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Changes of Geochemical Elements in Lake Sediments from Hållvastö, Sweden: An Implication for Climate Reconstruction During Transition from the Baltic Ice Lake to the Yoldia Sea Stage

Berbagai Perubahan Unsur-Unsur Geokimia dalam Sedimen Danau dari Hållvastö, Swedia: Suatu Implikasi Untuk Rekonstruksi Iklim Selama Transisi dari Danau Es Baltik ke Fase Laut Yoldia

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Abstract - Three varved sediment cores from Hållvastö have been investigated to reveal shift in climate condition linked to the local event in the Baltic Sea: i.e. the transition between the Baltic Ice Lake Stage to the Yoldia Sea Stage. That local event was marked by the color change in varve clay sequences, which point to the change in varved clay forming processes. Varve diagrams were constructed for all Hållvastö sections in order to obtain a relative age based on annual varve-thickness correlations, the relative age of the cores are corresponded to 10,640 - 10,850 varve year or 11,390 - 11,610 cal yr BP. The geochemical data for this study was acquired using the Itrax, an X-Ray Fluorescence core scanner, which provides insitu high resolution, continuous, and multi element analyses. The geochemical data from the Itrax are occupied to make the elemental profiles and correlation matrices. The geochemical data are linked with lithological and loss on ignition analyses to answer the research question. It was found that the strength of associations between the studied elements (Ti, Rb, K, Zr, Si, Ca, Sr, Mn and Fe) varied over time with changes in basin status, which are ultimately driven by changes in climate. Element profiles are demonstrated several changes which could be related with the changes in hydrological and sedimentary processes. Increasing in grain size from the Baltic Ice Lake to the Yoldia Sea varve clay sequence (as indicated by Zr/Rb) could be related to the warming event during the beginning of Holocene warming event. The ice melted faster than before and increased the amount of water as sediment transport agent, thus coarser materials input to the basin increased.

Keywords - Varve Clay, Baltic Sea, Baltic Ice Lake, Yoldia Sea, Paleoclimate, Itrax XRF core scanner.

Abstrak - *Tiga inti bor endapan varve dari Hållvastö diteliti untuk mengungkap perubahan kondisi lingkungan yang dikaitkan dengan peristiwa lokal di Laut Baltik yaitu transisi antara Fase Baltic Ice Lake dengan Fase Yoldia Sea. Peristiwa lokal tersebut ditandai dengan perubahan warna pada sekuen endapan lempung varve yang mengarah pada perubahan mekanisme pembentukannya. Diagram varve untuk seluruh endapan varve dari Hållvastö disusun untuk menentukan umur relatif berdasarkan korelasi ketebalan tahunan endapan varve, umur relatif yang diperoleh adalah 10.640 – 10.850 tahun varve atau 11.390 – 11.610 BP. Data geokimia untuk penelitian ini diperoleh menggunakan Itrax yaitu X-Ray Fluoroscence Core Scanner yang mampu menghasilkan data unsur kimia dengan resolusi tinggi, menerus dan multi unsur. Data geokimia tersebut digunakan untuk menyusun profil unsur dan matriks korelasi yang dikaitkan dengan hasil analisa litologi dan loss on ignition (LOI) untuk memperoleh hasil yang diharapkan. Dari hasil analisa dan korelasi tersebut diketahui bahwa terdapat hubungan saling keterkaitan yang kuat antara sejumlah unsur yang dianalisa (Ti, Rb, K, Zr, Si, Ca, Sr, Mn, dan Fe) dalam kurun waktu tertentu terkait dengan dinamika cekungan sedimentasi yang dikontrol oleh perubahan hidrologi dan proses sedimentasi. Peningkatan ukuran butir dalam endapan yang berasal dari Fase Danau Es Baltik ke Fase Laut Yoldia (ditunjukkan oleh Zr/Rb) dapat dikaitkan dengan perstiwa pemanasan pada awal Holosen. Lapisan es mencair dengan cepat dibandingkan dengan sebelumnya dan peningkatan volume dan energi dari tubuh air sebagai agen transportasi menyebabkan material sedimen yang lebih kasar masuk ke dalam lingkungan pengendapan.*

Kata kunci - *Lempung Varve, Laut Baltik, Danau Es Baltik, Laut Yoldia, Iklim Purba, Itrax XRF Core Scanner.*

INTRODUCTION

The concept of annually laminated or varved sediment has been introduced by Swedish Geologist Gerard de Geer in 1912. Varved sediments consist of distinct seasonal layers and are typical deposits in glacial lacustrine environments. In most cases, these individual layers are identified as representing certain seasons or even short-term events within seasons (*e.g.* spring floods, and autumn storms). In glacial environment, the varved sediment consists of distinct summer and winter layer. During summer, large amounts of melt water transport silt and sand to the lake or sedimentary basin, and during winter, when the basin is covered by ice, clay particles settle from suspension.

Glacial varved clays, which consist of silty summer and clayey winter layers, were deposited in the fresh water and brackish environment of Baltic during the last deglaciation of the Scandinavian Ice Sheet. The glacial varves can be found in many areas along the Baltic Coast and in the Baltic Sea (Wohlfarth *et al.*, 1998). The varve clay chronology has been widely used for dating in the paleoclimate studies. It provides the detailed chronology in the Quaternary sediment. The varve clay chronology is constructed by correlating the varve clay diagram, variation in the varve thickness itself could be occupied as an indicator for fluctuation in sedimentary mechanism which affected by the changes in paleoclimate condition.

This research is focused on the development of the Baltic Sea since the last glaciation of the Scandinavian Ice Sheet. The changes in varve's geochemical components are entangled with the changes in sedimentary processes and environmental condition, which were affected by the changes in climate condition during the last glaciation. This research is aimed to prove the climate change during the transition from the Baltic Ice Lake Stage to the Yoldia Sea Stage based on geochemical study of varve clay sequences, and also aimed to give a new insight in using the geochemical analysis on varve clay sequences to decipher the past climate variations.

Location

The study area is situated in the southern part of Sweden. Hållvastö is a small island situated at the tip of the Södertörn Peninsula (Figure 1). It is located about 5 km southeast of Trosa municipality and about 70 km south-west of Stockholm, in the county of Södermanland.

Methods

Three section split cores were used in this study including Hållvastö 2009 section 2 (length: 250 cm), Hållvastö 2009 section 3 (length: 250 cm), and Hållvastö 2009 section 4 (length: 250 cm). All studied cores were analyzed at the Core Processing Laboratory at the Department of Geological Sciences, Stockholm University.

Source: Private

Figure 1. Location map of study area. Sampling site is marked by red dots.

Varve-thickness analysis aims to determine the relative age of the sediment cores by correlating the varve thickness measurements to a known-age varve diagram. The Itrax XRF core scanner was employed to obtain high-resolution elemental profiles. Itrax is a non-destructive core scanner, which can provide several results including elemental profiles, optical and microradiographic images. The XRF scan was made using a molybdenum tube set at 30kv and 30 mA with a XRF exposure time of 50 s. All sequences were measured each millimeter in order to get high-resolution elemental data.

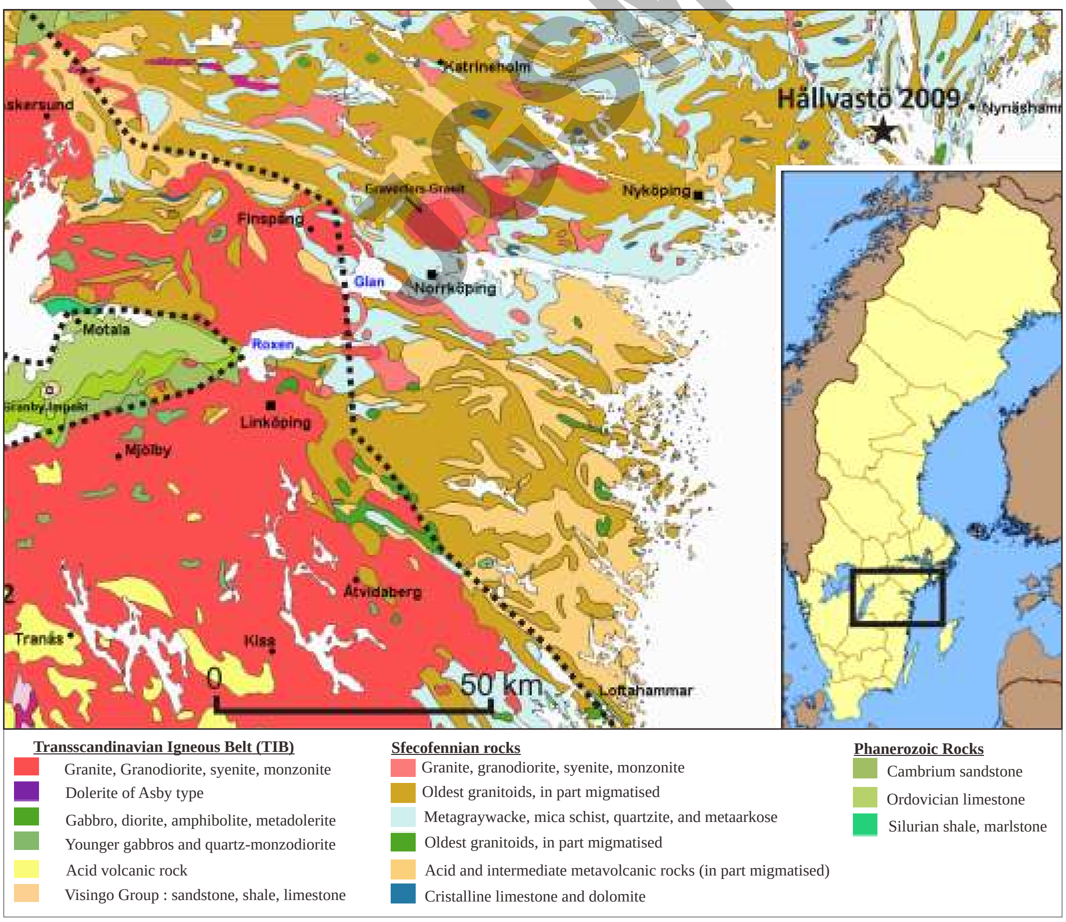
The data from Itrax were normalized by coherent and incoherent scattering to neutralize the effects of the water content and density changes during analysis and the aging of the X-ray tube (Lowemark *et al.*, 2010). The further analysis for Itrax data are correlation matrix to figure out the relationship between elements. Several elements (Ti, Rb, K, Zr, Si, Ca, Sr, Mn, and Fe) show good signals in the Itrax core scanner and can be used as indicator elements for environmental changes which are strongly driven by climate changes during the past. Those elements are plotted against depth to reveal the vertical changes in element peak, so the climate variation along the profile could be determined. The plotted elements are combining with the lithology, organic and carbonate content to reveal their correlation with the climate variability over period of time.

The organic matter content in a sediment sample is determined by measuring the weight loss in subsamples after burning at selected constant temperatures. Generally, the LOI analysis consists of two major steps: the first reaction is burning the samples at 500°-550°C to remove organic matter, and the second reaction is burning the samples at 900°-1000°C to remove the carbonate content (Heiri *et al*., 2001).

Geological Setting

The study area has been investigated by many authors from a clay-varve point of view: Stromberg (1994), Brunnberg (1995), Wohlfarth *et al.* (1998), and Björck et al. (2001). The region belongs to the Precambrian Baltic shield complex, which can be divided into two main groups: the Transcandinavian Igneous Belt and the Svecofennian rocks (Juhlin *et al.*, 2000; Gorbatschev & Bogdanova, 2000). The Precambrian Baltic shield consists of mainly granite and gneiss with the exception of some places, where it is interspersed with dolerite, gabbro and diorite.

The study site is surrounded by metamorphic and metasedimentary rocks. These comprise metaquartzite, quartzite, phylite and small amounts of basic igneous rock and consist of gabbro, dolerite and amphibolites (Figure 2). The surrounding area can be classified as a smooth irregular landscape with gently inclined low hills where till layers or bedrocks are exposed. Geological structures in the area are dominated by major fault lines in east-west direction.



Source: SGU bedrock map of Sweden, (2007).

Figure 2. Modified regional lithological map of the study area in the southern part of Sweden. The coring site is indicated by black stars. The borders of lithological groups are shown by dashed line.

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The highest part of the Södertörn Peninsula is the 110 m a.s.l Stora Tornberget (Brunnberg, 1995).

The area has been a part of the Baltic Sea since the final drainage of the Baltic Ice Lake (Björck, 2008). During the Yoldia Sea stage, the connection at Lake Vännern was wide enough to allow eastward penetration of marine water from the North Atlantic to the Baltic Sea, thus the study area had been influenced by marine water.

The Late Quaternary Development of the Baltic Sea

The Late Quaternary development of the Baltic Sea consisted of four different phases, the Baltic Ice Lake Stage, Yoldia Sea Stage, Ancylus Lake Stage, and Lihorina Sea Stage, Björck (2008). The detailed Late Quaternary development of the Baltic Sea is as followings:

The Baltic Ice Lake Stage (BIL)

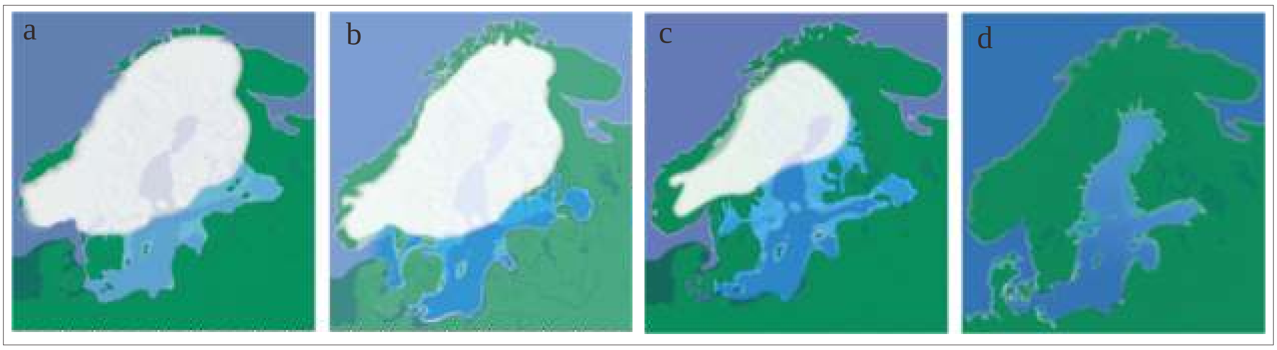
The Baltic Ice Lake stage started around 17000-16000 cal yr BP when the rapid deglaciation in the Baltic took place. The BIL had developed in the ice-free area of the southern part of the Baltic Sea (Figure 3a). The glaciolacustrine varved clays were formed because of intensive northward retreat of the Scandinavian Ice Sheet. Generally, the varved clays from the BIL have very low organic content since the glacial environment limited lake organic productivity. The Younger Dryas cooling (12 800 cal yr BP) caused a southward expansion of the Scandinavian Ice Sheet. Since the outlet at Mount Billingen had become blocked again, the water level in the BIL increased again quickly above sea level. Coincidently, the end of the BIL stage took place at the same time as the end of the Younger Dryas cooling (11 700 – 11 600 cal yr BP), and is defined by the final drainage at Mount Billingen.

The Yoldia Sea Stage

The Yoldia Sea stage (11 600 to 10 700 cal yr BP) is defined when the first marine ingression to the Baltic Sea took place; this stage lasted around 900 years. Some authors for example, Mörner (1995) and Brunnberg (1995) mentioned a 300 year long freshwater lake phase before the marine ingression. The fresh water phase produced varved clays as well, but with low organic content. The marine ingression to the Baltic Sea was a "gradual" event, which was initiated by a sudden change in climate condition at the start of the Holocene. The warmer climate had led to increased ice sheet melting and ice margin retreat, which widened the connection between the Baltic Ice Lake and the North Atlantic. The opening of the connection at Lake Vänern took a while until the connection was wide and deep enough to allow the eastward penetration of North Atlantic seawater (Figure 3b). The marine ingression phase lasted around 150 years. Thereafter the Baltic Sea became fresh again. The sediments that had been deposited during the Yoldia Sea stage are varved clays with low organic content and also contain the brackish dwelling bivalve mollusc Portlandia. During this stage, the Lake Vättern had become isolated and separated from the Baltic Sea.

The Ancylus Lake Stage (10 700 – 8500 cal yr BP)

The Ancylus Lake stage starts when the connection at the Lake Vänern became shallower and the marine water could no longer enter the Baltic Sea (Figure 3c). As a result of the shallowing of the connection at Vänern, the water level rose and this created a transgression in the Baltic. Some areas became submerged, as shown for example by drowned pine forest to the east of Skane. The sediments that deposited during this stage are characterized by low organic content and contain the fresh-water limpet Ancylusfluviatilis.



Source: Bjorck, (2008).

Figure 3. Late Quaternary development of the BIL; a). The configuration of the BIL at 11,700-11,600 cal yr BP; b). The configuration of the Yoldia Sea at the beginning of marine ingression at 11,400-11,300 cal yr BP; c). The configuration of the Ancylus Lake at 10,300 cal yr BP; d). The configuration of the Littorina Sea at 7,000 cal yr BP.

The Littorina Sea Stage (8500 cal yr BP to present)

The Littorina Sea stage is defined as the first sign of marine water in the Baltic Sea after the fresh-water Ancylus Lake stage (Figure 3d). This stage started around 8500 cal yr BP. Productivity had increased due to the saline water intrusion to the Baltic Sea. This stage is characterized by high primary productivity, high diversity of organisms and an increase in bottom water stratification.

RESULTS OF STUDY

Varve diagrams were constructed for all Hållvastö sections in order to obtain a relative age based on annual varve-thickness correlations (Figure 4). The relative age, based on the varve diagram correlations, suggests that, all sediment cores from Hållvastö date to the time late of the Baltic Ice Lake stage and Early Yoldia Stage. The relative age of the cores are corresponded to 10,640 - 10,850 varve year or 11,390 - 11,610 cal yr BP.

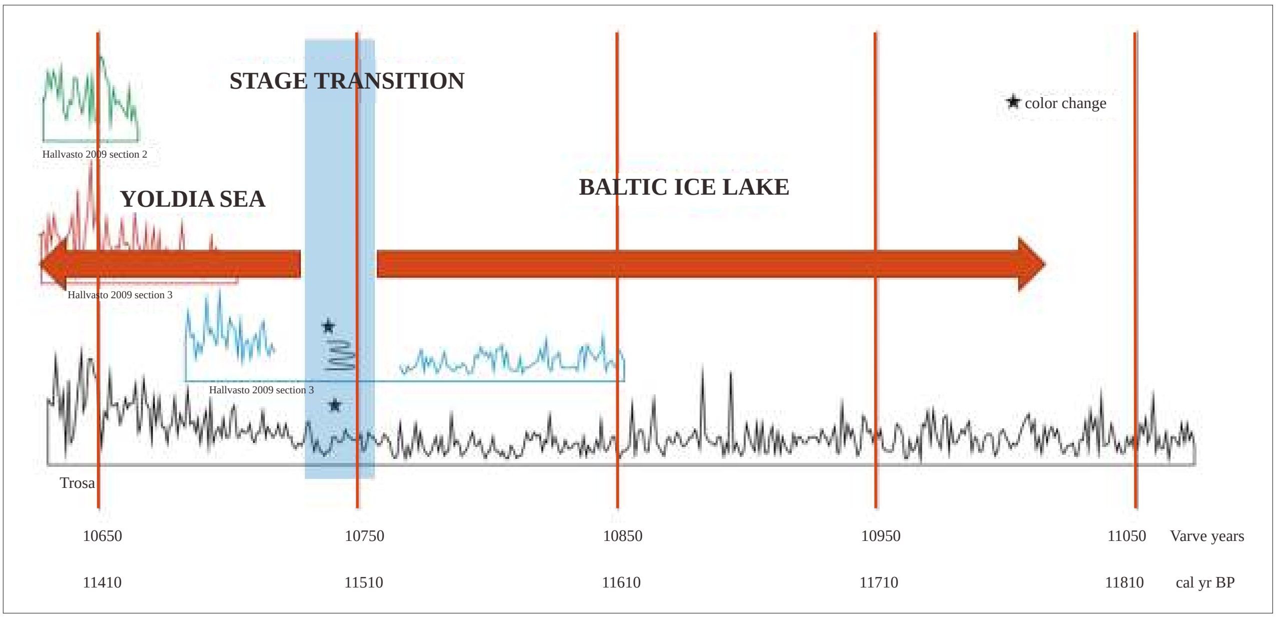
The coupling and decoupling of elements evidenced here reflects the history of the lake and changes in its paleoenvironment. It should be noted in reconstructions based on the elemental data must consider the fact that the basin history is variable enough for elements to take on different roles at different times, with the main exceptions of Ti, Rb, Zr and K. Many of the elements take on different roles, which in this system are related to sediment input, transport and sorting, catchment weathering, biological productivity, and redox.

Elements behavior

Several elements (Ti, Rb, K, Zr, Si, Ca, Sr, Mn, and Fe) show good signals in the Itrax core scanner and can be used as indicator elements for environmental changes which are strongly driven by climate changes during the past. Those elements are plotted against depth to reveal the vertical changes in element peak, so the climate variation along the profile could be determined. The plotted elements are combined with the lithology, organic and carbonate content to figure out their correlation with the climate variability over period of time.

In the paleoclimatic context, it is the relative changes in the elemental profiles, rather than the absolute concentrations, which are of interest (Croudace *et al.*, 2006). Si, K, Rb, Ti and Zr are common indicators for minerogenic input because most of those elements were derived from weathering processes of surrounding rock (Kylander et al., 2011). The only group of elements that correlate strongly (r > 0,7) in all section are Ti, Rb and K, which suggests an association with clay minerals and detrital input (Table 1).

Several elements play multiple roles within the system depending on their individual chemistry and variations in lake status. For example, Si is an essential element in non-clay silicate minerals (*e.g.*, quartz, potash feldspar, plagioclase, mica) and in clay minerals (illite, smectite, kaolinite), but is also abundant in, for example, opaline silica or diatoms (Peneirud, 2000).



Source: Brunnberg (1995).

Figure 4. Varve clay correlation, varve chronology show relative age is 10,640 - 10,850 varve year or 11,390 - 11,610 cal yr BP.

Table 1. Correlation Matrices for Each Unit in Hållvastö 2009 Section 4, All Data Are Normalized by Incoherent+Coherent. Red Color Represents Positive Correlation

Unit		K	Ca	Ti	Mn	Fe	Rb	Sr	Zr
Unit C (52-157 cm)	Si	**0,81**	0,63	0,68	0,67	0,22	0,52	0,61	**0,87**
	K		**0,77**	**0,90**	0,59	0,65	**0,74**	0,53	0,23
	Ca			0,56	0,60	0,08	0,69	0,69	0,64
	Ti				0,52	0,57	**0,83**	0,41	0,21
	Mn					0,40	0,46	0,42	0,30
	Fe						0,29	-0,12	-0,24
	Rb							**0,72**	0,36
	Sr								**0,78**
Unit B (157-229 cm)	Si	0,66	**0,89**	0,61	0,43	0,01	0,30	**0,71**	0,47
	K		0,47	**0,92**	0,56	0,65	**0,79**	0,08	-0,07
	Ca			0,45	0,51	-0,08	0,35	0,59	0,51
	Ti				0,58	0,51	**0,75**	0,11	-0,07
	Mn					0,62	0,33	0,10	-0,16
	Fe						0,29	-0,47	-0,57
	Rb							0,23	0,05
	Sr								**0,73**
Unit A (229-250 cm)	Si	**0,77**	0,61	0,55	0,44	0,54	0,39	-0,07	0,13
	K		**0,79**	**0,90**	0,66	0,63	0,48	-0,30	0,00
	Ca			0,54	0,58	0,63	**0,71**	-0,03	0,14
	Ti				0,67	0,54	0,47	**0,73**	0,11
	Mn					0,58	0,09	-0,22	-0,10
	Fe						0,15	-0,28	0,02
	Rb							-0,04	0,36
	Sr								0,05

Source: Private

Based on strong correlations between Si with detrital elements (K, Ti, Rb, and Zr) suggest the silica content was derived from minerogenic input and not from biogenic sources. The interpretation of minerogenic input is supported by the facts from the surrounding lithology. The surrounding lithology is a part of the Transcandinavian Igneous Belt and Svecovenian Rocks; they are rich in silica and alkali feldspar (Juhlin *et al*., 2000).

Calcium in lake sediments is related to carbonate weathering in the catchment and in-lake precipitation of $CaCO_3$ from the organism with co-precipitation of $SrCO_3$ (Cohen, 2003). In sedimentary successions, Sr is normally associated with carbonate minerals, in particular calcite and aragonite because of the substitution of Sr for Ca within the carbonate lattice. Strontium may also be associated with feldspar and biotite but at much lower concentrations than in carbonate minerals (Jin *et al.*, 2006). Sr and Ca in All Hållvastö cores indicate strong relationship with the detrital elements such as K, Si, Zr and Rb. It suggests an idea that Sr and Ca were related with the carbonate weathering in catchment area and not related with the lake precipitation.

Changes in hydrological regime

Glacial environment is considered as the high sensitive environment because it is strongly controlled by the variation of the climate condition; in this case temperature is the most influenced climate factor. The water that produced from the glacial melting is the main sedimentary agent in glacial environment. Therefore the change in the global temperature controls the sedimentation process in glacial environment. The variation in climate condition directly effects on the surface water body or hydrological regime. The rate of ice melting is the process that controlled by climate condition and it directly controls the surface water volume and sedimentary process. In this discussion, the authors would like to focus on the detrital inputs (sediment sources), grain size and productivity changes.

Some elements (Si, Ti, Rb, K, and Zr) could be used as indicators for minerogenic input to the lake, since they are abundant in allogenic minerals (Kylander et al., 2011). Biplots on several elements versus Ti indicated no scattering effects. It is suggested that no changes in sediment source among unit A, B, and C (Figure 5). The chemistry of sediments is strongly controlled by the grain size of the dominant mineral host and subsequent particle size sorting. Hållvastö cores point to several changes in detrital inputs. Zr in unit A shows steady pattern, although the peak increases slightly in the middle part. A decrease in clay fraction is found in the middle of unit B, but somehow silica as coarse fraction indicator does not show increase peak. Ti, K, and Rb show generally decrease peak areas from unit B to C

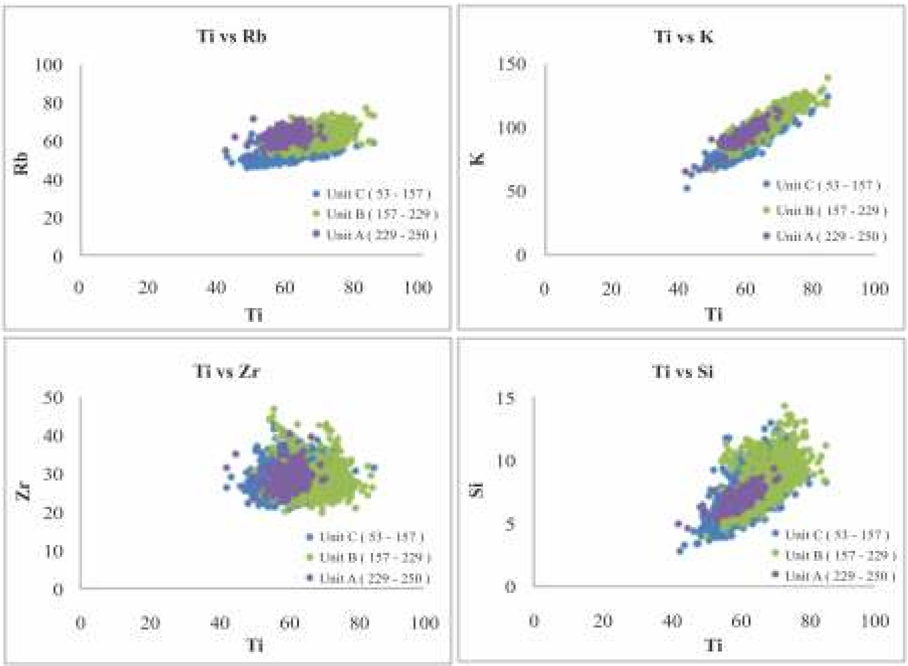


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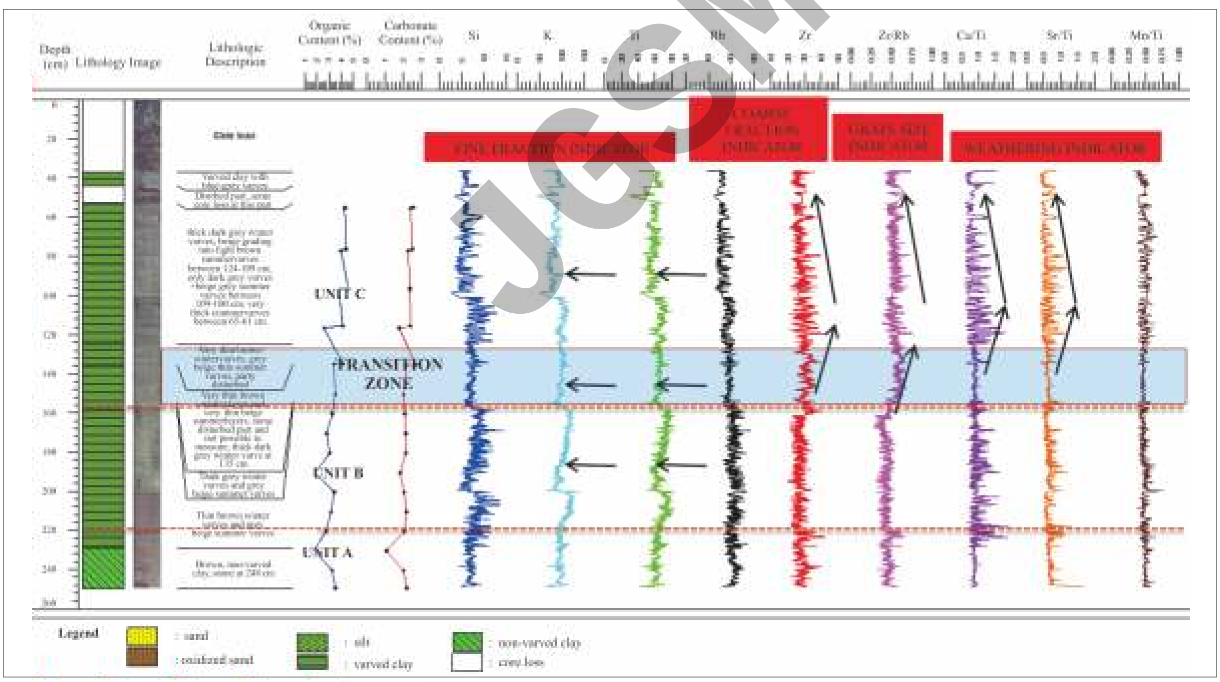
Figure 5. Biplot between Ti versus detrital elements in Hållvastö 2009 Section 4, which indicated no scattering effects.



Source: Brunnberg, (1995)

Figure 6. Lithologic profile of Hållvastö 2009 section 4. Arrows indicate those depth highlighted in the text. Si, K, Rb and Ti are indicator for fine fraction input; Zr for coarse fraction; Zr/Rb for grain size; Ca/Ti, Sr/Ti and Mn/Ti as weathering intensity.

(Figure 6). It suggests the clay fraction input to the sedimentary basin was lower than before and it was substituted by coarser fraction. It is clear that there are variations in the amounts and characters of the detrital material entering the basin. The nature of these additions, however, is unclear from the elemental changes discussed above; are these changes driven by increased hydrological activity or are we seeing the signal of other activity.

The behaviors of Rb and Zr are employed to acquire information on grain size and sediment composition. In finer-grained sediments, Zr/Rb can be used as a proxy for changes in grain size, with lower values representing fine-grained material and higher values representing coarse-grained material (Dypvik and Harris, 2001).

If we take a look at all Hållvastö cores as a complete section, there are very nice pattern in the Zr/Rb ratios. There is no significant increase of grain size from unit A to unit B, but there is increasing of grain size at the transition between unit B and unit C (Figure 6). The transition between unit C and D shows increase of grain size. Apparently, we could state that, the general trend for grain size increases from unit A trough unit D.

The productivity indicator elements such as Mn, Ca and Sr could not be used for inferring the biological productivity. Based on the Baltic Sea reconstruction by Björck (2008), the phase in Baltic Sea was the end of Baltic Ice Lake stage and the beginning of Yoldia Sea stage. During these stages, the Baltic Sea had not received the marine water from the North Atlantic; it could be the answer why the productivity level was low. Moreover, the thick ice sheet covered the Baltic Sea and it was not favorable environment for living organism. That interpretation is supported by the loss on ignition data where the carbonate and organic content are at low level. It is more than enough to propose an idea that the lack of biodiversity in the Baltic Sea at that time caused by the climate condition.

DISCUSSION

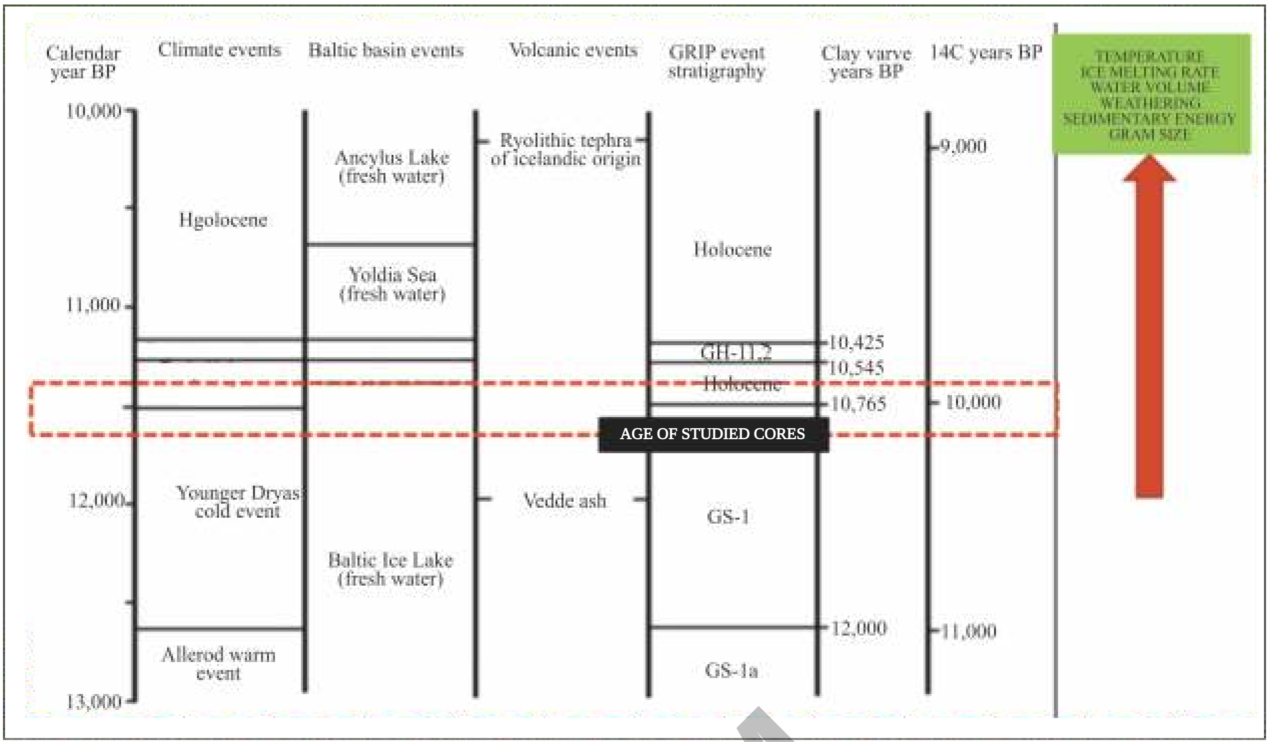
The age of the transition between the Baltic Ice Lake stage and the Yoldia Sea stage is dated to the beginning of Holocene. The stage transition is indicated by the change in color from grey beige to brownish grey in the Baltic Ice Lake and Yoldia Sea varve clay sequence respectively (Brunnberg, 1995; Stormberg, 1994). The color change is dated to 10,740 in varve years BP or 11,500 cal yr BP. Unit B and unit C in elemental profile represents the Baltic Ice Lake stage and the Yoldia Sea stage respectively. The transition between these stages is denoted by shifting in grain size proxy (Zr/Rb). The grain size becomes coarser from the Baltic Ice Lake varves to the Yoldia Sea varves. The change is obviously not very clear at the transition zone between unit B and unit C, but it becomes clear change at upper part. The signals of climate change were found approximately 30 years before the real change. It is indicated by the sudden decreasing of clay material inputs (Figure 6) and increasing of weathering process at catchment area. The weathering intensity is strongly affected by the ice-melting rate, since the ice melting rate is directly controlled by the global temperature. It can be concluded that the climate instabilities were occurred in particular time before and after the real transition. The time span for climate instabilities during the transition between the Baltic Ice Lake stage to the Yoldia Sea stage is covered approximately 30 years before and 30 years after the transition.

Many authors have been in the same point of view regarding the influence of warmer climate at the beginning of Holocene with the local event in the Baltic Sea (Brunnberg, 1995, Stormberg, 1994; Sohlenius *et al*., 2001; Björck *et al*., 2001; Björck *et al*., 2002; Björck, 2008; etc). The end of the Baltic Ice Lake stage or the beginning of the Yoldia Sea stage was obviously initiated the beginning of Holocene, climate became warmer thus the ice melted faster than before. The evidence of faster ice sheet retreating is the increasing in grain size which related with the increasing of sediment transportation energy. Rapid melting of the ice sheet will produce large amount of water, which can carry large amount of sediment materials. Moreover, the varves sequence from the Yoldia Sea are thicker than the Baltic Ice Lake varves, it could be related to the high amount of material which transported by the water from the melted ice sheet.

Stormberg (1994) observed a change in the rate of ice recession from 50-75 m/year to 100-200 m/year at 1,500 BZ corresponding to 10,740 varve year BP in the Stormberg Time Scale. He also mentioned that the change was rapid event. It is suggest that during the transition from the Baltic Ice Lake stage to the Yoldia Sea stage, the ice melting speed has been increased quickly. The ice melting line was moved further to the north and resulted in increasing of sedimentary material input to the lake or sedimentary basin (Figure 7).

CONCLUSION

The grain size proxy (Zr/Rb) indicated the change in grain size from the Baltic Ice Lake to the Yoldia Sea varve clay sequence. The grain size became coarser which is linked to the warmer climate event. Warmer climate event at the beginning of Holocene has been increased the ice melting rate from 50-75m/year to 100-200m/year at 1,500 BZ corresponding to 10,740 varve year BP in the Stormberg Time Scale. It is responsible for increasing the amount of water produced from ice melting, the transportation energy had increased and coarser sediments were transported into the sedimentary basin. Several changes in detrital input especially the changes in clay materials input (as indicated by of Ti, Rb, and K) are found at ±30 years before and after the stage transition, which indicated the climate instability occurs at certain time period before and after the main event. The productivity indicators such as organic content and carbonate



Source : Björck et al., (2002)

Figure 7. Event stratigraphy for the Last Glacial–Holocene transition in eastern middle Sweden related to the isotopic event stratigraphy. The events are subdivided into climatic, Baltic basin and volcanic events.

content indicates that there is no significant changes in productivity levels, since the Baltic Sea remain cold without saline water incursion. Generally, the condition in the Baltic Sea was still not favorable for living organism. Based on biplot diagrams there was no significant change in sediment sources between the Baltic Ice Lake and Yoldia Sea varve clay sequence. The extent distribution of the Svecovenian Rocks is the main factor controling the less variation in the sediment source. Changes in sediment transportation energy might not change the sediment sources.

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REFERENCES

Björck, J., Possnert, G., & Schoning, K., 2001. Early Holocene deglaciation chronology in Vastergotland and Narke, southern Sweden – biostratigraphy, clay varve, 14C and calendar year chronology. *Quaternary Science Reviews*, 20: 1309-1326.

Björck, J., Wastegård, S., Andrén, T., Sohlenius, G., & Schoning, K., 2002. An event stratigraphy for the Last Glacial–Holocene transition in eastern middle Sweden: results from investigations of varved clay and terrestrial sequences. *Quaternary Science Reviews*, 21: 1489–1501

Björck, S. 2008. The late Quaternary development of the Baltic Sea. *In*: von Storch, H. Ed., 2008. *Assessment of Climate Change for the Baltic Sea Basin*. Springer.

Brunnberg, L., 1995. The Baltic Ice Lake. *Quaternary International*, 28: 177-178.

Cohen, A.S., 2003. *Paleolimnology: The History and Evolution of Lake Systems*. Oxford University Press. Oxford, 528p.

Croudace, I.W., Rindby, A., & Rothwell, R.G. Ed., 2006. ITRAX: Description and evaluation of a new multi-function x-ray core scanner. *In*: Rothwell, R.G., 2008. *New Techniques in Sediment Core Analysis*. Geological Society of London, London: 51-63.

Dypvik, H., & Harris, N.B., 2001. Geochemical facies analysis of fine grained siliciclastic using Th/U, Zr/Rb and (Zr/Rb)/Sr ratios. *Chemical Geology*, 181: 131-146

Gorbatschev, R. & Bogdanova, S., 2000. *Aspects of the Proterozoic boundary between SE and SW Sweden*. Department of Geology Lund University Sweden.

Heiri, O., Lotter, A.F., & Lemck, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Palaeolimnology*, 25: 101-110.

Jin, Z., Li, F., Cao, J., Wang, S., & Yu, J., 2006. Geochemistry of Daihai Lake sediments, Inner Mongolia, North China: implications for provenance, sedimentary sorting, and catchment weathering. *Geomorphology,* 80: 147–163.

Juhlin, C., Wahlgren, CW., & Stephens, M.B., 2000. Seismic imaging in the frontal part of the Sveconorwegian orogen, south-western Sweden. *Precambrian Research*, 102: 135-154.

Kylander, M., Ampel, L., Wohlfarth, B., & Veres, D., 2011. High-resolution X-Ray Fluorescence core scanning analysis of Les Echets (France) sedimentary sequence: new insights from chemical proxies. *Journal of Quaternary Science*, 26: 109-117.

Löwemark, L., Chen, H.F., & Yang, T.N., 2010. Normalizing XRF scanner data: a cautionary note on the interpretation of high-resolution records from organic-rich lakes. *Journal of Asian Earth Sciences*, 40: 1250-1256.

Mörner, N.A., 1995. The Baltic Ice Lake – Yoldia Sea transition. *Quaternary International*, 27: 95-98.

Peinerud, E.K., 2000. Interpretation of Si concentrations in lake sediments: three case studies. *Environmental Geology*, 40: 64-72.

Sohlenius, G., Emeis, K.C., Andrén, E., Andrén, T., & Kohly, A., 2001. Development of anoxia during the Holocene fresh – brackish water transition in the Baltic Sea. *Marine Geology*, 177: 221-242.

Stormberg, B., 1994. Younger Dryas deglaciation at Mt. Billingen, and clay varve dating of the Younger Dryas/Preboreal transition. *Boreas,* 23: 177-193.

Wohlfarth, B., Björck, S., Posnert, G., & Holmquist, B., 1998. An 800-year long, radiocarbon-dated varve chronology from south-eastern Sweden. *Boreas*, 27: 243-257.