A palynological study across the Ordovician Kinnekulle bentonite, Sweden

Johan Nordas

Dissertations in Geology at Lund University,
Bachelor's thesis, no 449
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Contents

Cover Picture: Ordovician diacromorhp acritarch

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Abstract: A palynological analysis across the Ordovician (Sandbian) Kinnekulle bentonites in south Central Sweden has been performed. The sedimentary successions were recovered from the Borenshult -1 drillcore in the Motala area, south central Sweden. The lithology is dominated by mudstones and two thick bentonite beds. Acritarchs dominate the palynological assemblage but a few chitinozoans and scolecodonts were encountered. The composition of acritarchs is stable throughout the core with the exception of the two consecutive top-most samples in which every morphological group diminishes and disappear except the sphaeromorph type. The acritarch abundance changes within the core, the earliest sample shows a steady state until it reaches the oldest bentonite layer. At this point the acritarch abundance decrease rapidly and then recovers. In the period between the bentonite layers a higher abundance is recorded. In the second layer, the signature seen in the first layer is repeated. An upswing in acritarch abundance yet again occur in the layers resting on the bentonite. In the top-most layers of the core, the acritarchs almost disappear. The scolecodonts and chitinozoans occur only in very low abundance throughout the core. The acritarchs were counted and divided into functional traits depending on their morphology based on the visual traits of the processes. The biomass density is lower in the bentonite layers compared to the non-volcanic parts. Directly on top of both the bentonite beds an increase of acritarch abundance can be observed. The acritarch assemblage indicates a lowering of the sea-level at the topmost the samples.

Keywords: Acritarch, bentonite, Ordovician, Borenshult-1, Sweden, Kinnekulle

Supervisor: Vivi Vajda

Subject: Paleontology

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En palynologisk studie över Ordovisiska Kinnekullebentoniten, Sverige

JOHAN NORDAS

Nordas, J., 2015: A palynological study across the Ordovician Kinnekulle bentonite, Sweden. *Examensarbeten i geologi vid Lunds universitet*, Nr. 449, 15 sid. 15 hp.

Sammanfattning: En palynologisk analys över Ordoviciums (Sandbian) Kinnekulle bentonit från södra delarna av mellersta Sverige har gjorts. Den sedimentära succsessionen är hämtad från Borenshult-1 borrkärnan som togs i Motala, syd-mellersta Sverige. Litologin domineras av mudstone och två tjocka bentonitlager. Akritarker dominerar den palynologiska sammansättningen och endast ett fåtal chitinozoer och scolecodonter kunde hittas. Kompositionen av akritarker är stabil igenom borrkärnan förutom i de två översta proverna där den sphaeromorpha gruppen är den enda morfologiska gruppen som inte minskar i andel och försvinner. Mängden akritarker förändras borrkärnan och i de tidigaste avlagringarna ser man ett ”steady-state” som bryts då det äldsta bentonitlagret nås. Då sker en snabb minskning i mängden akritarker som sedan hämtar sig. Mellan det äldre och yngre bentonitlagrena kan man se en större mängd akritarker. I det yngre bentonitlagret sker en upprepning av händelseförloppet som skedde i den äldre bentoniten. Efter bentoniten sker igen en ökning av andelen akritark men i de två översta proverna försvinner nästan hela akritarkgruppen. Scolecodonter och chitinozoer finns i endast låga mängder igenom hela borrkärnan. Akritarkerna räknades efter att ha delats in i funktionella grupper beroende på deras visuella morfologiska egenskaper. Biomassan är lägre i bentoniten i jämförelse med de icke-vulkaniska delarna och direkt ovanför båda bentonitlagrena kan man se en ökning av mängden akritarker. Förändringana i akritarksammansättningen pekar på att havsnivån sänks i det yngsta proverna.

Nyckelord: Akritark, bentonit, Ordovicium, Borenshult-1, Sverige, Kinnekulle

Handledare: Vivi Vajda

Ämnesinriktning: Paleontologi

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1 Introduction

During the Ordovician, Baltica was drifting northwards away from the large southern continent Gondwana. In the late Ordovician two periods of large scale volcanic activity occurred as a result of the continental drift (Harper et al., 2010). A number of bentonites (volcanic ash beds) are present in the lower part of the Upper Ordovician within Baltoscandia. In this study I focus on the Kinnekulle Bentonite, which represents the major eruption of the Ordovician and dated to have occured approximatly around 454Ma (Huff et al., 1996; Sell et al. ,2013).

The drillcore used in this study, Borenshult-1, was drilled in the vicinity of the city of Motala, Östergötland, in the south-central parts of Sweden (Fig.1). This stratigraphic section is exposed at Kinnekulle in Västergötaland, south-central Sweden (Fig 1.) By observing the occurrence of different acritarch morph-types and the percentage of the occurring acritarchs before, during and after these two periods of volcanic activity an estimation of Baltica's palaeoenvironment will be made with Staplin's model from 1961 (Jacobson, 1979). Jacobson uses a similar method by using acritarchs as a palaeoenvironmental indicator and manages correlate his findings with the results made with other palynomorphs occurring during the Ordovician such as scolecodonts and chitinozoans. These two groups, and the AOM (Amorphous Organic Matter) will be mentioned since they have major effect on the palaeoecosystem and palaeoenvironment but they are not in the focus of this study.

1.1 Microfossils

In 1963 W. R.Evitt used the term *Acritarch* to describe a group of small fossils of unknown origin: "Small microfossils of unknown and probably varied biological affinities consisting of a central cavity enclosed by a wall of single or multiple layers and of chiefly organic compositions; symmetry, shape, structure, and ornamentation varied; central cavity closed or communicating with the exterior by varied means, for example: pores, a slitlike or irregular rupture, a circular opening (the pylome)".

Evitt argued that some of the acritarchs are dinoflagellates, but today we know that acritarchs mainly represent green algae but further include multiple groups, both animals and plants in different life stages such as metazoan eggs or cyst (Moczydlowska et al., 2011). Acritarchs can be found globally in marine palaeoenvironments and many forms were pelagic and had a global distribution. Because of this trait, the acritarchs are mainly used to correlate successions globally (Vecoli and Le Hérissé, 2004).

Chitinozoans are bottle-shaped microfossils of an unknown origin that appeared during early Ordovician and went extinct in the late Devonian (Paris and Nõlvak, 1999; Servais and Paris, 2000).

Scolecodonts are the remaining parts of the jaw apparatuses belonging to predatory worm species, which are members of the polychaete class and the *Annelida* phylum (Hints and Eriksson, 2010).

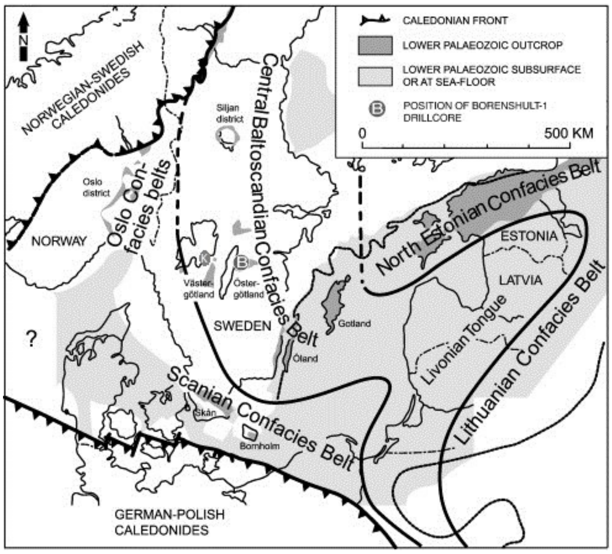


Figure 1: Shows the location, indicated with a "B" on the map of the Borenshult-1 drillcore-sampling area which is located at the city of Motala in Östergötland, south-central Sweden. The area of Kinnekulle is marked with a "K" on the map. Modified from Pouille et al., 2014.

Cryptospores appeared in Gondwana dating Mid-Ordovician and can be found in modern Argentina. On Baltica, the earliest record of spores from land plants is from the Katian (Badawy et al., 2014). Trilete spores representing vascular plants have in Sweden been recovered from Silurian successions where a shallowing up sequence is seen by the successively higher input of spores from land plants in the assemblages (Mehlqvist et al., 2012; 2014; 2015).

1.2 Ordovician

1.2.1 Globaly

Twenty one samples During the Ordovician, 485 to 443 million years ago, the main part of the landmasses were located on the Southern Hemisphere (Figure 2). The largest landmass is called Gondwana and this super-continent split during the Jurassic and Cretaceous into todays' Antarctica, South America, Africa, Australia and China (Scotese, 2001). Northern parts of China represent the northern part of Gondwana, while south China formed the western part of this large continent. South America was located in the eastern part and, the Sahara Desert in the south (Scotese, 2001; Harper et al., 2010).

Siberia, Baltica and Laurentia (North America) were not part of Gondwana and these continental plates formed most of the land outside Gondwana (Scotese, 2001). The Northern Hemisphere was represented by the great Panthalassic Ocean. West of Gondwana was the Paleo-Tethys Ocean and to the east the

Iapetus Ocean (Scotese, 2001; Harper et al., 2010).

1.2.2 Sweden

During the Ordovician Baltica was located in the southern sub-equatorial region (Fig. 2). Baltica had a northward movement towards Laurentia, which resulted in large volcanic activities (Harper et al., 2010).

1.3 Aims

The aim of the study is to learn to differentiate morpho -groups of acritarchs and to calculate their abundance. The aim is further to learn and carry out palynofacies analyses. The data will then be used to assess the palaeoenvironmental setting of the late Ordovician succession in the examined area within the Borenshult-1 drill core. Palynostratigraphy is outside the scope of this study.

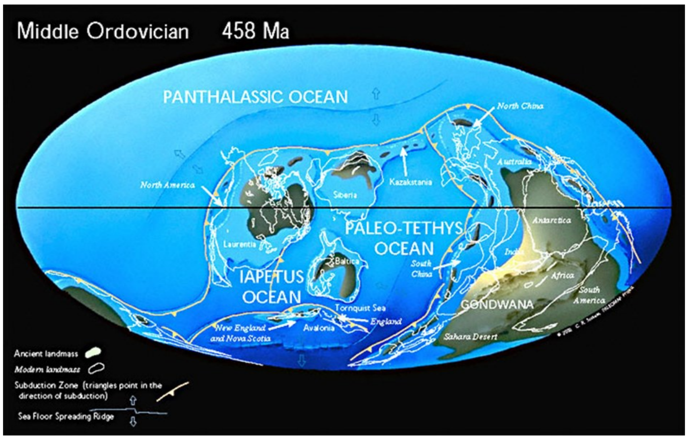
1.4 Geological setting

Kinnekulle is a plateau which is located on the southwestern shore of the lake Vänern in the county of Västergötland, Sweden. It consists of sedimentary rocks dating from Cambrian to the Silurian (Calner and Ahlberg, 2011). The highest point which lies 306 meter above the sea level consists of Permian magmatic diabase surrounded with Silurian shale. Beneath the shale is a layer of Ordovician limestone, underlain by Ordovician and Cambrian alum shales. Below the alum shale lays a bed of Cambrian Sandstone. The sandstone rest upon the Cambrian peneplain made of crystalline basement rock (Calner and Ahlberg, 2011).

Bentonite can be found in the drill core, this was formed when tephra was settled on the seafloor. The tephra derived from two volcanic events southwest of Baltica in the Iapetus Ocean (Thorsvik and Rhenström, 2003).

2 Methods

Twenty one samples were extracted from the drill core labelled ”Borenhults-1” from Motala, Östergötland. The drillcore is 71,33m with a diameter of 39 mm (Pouille et al., 2013). The interval 40.1 meters to 36.6 meters was targeted, and can be correlated to bentonites exposed at Kinnekulle representing the upper Ordovician. The samples were processed by Global Geolab Limited, Canada. They used the standard palynological processing methods. Modern *Lycopodium* spores were added to the samples in order to assess the palaeo-productivity. The core and the samples are stored at the Department of Geology, Lund University. A light microscope with a 40x magnifying lens was used when analysing the organic matter from the samples. Photographs of acritarchs and palynological assemblages were taken by Johan Nordas.



Figur 2: Global paleogeographical map and the position of Baltica during the middle Ordovician (Scotese, 2001)

The acritarchs were categorized into different morphological groups (Fig. 3) based on the visual traits that could be observed in the microscope. After categorizing the observed acritarchs, the *Lycopodium* spores and acritarchs were counted (in total 300 per sample) in order to get the ratio between the two groups (Table I).

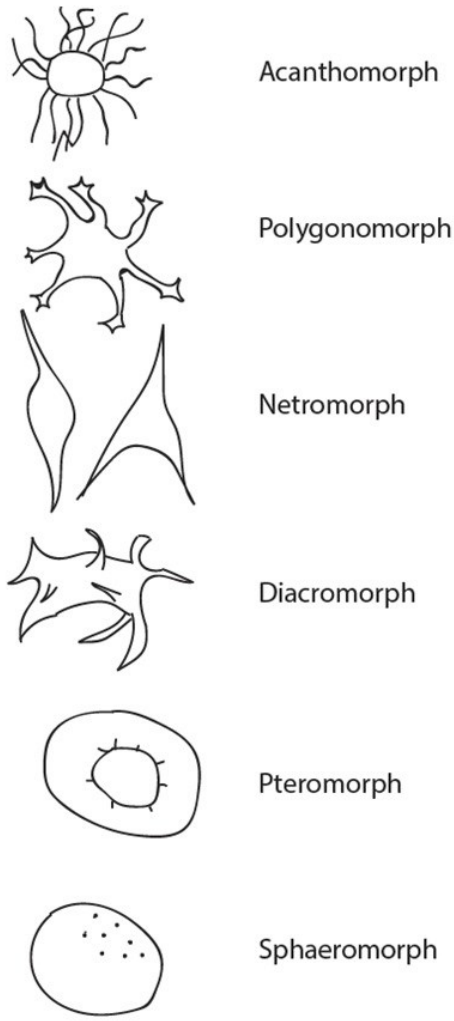


Figure 3: Shows the categorization of acritarchs used in this article.

3 Results

The following morphological groups were identified (Table I; Figures 3 and 4): *Sphaeromorpha* (1): sphere -shaped cell, no visual markings on the cellular wall or processes. *Acanthomorpha* (2): processes that were either thorn-, hair-, needle-, spike-like and/or with granulation on the cellular wall. *Diacromorhpa* (3): large and plain, processes on cellular wall. *Polygonomorpha* (4): processes with bifurcates. *Netromorpha* (5): cell with 3 or more long and slim spike-like processes. *Pteromorpha* (6) The cell wall or membrane is surrounded by a flat thin wing. *Lycopodium* (7): Modern *Lycopodium* spores have a characteristic brick-like structure on the cellular wall, a so called reticulum.

In total six acritarch groups were identified, the most abundant is the polygonomorph group (Fig. 3). The observed arcitarchs and lycopodium spores can be seen in Table I. The sphaeromorph group is the only acritarch group that can be found in every sample and it is almost as abundant as the polygonomorph group. The rarest group of acritarchs are the members of the pteromorph group that could only be found in two contiguous samples 38.98m and 39.00m.

A palynofacies analysis was also made on the 21 samples. The categories were first observed in the samples and then counted. The categories found in the samples were: *acritarchs*, *chitinozoans*, *scolecodonts*, *Zoo-clasts*, which are undefinable parts from animals, *AOM* and *Lycopodium* spores. These were also counted to a maximum limit of 300 in every sample (Table II).

Staplin (1961) introduced the model used in this study where different acritarch groups are used to interpret the palaeoenvironment. He divided the acritarchs in the following morphogroups; sphaeromorph, acanthomorph/diacromorph and polygonomorph acritarchs (Fig. 3). These morphological groups are used to determine the distance to the reefs and the shore for where these groups occurred during the Ordovician (Jacobson, 1979). Further, the relative abundance of each acritarch group together with the lithology from where the samples were extracted may serve as estimation of how the succession of the palaeo-ecosystem developed. He also mentions that neither diagenetic processes, wave action nor scavengers play any important role in the occurrence of acritarchs. According to Staplin, acritarchs in general will be found in high numbers offshore in calmer waters but he states that the different groups still have their preferred habitat. The sphaeromorph group will occur both offshore and at the reef. The acanthomorph/diacromorph group will rarely be found at the reefs, but these will occur in high density further offshore. The polygonomorph group can only be found offshore.

Below the basal bentonite layer (40,1 – 39,2m) the acritarchs show their highest diversity, with members of almost every trait group represented, at sample 39.5m the lithology becomes darker and more organic which is reflected in the high rate of zoo-clasts in this layer. Within the first bentonite layer, samples 39,1 – 38.85m, a drop of abundance of the acritarch community followed by peak is seen. This is subsequently followed by a decrease to a lower value at 21%. The AOM is increase with the falling number of acritarchs and vice versa.

During the short period of non-volcanic activity, samples 38.73 - 38.35m, acritarch density increases until it reaches the second bentonite layer where the diversity and the abundance of acritarchs crashes. However, the zoo-clasts reach a relatively high abundance in the lower part of this “non-volcanic” interval, which could be an effect of the high rate of nutrition and open niches after the first volcanic emission. The zoo-clasts decline after the peak and the group stay in a stable state until it reaches its next peak in the middle of the second bentonite layer.

The samples 38.06 - 36.7m are taken from the second bentonite layer. The densities of acritarchs are low overall, with its lowest point at sample 37.5m (2%). In the basal part, up to the middle of the second bentonite layer lycopodium spores make up roughly 50% of the palynomorph assemblage. This high number is only higher in two topmost consecutive samples of the core. Zoo-clast values are also low until sample 37.0m where zoo-clast as well as acritarchs increases in abundance. At sample 36.6m AOM dominates and that could be seen as a cluster of small unidentifiable “fluffy” particles through the entire sample. This bed containing the high AOM (36.6m and above the second bentonite layer) contains carbonates.

The relative abundance of acritarchs stays stable until it peaks at 36.4m to the highest point observed and then declines down to 3% within the topmost sample at 35.2m. The diversity changes at this level and the acanthomorph/diacromorph and the polygonomorph groups (groups preferring pelagic environments) diminish and at 35.2m only sphearomorph can be found which indicates that the water level is decreasing. In the sample 35.4 and 35.2 lycopodium spores are most abundant (57% and 87%).

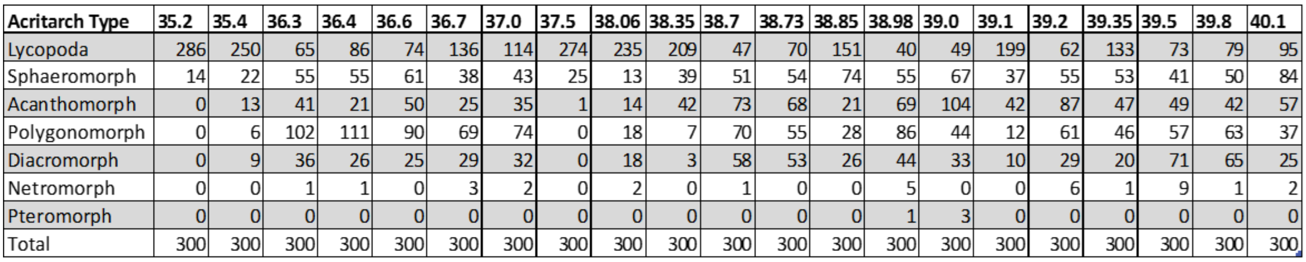
Throughout the core neither the scolecodont nor chitinozoa reach any significant levels, they occur in low abundance not exceeding 1%.

4 Discussion

While counting the acritarchs I noticed that the samples taken from the bentonite layers were almost barren of biomass material, most of the observed particles were clusters of small diffuse fragments and oddly shaped and damaged lycopodium spores (Fig. 3, number 7 a-f), that could have easily been mistaken for a sphaeromorph acritarch, except it kept the triangular outer wall. Something that is also noteworthy is the absence of almost any acritarchs in top two samples.

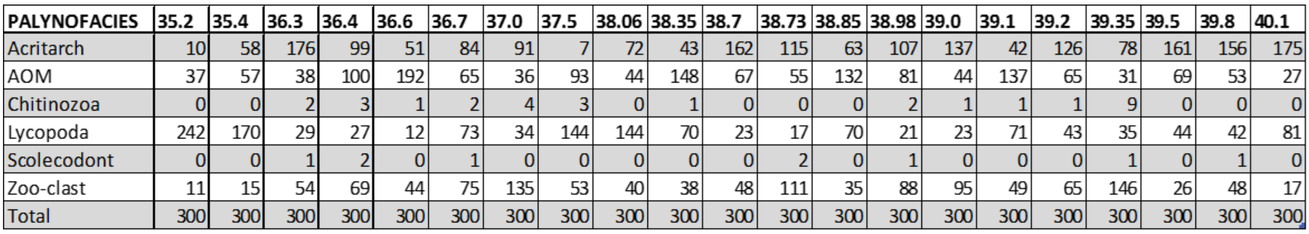
A count of palynogical groups was also done and the observation from that count is shown in Table II and photos taken of the slides are shown in figure 5. Acritarchs are the most abundant palynological group

Table I: In every sample, acritarch-morphs and lycopodaium spores were counted. The table shows how many of the acritarch morpho-groups and lycopodaium spores that were found in the sample. 300 were totally counted from every sample.



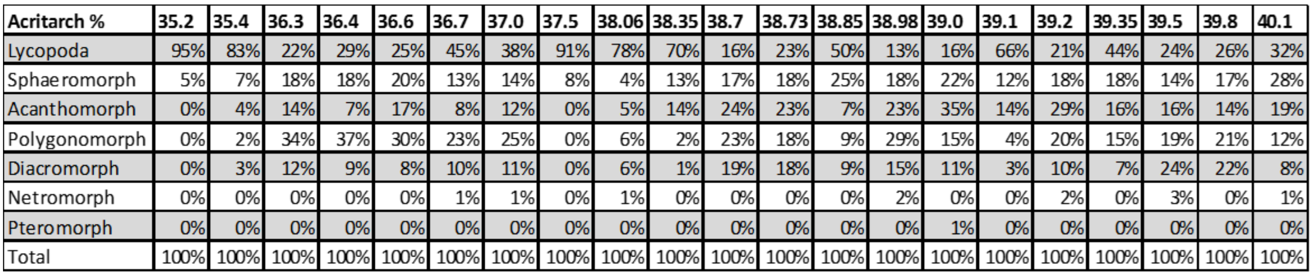
Acritarch Type	35.2	35.4	36.3	36.4	36.6	36.7	37.0	37.5	38.06	38.35	38.7	38.73	38.85	38.98	39.0	39.1	39.2	39.35	39.5	39.8	40.1
Lycopoda	286	250	65	86	74	136	114	274	235	209	47	70	151	40	49	199	62	133	73	79	95
Sphaeromorph	14	22	55	55	61	38	43	25	13	39	51	54	74	55	67	37	55	53	41	50	84
Acanthomorph	0	13	41	21	50	25	35	1	14	42	73	68	21	69	104	42	87	47	49	42	57
Polygonomorph	0	6	102	111	90	69	74	0	18	7	70	55	28	86	44	12	61	46	57	63	37
Diacromorph	0	9	36	26	25	29	32	0	18	3	58	53	26	44	33	10	29	20	71	65	25
Netromorph	0	0	1	1	0	3	2	0	2	0	1	0	0	5	0	0	6	1	9	1	2
Pteromorph	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0
Total	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300

Table II: The palynofacies results, absolute counts. 300 were totally counted from every sample.



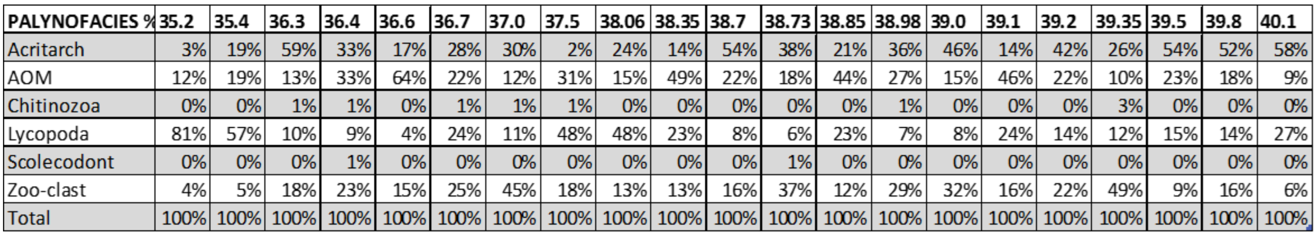
PALYNOFACIES	35.2	35.4	36.3	36.4	36.6	36.7	37.0	37.5	38.06	38.35	38.7	38.73	38.85	38.98	39.0	39.1	39.2	39.35	39.5	39.8	40.1
Acritarch	10	58	176	99	51	84	91	7	72	43	162	115	63	107	137	42	126	78	161	156	175
AOM	37	57	38	100	192	65	36	93	44	148	67	55	132	81	44	137	65	31	69	53	27
Chitinozoa	0	0	2	3	1	2	4	3	0	1	0	0	0	2	1	1	1	9	0	0	0
Lycopoda	242	170	29	27	12	73	34	144	144	70	23	17	70	21	23	71	43	35	44	42	81
Scolecodont	0	0	1	2	0	1	0	0	0	0	0	2	0	1	0	0	0	1	0	1	0
Zoo-clast	11	15	54	69	44	75	135	53	40	38	48	111	35	88	95	49	65	146	26	48	17
Total	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300

Table III: The different acritarch morpho-groups and lycopodium spores expressed as %.



Acritarch %	35.2	35.4	36.3	36.4	36.6	36.7	37.0	37.5	38.06	38.35	38.7	38.73	38.85	38.98	39.0	39.1	39.2	39.35	39.5	39.8	40.1
Lycopoda	95%	83%	22%	29%	25%	45%	38%	91%	78%	70%	16%	23%	50%	13%	16%	66%	21%	44%	24%	26%	32%
Sphaeromorph	5%	7%	18%	18%	20%	13%	14%	8%	4%	13%	17%	18%	25%	18%	22%	12%	18%	18%	14%	17%	28%
Acanthomorph	0%	4%	14%	7%	17%	8%	12%	0%	5%	14%	24%	23%	7%	23%	35%	14%	29%	16%	16%	14%	19%
Polygonomorph	0%	2%	34%	37%	30%	23%	25%	0%	6%	2%	23%	18%	9%	29%	15%	4%	20%	15%	19%	21%	12%
Diacromorph	0%	3%	12%	9%	8%	10%	11%	0%	6%	1%	19%	18%	9%	15%	11%	3%	10%	7%	24%	22%	8%
Netromorph	0%	0%	0%	0%	0%	1%	1%	0%	1%	0%	0%	0%	0%	2%	0%	0%	2%	0%	3%	0%	1%
Pteromorph	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table IV: The palynofacies count expressed as %.



PALYNOFACIES %	35.2	35.4	36.3	36.4	36.6	36.7	37.0	37.5	38.06	38.35	38.7	38.73	38.85	38.98	39.0	39.1	39.2	39.35	39.5	39.8	40.1
Acritarch	3%	19%	59%	33%	17%	28%	30%	2%	24%	14%	54%	38%	21%	36%	46%	14%	42%	26%	54%	52%	58%
AOM	12%	19%	13%	33%	64%	22%	12%	31%	15%	49%	22%	18%	44%	27%	15%	46%	22%	10%	23%	18%	9%
Chitinozoa	0%	0%	1%	1%	0%	1%	1%	1%	0%	0%	0%	0%	0%	1%	0%	0%	0%	3%	0%	0%	0%
Lycopoda	81%	57%	10%	9%	4%	24%	11%	48%	48%	23%	8%	6%	23%	7%	8%	24%	14%	12%	15%	14%	27%
Scolecodont	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Zoo-clast	4%	5%	18%	23%	15%	25%	45%	18%	13%	13%	16%	37%	12%	29%	32%	16%	22%	49%	9%	16%	6%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

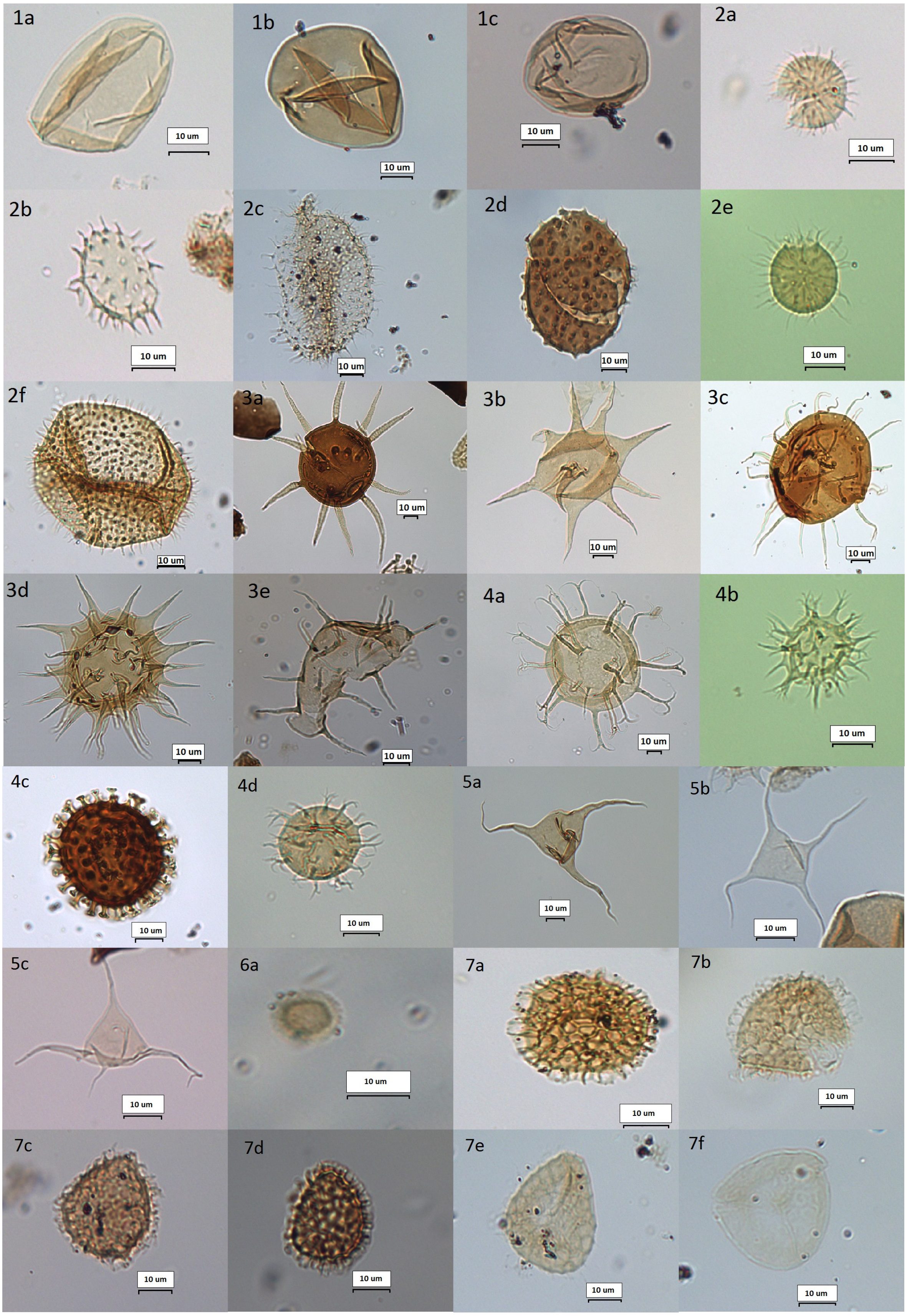


Figure 4: Different morphotypes of acritarchs observed and categorized in the examined samples. The photographs were taken with a lightmicroscope at 40x enhancement. Sphaeromorph (1a - c), acanthomorph (2a - f), diacromorph (3a - e), polygonomorph (4a - d), netromorph (5a - c), pteromorph (6a) and 7a - f shows spores of lycopoda.

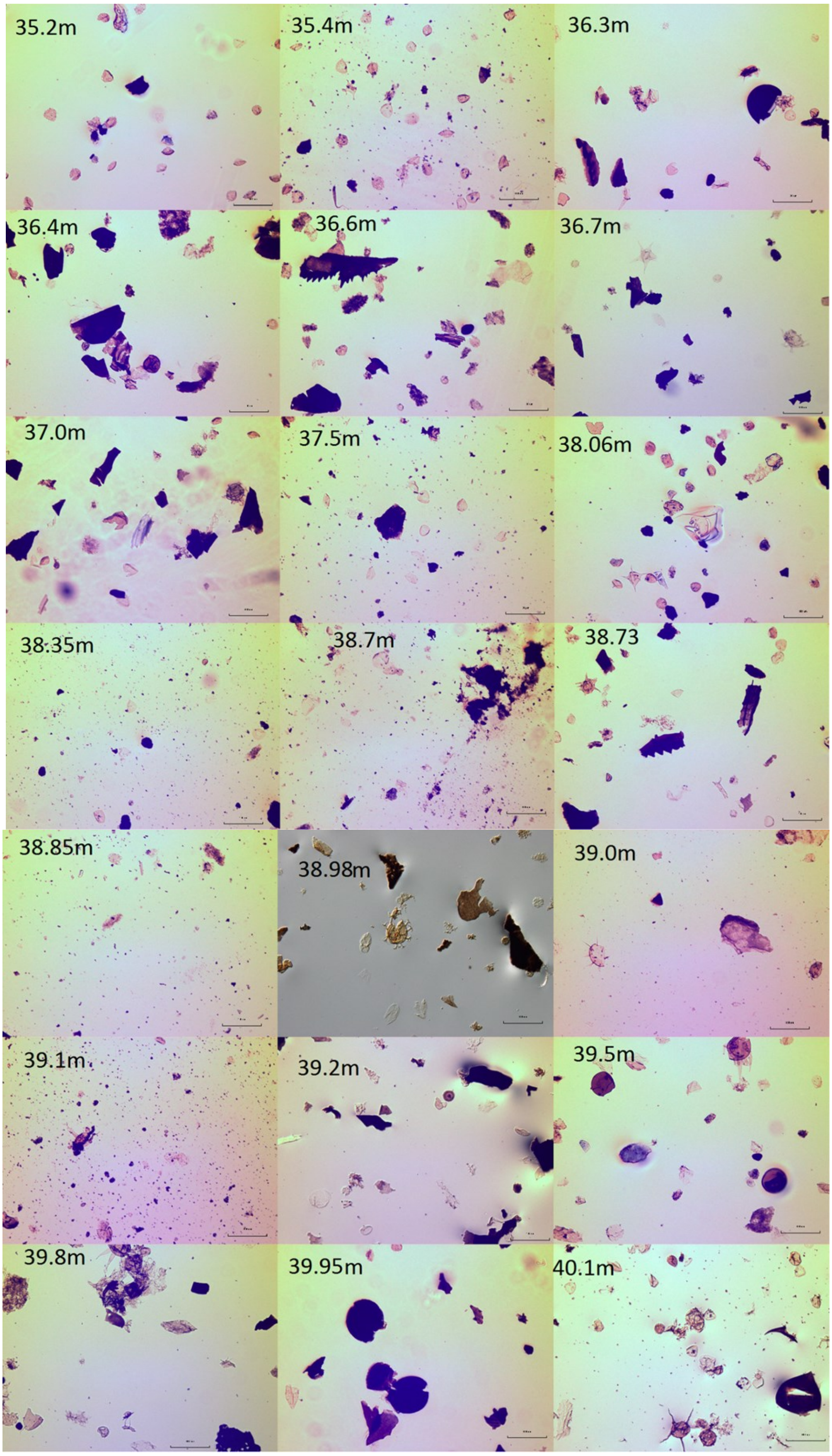
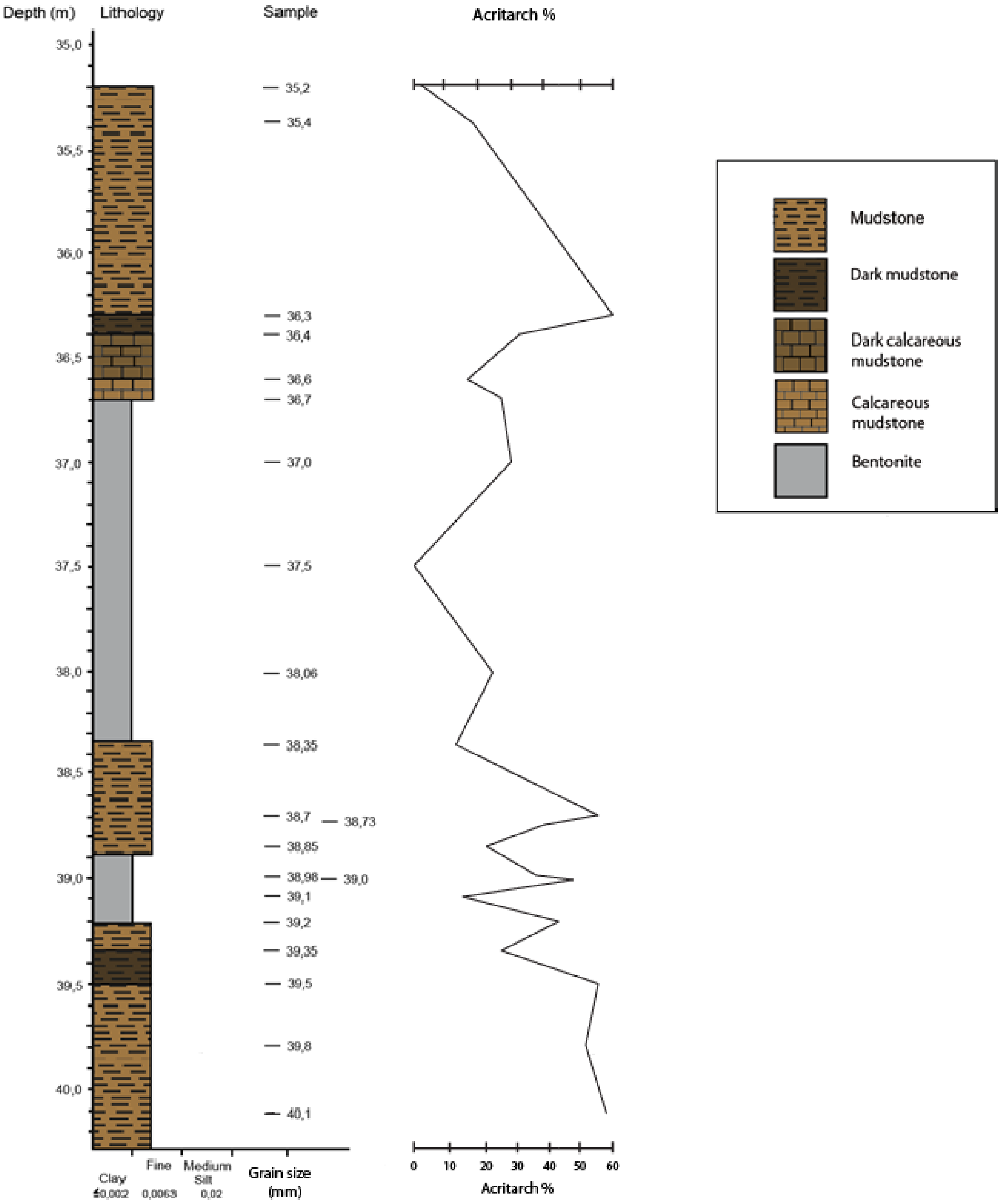


Figure 5: Examples of palynofacies seen in the studied samples. The numbers indicate the depth (m) in the core but they also represent the sample number. The photographs are taken in a light microscope with a 10x lens.



Figur 6: Lithological succession and sample levels of the Borenhult drillcore.. The graph illustrates the acritarch abundance through the sampled interval of the core.

and both scolecodonts and chitinozoa were rare. The topmost layer contains almost only lycopodium spores. Some samples were dominated by small fragments of unknown affinity, named as AOM (Table II). AOM is extremely abundant both in large groups but also spread out evenly through the entire sample as single grains, in this case I only counted the groups and not the individual particles.

The lack of acritarchs in the bentonite is here interpreted as the result of two independent parameters which may interplay; drastic changes in the environment, culminating in a dead ecosystem, which derived from the long period of volcanic activity and ash clouds darkening this area from sunlight and the ability to photosynthesize. The other reason could be the forming of the bentonite itself. Tephra have to be packed three to four times it original density in marine environment for bentonite to form (Huff et al., 1996) and might destroy the dead plankton and thus result in the lack of microfossils.

The most interesting is though the intense increase of acritarchs in the samples taken in the upper parts of the bentonite beds, here the ratio of lycopodium spores vs. acritarchs was low compared to the samples found at some distance from the bentonite beds. The bentonite found in Kinnekulle is a K-bentonite or potassium rich bentonite (Perrier et al., 2012), which is a hyper plant fertilizer in aquatic ecosystems and thus may explain the rapid increase of biomass after the earlier lower levels. This increase of acritarchs after the input of tephra may be an analogue to the modern massive algal blooms seen around the world especially in fresh-water systems as the result of a unnatural high rate of potassium derived from the the agriculture spill water. These acritarch blooms would most likely have had a similar poisonous effect on the palaeoenvironment as seen in present days algal blooms and could be an explanation to the increase and decrease of acritarch abundance in the layers directly above the bentonite.

As shown in the log (Figure 6) I also found an area with calcium that lay on top of the younger bentonite layer, this might be another result of an ecosystem without any nutrient limitations and all that remains are cell walls and protective husks of planktons. My supervisor Vivi Vajda wanted me to also look at the palynofacies in every sample to see if there was any competition from other organism groups such as high abundance of chitinozoa or scolecodonts, which could cause low numbers on acritarchs. As evident from table II and IV, neither chitinozoa nor scolecodont reach any significant levels in any of the samples. This would suggest that competition and predation from these groups should not have been the reason of the low acritarch density at those times.

In the two top samples, the abundance of acritarchs decreases and in the topmost sample the observed acritarch abundance is approximately 3% and the only morpho-type that can be found are the*Sphaeromorph.* This decrease of the total acritarch community and the diversity of morpho-groups is an indication of changes in the palaeoenvironment. As mentioned in the results the sphaeromorph group is the only acritarch morpho-group that can be found in both reef and deep water environments, this tentatively may suggest a lowering of the sea-level during the late Ordovician. I also want to mention that some of the samples had been contaminated before the fixation which resulted in three samples, all having an undefined and most likely modern pollen, of the same species, that belong to a land plant in them and also an observed *Betula sp.* pollen grain.

5 Conclusions

A study was made on late-Ordovician successions from Östergötland, Sweden. Up to six different acritarch morphologic groups were found throughout the section. The lithology is dominated by mudstone with carbonates. The acritarch assemblage and the lithology indicate a calm sub-equatorial ocean that becomes shallower after the second period of volcanic activity. In the bentonite beds the density of biomass is lower than in the rest of the samples. Above the two bentonite sections two zones with higher density of acritarchs compared to the other samples occur, which is probably a direct reaction to the release of potassium-rich tephra into the marine environment that first destroyed the ecosystem followed by a rapid comeback due to high levels of nutrients.

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