Lagerås, 2007). Then during the Little Ice Age there are no large changes and the data looks stable and constant which could be possible as there was cold climate condition which results in less river runoff and soil erosion.

In the Gemini core which shows the last 500 years from ~1511 to 2011 years AD. There is an increase in the coarser fractions (16-63 µm) from 2% to 6% in the last 200 years this can be interpreted as the forests present near the area where the core is taken. In this area the human impact is low and more trees are growing due to which there is less top soil erosion. This significant increase could be because of the surface runoff and precipitation or could also be possible from the industrial revolution in the 18th and 19th century when the arable area of increases with 60 % in Sweden (Lagerås, 2007) or due to the decreased amount of wetlands in the early 20th century in the area, the drainage and ditching occurred and resulting in the transport of coarser silt to the basin.

5.2 Yttre Redden, Karlskrona

The grain size distribution in Karlskrona display significant variations and a large increase in the finer fractions during the Littorina transgression (maximum ~4000 years AD)/Holocene Thermal Maximum which can be interpreted as substantial changes in sedimentation environment with a fluctuating water depth. During this time water table became higher and there was calmer environment than today. There were different separate transgressions due to the collapse between the Antarctic Ice Sheet with its immense ice shelves and also from the melting of the North American Ice Sheets which results in sea level rise (Berglund, 2002). The water column near the shore also got increased which made the coastal waters calmer as well which lead to increased sedimentation of the finer particles (<4 µm). Also from the sea level changes there could be coastal soil erosion. From evidence the main Littorina transgression sediments are defined by the transition to marine clayey gyttja (very fine sediments) (Yu, 2003). During Littorina transgression there was a rapid increase in the saline water throughout the Baltic Sea Basin and also organic content increased in the sediments which can be supported by the increase in the Br from XFR data in this time period. In this study I also noticed that the sedimentation rate is higher during this time of period about ~1 mm/yr. as compare to the upper part of the core which is about ~0.5 mm/yr.

After the Littorina transgression around 4000 BC there is a decrease in the clay fraction and increase in the coarser fraction. This decrease is seen till 3000 BC which can be interpreted as coastal erosion. After the transgression of the Littorina, the uplift was greater than the global sea level which results in regression (Zillén et al., 2008). These fluctuations in the sea level could possibly explain the eroision of top soil.

In the Karlskrona core the changes in the grain size started earlier as they were expected. The decrease in the very fine to fine silt fractions from 1000 BC in the sedimentation pattern could be probably due to the restructuring of agriculture and pasture farms during that time (Middle Bronze Age). There was a drastic landscape change around 800 BC due to the deforestation expanding pasture landscape in the coastal plains in the southern Sweden (Berglund, 1991). In this time period the human impact was more due to the well-developed transhumance system (seasonally shifting livestock from one grazing field to another) was introduced instead of wood pasturing (Berglund, 1991). The sudden increase in coarser fraction medium silt to coarse silt around 500 AD could be the because of the bottom current activity and in the upper part of the core there are no changes seen, the plot is constant and stable. Around 200 AD there is an increasing shift in clay which could be due to the reforestation and also at that time the landscape was more stable and low soil erosion was recorded (Berglund, 1991).

The Gemini core of Karlskrona shows the last 400 years from ~1600 to 2011 AD (Figure 14). There is a substantial change seen in the coarser fraction from the last 300 years. The significant increase in the coarser fractions medium to coarse silt as well as sand could be because of two reasons. In late 16th century the town of Karlskrona was founded, the land was deforested for the urban and commercial growth. Also the population of Karlskrona grew rapidly, in 1750 the population of Karlskrona was 10,000 and became one of the biggest city in the country. The other reason of this large change in the coarser fractions could also be because of the drainage of the wetlands and ditching of fields in the vicinity of Karlskrona, which resulted in transport of coarser fraction to the basin.

The decreasing trend of Zr/Ti, K/Ti and K/Rb ratios of XRF data in the HTM/Littorina transgression indicates that the there was an increase in the fine fraction and confirms the results that can be seen in the particle size analysis data of the same core. The values of Br fluctuates in this time period may be because of the different separate Littorina transgressions and decreases at the upper part also showing more terrestrial input and more organic content in the sediments.

6 Error analysis

This is the first time, I performed grain size analysis to this extent. We combine 4-5 cm intervals of samples so there might be some data which does not show the realvalue of that depth. Pretreatments were done very accurately, still there are chances of losing the material when shifting the sample material from centrifuge tubes to beakers. Karlskrona dates from upper part of long core are uncertain. The age models of the gemini cores are based on the extrapolation of the long cores.

7 Conclusion and comparison of two systems

This study uses particle size analysis data to demonstrate the anthropogenic and climate influence seen in the sedimentation pattern in both Gåsfjärden and Karlskrona basin. From the results the environment in both Gåsfjärden and Karlskrona has not been same during the last 5000 years. Clay (<4µm) fraction dominates in both of the cores (Gåsfjärden and Karlskrona) as compared to very fine to fine silt (4 -16µm), medium to coarse silt (16-63µm) and sand (>63µm).

There are anoxic conditions found in the Gåsfjärden basin since it is a stagnant basin while in Karlskrona very little laminations are observed in the whole core. There are more coarser sediments found in the Karlskrona basin as compare to Gåsfjärden and the presence of organic matter in both the cores are very high. The signs of soil erosion and first time lake eutrophication are seen around 800 BC in Gåsfjärden area perhaps as a result of land use change and nutrient input into the basin.

For Gåsfjärden long core the notable changes are observed in the grain size since approximately Roman Warm Period while in Karlskrona long core the significant variations are seen in Holocene Thermal Maximum/Littorina Transgression. These changes are also supported by the XRF (K/Ti, K/Rb and Zr/Ti) data.

Karlskrona is more influenced by the Littorina Transgression as compare to Gåsfjärden. In Gåsfjärden region the landscape is mostly influenced by the agriculture and deforestation in the past 5000 years whereas Karlskrona is more impacted by the human influence in recent years. The drainage and ditching of wetlands in Karlskrona occurred approximately 100 years before Gåsfjärden area

8 Acknowledgements

First of all I would like to express my profound gratitude to my supervisor Helena Filipsson not only for her invaluable assistance, support and guidance but also for her most useful comments on the draft of the thesis. I am also grateful to my co-supervisor Anupam Ghosh for his most valuable help and suggestions throughout this study. I would also like to express my deepest acknowledgement to Nathalie Van der Putten for her amiable help and assistance rendered throughout my lab work. I also want to thank my friends at Lund University for their help whenever I needed. Finally, I owe my special gratitute to my family members for their unconditional love, encouragement and financial support during my stay here in Sweden, this work would have not been possible without them.

References

Andrén, T., Björck, S., Andrén, E., Conley, D., Zillén, L. & Anjar, J., 2011: The Development of the Baltic Sea Basin During the Last 130 ka. The Baltic Sea Basin, Central and Eastern European, *Springer*, 75-97.

Andrén, T., 2003a: Baltiska Issjön – eller hur det började, *Havsutsikt 1*, 4-5.

Andrén, T., 2003b: Yoldiahavet – en viktig parentes, *Havsutsikt 2*, 6-7.

Andrén, T., 2003c: Ancylussjön – fortfarande ettn mysterium, *Havsutsikt 3*, 8-9.

Andrén, T., 2004: Littorinahavet – en salt historia, *Havsutsikt 1*, 8-9.

Andersson, P. L.,Palm, L., 2001: Livet, kärleken och döden. Historiska institutionen, Göteberg, Sweden, 203pp.

Antonsson, H., Jansson, U., 2011: Agriculture and forestry in Sweden since 1900. *The Royal Swedish Academy of Agriculture and Forestry, Stockholm*.

Beierle, B.D., Lamoureu, S.F., Cockburn, J.M.H. & Spooner, I., 2002: A new method for visualizing sediment particle size distribution. *Journal of Paleolimnology 27*, 279–283.

Bennike, O., Jensen, J.B. & Lemke, W., 1998: Fauna and flora in submarine early Holocene lake-marl deposits from the southwestern Baltic Sea. *The Holocene 8*, 353-358.

Berglund, B.E., 1971: Littorina transgressions in Blekinge, South Sweden — A preliminary survey. *Geologiska Föreningen i Stockholm Förhandlingar 93*, 625–652.

Berglund, B.E., Larsson, L., Lewan, N., Olsson, G.A. & Skansjö, S., 1991: Ecological and social factors behind the landscape changes. *In* Berglund, B.E. (eds.): The cultural landscape during the 6000 years in southern Sweden – the Ystad Project. *Ecological Bulletins 41*, 425 445.

Berglund, B.E., 1991: The cultural landscape during 6000 years in southern Sweden. *Ecological Bulletins 41*, Munksgaard, Copenhagen.

Berglund, B.E., Lagerås, P., Regnell, J., 2002: Odlingslandskapets historia i Sydsverige - en pollenanalytisk syntes, *In* Berglund, B.E., Börjesson, K. (eds.): Markens minnen. Swedish National Heritage Board, Stockholm, 150-169.

Berglund, B.E., Sandgren, P., Barnekow, L., Hannon, G., Jiang, H., Skog, G. & Yu, S., 2005: Early Holocene history of the Baltic Sea, as reflected in coastal sediments in Blekinge, southeastern Sweden. *Quaternary International 130*, 111-139.

Blashchishin, A. I., 1976: Mineralnyj sostav donnykh osadkov. *In* Gudelis, V.K., Emelyanov, E.M (eds.): Geologiya Baltijskogo Morya. Mokslas, Vilnius, 221–255.

Blott, S.J. & Pye.K., 2001: GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments Earth Surf. Process. *Landforms 26*, 1237–1248.

Brady, N.C., 1990: The Nature and Properties of Soil, MacMillan, New York.

Björck, S., 2008: *Assessment of climate change for the Baltic Sea Basin, Springer, 398 pp*

Björck, S., 1995: A Review of the History of the Baltic Sea, 13.0–8.0 ka BP. *Quaternary International 27*, 19–40.

Cederwall, H. & Sjöberg, B., 1995: Baltic marine bottomfauna after the inflow of saline water in 1993-94. The Baltic Sea 1994, Swedish report on the environmental state of the Baltic proper, *Stockholm Marine Research Institute, Sweden,*

Conley, D. J., Markager, J. S., Andersen, T. E. & Svenden, L.M. 2002: Coastal eutrophication and the Danish National Aquatic Monitoring and Assessment Program. *Estuaries 25*, 848-861.

Conley, D. J., Björck, S., Bonsdorff, E., Destouni, G., Gustafsson, B., Hietanen, S., Kortekaas, M., Kuosa, H., Meier, M., Muller- Karulis, B., Nordberg, K., Nurnberg, G., Norkko, A., Pitkänen, H., Rabalais, N., Rosenberg, R., Savchuk, O., Slomp, C. P., Voss, M., Wulff, F., and Zillen, L., 2009a: Hypoxia related processes in the Baltic Sea, *Environ. Sci. Technol 43*, 3412–3420.

Conley, D. J., Paerl, H. W., Howarth, R. W., Boesch, D. F., Seitzinger, S. P., Havens, K. E., Lancelot, C. & Likens, G. E., 2009b: Controlling eutrophication by reducing both nitrogen and phosphorus, *Science 323*, 1014–1015.

DeVries, J.L., Vrebos, B.A.R., 2002: Quantification of infinitely thick specimens by XRF analysis, *In* van Grieken, R.E., Markovicz, A.A. (eds.): Handbook of X-Ray Spectrometry, (eds. 2). *Marcel Dekker, New York*, 341–405.

Döös, K., Meier, H.E.M. & Döscher, R., 2004: The Baltic halin conveyor belt or the overturning c irculation and mixing in the Baltic. *Ambio 33,* 261-266

Friedman, G.M., 1979: Differences in size distributions of populations of particles among sands of various origins. *Sedimentdogy 26*, 3-32.

Friedman, C.M. & Sanders, J.E., 1978: Principles of Sedimentology. John Wiley & Sons, New York

Gustafsson, B. & WESTMAN, P., 2002: On the causes or salinity variations in the Baltic Sea during the last 8500 years. *Paleoceanography 17*, 1-14.

Hangstum, P.J., Reinhardt,E.G., Boyce, J.I. and Clark, C., 2006: Changing sedimentation patterns due to historical land-use change in Frenchman's Bay, pickering, Canada: evidence from high resolution textural analysis, *J Paleolimnol 37,* 603-618

Hart, J.F., 1996: Turmoil in tobaccoland. *Geographical Review 86*, 550–572.

Heiskanen, A. S., 1998: *Factors governing sedimentation and pelagic nutrient cycles in the northern Baltic Sea*. Ph.D. thesis, University of Helsinki, *Monographs of Boreal Environment Research . 8*, 1-80 pp.

Helcom., 1996: Third periodic assessment of the state of the marine environment in the Baltic Sea 1989-1993. background document. Baltic Sea *Environ. Proc. No. 64B*, 252 pp.

Helcom., 2008: Manual for Marine Monitoring in the COMBINE Programme of HELCOM. URL: http://www.helcom.fi/groups/monas/CombineManual/PartA/en_GB/main/

Hilson, M., 2001: Swedish Approaches to theRise of Labour: A British Perspective, *Scandinavian Journal of History*, 26:2, 103-121

Hyvarinen, H., Donner, J., Kessel, H. & Raukas, A., 1988: The Litorina Sea and Limnaea Sea in the northern and central Baltic. *Ann. Acad. Science. Fenn 148A*, 25-35

Hänninen, J., VUORINEN, I., HELMINEN, H. Kirkkala, T. & Lehtile, K. 2000: Trends and gradients in nutrients concentrations and loading in the Archipelago Sea, Northern Baltic, in 1970-1997. *Coast.al and Shelf Science 50*, 153-171.

Ignatius, H., Axberg, S., Niemistö, L. & Winterhalter, B., 1981: Quaternary geology of the Baltic Sea. *In* Voipio A (eds): The Baltic Sea. *Elsevier Oceanography Series 30*, *Elsevier, Amsterdam*

Ihse, M., 1995: Swedish agricultural landscapes - patterns and changes during the last 50 years, studied by aerial photos. *Landscape and Urban Planning 31*, *Elsevier.* 21-37

Jensen, J.B., Bennike, O., Witkowski, A., Lemke, W., & Kuijpers, A., 1999: Early Holocene history of the southwestern Baltic Sea, the Ancylus Lake stage. *Boreas 28*, 437–453.

Kairyte, M. T., Stevens, R. L., Trimonis. E. 2005: Provenance of silt and clay within sandy deposits of the Lithuanian coastal zone (Baltic Sea). *Marine Geology 218,* 97 – 112.

Kaplan, J. O., Krumhardt, K. M., & Zimmermann, N., 2009: The prehistoric and preindustrial deforestation of Europe, *Quaternary Sci. Rev 28*, 3016–3034

Karlson, K., Rosenberg, R. & Bonsdorff, E. 2002: Temporal and spatial large-scale effects of eutrophication and oxygen deficiency on benthic fauna in Scandinavian waters *Oceanogr. Mar. Biol. Annu. Rev. 40*, 427-489.

Koff, T. & Punning, J.M., 2002: the last hundred years of land use in Estonia as inferred from pollen records. *Ann.Bot.Fennici 39*: 213-224.

Lagerås, P., 2007: The ecology of expansion and abandonment. Medieval and Post-medieval land-use and settlement dynamics in a landscape perspective. *Swedish National Heritage Board, Stockholm.*

Likens, G. E., Bormann, F. H., Johnson, N. M., Fisher, D. W. & Pierce, R. S., 1970: Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. *Ecological Monographs 40*, 23–47.

Lambeck, K., & Chappell, J., 2001: Sea level change through the Last Glacial cycle. *Science292*, 679–686.

Lambeck, K., Purcell, A., Zhao, J., Svensson, N. O., 2010: The Scandinavian ice sheet: from MIS 4 to the end of the Last Glacial Maximum. *Boreas 39*, 410–435.

Larsson, U. & Andersson, L., 1999: Nutrients in the surface water in the basins of the Baltic Sea. Baltic Sea 1998, Swedish report on the environmental state of the Baltic proper, *Stockholm Marine Research Institute*, 2-5.

Larsson, U. & Andersson, L., 1999: Nutrients in the surface water in the basins of the Baltic Sea. Baltic Sea 1998, Swedish report on the environmental state of the Baltic proper, *Stockholm Marine Research Institute*, 2-5.

Lowe, J. & Walker, M., 1997: Reconstructing Quaternary Environments (2nd ed.). *Addison-Wesley-Longman.* London, 446pp.

Lundberg, C., 2005: *Eutrophication in the Baltic Sea-from area-specific biological effects to interdisciplinary consequences*. Phd thesis, Åbo

Lundberg, C., 2005: *Eutrophication in the Baltic Sea-from area-specific biological effects to interdisciplinary consequences*. Phd thesis, Åbo Akademi University ,Åbo, Finland.

Mary, H., 2001: Labour Politics in a Naval Dockyard: The Case of Karlskrona, Sweden c. 1880-1925. *Internationaal Instituut voor Sociale Geschiedenis*. 341-369.

Matthäus, W. & Franck, H., 1992: Characteristics of major Baltic inflows: a statistical analysis. *Cont. Shelf Res. 12,* 1375-1400.

Morell, M., 2001: Jordbruket i industrisamhället 1870-1945. *Natur och Kultur/LTs förlag, Stockholm.*

Myrdal, J., 1997: The agricultural transformation of Sweden, 1000–1300, *In* Medieval farming and technology, the impact of agricultural change in Northwest Europe, edited by: Astill, G. and Langdon, J., Brill. L, *The Netherlands*, 147–171,

Myrdal, J. & Morell, M., 2011: The Agrarian History of Sweden, From 4000 BC to AD 2000, *Nordic Academic Press, Lund.*

Nausch, G., Matthäus, W. & Feistel, R., 2003: Hydrographic and hydrochemical conditions in the Gotland Deep area between 1992 and 2003. *Oceanologia 45,* 557-569.

Olausson, E., 1982: Stable isotopes. *In* E. Olausson (eds.): *The Pleistocene/Holocene Boundary in South-Western Sweden*. *Sveriges Geologiska Undersökning C794,* 187–210.

Persson, C., 1978. Datering av Ancylus- och Littorinatransgressionerna på södra Gotland. *Sveriges Geologiska Undersökning C745*. 34 pp.

Plastino, W., Kaihola, L., Bartolomei, P. & F. Bella., 2001: Cosmic Background Reduction In The Radiocarbon Measurement By Scintillation Spectrometry At The Underground Laboratory Of Gran Sasso*, Radiocarbon, 43(2A),* 157–161.

Ruskule, A., Kuris, M., Leiputė, G., Vetemaa, M. & Zableckis, S., 2009: See the Baltic Sea unique asset we share, *Baltic environmental forams*.

Seifert, T., & Kayser, B., 1995: A high resolution spherical grid topography of the Baltic Sea. *Meereswissenschafliche Berichte Warnemunde 9*, 72-88.

SMHI., 2004: Swedish Meteorological and Hydrological Institute. Oceanography, information and data reports.URL: http://www.smhi.se (in Swedish, acc 04/12/31).

Stigebrandt, A., 2001: Physical Oceanography of the Baltic Sea. *In* A systems analysis of the Baltic Sea Springer –Verlag Berlin Heidelberg. *Ecological Studies 148*, 19-74.

Stanèikaite, M., Sinkunas, P., Risberg, J., Seiriene, V., Blazauskas, N., Jarockis, R., Karlsson, S. & Miller, U., 2009: Human activity and the environment during the Late Iron Age and Middle Ages at the Impiltis archaeological site, NW Lithuania, *Quatern. Int. 203*, 74–90.

Taboada, T., Cortizas, A. M., Garcia, C., Garcia-Rodeja. E., 2006: Particle-size fractionation of titanium and zirconium during weathering and pedogenesis of granitic rocks in NW Spain. *Geoderma 131,* 218-236.

Taipale, K. & Saarnisto, M., 1991: Tulivuorista jääkausiin.WSOY, *Porvoo*.

Weltje, G. J., Tjallingii, R., 2008: Calibration of XRF core scanners for quantitative geochemical logging of sediment cores. *Theory and application 274. Issues 3–4*, 423–438.

Wentworth C.K., 1922: A scale of grade and class terms for clastic sediments. *Journal of Geology* 30: 377–392.

Winterhalter, B., 2001**:** The Basys coring site in the North Central Baltic Sea Basin a geological description. *Baltica 14*, 9-17.

Wulff, F., Stigebrandt, A. & Rahm, L., 1990: Nutrient Dynamics of the Baltic Sean. *Marine Eutrophication 19*, 126-133.

Yu, S.Y., 2003: The Littorina transgression in Southeastern Sweden and its relation to mid-Holocene climate variability, *Lundqua Thesis 51.*

Ziegler, M., Jilbert, G. J. de Lange, L. J. Lourens. & G.-J. Reichart 2008: Bromine counts from XRF scanning as an estimate of the marine organic carbon content of sediment cores, Geochem. Geophys. *Geosyst 9.*

Zillén, L., Conley, D. J., Andrén, T., Andren, E., and Björck, S. 2008: Past occurrences of hypoxia in the Baltic Sea and the role of climate variability, environmental change and human impact, *Earth Sci. Rev. 91*, 77–92.

Tidigare skrifter i serien "Examensarbeten i Geologi vid Lunds universitet":

283. Holm, Johanna, 2011: Geofysisk utvärdering av grundvattenskydd mellan väg 11 och Vombs vattenverk. (15 hp)
284. Löfgren, Anneli, 2011: Undersökning av geofysiska metoders användbarhet vid kontroll av den omättade zonen i en infiltrationsdamm vid Vombverket. (15 hp)
285. Grenholm, Mikael, 2011: Petrology of Birimian granitoids in southern Ghana - petrography and petrogenesis. (15 hp)
286. Thorbergsson, Gunnlaugur, 2011: A sedimentological study on the formation of a hummocky moraine at Törnåkra in Småland, southern Sweden. (45 hp)
287. Lindskog, Anders, 2011: A Russian record of a Middle Ordovician meteorite shower: Extraterrestrial chromite in Volkhovian-Kundan (lower Darriwilian) strata at Lynna River, St. Petersburg region. (45 hp)
288. Gren, Johan, 2011: Dental histology of Cretaceous mosasaurs (Reptilia, Squamata): incremental growth lines in dentine and implications for tooth replacement. (45 hp)
289. Cederberg, Julia, 2011: U-Pb baddelyit dateringar av basiska gångar längs Romeleåsen i Skåne och deras påverkan av plastisk deformation i Protoginzonen (15 hp)
290. Ning, Wenxing, 2011: Testing the hypothesis of a link between Earth's magnetic field and climate change: a case study from southern Sweden focusing on the 1st millennium BC. (45 hp)
291. Holm Östergaard, Sören, 2011: Hydrogeology and groundwater regime of the Stanford Aquifer, South Africa. (45 hp)
292. Tebi, Magnus Asiboh, 2011: Metamorphosed and partially molten hydrothermal alteration zones of the Akulleq glacier area, Paamiut gold province, South-West Greenland. (45 hp)
293. Lewerentz, Alexander, 2011: Experimental zircon alteration and baddeleyite formation in silica saturated systems: implications for dating hydrothermal events. (45 hp)
294. Flodhammar, Ingrid, 2011: Lövestads åsar: En isälvsavlagring bildad vid inlandsisens kant i Weichsels slutskede. (15 hp)
295. Liu, Tianzhuo, 2012: Exploring long-term trends in hypoxia (oxygen depletion) in Western Gotland Basin, the Baltic Sea. (45 hp)
296. Samer, Bou Daher, 2012: Lithofacies analysis and heterogeneity study of the subsurface Rhaetian–Pliensbachian sequence in SW Skåne and Denmark. (45 hp)
297. Riebe, My, 2012: Cosmic ray tracks in chondritic material with focus on silicate mineral inclusions in chromite. (45 hp)
298. Hjulström, Joakim, 2012: Återfyllning av borrhål i geoenergisystem: konventioner, metod och material. (15 hp)
299. Letellier, Mattias, 2012: A practical assessment of frequency electromagnetic inversion in a near surface geological environment. (15 hp)
300. Lindenbaum, Johan, 2012: Identification of sources of ammonium in groundwater using stable nitrogen and boron isotopes in Nam Du, Hanoi. (45 hp)
301. Andersson, Josefin, 2012: Karaktärisering av arsenikförorening i matjordsprofiler kring Klippans Läderfabrik. (45 hp)
302. Lumetzberger, Mikael, 2012: Hydrogeologisk kartläggning av infiltrationsvattentransport genom resistivitetsmätningar. (15 hp)
303. Martin, Ellinor, 2012: Fossil pigments and pigment organelles – colouration in deep time. (15 hp)
304. Rådman, Johan, 2012: Sällsynta jordartsmetaller i tungsand vid Haväng på Österlen. (15 hp)
305. Karlstedt, Filippa, 2012: Jämförande geokemisk studie med portabel XRF av obehandlade och sågade ytor, samt pulver av Karlshamnsdiabas. (15 hp)
306. Lundberg, Frans, 2012: Den senkambriska alunskiffern i Västergötland – utbredning, mäktigheter och faciestyper. (15 hp)
307. Thulin Olander, Henric, 2012: Hydrogeologisk kartering av grundvattenmagasinet Ekenäs-Kvarndammen, Jönköpings län. (15 hp)
308. Demirer, Kursad, 2012: U-Pb baddeleyite ages from mafic dyke swarms in Dharwar craton, India – links to an ancient supercontinent. (45 hp)

309. Leskelä, Jari, 2012: Loggning och återfyllning av borrhål – Praktiska försök och utveckling av täthetskontroll i fält. (15 hp)
310. Eriksson, Magnus, 2012: Stratigraphy, facies and depositional history of the Colonus Shale Trough, Skåne, southern Sweden. (45 hp)
311. Larsson, Amie, 2012: Kartläggning, beskrivning och analys av Kalmar läns regionalt viktiga vattenresurser. (15 hp)
312. Olsson, Håkan, 2012: Prediction of the degree of thermal breakdown of limestone: A case study of the Upper Ordovician Boda Limestone, Siljan district, central Sweden. (45 hp)
313. Kampmann, Tobias Christoph, 2012: U-Pb geochronology and paleomagnetism of the Westerberg sill, Kaapvaal Craton – support for a coherent Kaapvaal-Pilbara block (Vaalbara). (45 hp)
314. Eliasson, Isabelle Timms, 2012: Arsenik: förekomst, miljö och hälsoeffekter. (15 hp)
315. Badawy, Ahmed Salah, 2012: Sequence stratigraphy, palynology and biostratigraphy across the Ordovician-Silurian boundary in the Röstånga-1 core, southern Sweden. (45 hp)
316. Knut, Anna, 2012: Resistivitets- och IP-mätningar på Flishultsdeponin för lokalisering av grundvattenytor. (15 hp)
317. Nylén, Fredrik, 2012: Förädling av ballastmaterial med hydrocyklon, ett fungerande alternativ? (15 hp)
318. Younes, Hani, 2012: Carbon isotope chemostratigraphy of the Late Silurian Lau Event, Gotland, Sweden. (45 hp)
319. Weibull, David, 2012: Subsurface geological setting in the Skagerrak area – suitability for storage of carbon dioxide. (15 hp)
320. Petersson, Albin, 2012: Förutsättningar för geoenergi till idrottsanläggningar i Kallerstad, Linköpings kommun: En förstudie. (15 hp)
321. Axbom, Jonna, 2012: Klimatets och människans inverkan på tallens etablering på sydsvenska mossar under de senaste århundradena – en dendrokronologisk och torvstratigrafisk analys av tre småländska mossar. (15 hp)
322. Kumar, Pardeep, 2012: Palynological investigation of coal-bearing deposits of the Thar Coal Field Sindh, Pakistan. (45 hp)
323. Gabrielsson, Johan, 2012: Havsisen i arktiska bassängen – nutid och framtid i ett globalt uppvärmningsperspektiv. (15 hp)
324. Lundgren, Linda, 2012: Variation in rock quality between metamorphic domains in the lower levels of the Eastern Segment, Sveconorwegian Province. (45 hp)
325. Härling, Jesper, 2012: The fossil wonders of the Silurian Eramosa Lagerstätte of Canada: the jawed polychaete faunas. (15 hp)
326. Qvarnström, Martin, 2012: An interpretation of oncoid mass-occurrence during the Late Silurian Lau Event, Gotland, Sweden. (15 hp)
327. Ulmius, Jan, 2013: P-T evolution of paragneisses and amphibolites from Romeleåsen, Scania, southernmost Sweden. (45 hp)
328. Hultin Eriksson, Elin, 2013: Resistivitetsmätningar för avgränsning av lakvattenplym från Kejsarkullens deponis infiltrationsområde. (15 hp)
329. Mozafari Amiri, Nasim, 2013: Field relations, petrography and 40Ar/39Ar cooling ages of hornblende in a part of the eclogite-bearing domain, Sveconorwegian Orogen. (45 hp)
330. Saeed, Muhammad, 2013: Sedimentology and palynofacies analysis of Jurassic rocks Eriksdal, Skåne, Sweden. (45 hp)
331. Khan, Mansoor, 2013: Relation between sediment flux variation and land use patterns along the Swedish Baltic Sea coast. (45 hp)

LUNDS UNIVERSITET

Geologiska institutionen
Lunds universitet
Sölvegatan 12, 223 62 Lund