Depositional history of the Neoproterozoic Visingsö Group, south-central Sweden

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Dissertations in Geology at Lund University,
Bachelor's thesis, no 504
(15 hp/ECTS credits)

Department of Geology
Lund University
2017

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Contents

Cover Picture: Outcrop of the Visingsö Group on the island of Visingsö. Photo: Viktor Ahrenstedt 2017

Abstract

VIKTOR AHRENSTEDT

Ahrenstedt, V., 2017: Depositional history of the Neoproterozoic Visingsö Group, south-central Sweden. *Dissertations in Geology at Lund University*, No. 504, 13 pp. 15 hp (15 ECTS credits).

Abstract: The Neoproterozoic sedimentary rocks of the Visingsö Group are one of few remaining rocks from this time. They provide a vital clue to understanding how the landscape looked at this time. The various environmental factors that prevailed and affected deposition are key to paint a bigger picture. The Visingsö Group shows how a local, fairly shallow, environment is subject to a long-term transgression. The three different formations in the Visingsö-Group represent three different depositional settings: The sandstones of the lower formation represent a fluviatile deltaic setting, the alternating beds of the middle formation represent a pro-delta environment and the shales of the upper formation represent a depositional setting alternating between marine and tidal-influenced.

Keywords: Sedimentology, depositional history, Visingsö Group, Neoproterozoic

Supervisor: Mikael Calner

Subject: Bedrock Geology (Sedimentology)

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Sammanfattning

VIKTOR AHRENSTEDT

Ahrenstedt, V., 2017: Depositionshistorien i den neoproterozoiska Visingsögruppen. *Examensarbeten i geologi vid Lunds universitet*, Nr. 504, 13 sid. 15 hp.

Sammanfattning: De neoproterozoiska sedimentära bergarterna i Visingsögruppen är en av få kvarvarande spår från den här tidsperioden i Sverige. Tack vare dessa har vi en möjlighet att förstå hur landskapet såg ut under denna tiden. De olika miljöfaktorer som påverkade sedimenten när dessa deponerades är nyckeln till att kunna måla en större bil. Det vi ser i Visingsö-gruppen är hur en lokal, förhållandevis grund, miljö som utsätts för en längre transgression. De tre olika formationerna i Visingsögruppen representerar tre olika depositionsmiljöer: Sandstenarna i den nedre formationen representerar en fluvial delta-miljö, de alternerande bäddarna i mellanformationen representerar en miljö som har avsatts i kanten på ett delta och skiffrarna i den övre formationen blev avsatta delvis i en marin miljö och delvis i en miljö präglad av tidvatten.

Nyckelord: Sedimentologi, depositionshistoria, Visingsögruppen, neoproterozoikum

Handledare: Mikael Calner

Ämnesinriktning: Berggrundsgeologi (Sedimentologi)

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1 Introduction

Within south-central Sweden lies one of the great lakes of Sweden, Lake Vättern. The lake was formed due to rifting in the underlying crystalline basement. When the rift formed the associated down-faulting trapped and preserved an overlying sedimentary succession within its boundaries. Most of these rocks are at the bottom of the lake but parts of the succession are still accessible along the lake shores and at Visingsö. The first studies on the rocks of the Lake Vättern area started over 150 years ago. Authors such as Nathorst (1879), Linnarsson (1880) and Holm (1885) were among the first to attempt to understand the nature of the Visingsö Group. For a long time the age of the sediments were the most important question, and suggestions such as Cambrian and Triassic were put forward. Today we know that they belong to the Neoproterozoic, and as such, one of the few remaining evidences from this time period in Sweden. Today the area is covered by thick Quaternary deposits, which mean that the Visingsö Group is mainly available in a few coastal outcrops around the lake, as well as in boreholes.

1.1 Aim of the study

The aim of the study is to with the help of existing literature provide a general overview of the depositional history of the Visingsö Group. The goal is to establish what the different types of depositional settings were and how they changed over time. Furthermore to be able to tell something about different environmental factors like climate that prevailed during the time of deposition.

2 Geology

2.1 Stratigraphy

The Visingsö group has been subdivided into three lithostratigraphic units, informally named the lower, middle and upper formations (Fig. 1; Collini 1951; Vidal 1985).

2.1.1 Lower formation

The lower formation, commonly known as the Visingsö sandstone, predominately consists of medium to coarse-grained quartz sandstones. The colour of the sandstones vary between white, yellow and red. At times beds consisting of conglomerates, siltstones and arkoses occur (Vidal 1974). Collini (1951) estimated that the 'lower formation' had a thickness of over 145 m. Lind (1972) conducted gravimetric investigations in the southern parts of the lake Vättern area and found that the sandstone had a thickness of about 400 m there. Boreholes in the same area showed a minimum thickness of 176 m. In the area of Karlsborg, at the north-western margin of the extent of the sandstone, another borehole showed a minimum thickness of 195 m.

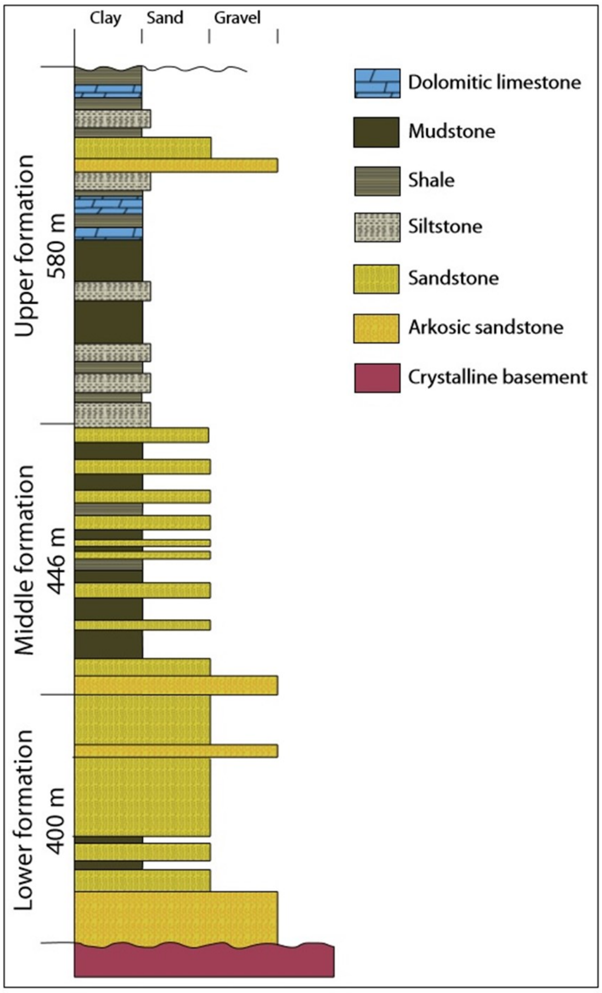

Fig. 1. Lithology of the Visingsö Group. Modified from

Furthermore the lower formation can be found on the eastern margins of the lake (Fig 2.) where outcrops exist around the town of Gränna, at the western side of Mount Omberg and in the area of Lemunda northwest of Motala (Vidal 1976). In the Lemunda area the sandstones are relatively well exposed along the shore and in old quarries and has an estimated thickness of 105 m (Vidal 1976). The boundary between the lower and the middle formations have so far only been observed in the Girabäcken valley north of Gränna (Collini 1951). But the successions at Lemunda displays a similar lithology as the ones in Girabäcken so it is possible that the boundary occurs there as well (Vidal 1976).

2.1.2 Middle formation

The middle formation is primarily located within the eastern parts of the Vättern basin (Fig 2) and outcrops are found on the eastern shore of Visingsö Island, in

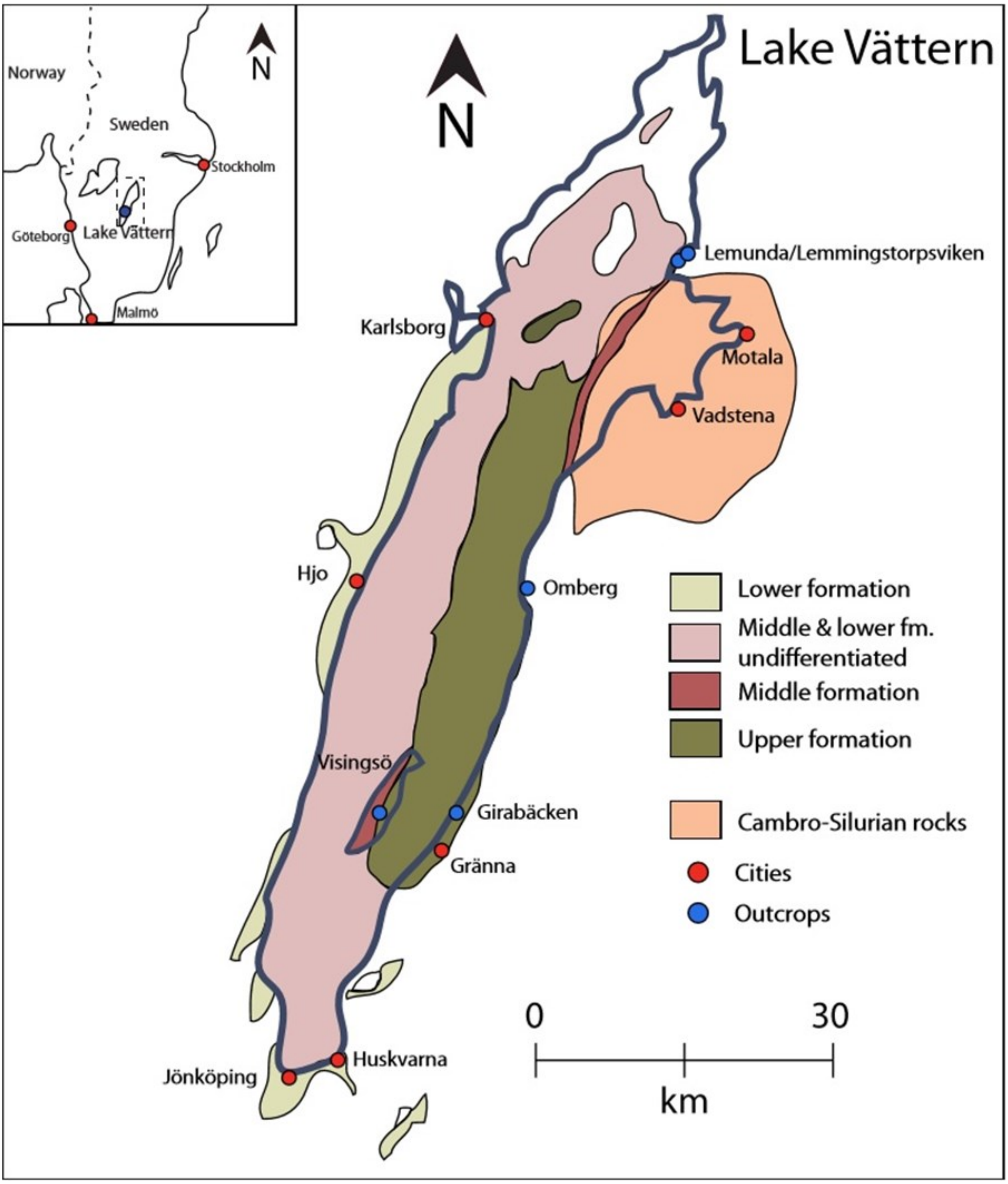

Fig. 2. Distribution of sedimentary rocks within the lake Vättern area. Modified from Axberg & Wadstein (1980)

the vicinity of Gränna, on the western side of Mount Omberg and in the Lemmingstorpsviken area (Vidal, 1976). Collini (1951) estimated the thickness of the middle formation to 315 m.

The lithology consists of grey, green and red-brown quartz arenite, arkoses, conglomerate-breccia, mud- and siltstone (Fig. 3; Vidal, 1976). There are abundant cross bedding, channelling, ripple marks and desiccation cracks in the succession (Fig. 4; Vidal 1979). Most of the coarse-grained rocks lack microfossils (Vidal 1976). West of Motala on the islands of Jungfrun and Fjuk, the middle formation includes coarse arkosic sandstones, monomict conglomerates and 'boulder beds' known as the Lilla Hals boulder beds (Fig 5). The sizes range from blocks to angular pebbles. Vidal & Bylund (1981) concluded that the Lilla Hals boulder beds were not of glacial origin but instead the result of debris flow along fault-bounded margins.

Fig. 3. Outcrop on the southeastern shore of Visingsö showing various sandstone and siltstone facies of the middle formation. Photo: Ahrenstedt 2017

Fig. 4. Desiccation cracks in the middle formation, southeastern Visingsö. Photo: Ahrenstedt 2017

Fig. 5. Coarse-grained, feldspar-rich sandstones from the middle formation, southeastern Visingsö. Photo: Ahrenstedt 2017

Fig. 6. Large, dome-shaped stromatolites at the northern tip of Visingsö. Photo: Ahrenstedt 2017

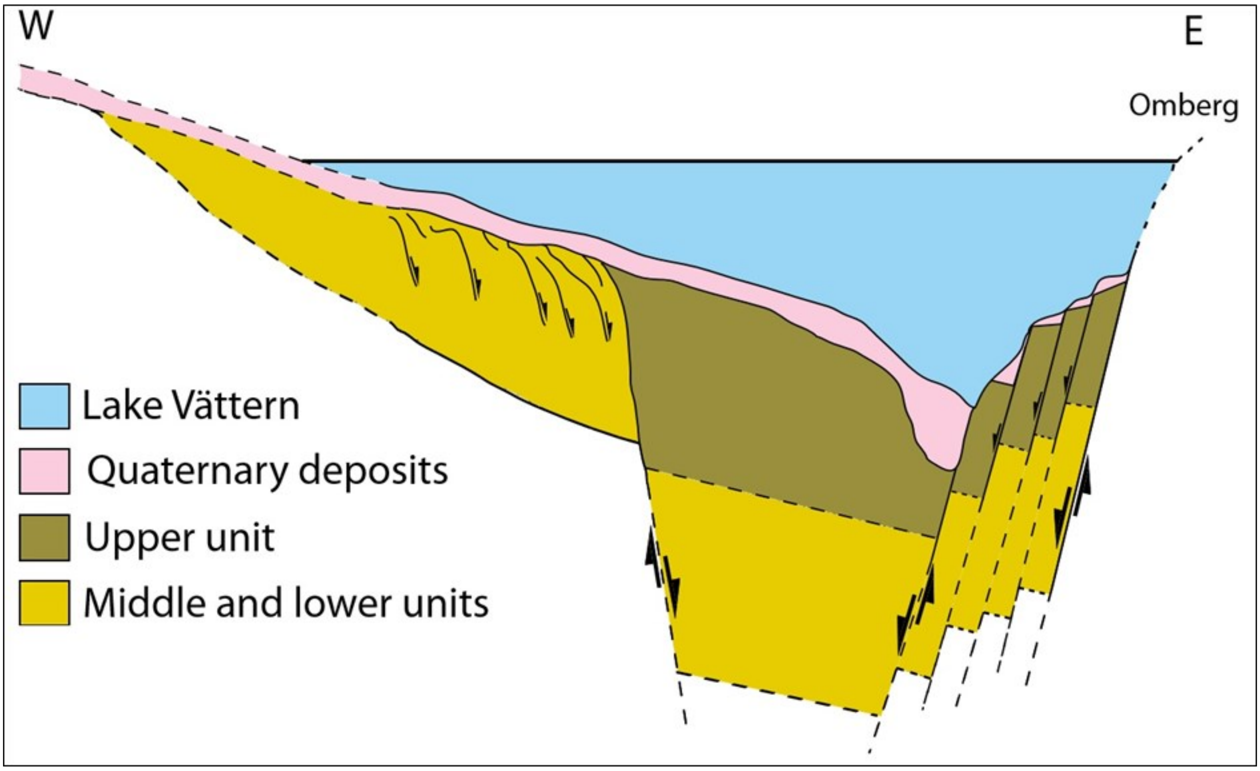

Fig. 7. Tectonical interpretation of the Vättern Basin in a line from Mount Omberg and to the west. Based on Axberg & Wadstein (1980)

2.1.3 Upper formation

The upper formation has an estimated thickness of 580 m (Collini, 1951). It is restricted to the eastern- and northern shores of Visingsö, coastal sections north and south of Gränna and the western side of Mount Omberg (Vidal, 1976). Previous work has not been able to determine the boundary between the middle and upper formations (Collini, 1951).

The lithology consists of alternating beds of black and grey green micaceous shales and siltstones (Vidal, 1976). There is also banded algal dolomites and in several places, such as on the northern tip of Visingsö and on Omberg, these form large, mound-shaped stromatolites (Fig 6). The formation displays abundant ripple marks and desiccation cracks (Vidal, 1976).

2.2 Tectonics

Lake Vättern, along which most of the remnants of the Visingsö Group is located, lies within the Scania-Vättern tectonic zone (Axberg & Wadstein 1980). East of the tectonic zone lies the granites and volcanic rocks of south-eastern Sweden. To the west the Sveonorwegian gneisses are located. The lake, and the tectonic zone, acts as a divide between these two geological provinces (Axberg & Wadstein 1980). In the area of the tectonic zone where the Visingsö-Group is present, eastwardly directed overthrusts dominate with the sediments preserved in downfaulted areas (Axberg & Wadstein 1980). Collini (1951) suggested that the depression where Vättern can be found today was formed in the late Precambrian and that this would have been due to horizontal tensional movements.

Adjacent to the Visingsö-Group, in the north-eastern parts of Vättern, lies the lower Palaeozoic rocks of the Motala bay area (Fig 2). They are preserved in the east-west aligned Motala-Norrköping fault system that intersects with the Scania-Vättern zone (Axberg & Wadstein 1980).

The bottom of Vättern is almost completely covered by sedimentary rocks belonging to the Visingsö-Group. Some crystalline rocks can be found in the northern parts but more than 90% of the area is composed of sedimentary rocks (Fig 2) (Axberg & Wadstein 1980).

Several authors have described the Vättern trench as a graben structure (De Geer 1910; Lind 1972). Collini (1951) couldn't find tectonic structures on the western shores of the lake that woul confirm the graben theory. He suggested instead that the contact between the crystalline rock and the Visingsö Group in this area is a denudation boundary. A fault structure is located along the N-S axis of the lake. It separates the middle and lower units from the upper one. It cuts the island of Visingsö into two parts. West of this fault, beds are undulating and their dip decreases in a westward direction pointing to a lessening of tectonic influence (Fig. 7; Axberg & Wadstein 1980).

2.3 Age of the Visingsö Group

Isotopic studies of K-Ar on detrital mica the Visingsö Group gave an age of 1060 – 985 Ma (Magnusson 1960). Rb-Sr dates from whole rock samples of the upper unit yielded an age of 663 ±7 Ma. Bonhomme & Welin (1983) considered this age to represent a diagenetic event that took place after deposition had ceased and would therefore give a minimum age for the upper formation.

Based on microfossil assemblages, as well as stromatolites, the Visingsö Group has been given an approximate age of 800–700 Ma. The Visingsö Group species-assemblages, as well as the stromatolites can be correlated with contemporary assemblages recovered from other sedimentary groups that have been chronostratigraphically constrained. These groups can be found in the Norwegian Caledonides (Hedmark, Vadsø and Tanafjord groups), Greenland (Thule and Eleonore Bay groups), the western USA (Chuar, Uinta Mountains and Pahrump groups) and Canada (Little Dal, Mount Harper and Fifteen mile groups; (Moczydlowska et al. 2017).

A biostratigraphic minimum age for the Visingsö-Group can be established using some of the microfossils present in the rocks. The same microfossil taxa can be found in the Kwagunt Formation of the upper Chuar Group, and the informal unit Collison Lake dolostone of the lower Mount Harper Group. These provide a minimum age of c. 740 Ma for the Visingsö Group (Moczydlowska et al. 2017).

Detrital ziron U-Pb ages from the lower formation gave a maximum depositional age for the Visingsö Group at 886 ± 9Ma. The zircon ages along with the biostratigraphy limits the Visingsö Group to the age span 886 – 740 Ma which falls within the Tonian period (Moczydlowska et al. 2017).

2.4 Provenance

The material that makes up the Visingsö Group comes from exposed rocks that can be tied to several orogens in the area; The 1.14 Ga Sveconorwegian, the 1.47-1.38 Ga Hallandian, and the 1.66-1.52 Ga Gothian. Furthermore the Trans Scandinavian Igneous Belt (1.86-1.66 Ga), Svecokarelian rocks (2.0 – 1.75 Ga) and several swarming dolerite dykes (1.6 – 0.95) were among the sources for the zircons (Moczydlowska et al. 2017). The examination of detrital zircons by Moczydlowska et al. (2017) showed that in the lowermost part of the stratigraphy, the youngest zircons could be found. Two possible scenarios could give rise to this: Either successively older rocks were being weathered and eroded in the hinterland and then deposited, or a depositional system existed that continued to expand outwards and covered the local younger material with older material from elsewhere. In their paper Moczydlowska et al. (2017) concludes that they were unable to tell which of the two scenarios had occurred.

2.5 Palaeontology

The Visingsö group holds a rich microfossil-record. The assemblages present consist of stromatolites and organic walled microfossils (OWM) such as cyanobacteria and acritarchs including vase-shaped microfossils (VSM; Vidal, 1972, 1976; Martí Mus & Moczydlowska, 2000; Loron 2016).

Acritarchs are a biologically heterogenous group within the group Acritarcha, which is a nomenclatural informal category (Evitt, 1963). They are thought to be the spores or cysts of marine planktonic algae (Vidal 1979). The VSM's have a global distribution and can be found in Neoproterozoic rocks all over the world. They occur in different lithologies within shallow marine settings and are interpreted as marine planktonic organisms (Knoll & Vidal, 1980). The rocks in which they are found were once marine sediments deposited in tropical to temperate climatic zones. This suggests that the VSM's hails from stenothermal organisms living in tropical and warm shelfal waters (Knoll & Calder 1983; Fairchild et al. 1991).

Stromatolites are bacterially mediated sedimentary rocks in which bacterial mats formed laminated structures. They are commonly associated with tidal environments in tropical latitudes (Vidal 1972).

3 Materials and methods

The paper is mainly a literature study where previous work on the Visingsö Group were used for interpretations of the depositional environment. A shorter field work for reconnaissance and photographic documentation took place on the island of Visingsö and in the Girabäcken valley in May 2017.

4 Results

The lower formation of the Visingsö Group consists mainly of sandstones. Vidal (1974) found that these sandstones displayed cross-bedding and interpreted the depositional environment to be fluviatile deltaic. Furthermore the siltstones in this formation would have been formed during times of marine ingressions. This conclusion is supported by the presence of silty layers that are acritarch bearing.

The middle formation largely consists of mica-rich, feldspathic arenites and silty sediments. These alternate with conglomerates (Vidal 1976). The less mature content of the sediments indicates a change in either the source of the material or the length of the transport. Various indications of shallow-marine settings exists such as: ripple marks, cross-bedding, desiccation cracks, truncated beds and a few finds of acritarchs in arenitic and silty deposits. Sedimentation breaks are thought to have been frequent but short (Vidal 1976). The lack of fossil material coupled with well-oxidized sediments led Vidal (1976) to conclude the sediments were deposited in an oscillating pro-delta zone. A few of the beds did contain a large number of acritarchs indicating that the water-depth in the shallow marine environment did differ at times (Vidal 1976).

The upper formation consists of alternating algal calciulite, silt, silty argillite and shales. The sediments are rich in acritarchs and contain stromatolites that indicates an alternating subtidal to shallow marine environment (Vidal 1976). The acritarchs that are found here have a worldwide distribution, which implies that the area was part of, or had a connection to, the open ocean (Vidal 1985).

The total organic carbon (TOC) amounts in some of the shales from the upper unit reach an average value of 3.56 mg C/g (Samuelsson & Strauss 1999). Other Neoproterozoic shales have an average TOC value of 2.30 mg C/g (Strauss et al. 1992). Knoll & Vidal (1980) argue that the high TOC amounts points to a high rate of organic productivity as well as high amounts of burial of organic matter. Furthermore they argued that coupled with the presence of phosphate nodules the high TOC amounts indicate that the upper formation has been subject to upwelling of water that were rich in nutrients.

The stromatolites shows that the temperatures during the deposition of the upper formation were warm and tropical (Vidal 1972).The presence of detrital biotite in abundance further tells us that the climate was dry (Vidal 1985). Early diagentic berthierine is present in the shales of the upper formation as well as within VSM's preserved in phosphate nodules. Berthierine is thought to precipitate under reducing conditions in shallow and warm waters (< 60 m, > 20°C) (Morad & Al-Aasam 1994). Vidal & Bylund (1981) used samples from the middle formation to palaeomagnetically determine the palaeolatitude to have been between 15° and 40°. Such latitudes are consistent with environments that can form phosphate nodules and berthierine (Morad & Al-Asam 1994). Geographic reconstructions of the continents during the Neoproterozoic also places Baltica at low to middle latitudes within the southern hemisphere (Torsvik et al. 1996). Collini (1951) argued that the sediments of the middle formation differs from the lower formation due to climactic factors. He suggests that the climate was much colder and drier which would have caused mechanical weathering of the rocks. VSM's are found within sediments deposited in tropical to temperate climatic zones (Knoll & Calder 1983; Fairchild et al. 1991). The waters would have been well oxygenated and nutrient rich, and no major changes in seasonal temperatures (Mus & Moczydlowska 2000).

5 Discussion and conclusions

The sedimentary evidence within the three different formations shows that the Visingsö Group intermittently was deposited in very shallow waters. Recurrent occurrences of desiccation cracks, as well as the stromatolites in the upper formation, implies that the sediments at times have been subaerially exposed.

The lower formation represents a fluviatile-deltaic depositional system, the middle formation a pro-delta prograding into shallow marine environments, and the upper formation represents a shallow-marine, tidal influenced shelf area.

The Visingsö Group forms a pattern of continuous, long-term transgression, with the different formations representing deposition in successively deeper marine environments. If this apparent transgression is caused by an actual increase in sea-level or if it is dependent on other factors is hard to determine. The climate during the deposition seems to have been temperate to tropical. The evidence in the upper formation points towards a tropical environment whereas the possibility of mechanical weathering in the middle formation could indicate a colder climate. The transition from a temperate to tropical climate could be explained by Baltica drifting into more tropical latitudes after the break-up of Rodinia.

6 Acknowledgements

I would like to thank my supervisor Mikael Calner for his support throughout the project, as well as for the guidance he provided during the field work. Furthermore I would like to thank Anders Lindskog for his feedback as well as many discussions concerning the Visingsö Group. And a final thank you goes out to friends and family for their continued support.

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