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Palaeoenvironments, palaeoecology and palaeobiogeography of Late Cretaceous (Campanian) faunas from the Kristianstad Basin, southern Sweden, with applications for science education

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LITHOSPHERE AND BIOSPHERE SCIENCE | DEPARTMENT OF GEOLOGY | LUND UNIVERSITY 2018

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Litholund Theses 32

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Elisabeth Einarsson

LUND UNIVERSITY

Lithosphere and Biosphere Science
Department of Geology

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Front cover: Reconstruction of the Late Cretaceous (Campanian) sea of the Kristianstad Basin southern Sweden, including a trophic interaction between the mosasaur *Prognathodon* and the polycotylid plesiosaur surrounded by belemnites, aquatic birds and the bony fishes *Enchodus*. Illustration by Gabriel Ugueto.

Back cover: The author studying the Late Cretaceous (Campanian) sediments and fossils at Ullstorp, Kristianstad Basin, southern Sweden together with the children Caspian and Fideli. Photo credit: Stefan Einarsson

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-Mamma och pappa-

”Gå din egen väg den enda rätta”

-Mormor-

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Abstract

This thesis is thematically divided into two sections: Part 1 presents studies related to the palaeoenvironments, palaeoecology and palaeobiogeography of the Late Cretaceous (Campanian) faunas from the Kristianstad Basin of southern Sweden; Part 2 reports on applications of palaeontological research for science education in schools.

Part 1 was based on personally conducted fieldwork and biostratigraphical analysis at various Santonian-Campanian localities throughout Skåne. However, the most complete section at Åsen provided the primary data source and was systematically excavated with a team of volunteers, who employed wet-sieving methods to extract bulk fossil material from each bed within the sequence. A series of globally correlated temperature-induced changes was detected in the stepwise declining abundance and disappearance of rudists, sclerorhynchids and the rajiforms *Rhinobatos* and *Squatirhina*, as well as marine crocodilians, various mosasaurid lizard taxa. A range of local palaeoenvironments were also reconstructed, including estuaries, rocky coastlines, sandy beaches, drowned river valleys, shallow neritic settings, and deeper offshore conditions. An archipelago bordering the Fennoscandian landmasses also supported continental ecosystems comprising ferns, conifers and early flowering plants, with dinosaurs, pterosaurs and non-marine turtles. Trophic levels within the marine system incorporated red algae and dinoflagellates as primary producers, with corals, brachiopods, bivalves, echinoids, barnacles and decapod crustaceans as benthos, and belemnites within the water column. Actinopterygian fish, sharks, rays and chimaeroids, chelonioid sea turtles, marine crocodilians, polycotylid and elasmosaurid plesiosaurians, various mosasaurids and aquatic hesperornithiform birds collectively represented middle level and apex predators. Herbivorous and carnivorous dinosaurs, lizards and soft-shelled tryonichid turtles evidence elements of terrestrial island communities. The palaeobiogeographical relationships and dispersal of these local assemblages was probably influenced by marine transgressions and regressions. These would have affected habitat availability and connectivity via changing water depths.

Part 2 presents three school education projects aimed at increasing awareness of geoscience and natural history in schools. The better integration of geological time concepts and geosciences into the Swedish school curriculum is also discussed. The first study described a project whereby fossils were found in the sandboxes in preschools, and their use as a tool for learning about dinosaurs, fossils and natural history. A survey of teachers and children found that both increased their knowledge base through this approach, and that the local context of the fossils in particular generated interest about the subject. The concepts of geological time was similarly addressed in the second study, which utilized timescale projects and other hands-on activities to create memory triggers for children and students, and to demonstrate how the perspective of 'deep time' is relevant for understanding large-scale Earth processes, such as evolution and environmental change. The integration of geosciences into the Swedish school curriculum is currently inadequate. Therefore, the final paper in this sequence discusses how geosciences form an interdisciplinary bridge between school subjects and can be used to teach geography and biology at all school levels.

Fig. Trophic interaction. Reconstruction of the Late Cretaceous (Campanian) sea of the Kristianstad Basin southern Sweden, including a trophic interaction between the mosasaur *Prognathodon* and the polycotylid plesiosaur surrounded by belemnites, aquatic birds and the bony fishes *Enchodus*. Illustration by Gabriel Ugueto.

List of papers

This thesis comprises ten papers thematically divided into two sections: (1) chapters one–seven are written in English and document aspects of the Late Cretaceous faunal assemblages from the Kristianstad Basin in Skåne, southern Sweden; and (2) chapter eight–ten are written in Swedish and discuss applications of palaeontological research in preschool to upper secondary school science education. Papers I and II have been reproduced with permission from the Taylor and Francis Group. Papers III – V have been reproduced with permission from the Lyell Collection. Paper VI has been submitted to Paleo3. Paper VIII has been reproduced with permission from Geografilärarnas riksförening; the appendix is reproduced with permission of Geologins dag. Papers VII, IX and X are manuscripts prepared for publication.

Part I

Paper I:
Einarsson, E., Lindgren, J., Kear, B. P., & Siverson, M. (2010). Mosasaur bite marks on a plesiosaur propodial from the Campanian (Late Cretaceous) of southern Sweden. *GFF*, *132*(2), 123-128 (doi.org/10.1080/11035897.2010.496534).

Paper II:
Scheyer, T. M., Mörs, T., & Einarsson, E. (2012). First record of soft-shelled turtles (Cryptodira, Trionychidae) from the Late Cretaceous of Europe. *Journal of Vertebrate Paleontology*, *32*(5), 1027-1032 (doi.org/10.1080/02724634.2012.694004).

Paper III:
Einarsson, E., Praszkier, A., & Vajda, V. (2016). First evidence of the Cretaceous decapod crustacean Protocallianassa from Sweden. *Geological Society, London, Special Publications*, *434*(1), 241-250 (doi.org/10.1144/SP434.6).

Paper IV:
Bazzi, M., Einarsson, E., & Kear, B. P. (2016). Late Cretaceous (Campanian) actinopterygian fishes from the Kristianstad Basin of southern Sweden. *Geological Society, London, Special Publications*, *434*(1), 277-292 (doi.org/10.1144/SP434.5).

Paper V:
Poropat, S. F., Einarsson, E., Lindgren, J., Bazzi, M., Lagerstam, C., & Kear, B. P. (2016). Late Cretaceous dinosaurian remains from the Kristianstad Basin of southern Sweden. *Geological Society, London, Special Publications*, *434*(1), 231-239 (doi.org/10.1144/SP434.8).

Paper VI:
McLoughlin, S., Haig, D. W., Siversson, M., & Einarsson, E. (2018). Did mangrove communities exist in the Late Cretaceous of the Kristianstad Basin, Sweden? *Palaeogeography, Palaeoclimatology, Palaeoecology*. *Submitted manuscript (preliminary acceptance 14.02.2018).*

Paper VII:
Einarsson, E., Iqbal, F., Kear, B. P., & Vajda, V. (2018). Sub-tropical Scandinavia, Late Cretaceous ecosystems in the Kristianstad Basin of southern Sweden. *Manuscript*.

Part II

Paper VIII:
Einarsson, E. (2018). Dinosaurier i förskolan – att introducera naturvetenskap utifrån förskolans läroplan genom barnens intresse och nyfikenhet för dinosaurier. *Manuskript*.

Paper IX:
Einarsson, E. (2018). Geologiska tidslinjer i undervisningen för utveckling av tidsmedvetenhet från förskola till gymnasieskola. *Manuskript*.

Paper X:
Einarsson, E., & Örbring, D. (2016). Ämnesdidaktiska hörnet: skolämnet geografi i relation till geologi. *Geografiska notiser*, (2), 61-63 (geografitorget.se/gn/nr/2016/bil/2-04.pdf).

Summary of papers

Part I

Paper I: Vertebrate trophic interactions
Einarsson, E., Lindgren, J., Kear, B. P., & Siverson, M. (2010). Mosasaur bite marks on a plesiosaur propodial from the Campanian (Late Cretaceous) of southern Sweden. *GFF*, *132*(2), 123–128.

The discovery of deeply incised gouges, shallow scrapes and scratches on an ostelogically immature polycotylid plesiosaur propodial from the latest early Campanian (*B. mammillatus* zone) from Åsen represents a rare example of predation or scavenging by both a large mosasaur (*Prognathodon*) and lamniform sharks similar to *Squalicorax*. Previously documented trophic interactions between marine reptiles are meagre, whereas interactions between lamniform sharks and plesiosaurs are more common. The implications for trophic interactions within the Kristianstad Basin marine vertebrate assemblage are discussed.

Paper II: Non-marine turtles
Scheyer, T. M., Mörs, T., & Einarsson, E. (2012). First record of soft-shelled turtles (Cryptodira, Trionychidae) from the Late Cretaceous of Europe. *Journal of Vertebrate Paleontology*, *32*(5), 1027–1032.

This work presents the first record of a trionychid turtle from the late early Campanian (*B. mammillatus* zone) at Ivö Klack, and extends the European stratigraphic record of the group back 15 Ma from the Palaeocene to the Late Cretaceous. The Kristianstad Basin trionychids were either endemic or represent a dispersal link from Asia to North America. The costal fragment has a distinctive grooved surface and can be distinguished histologically by a plywood-like arrangement of the collagen fibre bundles within the bone of the soft shell.

Paper III: Crustaceans
Einarsson, E., Praszkier, A., & Vajda, V. (2016). First evidence of the Cretaceous decapod crustacean *Protocallianassa* from Sweden. *Geological Society, London, Special Publications*, *434*(1), 241–250.

The first evidence from Sweden of the burrowing ghost shrimp, *Protocallianassa faujasi*, is described from the latest early Campanian *B. mammillatus* zone at Ivö Klack, as well as the earliest late Campanian *B. balsvikensis* zone 'balsvikensis yellow' bed at Åsen. Numerous, heavily calcified chelipeds (claws) were found within carbonate-cemented nodules interpreted as infilled burrow chambers. The reduced abundance of bivalves within the 'balsvikensis yellow' bed, compared with other sedimentary packages at Åsen, is consistent with extant ghost shrimp communities, which are ecologically exclusive of bivalves in modern shallow marine ecosystems.

Paper IV: Bony fishes
Bazzi, M., Einarsson, E., & Kear, B. P. (2016). Late Cretaceous (Campanian) actinopterygian fishes from the Kristianstad Basin of southern Sweden. *Geological Society, London, Special Publications*, *434*(1), 277–292.

Actinopterygians (ray-finned fish) are extremely abundant at most sampled localities in the Kristianstad Basin but are represented by isolated teeth, vertebrae, scales and fin spines. Here we reassess specimens from the *G. granulataquadrata* zone at Ullstorp, *B. mammillatus* zone at Ignaberga, Ivö Klack and Åsen and *B. balsvikensis* zone at Åsen and Balsvik. Identified taxa include indeterminate lepisosteids, the durophagous pycnodontids *Anomoeodus subclavatus* and probably *Anomoeodus phaseolus*, the 'swordfish-like' macropredatory pachycormid *Protosphyraena*, an indeterminate large ichthyodectid, the ubiquitous pachyrhizodontid *Pachyrhizodus* and small teleosts, especially the enchodontid *Enchodus* cf. *gladiolus*. The compositional aspect of this fauna is consistent with coeval assemblages from elsewhere in Europe and North America indicating taxon interchange and the typically cosmopolitan character of Late Cretaceous actinopterygians.

Paper V: Dinosaurs
Poropat, S. F., Einarsson, E., Lindgren, J., Bazzi, M., Lagerstam, C., & Kear, B. P. (2016). Late Cretaceous dinosaurian remains from the Kristianstad Basin of southern Sweden. *Geological Society, London, Special Publications*, *434*(1), 231–239.

The Kristianstad Basin had produced rare dinosaur fossils, which are currently the only documented body remains from Sweden. They provide a record of terrestrial ecosystems that would have inhabited an island archipelago bordering the Fennoscandian landmass. Three phalanges from Åsen pertain to leptoceratopsid neoceratopsians resembling the North American taxon *Leptoceratops*, and indeterminate small ornithopods similar to *Thescelosaurus* and *Hypsilophodon*. An incomplete right tibia from Ugnsmunnarna provides the first evidence of a non-avian theropod and is comparable to the megaraptorid *Australovenator*.

Paper VI: Palaeoenvironment
McLoughlin, S., Haig, D. W., Siversson, M., & Einarsson, E. (2018). Did mangrove communities exist in the Late Cretaceous of the Kristianstad Basin, Sweden? *Palaeogeography, Palaeoclimatology, Palaeoecology*. Manuscript/in press.

Mangrove-like environments have been reconstructed for the early Campanian 'oysterbank' bed at Åsen. However, we reinterpret this here as an inner neritic sandy-substrate

setting adjacent to the mouth of a drowned river valley. Attachment surfaces from oyster shells (*Acutostrea incurva*) reveal woody axes with leaf scars and bark impressions implying cementation onto conifer driftwood rather than in situ mangrove stems and roots. Foraminiferans recovered from sediment found within the oyster shells also differ from those constituting modern mangrove communities. Associated shark teeth further indicate an offshore setting. Notably, the 'oysterbank' bed records reduced macroinvertebrate diversity relative to other localities within the *B. mammillatus* zone implying either contrasting preservational processes or a more specialized palaeocommunity structure. Based on our results and the global palynological record, we conclude that mangrove ecosystems probably developed much later during the Maastrichtian and early Cenozoic.

Paper VII: Palaeoecology
Einarsson, E., Iqbal, F., Kear, B. P., & Vajda, V. (2018). Sub-tropical Scandinavia, Late Cretaceous ecosystems in the Kristianstad Basin of southern Sweden. *Manuscript*.

A comprehensive bed-by-bed assessment of assemblage composition was undertaken between the informal *B. mammillatus* zone informal biostratigraphical subdivisions of the 'coquina bed', 'greensand' and 'oysterbank', versus the *B. balsvikensis* zone 'balsvikensis green' and 'balsvikensis yellow' beds at Åsen. Belemnites and bivalves were found to be the dominant fossils within all sections, but with an overall higher abundance of bivalves in the *B. mammillatus* zone, as opposed to belemnites within the *B. balsvikensis* zone. Corals are also prolific within the 'coquina bed'and overlying strata up to the 'balsvikensis green' bed, and imply very shallow water depths. A distinct shift to deeper water offshore conditions occurs in the 'balsvikensis yellow' bed, where decapod crustaceans predominate. Finally, Åsen also preserved a wide range of vertebrate material, but with lower diversity than other *B. mammillatus* zone assemblages, implying a geographically enclosed environment, which we reconstruct as a drowned river valley setting.

Part II

Paper VIII: Dinosaurs in preschool education
Einarsson, E. (2018). Dinosaurier i förskolan – att introducera naturvetenskap utifrån förskolans läroplan genom barnens intresse och nyfikenhet för dinosaurier. *Manuskript*.

Playground sandboxes in preschools throughout the Kristianstad area include sand with fossils from local quarries. This was undertaken as part of the curriculum module "Åhus during the Age of Dinosaurs", to which an objectives / outcomes table was developed to enhance learning about natural and geological history by using dinosaurs, fossils and perspectives of time. Accompanying teaching materials were also developed and tested at preschools, with the results measured via interviews with both teachers and children. Teachers were found to be better informed and more comfortable with communicating about science via dinosaur-related themes. Children were also engaged by the sandbox activity and inspired by the local context of dinosaurs within their immediate area by using new terminology and methods when searching for fossils in the sandboxes.

Paper IX: Developing time awareness
Einarsson, E. (2018). Geologiska tidslinjer i undervisningen för utveckling av tidsmedvetenhet från förskola till gymnasieskola. *Manuskript*.

Educating students of different age about perspectives of 'deep time' can be enhanced by activities that communicate about geological timescales and their impact on our modern biodiversity and environments. Time is typically perceived as an abstract dimension based on human lifetimes and experiences. The concept of millennia can also usually be understood, based on cultural records and archaeological artefacts. However, the geological perspective of time spans billions of years, and can be far more difficult to grasp. This study appraises methods for teaching 'deep time' in schools, including hands-on activities and accompanying lecture materials that provide memory triggers for discussing geological time periods and fossils. These were found to provide context for explaining large-scale processes, such as evolution and adaptations, as well as extinction and climate alteration, all of which cover key units within the curriculum and impart awareness about the timeframes of major Earth change.

Paper X: Geoscience in Swedish schools
Einarsson, E., & Örbring, D. (2016). Ämnesdidaktiska hörnet: skolämnet geografi i relation till geologi. *Geografiska notiser*, (2), 61-63 (geografitorget.se/gn/nr/2016/bil/2-04.pdf).

Geosciences provide an interdisciplinary bridge between curriculum subjects in preschools to upper secondary schools, and enhance understanding of other fields, such as geography and biology. This paper advocates the inclusion of geosciences as a core subject at upper secondary school level, and the integration of approaches to teaching time awareness as an introduction to geosciences. The goal is to engender better knowledge of the contextual importance of the geosciences in society, and its crucial role in sustainable development, as well as scientific research into climate change and evolution.

Acknowledgements

"Imagine where you are sitting right now, it may have looked like this several millions years ago", the teacher said and pointed to the picture emerging from an overhead device at the front of the classroom. The picture illustrated the plant-eating dinosaurs in a forest of conifers and ferns. This was the moment when I, 8 years old, decided to become a palaeontologist, fascinated by how to reconstruct the world of dinosaurs. Through fossil discoveries in my own garden and during several visits to Ignaberga and Ivö Klack, I quickly became aware of the Kristianstad and Hässleholm areas' unique conditions for studying Swedish fossils from the age of the dinosaurs. Determined to follow my dreams, the Late Cretaceous palaeoecosystem of the Kristianstad Basin became the focus of my thesis—a work that would not have been possible without support from numerous key people.

I would like to start by thanking my supervisors Benjamin Kear and Vivi Vajda. Together, you have formed an excellent combination to provide insights into Late Cretaceous palaeoenvironments, palaeoecology and palaeobiogeography, with Benjamin's expertise in faunas (marine reptiles and archosaurs) and Vivi's expertise in the fossil flora and catastrophic events. In particular, I would like to thank Benjamin for discussions and planning of projects and upcoming papers. I would like to thank Vivi for joint manuscript writing, discussions, planning, assistance using Adobe Illustrator, and guidance in the academic world in general. Thanks, Vivi, for always being available and for giving me a lot of invaluable support and encouragement throughout my PhD-project. Thank you both for providing me the freedom to pursue my own ideas and collaborations to complete this thesis.

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Since I became interested in palaeontology and decided to become a palaeontologist when I was 8 years old, many people have influenced and supported me until today. I have always experienced a lot of support in my interest from all the teachers I had in school. During the workplace practice in junior high school I traveled from Hästveda in northern Skåne to the Museum of Evolution in Uppsala where I met Solveig Stuenes, who gave me guidance in the world of palaeontology. The practice made me even more convinced that it was a paleontologist I would become in the future. A lot of written projects in school were about dinosaurs, of which the final high school project obviously was about the extinction of the dinosaurs. In my Masters thesis I was given the opportunity to investigate morphological differences between Triassic and Jurassic rhamphorhynchoid and pterodactyloid pterosaurs by visits to Solnhofen, Eichstätt and Munich in Germany where I also met Peter Wellnhofer. The supervisor for my Masters thesis project was Anita Löfgren. Thank you Anita for continuous support and encouragement both through the Masters thesis project, but also afterwards during my PhD-project. Your support has meant a lot to me.

My parents, Ingrid and Krister Einarsson, siblings, Erika with family, Emil with family, Emanuel and Elias, extra-brother Markus, in-laws Bittan and Roland Persson, aunt Annika Persson with family, uncle Jan Olofsson with family and brother in law Roger Persson with family have always supported me and provided opportunities to continue with palaeontology and fulfill my dream (even if you do not really share my interest and passion for palaeontology).

To my beloved family—husband Stefan and children Caspian and Fideli—when you read this the thesis is finally finished! It has been a stressful time for all of us, but now we can look forward together. Thank you Stefan for your great support and patience during my work with the thesis. Since you are also a teacher, we had many interesting discussions about issues regarding children's and student's learning about fossils, dinosaurs and time perspectives and you also participated during some of the fieldwork at Åsen and Ullstorp (even if you never realized the fun and excitement of the searching for fossils ☺). On the other hand, there are some who are currently very interested in digging, sieving, hammering and searching for fossils. These are my children Caspian (6 years old) and Fideli (4 years old), even if they dream of becoming a

designer and car mechanic in the future. There are some distinct characteristics that make it easy to say that my children have a mother who is a palaeontologist. These include the children's large collections of rocks and fossils. It is hard to forbid the children compiling these collections, since I have my own fossil collection at home. Another clue is when, in the limestone quarry, they break the rock with a hammer and burst out: "Mom, I think I've found conglomerate here!" A third aspect concerns their philosophical thoughts about time when they ask me the following questions: "What comes after the humans?; Can dinosaurs come back again after the humans have died out?; The first human on earth didn't have any mother, where did she or he come from?; Where were the humans during the age of dinosaurs?" The fourth aspect is when my children want us to go together and look closely at a bird and when we get near enough they whisper "watch mom, the bird really has dinosaur feet". With these events in the family history, it's nice to hear that the son, just like other children of his age, has *Tyrannosaurus rex* as his favorite dinosaur, while the younger daughter's favorite is "dinosaurus rex" just like other children of preschool age. Many thanks to you both Caspian and Fideli for your patience and for all your inspiration!

– Mamma älskar er – glöm aldrig det!

Grandmother and Grandfather—you would have loved this! In memory of my grandfather Gustav Olofsson who collected interesting rocks that we discussed. My grandfather also joined me during my very first visit to Åsen and the excavation around 2000. Also in memory of my greatest inspiration source, my grandmother Hanna Olofsson, who always encouraged me in many and varied ways to follow my own path and my dreams of becoming a palaeontologist. I miss you so much! To follow your own way and your dreams is not always easy, but is something that I warmly recommend everyone to do. Although this thesis is a major milestone in my life, it is definitely not the end of my journey but rather the beginning of something new. I will always try to follow my own way—a path that will now lead me straight into the center of the Kristianstad Basin towards new exciting adventures!

Ett stort och varmt tack till er alla!

Part I

Palaeoenvironments, palaeoecology and palaeobiogeography of Late Cretaceous (Campanian) faunas from the Kristianstad Basin, southern Sweden

Introduction

During the Campanian stage of the Late Cretaceous (Fig. 1), the Kristianstad Basin in southern Sweden was inundated by a shallow epicontinental sea that surrounded an archipelago of eroded granitic basement islands (Lidmar-Bergström 1982). These bordered the Boreal Fennoscandian landmass and supported Late Cretaceous subtropical to warm temperate biotas that are important for reconstructing global palaeoecological and palaeobiogeographical patterns. The diverse marine fauna includes belemnites, bivalves, corals, echinoderms, barnacles, decapod crustaceans, brachiopods, bryozoans, polychaetes and gastropods (e.g. Surlyk & Christensen 1974; Einarsson et al. 2016; Einarsson et al. this thesis), actinopterygian fish (Bazzi et al. 2016), sharks, rays and chimaeroids (e.g. Siverson 1993a; Siversson et al. 2016; McLoughlin et al. this thesis), chelonioid and trionychid turtles (Persson 1959; Scheyer et al 2012), dyrosaurid marine crocodiles (Persson 1959), polycotylid and elasmosaurid plesiosaurs (Persson 1959; Einarsson et al. 2010; Sachs et al. 2016; Kear et al. 2017), mosasaurs (Lindgren & Siverson 2002; Lindgren 2004) and hesperornithiform birds (Rees & Lindgren 2005). These occupied a range of palaeoenvironments including estuaries, drowned river valleys, rocky and sandy beach areas, as well as shallow neritic and deeper offshore settings (Lundegren 1934; Surlyk & Christensen 1974; Koppelhus & Batten 1989; Siversson et al. 2016: McLoughlin this thesis). Coeval non-marine assemblages comprised pterosaurs, neoceratopsians, ornithopods and non-avian theropod dinosaurs (Lindgren et al. 2007; Poropat et al. 2016) with vegetation dominated by conifers, deciduous trees, ferns and low-growing flowering plants (Friis & Skarby 1981, 1982). The Kristianstad Basin represents one of the most prolific and historically famous Mesozoic fossil sites in Scandinavia.

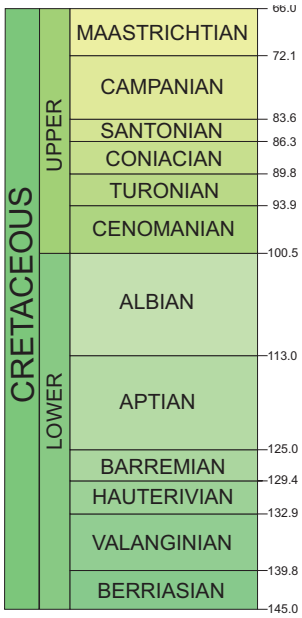

Fig. 1. International subdivision of the Cretaceous period into series and stages. The Campanian stage represents 83.6 –72.1 Ma (after ICS 2017).

The first documented fossil discoveries within the Kristianstad Basin were made at Ignaberga and Ivö Klack (Blaksudden) in 1725 by Magnus Bromell (Bromell 1729). Kilian Stobaeus published the *Opuscula* (1752), which included the first illustrated *Belemnellocamax mammillatus* as *Belemnites*. Late Cretaceous belemnites were also illustrated by Wahlenberg (1821) and Nilsson (1826, 1827, 1835, 1857). Nilsson (1827) listed other fossils in his *Petrificata Suecana Formationis Cretaceae* (1827). Lundgren (1888a, 1888b), Moberg (1884, 1885), De Geer (1889), Hadding (1927, 1929, 1932), Lundegren (1931, 1934), Brotzen (1945), Hessland (1950) and Birkelund (1957) carried out early sedimentological studies. The work of Lundegren (1934) is of particular significance because he included descriptions of all Cretaceous localities accessible at that time. Revisions have since been undertaken by Surlyk (1973, 1980), Bruun-Petersen (1975), Christensen (1975, 1984), Bergström & Sundquist (1978), Kornfält

et al. 1978, Lidmar-Bergström (1982), Bergström (1982), Gabrielson & Holland (1984), Erlström & Gabrielson (1985, 1992) and Kornfält & Bergström (1989). The limestone and kaolin quarries at Ivö Klack (Blacksudden), Axeltorp, Balsvik, Åsen, Ignaberga and Ullstorp were described by Grönwall (1915), Lundegren (1931), Bjerning (1947), Lundegårdh (1971), Bergström & Shaikh (1980) and Erlström & Gabrielson (1985, 1992). Kaolin quarrying was active during the early 20th century at Ivö Klack, Axeltorp and Åsen, with the principal companies being the Ifö-verken (Ifö sanitär AB) and Höganäs keramik. The limestone from the active quarries at Ignaberga and Ullstorp is used as an alkaline conditioner for soil improvement.

The biostratigraphic framework used to age-correlate and compare the fossil assemblages was established and refined by Blainville (1827), d´Orbigny (1840), Shlüter (1876), De Geer (1881), Lundgren (1895), Moberg (1884, 1885), de Morgan (1882), Stolley (1897), Hennig (1910), Lundegren (1930, 1932, 1934), Brotzen (1938, 1945, 1960), Jeletzky (1949), Christensen (1972, 1975, 1976, 1988, 1990, 1997a, 1997b), Siverson (1993a) and Siversson et al. (2016). Niebuhr et al. (2011) also restricted the *B. lanceolata* biozone from lower Maastrichtian to upper upper Campanian in age.

Studies of the various invertebrate fossil taxa and assemblages were historically undertaken by Lundgren (1876, 1885a, 1885b, 1895), Moberg (1884, 1885), Hennig (1892, 1894), Törnebohm & Hennig (1904), Hadding (1919), Lundegren (1934), Carlsson (1938), Troedsson (1946, 1954), Hägg (1954) and Brotzen (1960). More recent contributions include those of Christensen (1969), Brood (1972), Surlyk & Christensen (1974), Birkelund & Bromley (1979), Erlström & Gabrielson (1992), Sørensen & Surlyk (2008, 2010, 2011), Surlyk & Sørensen (2010), Sørensen et al. (2011, 2012) and Gale & Sørensen (2015). Further examinations are presented by Einarsson et al. (2016), McLoughlin et al. (this thesis), Einarsson et al. (this thesis), and Andersson Medhanie (2017).

Nilsson (1827), Davis (1890) and Bazzi et al. (2016) described actinopterygian fish fossils from the Kristianstad Basin. Sharks and rays have been studied in detail by Siverson (1989, 1992a, 1992b, 1993a, 1993b, 1995), Rees (1999), Siverson & Cappetta (2001), Siversson et al. (2015) and Siversson et al. (2016), and have identified over 50 species. Marine reptiles were first described from Ivetofta by Nilsson (1835) and Hisinger (1837), Schröder (1885) and Wiman (1916). Further amniote material was documented by Moberg (1884, 1885), Lundgren (1888c), Hennig (1910), Lundegren (1934), Troedsson (1946, 1954) and illustrated by Holm (1915–1923) in several unpublished plates (Persson 1959). Persson (1954, 1959, 1962, 1963, 1967, 1990, 1996) described mosasaurs, plesiosaurs, cheloniid sea turtles and the marine crocodile *Aigialosuchus villandensis*. Recent mosasaur research has also been conducted by Lindgren and Siverson (2002, 2004, 2005), Lindgren (2004, 2005a, 2005b) and Gren & Lindgren (2014). Plesiosaurs being assessed by Einarsson et al. (2010), Sachs et al. (2016) and Kear et al. (2017). Scheyer et al. (2012) identified and described non-marine trionychid turtle. Dinosaurs, including aquatic hesperornithiform birds, neoceratopsians, ornithopods and non-avian theropods were discussed by Rees & Lindgren (2005), Lindgren et al. (2007) and Poropat et al. (2016). Putative 'carnivorous dinosaur teeth' reported by Persson (1959, p. 474, pl. 20, fig. 4) were misidentified (Lindgren & Siverson 2002), and actually belong to the pachycormid fish *Protosphyraena* (Bazzi et al. 2016).

The Late Cretaceous flora of the Kristianstad Basin predominantly derives from late Santonian–early Campanian strata, has been described mainly by Nykvist (1957), Skarby (1964, 1968, 1974), Friis & Skarby (1981, 1982), Skarby & Nilsson (1982), Friis (1983, 1984, 1985a, 1985b, 1990), Srinivasan & Friis (1989) and Koppelhus & Batten (1989). Studies of the Kristianstad Basin fossil biota have dealt primarily with taxonomic documentation, whereas broad faunal assessments and discussions about palaeocommunity structure have been initiated during recent years (Sørensen et al. 2013) and is continued in this thesis.

Scope of this thesis

This thesis aims to place the Kristianstad Basin fossil assemblages within a palaeoenvironmental, palaeoecological and palaeobiogeographical context set in a biostratigraphical framework to assess detailed variations of palaeocommunities through time. The study incorporates fieldwork and biostratigraphical analysis at several Upper Cretaceous (Santonian and Campanian) key localities in Skåne, revealing new data and descriptions of fossils communities and lithology. The main focus will be on the more accessible Campanian strata. Key questions include:

- **Palaeoenvironments**: Which palaeoenvironments are represented within the Kristianstad Basin and how did Campanian global cooling affect marine faunas through time?
- **Palaeoecology**: How did different components of the Kristianstad Basin ecosystem interact?
- **Palaeobiogeography**: What are the palaeogeographical relationships of the Kristianstad Basin assemblages and were these influenced by regional sea-level fluctuations during the Late Cretaceous?

Institutional abbreviations

NRM, Swedish Museum of Natural History, Stockholm, Sweden; UU, Department of Palaeobiology, Uppsala University, Uppsala, Sweden; LO, Department of Geology, Lund University, Lund, Sweden; PMU, Palaeontological collections, Museum of Evolution, Uppsala University, Sweden.

Materials and methods

The Kristianstad Basin fossils are generally fragmentary and isolated, and were transported and buried in high-energy environments. Specimens collected for this thesis were recovered during field excavations conducted with a team of volunteers between 2010–2012 at the kaolin quarry at Åsen, south of Näsum in northeastern Skåne. Additional fieldwork was also undertaken at other sites in 2015 and 2017. Historical collections were assessed at the NRM, UU, LO and PMU, together with privately held material belonging to Tord Engfors (Fjälkinge, Sweden) and Clarence Lagerstam (Lund, Sweden). Key faunal elements collected during the field excavations at Åsen complemented by specimens from collections (Fig. 2) were documented in separate publications on oysters with attachment scars (McLoughlin et al. this thesis), calcified nodules with chelipeds and casts of decapoda crustaceans (Einarsson et al. 2016), teeth, scales and fin spines of ray-finned fish (Bazzi et al. 2016), various dinosaur bones (Poropat et al. 2016) and an overview of the macroinvertebrate record from Åsen compiled as a supervised bachelor degree student project (Iqbal 2013; Einarsson et al. this thesis). Papers on plesiosaurian remains with bite marks (Einarsson et al. 2010) recovered from Åsen in 2001, and trionychid turtle dermal plate fragments (Scheyer et al. 2012) discovered at Ivö Klack in 1933, were based on material housed at LO and NRM. Finally, plesiosaurian specimens from NRM, UU, PMU and LO (Nordén 2011), as well as bivalves, gastropods and ammonites collected from Ullstorp Bed B (sensu Erlström & Gabrielson 1985) during fieldwork in 2015 (Andersson Medhaine 2017), have been studied by other supervised bachelor project students. These results will be published elsewhere in the future, and involve input from international specialist collaborators.

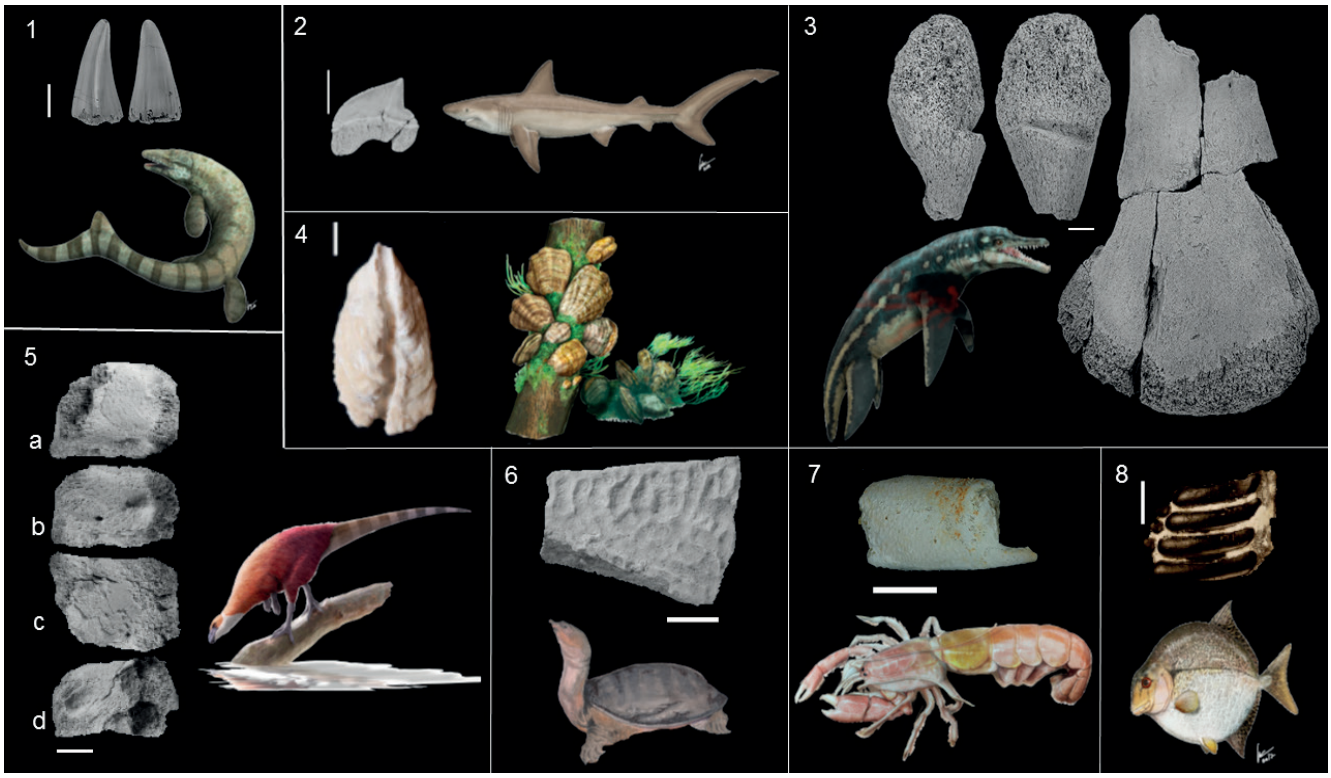

Fig. 2. Examples of fossils studied in this thesis. **1**. Marginal tooth from mosasaur *Prognathodon*, LO 10603t, from Åsen (Einarsson et al. 2010). **2.** Tooth in labial view from lamniform shark *Squalicorax lindstromi*, NRM P 16431, from Åsen (McLoughlin et al. this thesis). **3.** Propodial (limb bone) of a juvenile polycotylid plesiosaur, LO 10602t, from Åsen (Einarsson et al. 2010). **4.** Oyster left valve of *Acutostrea incurva* from Åsen with slightly curved cylindrical plant axis mould extending the length of the shell, NRM Mo183206 (McLoughlin et al. this thesis). **5.** Non-avian dinosaur indet. ornithopod left pedal phalanx, LO 12045t, from Åsen in: (a) dorsal; (b) medial; (c) ventral; and (d) lateral views (Poropat et al. 2016). **6.** Costal shell fragment in dorsal view of soft-shelled turtle Trionychidae indet., NRM-PZ R. 1519, from Ivö Klack (Scheyer et al. 2012). **7.** Cheliped of *Protocallianassa faujasi* NRM-PZ Ar 63929 from Åsen (Einarsson et al. 2016). **8**. Left prearticular dentitions of ray-finned fish pycnodontid *Anomoeodus subclavatus*, NRM-PZ P15753, from Ivö Klack (Bazzi et al. 2016). Scale bars for the fossils 10 mm. Illustrations by Gabriel Ugueto.

Field excavations for this project were conducted between June and August in 2010–2012, and targeted the unconsolidated marine quartz sand at Åsen, which is overlain by approximately 10–15 meters of Quaternary moraine. An excavator was hired to remove this overburden and cut a 4 m section through the Cretaceous strata for sequential sampling of each successive bed. Spades and other hand tools were used for bulk extraction of sand and fossils, which were manually transported in buckets for wet-sieving with a 2 mm mesh in a small pond on-site. Several tons of sand were processed during the three summers of excavations. Each sample was dried and picked by hand either on site, or in the laboratory (Fig. 3). All fossils collected during 2012 were included in a statistical study by sorting the fossils into bulk taxonomic units and then determing percentage by weight for each unit for comparison between beds (Iqbal 2013; Einarsson et al. this thesis). Some surface collecting of fossils exposed by weathering was also undertaken (e.g. oysters, chelipeds of decapods, worm tubes and vertebrate remains).

During 2015 and 2017, site surveys were conducted with Mikael Siversson (Western Australian Museum, Perth) to compare the Åsen assemblages with those from other Late Cretaceous fossil localities in the Kristianstad Basin, including Ballingslöv 1, Ballingslöv 2, Bjärlången (Bjärnum), Hanaskog, Balsvik, Ivö Klack, Maltesholm, Ullstorp, Ignaberga, Kjuge and Ringeleslätt. Site surveys to the Vomb Trough localities at Svenstorp, Eriksdal, Köpinge and Lyckås were also carried out. Biostratigraphical analysis of belemnitellid index taxa enabled refined age assessment of vertebrate yielding quartz sand at Ullstorp (Bed B sensu Erlström & Gabrielson 1985) and a preliminary age estimate of the basalmost layer in a relatively thick (~10 m) section of medium- to coarse grained quartz sand of pre-*mammillatus* zone age recently exposed at Ignaberga. Belemnite guards were also used to date bulk samples collected at Svenstorp. Both the Ullstorp and Ignaberga units were more specifically dated by measuring the length of the guard (L) versus the depth of the pseudoalveolus (D) in well-preserved specimens of *Gonioteuthis* (see Christensen 1975). Other objectives included bulk sampling of calcirudite at Ivö Klack and calcareous sandstone at Ullstorp for elasmobranch remains. The vertebrate content in these samples was enriched by means of acetic acid preparation and subsequent density separation (Jeppsson et al. 1999). Calcareous sandstone sampled at Svenstorp was broken down by submerging the samples in Glauber's salt solution and then exposing them to repeated freeze/thaw cycles. Collection of infaunal macroinvertebrate fossils from Bed B (sensu Erlström & Gabrielson 1985), wet-sieving of the conglomeratic Bed C (sensu Erlström & Gabrielson 1985), and some surface collecting of fossils was also undertaken at Ullstorp.

Fig. 3. Fieldwork at Åsen. **A.** Excavator removing the overburden moraine. **B.** The section through the Upper Cretaceous strata. **C.** Bulk extractions from 'balsvikensis yellow' with spades. **D.** Transportation of the sand to the pond. **E.** Buckets with sand that are going to be sieved. **F.** Sieving the sand in the pond. Sieves have the mesh size of 2 mm. **G.** Remaining fossils in the sieve after sieving. **H.** Sorting and identification of fossils that were extracted from the sand.

Geological setting

Global sea-level rises during the Late Cretaceous (Campanian) inundated large areas of the European and Russian platforms where shallow epicontinental seas were formed. These were connected to the emergent Atlantic Ocean and bordered by the Hercynian middle European island in the south, and the Precambrian Fennoscandian Shield (incorporating southern Sweden) to the northwest (Fig 4; Surlyk & Christensen 1974; Sahagian et al. 1996; Kominz et al. 2008; Blakey 2018). Palaeolatitudinally, the northwestern Swedish extremity of this epeiric system was situated at palaeolatitude 47–49°N (Kent & Irving 2010; van Hinsbergen et al. 2015).

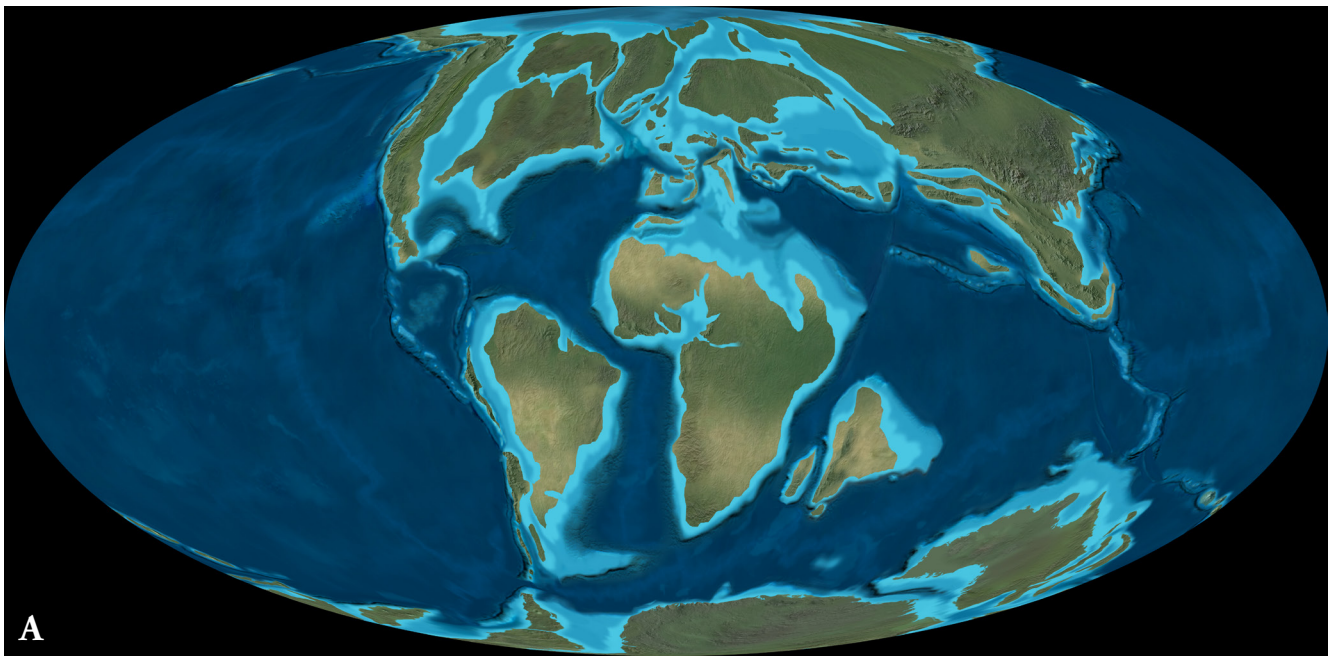

Fig. 4. Campanian palaeogeography. **A.** Palaeogeography of the world 80 Ma. **B.** Palaeogeography of Europe 75 Ma. Ilustration by Ron Blakey License #10317-0.

Tectonic and depositional context of southern Sweden

The southern margin of Fennoscandia is a horst and graben complex that includes a weak crustal lineament called the Sorgenfrei-Tornquist zone; this stretches from Skåne in the northwest, to northern Denmark, and the island of Bornholm in the southeast. It delimits the Precambrian crustal provinces of Baltic Shield (= Fennoscandian Shield) from Palaeozoic Europe (Hansen et al. 2000). Compressional deformation of the Sorgenfrei-Tornquist zone during the Santonian to Maastrichtian divided Skåne along the Romelåsen fault. This deformation caused differential subsidence and uplift along the Romelåsen, Christiansö, Linderödsåsen and Nävlingeåsen faults, contributing to the development of the Hanö Bay Basin and the Kristianstad Basin, and activity along the Hallandsåsen ridge fault caused subsidence that generated the Båstad Basin. Both the Kristianstad and Båstad basins have also undergone southwesterly tilting, with the Kristianstad Basin subsequently inclined towards the Nävlingeåsen and Linderödsåsen ridges (Christensen 1975; Bergström & Sundquist 1978; Norling & Bergström 1987: Erlström et al. 1997).

Sedimentation during the Santonian to Maastrichtian deformation phase occurred within the Danish Subbasin (Malmö area), Vomb Trough (Ystad area), Kristianstad Basin, Hanö Bay Basin, Båstad Basin (Christensen 1975; Erlström & Gabrielson 1992) and Särdal (Fig 5; Bergström et al. 1973; Christensen 1984). Limestones predominate in the Danish Subbasin (Brotzen 1945), with glauconitic sandstones and siltstones in the Vomb Trough (Anderegg et al. 1968; Vajda & Solakius 1999), biocalcarenites in the Båstad Basin, and biocalcarenite and glauconitic quartz sand in the Kristianstad Basin (Hessland 1953). Differing amounts of clastic terrigenous input including boulder beds, conglomerates and pebbles indicate close proximity to land, represented by the mid-Skåne high/islands of the Nävlingeåsen, Linderödsåsen (Erlström & Gabrielson 1992), and Romeleåsen basement ridges (Norling & Bergström 1987). Lower terrigenous content in the Danish Subbasin and Vomb Trough suggests more open marine conditions with regional currents. In contrast, sedimentation within the Kristianstad Basin reflects a protected shallow inner shelf bay with limited mixing from other water bodies (Erlström & Gabrielson 1992). Deposition also persisted into the Maastrichtian-Danian in the Danish subbasin, versus the Kristianstad and Båstad basins where it terminated in the latest Campanian (Norling & Bergström 1987). Compression and uplift of the Nävlingeåsen during the Santonian to early Campanian is revealed by the vertical beds at Eriksdal in the Vomb Trough (Vajda-Wigforss-Lange 2006), and the tilted sections at Ringeleslätt and Ignaberga in the Kristianstad Basin (Christensen 1975). The Precambrian basement at Ringeleslätt also manifests slickensides and conglomerates with angular pebbles produced by movements of the Nävlingeåsen (Christensen 1975; Kornfält et al. 1978).

Fig. 5. Upper Cretaceous sedimentation areas in southern Sweden. **Yellow** = Båstad Basin. **Green** = Danish Subbasin. **Red** = Vomb Trough. **Purple** = Kristianstad Basin. Särdal and Hanö bay Basin are also presented. Illustration: Emma Olsson.

Depositional history within the Kristianstad Basin

The area of the Kristianstad Basin extends from Hässleholm to Åhus and from Listerlandet to Maglehem (Troedsson 1954). Its southwestern dermacation are at Linderödsåsen and Nävlingeåsen, while the northern edge is diffuse (Christensen 1975), as a result of post-Mesozoic tectonics with uplift of the the south Småland Peneplain including northwestern Skåne (Lidmar-Bergström et al. 2013; Japsen et al. 2016) and also by both Cretaceous weathering and post-Cretaceous glacial-erosion (Högbom 1899; Lidmar-Bergström 1982, 1989; Magnusson & Lidmar-Bergström 1983; Erlström et al. 1997; Japsen et al. 2002), which has left some 30 identified outliers of lower-Campanian to upper upper Campanian rocks at N. Sandby, Stoby, Glumlösa, Hästveda, Ballingslöv, Vankiva, Bjärnum, Vittsjö and Emmaljunga (Troedsson 1954). The Kristianstad Basin continues offshore southeastwards and terminates in Hanö Bay (Norling & Bergström 1987; Erlström & Gabrielson 1992).

The Precambrian crystalline basement of the Kristianstad proto-basin was subjected to intense weathering from the latest Triassic to Early Cretaceous (Christensen 1975; Kornfält et al. 1978; Lidmar-Bergström 1982; Lidmar-Bergström & Magnusson 1984). The weathered basement built up an irregular topography of resistant hills above surrounding lowlands which formed the islands and peninsulas of the archipelago during the subsequently Late Cretaceous rising sea (Christensen 1975; Kornfält et al. 1978). Today these islands and peninsulas are represented by Fjälkingebacke, Kjugekull, Västanåberget, Listerlandets klackar (Lundegren 1934), Ivö Klack, Oppmannaberget, Vångaberget and Ryssberget (Grönwall 1915). Five transgressive pulses reached the Kristianstad Basin (Christensen 1975; Kornfält et al. 1978): 1. during the Cenomanian, 2. Santonian to early early Campanian, 3. latest early Campanian (*Belemnellocamax mammillatus* zone) to earliest late Campanian (*Belemnellocamax balsvikensis* zone), 4. early late Campanian (*Belemnitella mucronata* zone), and 5. late late Campanian (*Belemnitella lanceolata* zone) (Lundegren 1932; Christensen 1975). The Santonian transgression reached Ringeleslätt and Ignaberga (Lundegren 1932; Christensen 1975; Siversson et al. 2016). This extended further during the latest early Campanian to reach Bjärnum, Balsvik, Ebbetorp and Norje (Lundegren 1932), with water depths estimated at around 50 m (Van der Zwaan et al. 1990). During the early late Campanian water depths increased up to 75 m (Lundegren 1932), and again to 100–200 m during the late late Campanian, based on the proportion of planktic foraminifers within the calcisiltites at Bjärnum (Gabrielson & Holland 1984). Connection with the Båstad Basin probably also occurred at this time (Gabrielson & Holland 1984), as indicated by comparable fossil assemblages, outliers and flints (Christensen 1975; Bergström 1981; Lidmar-Bergström 1982).

Kristianstad Basin Cretaceous lithology and palaeoenvironments

Barremian faulting from Nävlingeåsen to Åhus divides the Kristianstad Basin into two half-grabens (Kornfält et al. 1978) that contain up to 250 m of strata close to the horsts. The Cretaceous sequence wedges out towards the northwest (Erlström & Gabrielson 1992). The oldest deposits are Barremian calcareous glauconitic sands identified from drill cores at Härlöv (UB1) (Kornfält et al. 1978; Norling 1981). Other cores at Sixtorp and Åhus produce basal sediments of Aptian–Albian (Guy-Ohlson 1984), and Cenomanian age (Christensen 1975), respectively. Sections exposed in quarries and surface outcrops range from the lower middle Santonian (Lundegren 1934; Christensen 1975; unpublished data) to the upper upper Campanian (Lundegren 1934; Lindgren & Siverson 2002; Siverson 1993a, 1993b) previously considered earliest Maastrichtian in age but recently revised according to Niebuhr et al. (2011). The lowermost beds within the Kristianstad Basin comprise about 40 m of kaolinitic clays formed from deeply weathered crystalline basement feldspars (Lundegren 1934). These are thickest in the northeastern part (Kornfält et al. 1978) and are overlain locally by reworked kaolin clay, fluviatile-deltaic clay and sand (Christensen 1975). At Åsen this sequence is between 15 and 20 m thick, but only around 3–8 m at Holmaudden and Axeltorpsviken (Grönwall 1915; Lundegren 1931). The clay contains charcoalified conifer driftwood (Nykvist 1957) and sporomorphs (Ross 1949; Skarby 1964, 1974, 1968) transported by floods (Kornfält et al. 1978).

Weathered quartz sand from the crystallin basement was transported into the deltaic system and nearshore shallow margins during the Late Cretaceous transgressions (Christensen 1975; Kornfält et al. 1978). This formed drowned valleys (e.g. at Åsen) and created beach deposits of the Holmasandstone, Ryedalsandstone (Holst 1888), and feldspar-rich Åhussandstone (Hennig 1894; Hessland 1953). The quartz sand deposits subdivided into a glauconitic greensand, with sequentially overlying calcareous sand intermixed with shells, and clean quartz sand (Kornfält & Bergström 1989). Deeper water glauconitic greensands have also been found in the Åhus and Härlöv drill cores. Hardgrounds at Ullstorp and Ignaberga otherwise indicate a shallow nearshore environment (Christensen 1975; Kornfält et al. 1978).

An early Campanian rocky, high-energy island setting is represented at Ivö Klack (Voigt 1929; Lundegren 1934). Large crystalline boulders host encrusting bivalves, brachiopods and serpulids with interspersed shell banks. Tidal and wave action resulted in the formation of coarse-grained calcirudites (skalkalk) (Surlyk & Christensen 1974; Christensen 1975). Calcarenites (skalgruskalk) occur at e.g., Ignaberga (Ignabergakalksten), Maltesholm,

Ullstorp and Ringeleslätt and consists of bivalve shell fragments with belemnites, gastropods, echinoderms, bryozoans, calcareous algae and brachiopods that have all been sorted by wave action and currents within a nearshore high-energy environment (Troedsson 1946; Christensen 1975; Kornfält et al. 1978; Kornfält & Bergström 1989). The calcarenite deposits are thickest along the horst palaeoshorelines, and around the island crystalline highs.

Upper Campanian offshore calcisiltites (skalstoftkalk) have been found at Hanaskog (Hanaskogskalksten), Bjärnum (Bjärnumskalksten), Ballingslöv and Balsvik (Lundegren 1932; Troedsson 1954). The calcisiltite formed in relatively deep, calm water (below wave base) and incorporates fine-grained shell particles and chalk (Gabrielson & Holland 1984), it is rich in echinoids, molluscs, bryozoans, brachiopods and calcareous algae. The Hanaskogskalkstenen also includes spotted flint with enclosed fragments of quartz, feldspar and shells (Lundegren 1932; Troedsson 1954; Kornfält et al. 1978; Kornfält & Bergström 1989).

Storm deposited, or turbidic conglomerates comprising terrigenous crystalline pebbles, intraclasts, shell fragments and belemnites are commonly associated with the hardgrounds (Hadding 1927; Lundegren 1934; Surlyk 1980; Erlström & Gabrielson 1985, 1992). They have been used to trace the Campanian shorelines at Ignaberga, Ullstorp, Ugnsmunnarna, Filkesboda, Bjärnum, Västra Olinge, Maltesholm, Gillaruna, Tykarpsgrottan and Balsvik. Turbidites are also associated with the deeper part of the basin (Lundegren 1932; Moberg 1884, 1885; Erlström & Gabrielson 1985, 1992).

Kristianstad Basin biozonations

The Kristianstad Basin has been age-correlated using belemnitellid belemnites, which have a wide distribution across the North European and North American provinces of the North Temperate Realm (Boreal realm) and northern European margin of the Tethyan Realm (Christensen 1976, 1990, 1997a, 1997b). The North European Province has been divided into two Coniacian to Early Campanian belemnite subprovinces: a Central European subprovince incorporating Ireland, England, northern Germany, The Netherlands, Belgium, northern France, and northern Poland, and the Central Russian subprovince comprising the northwestern part of the Russian platform. The Kristianstad Basin manifests an intermediate Balto-Scandian belemnite fauna that disappeared by the latest Campanian, to be replaced with a single North European belemnite Province during Late Campanian (Christensen 1975; Niebuhr et al. 2011).

Informal belemnite biozones within the Kristianstad Basin (Fig. 6) include the:

- upper upper Campanian *Belemnella lanceolata* zone (formerly referred to the lowermost lower Maastrichtian)
- lower upper Campanian *Belemnitella mucronata* zone
- lowermost upper Campanian *Belemnellocamax balsvikensis* zone
- uppermost lower Campanian *Belemnellocamax mammillatus* zone
- lower lower Campanian *Gonioteuthis quadrata quadrata* zone
- lowermost lower Campanian *Gonioteuthis granulataquadrata* zone
- upper Santonian *Gonioteuthis granulata* zone
- upper middle Santonian *Gonioteuthis westfalicagranulata* zone
- lower Santonian–lower middle Santonian *Gonioteuthis westfalica westfalica* zone

The Campanian ranges from 83.6 Ma to 72.1 Ma (ICS 2017), with the early Campanian spanning 3 Ma, and the late Campanian 8 Ma (Obradovich 1993). The Santonian–Campanian boundary is identified by extinction of the crinoid *Marsupites testudinarius* in the Global Stratotype Section at Lake Waxahachie in Ellis County, Texas. U.S.A. According to Gale et al. (1995), this coincides with the first appearance datum (FAD) of *Gonioteuthis granulataquadrata* in northwest Germany that also represents the lowermost lower Campanian in the Kristianstad Basin. The *Gonioteuthis quadrata quadrata* zone of the Kristianstad Basin is laterally equivalent to the lingua/quadrata Zone and pilula Zone of northern Germany (Christensen 1986) and is only represented by Bed E at Ullstorp (M. Siversson pers. comm. 2017; unpublished data). The *G. quadrata quadrata* zone of the Kristianstad Basin includes the *Belemnitella praecursor/alpha*. The presence of *B. alpha* will give a better resolution than *B. praecursor* (see Christensen 1986). *Gonioteuthis* is otherwise characteristic of the Coniacian – lower Campanian in the Central European subprovince, while *Belemnitella* defines coeval strata in the Central Russian subprovince; both genera coexist in the Kristianstad Basin (Christensen 1975). *Actinocamax* disappeared from the Kristianstad Basin between the *G. quadrata quadrata* zone and the *Belemnellocamax mammillatus* zone (Christensen 1990; unpublished data).

Belemnellocamax grossouvrei is dispersed throughout the North European Province (Christensen 1986), while *B. mammillatus* is prolific in southern Sweden with isolated finds from northern Germany, eastern Poland and the eastern Russian Platform (Christensen & Schulz 1976). *B. grossouvrei* probably evolved into *B. mammillatus*, and the few examples of *B. grossourvrei* found with *B. mammillatus* at Ivö Klack, Ugnsmunnarna and Ignaberga (see Christensen 1975) are likely extreme morphotype variations of *B. mammillatus* (M. Siversson pers. comm. 2017). The informal *B. mammillatus* zone of the Kristianstad Basin spans approximately 330 000 years (Lindgren & Siverson 2002) and is correlated with the uppermost lower Campanian *Belemnitella mucronata senior–Gonioteuthis quadrata gracilis* Zone in northwestern Germany (Christensen 1975).

The base of the upper Campanian in the Kristianstad Basin is defined by the extinction of *Gonioteuthis* (Christensen 1996) and the first appearance of *B. balsvikensis* (evolved from *B. mammillatus*; Christensen & Schulz 1976; Christensen 1996). One exception is the *B. balsvikensis* found together with the *G. quadrata scaniensis* below the base of the upper Campanian within the latest early Campanian *B. mammillatus* zone, 'bed 3' (oysterbank) at Åsen, indicating an overlap between the FAD of *B. balsvikensis* and last appearance datum (LAD) of *Gonioteuthis* (Siversson et al. 2016).

The *B. balsvikensis* index taxon is almost unknown outside of the Kristianstad Basin, with the exception of two specimens from northern Germany (Christensen & Schulz, 1976). *Belemnellocamax* disappeared during lower upper Campanian (Christensen 1990), and then *Belemnitella* flourished across the North European Province (Christensen 1975) and northern Tethys. The *Belemnitella* zonation includes the *B. mucronata* Zone (lower upper Campanian) and *B. langei* zones (upper upper Campanian) at Lägerdorf and Kronsmoor (Christensen 1996; Keutgen 2011) and *B. mucronata* zone (lower upper Campanian), *B. woodi* (upper lower Campanian) and *B. minor I* and *II* (upper upper Campanian) at Mons Basin and Maastricht Aachen-Liége area (Keutgen 2011). The *B. mucronata* zone is represented in the Kristianstad Basin, and is followed by a 6 Ma hiatus (Lindgren & Siverson 2004). The *B. langei* zone has been identified in the Båstad Basin at the Malen and Gropemöllan, and in the Vomb Trough at Svenstorp and Köpinge Mölla (Christensen 1986, 1993; Lindgren 2004; unpublished data). The earliest representatives of *Belemnella* occur in the upper upper Campanian and are known throughout most of the North European Province represented by the *B. lanceolata* and *B. inflata* biozones at Kronsmoor and Tercis les Bains and the *B. lanceolata* zone within the Lägerdorf and Kristianstad Basin (Christensen 1975; Keutgen 2011; Niebuhr et al. 2011).

Finally, the Campanian–Maastrichtian boundary is globally defined by the first appearance of the ammonite *Pachydiscus neubergicus* (Odin & Lamaurelle 2001). In the Boreal Realm (Kronsmoor in northern Germany, and Tercis les Bains in southwest France), this level lies above the *Belemnella lanceolata* and *Belemnella inflata* zones (Niebuhr et al. 2011), which are approximately 450 ky below the boundary (Schulz 1979). The benthic foraminiferan *Neoflabellina praereticulata* is lost in the lowermost Maastrichtian in the Boreal Realm (Niebuhr et al. 2011). This correlation defines the *B. lanceolata* zone as upper upper Campanian (former lower Maastrichtian) in the Kristianstad Basin.

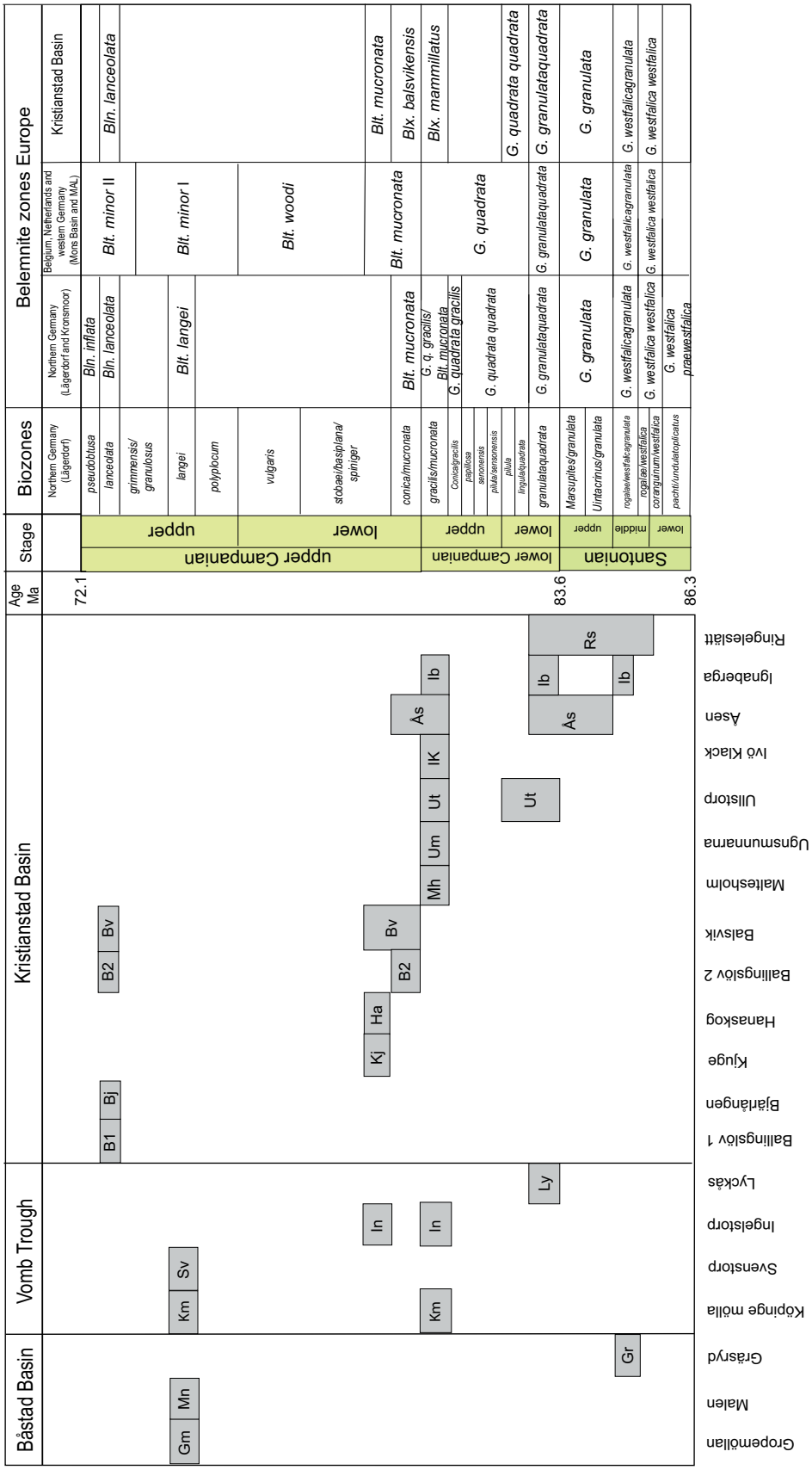

Fig. 6. Biostratigraphical chart of the Upper Cretaceous belemnite zonation of the Kristianstad Basin, correlated with biozones of northern Germany (Lägerdorf) and belemnite zonation of northern Germany (Lägerdorf and Kronsmoor) and northwestern Europe represented by Belgium, Netherlands and western Germany (including the Mons Basin and Maastricht Aachen-Liége area (= MAL)) (based on Christensen 1986, 1988, 1993; Siverson 1993a; Erlström & Guy-Ohlson 1994; Niebuhr et al. 2011; Keutgen 2011; unpublished data). **Abbreviations**: Blt = *Belemnitella*, Bln = *Belemnell*a, Blx = *Belemnellocamax*. B1 = Ballingslöv 1, B2 = Ballingslöv 2, Bj = Bjärnum, Bv = Balsvik, Gm = Gropemöllan, Gr = Gräsryd, Ha = Hanaskog, Ib = Ignaberga, IK = Ivö Klack, In = Ingelstorp, Ly = Lyckås, Mh = Maltesholm, Mn = Malen, Rs = Ringeleslätt, Sv = Svenstorp, Um = Ugnsmunnarna, Ut = Ullstorp, Ås = Åsen.

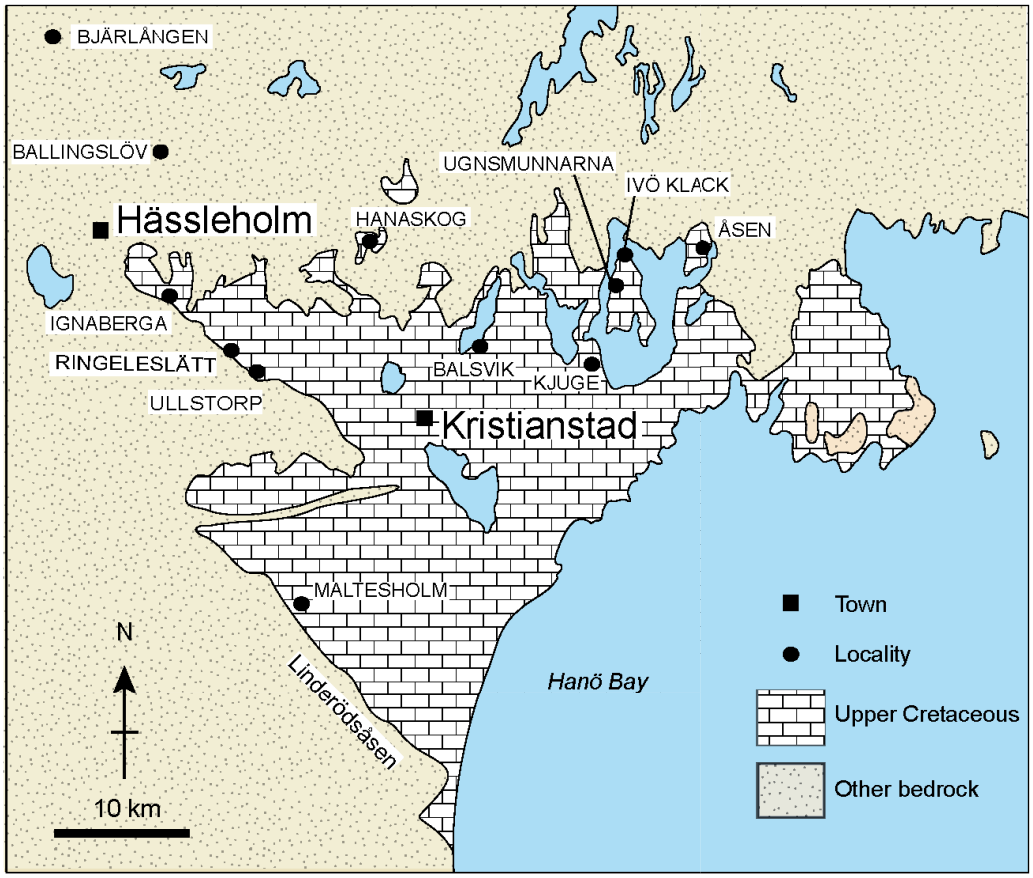

Fig. 7. Map including the studied localities within the Kristianstad Basin (after Siverson 1992a; Einarsson et al. 2016).

Survey of fossil-producing localities within the Kristianstad Basin

This is a review of the Santonian and Campanian biozones of the Kristianstad Basin based on key localities (Fig. 7) including both earlier and new studies of fossils and lithology.

Santonian (*G. westfalica westfalica* zone, *G. westfalicagranulata* zone and *G. granulata* zone)

Santonian deposits are exposed at Ringeleslätt, Ignaberga (Fig. 8) and Åsen, (e.g. Christensen 1975; Erlström & Gabrielson 1992; Friis & Skarby 1981), with erratic limestone boulders of Coniacian or Santonian age also present at Bjärlången (Siverson 1992b).

Ringeleslätt

Reference data. Grönwall (1915), Lundegren (1930, 1934), Brotzen (1938, 1960), Troedsson (1954), Christensen (1975).

Belemnite index taxa. Gonioteuthis westfalica westfalica, G. westfalicagranulata, G. granulata, G. granulataquadrata, Actinocamax verus, Belemnitella alpha.

Stratigraphic position. Uppermost lower Santonian–lowermost lower Campanian.

Lithology. The lithology comprises 3–4 m biocalcarenite and 0.3–0.4 m conglomerate with pebbles, cobbles and boulders (up to 1 m) of strongly weathered crystalline rocks (Brotzen 1960). Boulders were likely transported a short distance from the Nävlingeåsen (Christensen 1975). The boulder bed is deposited close to the Santonian–Campanian boundary (unpublished data). About 2 m of biocalcarenite and Quaternary deposits overlie the conglomerate (Lundegren 1934). Beds are tilted in a northeasterly direction at 45° adjacent to the horst, and 20°–30° distant to the horst (Lundegren 1934; Troedsson 1954).

Documented fossils. The biocalcarenite contains the bivalves *Inoceramus*, *Ostrea, Spondylus*, *Neithea*, *Lima* and *Pecten*, bryozoans, the brachiopods *Rhynchonella* and *Magas*, serpulids and echinoids; the foraminiferan *Cibicides* is also abundant (Brotzen 1960).

Ignaberga

Reference data. Erlström & Gabrielson (1992).

Belemnite index taxa. G. westfalicagranulata, G. granulataquadrata.

Stratigraphic position. Upper middle Santonian–lowermost lower Campanian.

Lithology. The old and new quarries at Ignaberga follow the northwest-southeast fault line along the Nävlingeåsen ridge (Erlström & Gabrielson 1992). In the western part of the new quarry, (below the hardground) 30 m of basal medium-grained calcareous quartz-arenite sandstone rests upon weathered Precambrian basement. This consists of glacuconite, feldspars and crystalline fragments with 20%-40% carbonate matrix (Erlström & Gabrielson 1992).

Documented fossils. Shark teeth are abundant and some (extremely worn teeth of *Ptychodus* spp.) are probably reworked from older eroded strata (Siversson et al. 2016; M. Siversson pers. comm. 2017).

Åsen

Reference data. Lundegren (1934), Nykvist (1957), Skarby (1968), Christensen (1975), Friis & Skarby (1981).

Belemnite index taxa. None recovered.

Stratigraphic position. Upper Santonian–lower Campanian.

Lithology. Åsen is presently used as a community dump and recycling centre (Einarsson et al. 2010; Sørensen et al. 2013). Kaolinitic clays are overlain by 15–20 m of fluviatile sandy and lacustrine argillaceous clays (Skarby 1968; Christensen 1975; Friis & Skarby 1981). The clays are covered by layers of gravel (30–40 mm grain size) and quartz sand that contain charcoal, roots and wood fragments from transported terrestrial plant material. The deposists together with the interpretation of the Höljedalen valley site suggests that Åsen represented a repeatedly flooded delta environment (Troedsson 1946). Comparable deposits with much less extent have been found at Axeltorp and Ivö Klack (Lundegren 1931).

Documented fossils. Confier wood from *Pinus* (Nykvist 1957), and angiosperms including *Platanus*, *Scandianthus*, *Silvianthemum* and *Actinocalyx* (Skarby 1968; Friis & Skarby 1981, 1982; Skarby & Nilsson 1982; Friis 1983, 1984, 1985a, 1985b, 1990; Srinivasan & Friis 1989).

Lowermost lower Campanian (*Gonioteuthis granulataquadrata* zone)

This biozone is partly mentioned above in connection to the description of the Santonian biozones and will here be described by beds B-C (sensu Erlström & Gabrielson 1985) at Ullstorp (Fig. 8).

Ullstorp (Beds B-C)

Reference data. Christensen (1975), Erlström & Gabrielson (1985), M. Erlström & M. Siversson (pers. comm. 2017).

Belemnite index taxa. *Belemnellocamax grossouvrei* misidentified as *Belemnellocamax mammillatus* (Erlström & Gabrielson 1985), *Actinocamax verus*, *Belemnitella alpha*, *Gonioteuthis granulataquadrata*.

Stratigraphic position. Lowermost lower Campanian (*Gonioteuthis granulataquadrata* zone: Lindgren et al. 2007; unpublished data).

Lithology. The section at Ullstorp consists of 10 m of calcareous sandstone and sandy biocalcarenites with interbedded conglomerates divided into beds A–G (sensu Erlström & Gabrielson 1985) covered with a 5 m of biocalcarenite (bioclastic limestone) (Erlström & Gabrielson 1985). Bed A comprises coarse-grained reddish quartzarenite with scattered quartz and feldspar pebbles of basement origin (gneiss). Bed B is a medium-grained sandy biocalcarenite. Bed C is a conglomerate dominated by pebbles of Precambrian basement rocks, glauconite and intraclasts of biocalcarenite. Bed D is a quartz-rich biocalcarenite with scattered conglomerates. Inoceramid shell fragments were transported to sand bars by storms from adjacent lagoonal environment (Erlström & Gabrielson 1985; M. Erlström pers. comm. 2017).

Documented fossils. Beds B and C host a diverse nearshore marine fauna. Bed B incudes red algae, abundant rudist bivalves and infaunal brachiopods, gastropods and ammonites (*Baculites*), (Andersson Medhaine 2017) and decapods (unpublished data). Bed B has also recently revealed mosasaurid vertebrae, sea turtle limb elements, neoceratopsian teeth and skeletal remains of other terrestrial vertebrates, hybondont shark teeth of *Meristodon* sp. and *Polyacrodus* sp., several lamniforms, the orectolobiform *Cederstroemia* sp., the squatiniform *Squatina* sp. and rajiform rays including sclerorhynchids (unpublished data). Bed C comprising thick-shelled bivalves (oysters and inoceramids), bryozoans, calcisponges (Erlström & Gabrielson 1985). *Belemnellocamax grossourvrei* is especially common in the conglomeratic Bed C which also produced teeth of the hybodont shark *Polyacrodus* sp. (Rees 1999), together with chimaeroids and a variety of lamniforms (including the apex predator *Cretoxyrhina mantelli*) and other elasmobranchs (unpublished data). Actinopterygians are represented by pycnodontids (*Anomoeodus* sp.) and the pachycormid *Protosphyraena* sp. (Bazzi et al. 2016). The dyrosaurid crocodilian *Aigialosuchus* (Persson 1959), elasmosaurid plesiosaurians and the mosasaurid *Platecarpus* (Lindgren & Siverson 2004) are also represented. Neoceratopsian dinosaurs (resembling the North American taxon *Leptoceratops*: Lindgren et al. 2007) and possible pterosaur bone fragments represent terrestrial amniote remains transported from nearby terrestrial environments (unpublished data).

Lower lower Campanian (*Gonioteuthis quadrata quadrata* zone)

This biozone is represented by bed E (sensu Erlström & Gabrielson 1985) at Ullstorp (Fig. 8) which includes a uniqe belemnite assemblage zone for the Kristianstad Basin (belemnites collected by M. Siversson 2002-2003; M. Siversson pers. comm. 2017; unpublished data).

Ullstorp (Bed E)

Reference data. Erlström & Gabrielson (1985), M. Siversson & M. Erlström (pers. comm. 2017).

Belemnite index taxa. *G. quadrata quadrata*, *B. grossouvrei*, *Actinocamax verus*, *Belemnitella praecursor/alpha.*

Stratigraphic position. Lower lower Campanian (*Gonioteuthis quadrata quadrata zone*; unpublished data)

Lithology. Bed E includes conglomerates with erosional intraclasts, glauconite and Precambrian basement pebbles. Bed F incorporates partly cemented calcareous fine-grained arenite with scattered pebbles in the basal section. (Erlström & Gabrielson 1985; M. Erlström pers. comm. 2017; unpublished data).

Documented fossils. Elasmobranchs from Bed E includes *Squalicorax lindstromi*, '*Carcharias*' aff. 'C'. *latus*, *Paraorthacodus* sp. and *Cretalamna* aff. C. *sarcoportheta* (collected by M. Siversson 2002-2003; M. Siversson pers. comm. 2017; unpublished data).

Uppermost lower Campanian (*Belemnellocamax mammillatus* zone)

Sampled and studied localities of this biozone included Ullstorp, Ugnsmunnarna, Ignaberga, Ivö Klack, Åsen and Maltesholm (Fig. 8). Biometric analysis of *B. mammillatus* populations within the *B. mammillatus* zone reveals different morphotypes and growth trajectories, indicating age differences between the localities represented by the following from the oldest (with shallow pseudoalveolus and isometric L/D growth) to the youngest (with deep pseudoalveolus and allometric L/D growth); Ugnsmunnarna, Ignaberga, Ivö Klack, Åsen and Maltesholm (unpublished data pers comm from W. K. Christensen to M. Siversson 2001).

Ullstorp (Bed G)

Reference data. Erlström & Gabrielson (1985).

Belemnite index taxa. Belemnellocamax mammillatus, Belemnitella mucronata.

Stratigraphic position. Uppermost lower Campanian.

Lithology. The *B. mammillatus* zone at Ullstorp, Bed G (sensu Erlström & Gabrielson 1985), consists of a bioturbated hardround with burrows and encrusting invertebrates (similar but not identical to that at Ignaberga) overlain by 'beach pebbles' with an epifauna disturbed by wave action. Uppermost strata comprise a galuconite-rich angular conglomerate with four sublayers formed by debris flows; comparable deposits are found at Attarp, Tullstorp, Bjärnum and Åhus. A medium- to coarse-grained biocalcarenite caps the succession and represents a high-energy nearshore setting (Erlström & Gabrielson 1985).

Documented fossils. Epifauna on beach pebbles. Bed G is overlain by a biocalcarenite including a diverse elasmobranch fauna. The fossil content of the biocalcarenite is not studied in this thesis.

Ugnsmunnarna

Reference data. de Morgan (1882), Moberg (1884), De Geer (1885, 1889), Lundgren (1895), Lundegren (1934), Persson (1959, 1960), Christensen (1975), Siverson (1992a).

Belemnite index taxa. Belemnellocamax mammillatus, Belemnitella mucronata, Gonioteuthis quadrata scaniensis.

Stratigraphic position. Uppermost lower Campanian.

Lithology. Natural outcrop on the island of Ivö that exposes a sandy (up to 50% quartz sand) medium- to coarse-grained biocalcarenite (Persson 1960; Christensen 1975; Siverson 1992a) with five distinct conglomerate layers comprising crystalline pebbles with large bivalve shell fragments or complete oysters and belemnites (Christensen 1975).

Documented fossils. Extremely diverse selachian fauna comprising paraorthacodontids (e.g. *Paraorthacodus conicus),* carcharhiniforms (e.g. *Galeorhinus, Palaeogaleus* and *Paratriakis*) synechodontiforms (e.g. *Synechodus filipi)* and especially lamniforms (e.g. *Squalicorax lindstromi*, the abundant '*Carcharias*' *tenuis, Cretalamna borealis* and *Cretalamna sarcoportheta*) (Siverson 1992a, 1992b, 1993a; Siversson et al. 2015). Cheloniid sea turtle fossils are also abundant (Siverson 1992a). The mosasaurs *Clidastes propython* (Lindgren & Siverson 2004), *Tylosarus ivoensis*, *Hainosaurus* sp. and *Platecarpus* have been identified from isolated teeth, jaw elements and vertebrae (Lindgren 1998; Lindgren & Siverson 2002; Lindgren 2005a). An incomplete tibia constitutes the first demonstrable evidence of non-avian theropod dinosaurs within the Kristianstad Basin (Poropat et al. 2016).

Ignaberga

Reference data. Moberg (1884), Lundgren (1895), Grönwall (1915), Voigt (1929), Hadding (1927), Lundegren (1934), Lowenstam & Epstein (1954), Brotzen (1960), Surlyk (1973, 1980), Christensen (1975), Bruun-Petersen (1975), Bergström & Sundquist

(1978), Erlström & Gabrielson (1992), Siverson (1992a), Lindgren & Siverson (2002).

Belemnite index taxa. Belemnellocamax mammillatus, Belemnitella mucronata, Gonioteuthis quadrata scaniensis.

Stratigraphic position. Uppermost lower Campanian.

Lithology. The ammonite *Hauericeras* has been recovered 5 cm below the erosion surface at the base of the 20–30 cm thick hardground, indicating a late Santonian or earliest early Campanian age (Birkelund & Bromley 1979). The hardground incorporating decapod crustacean burrows, and encrusting oysters, bryozoans and serpulids may thus represent a middle early Campanian hiatus, with the overlying conglomerate forming part of the *B. mammillatus* zone. The conglomerate comprises large crystalline pebbles in a medium- to coarse-grained biocalcarenite matrix. Flatter pebbles are commonly encrusted by oysters, bryozoans and serpulids suggesting a shallow shoreface setting. The conglomerate is overlain by 20 m of medium- to coarse-grained biocalcarenite with fragmented oyster shells, belemnites and echinoids interbedded with eight thin conglomerate layers. The biocalcarenite is interpreted as a high-energy inner shelf environment with water depths of 20–50 m. The interbedded thin conglomerates compositionally incorporate pebbles, shell fragment, and sparse intraclasts (Christensen 1975; Erlström & Gabrielson 1992) that probably derived from high-energy storms and currents along the Nävlingeåsen horst ridge (Bruun-Petersen 1975; Erlström & Gabrielson 1992).

Documented fossils. The biocalcarenite comprises 17%–34% bivalves and brachiopods, 10%–27% echinoids and asteroids, 8%–25% bryozoans, and 5%–10% coralline red algae (Bruun-Petersen 1975). The bivalve assemblage is dominated by oysters, free-living pectinids and inoceramids with no coeval infaunal species (Moberg 1884; Lundgren 1895; Lundegren 1934). Gastropods are rare (Carlsson 1938), whereas belemnites (*B. mammillatus*) are prevalent in the conglomerate beds (Christensen 1975), and ammonites are limited to a single taxon *Ammonites stobei* (Moberg 1884). Brachiopods are represented by the thicked-shelled *Isocrania egnabergensis* and *Terebratula* (Surlyk 1973); bryozoans are found encrusting shells and pebbles (Brood 1972). Echinoids include *Hemipneustes*, *Cidaris* and *Salenia areolata* (Erlström & Gabrielson 1992). Other faunal elements incorporate abundant sponges, corals, serpulids and the decapod crustacean *Calianassa* (Erlström & Gabrielson 1992). Selachians are abundant with *Paraorthacodus conicus* alone represented by 1000 teeth (Siverson 1989). Other elasmobranchs include orectolobiforms, heterodontiform *Heterodontus* sp. aff. *H. rugosus*, lamniforms, in particular '*Carcharias*' *tenuis*, *Squalicorax lindstromi* (referred to S. *kaupi* by Siverson 1992a), *Cretalamna borealis and Cretalamna sarcoportheta*, carchariniforms, such as *Paratriakis*, the synechodontiform palaeospinacid *Synechodus filipi* and rhinobatids *Rhinobatos* and *Squatirhina* (Siverson 1992a, 1992b, 1993a; Siversson et al. 2015, 2016). Actinopterygians are represented by pycnodontids (Bazzi et al. 2016). Marine reptiles comprise cheloniid sea turtles (Persson 1959; Siverson 1992a) elasmosaurid plesiosaurians (Persson 1959), and the mosasaurids *Eonatator stenbergii* (Lindgren & Siverson 2005), *Clidastes propython* (Lindgren & Siverson 2004), *Platecarpus* and *Hainosaurus* (Lindgren 1998), *Prognathodon* sp., and *Tylosarus ivoensis* (Lindgren & Siverson 2002; Lindgren 2005b).

Ivö Klack (Blaksudden)

Reference data. De Geer (1889), Lundgren (1895), Moberg (1903), Grönwall (1915), Voigt (1929), Lundegren (1934), Persson (1959), Brotzen (1960), Christensen (1969, 1975), Surlyk & Christensen (1974), Surlyk (1980), Sørensen & Surlyk (2008, 2010, 2011), Surlyk & Sørensen (2010), Sørensen et al. (2011, 2012), Gale & Sørensen (2015).

Belemnite index taxa. Belemnellocamax mammillatus, Belemnitella mucronata, Gonioteuthis quadrata scaniensis.

Stratigraphic position. Uppermost lower Campanian.

Lithology. Ivö Klack is the northernmost hill on Ivö Island, and has also historically been referred to as Blacksudden. It features an abandoned limestone and kaolin quarry, which closed in the 1950s (Lidmar-Bergström et al. 2013). During the latest early Campanian Ivö klack was an island in the northern part of the Kristianstad Basin archipelago (Persson 1959; Surlyk 1980). The intensely weathered basement at Ivö Klack was submerged and shaped by waves into a steep and irregular rocky shore, with boulder strewn, hummocky topography (Christensen 1969; Surlyk & Christensen 1974). The weathered basement was covered by 30 m of kaolin clay with large (up to 2 m in diameter) crystalline residual boulders. The kaolin is overlain by 3–4 m of lower Campanian quartz-sand and a thin fluviatile clay (Grönwall 1915; Skarby 1964, 1968 and Christensen 1975) not currently exposed in the quarry. The marine succession comprises 22–23 m of calcarenites and shellbanks that formed around transported crystalline boulders with a rich encrusting epifauna (Lundegren 1934; Surlyk & Christensen 1974; Christensen 1975). The largely endemic invertebrate assemblage indicates a high-energy setting with water depths of 5 m or less. Intertidal and photic zones are evidenced by hermatypic corals and wave eroded boulders (Christensen 1969; Christensen 1975; Surlyk & Christensen 1974; Sørensen et al. 2012).

Documented fossils. A high diversity of macroinvertebrates are mainly represented by encrusting epifauna that are segregated on different parts on the boulders. The

underside of the boulders is usually covered by serpulids and sabellids, the lateral surfaces are densely populated by the oysters *Arctostrea diluviana* and *Ostrea haliotoidea*, and large brachiopod *Ancistrocrania stobei*, and the tops are covered by the spondylid *Spondylus labiatus* (Surlyk & Christensen 1974; Surlyk & Sørensen 2010; Sørensen et al. 2012). Other macroinvertebrates include belemnites, gastropods, the echinoids *Trisalenia loveni* and *Polysalenia notabilis*, asteroids, crinoids, bryozoans, barnacles and the northernmost occurrences of zooxanthellate solitary corals (Persson 1959; Christensen 1969; Sørensen & Surlyk 2010, 2011; Gale & Sørensen 2015; Gale 2016). Actinopterygians representing pycnodontids and the pachycormiform *Protosphyraena* (Bazzi et al. 2016). The most common elasmobranchs include the heterodontiform *Heterodontus* sp. and the hemiscyllid *Chiloscyllium* sp. Other elasmobranchs are represented by *Hybodus* (based on a single tooth and cephalic spine: Rees 1999), the paraorthacodontid *Paraorthacodus conicus* (Siverson 1992b), the lamniforms '*Carcharias*' *tenuis, Squalicorax lindstromi, Cretalamna borealis, Cretalamna sarcoportheta*, *Cretoxyrhina mantelli*, *Scapanorhynchus perssoni* and *Anomotodon hermani* (Siverson 1992a; Siversson et al. 2015), the carchariniforms *Galeorhinus* and *Paratriakis*, and rhinobatid rays *Rhinobatos* and *Squatirhina* (Siverson 1993a). Both cheloniids (Persson 1959) and non-marine trionychid turtles (Scheyer et al. 2012) have been recorded, together with the dyrosaurid crocodilian *Aigialosuchus villandensis* (Persson 1959) and large aquatic hesperornithiform birds represented by *Hesperornis rossicus, Hesperornis* sp. and *Baptornis* sp. (Rees & Lindgren 2005). Plesiosaurian remains are common and include both polycotylids and the elasmosaurid *Scanisaurus* (Persson 1959; Kear et al. 2017), which has been compared with 'short-necked' aristonectines and the historical taxon *Cimoliasaurus* (Kear 2002; Sørensen et al. 2013); some plesiosaur bones also show evidence of bite traces from sharks (Persson 1959). Mosasaurid squamates are represented by *Eonatator stenbergii* (Lindgren & Siverson 2005), *Clidastes propython* (Lindgren & Siverson 2004), *Prognathodon* sp. (Lindgren 2005b), *Tylosaurus ivoensis* (Lindgren & Siverson 2002), *Hainosaurus* sp. (Lindgren 2005a) and *Platecarpus* (Lindgren 2004).

Åsen

Reference data. Lundegren (1931, 1934), Ross (1949), Nykvist (1957), Skarby (1964, 1968), Siverson (1992a), Lindgren & Siverson (2002), Eriksson et al. (2011), Iqbal (2013), Siversson et al. (2015, 2016), McLoughlin et al. (this thesis), Einarsson et al. (this thesis).

Belemnite index taxa. *Belemnellocamax mammillatus*, *Belemnitella mucronata, Gonioteuthis quadrata scaniensis.*

Stratigraphic position. Uppermost lower Campanian.

Lithology. The latest early Campanian transgression inundated earlier deltaic systems (Skarby 1968) and created a drowned river valley with an open seaway connection to the south (Lundegren 1934; Siversson et al. 2016), presently topographically delimited by the Höljeån valley with Ryssberget to the east, and Vångaberget in the west (Lundegren 1934). At Ryssberget the Ryedal and Holma quartz-sandstones and plant fossils indicate close proximity to land (Lundegren 1934). A depositional hiatus of approximately 3 Ma separates the late Santonian–early Campanian fluviatile sediments from the late early Campanian marine sequence (Skarby 1968). The marine sediments comprise about 4–5 m of laterally thinning unconsolidated glaciotectonized quartz sand (Siversson et al. 2016) spanning the *B. mammillatus* and *B. balsvikensis* zones. The biozones are separated from each other by a discontinuous bioturbated conglomerate with reworked belemnites (Lindgren & Siverson 2002; Lindgren et al. 2007; Siversson et al. 2016). The *B. mammillatus* zone component is 1.35–2.15 m thick and facies are subdivided into a sequential 'coquina bed', 'greensand bed' and 'oysterbank' (Iqbal 2013; Einarsson et al. this thesis). Siversson et al. (2016) designated the 'coquina bed' 'bed 2' and the 'greensand bed/oysterbank' 'bed 3', with a 0.5 m layer of coarse grained quartz sand rich in charcoal and belemnites intersected between the basal fluviatile clay and 'coquina bed'. The 'coquina bed' is 0.25 m thick and contains a storm-deposited coarse sand of green quartz and fragmented bones, shark teeth, belemnites, echinoids and oysters. The 0.5 m 'greensand bed' comprises a fine-grained sand with green quartz stained by glauconite or copper. The 'oysterbank' is a 0.6 m thick fine-grained calcareous quartz sand deposit with articulated oysters, belemnites, charcoal and bone fragments (Eriksson et al. 2011; Iqbal 2013; Siversson et al. 2016; Einarsson et al. this thesis). The nearby locality of Axeltorp produces greensand with plant debris and an oysterbank also dominated by *Acutostrea incurva* (Lundegren 1931; Christensen 1975).

Documented fossils. Charcoal fragments from conifers occur throughout the sequence (Iqbal 2013; Einarsson et al. this thesis). The macroinvertebrate assemblage diversity at Åsen is depauperate relative to other localities within the *B. mammillatus* zone, but have high abundance of bivalves and belemnites. Benthic elements include the oyster *Acutostrea incurva* that were attached to driftwood (one with *Podichnus centrifugalis* brachiopod boring traces), inoceramids, echinoid spines and plates, asteroids, the brachiopod *Crania cranolaris*, bryozoans, serpulids, the solitary coral *Micrabacia hilgardi*, the barnacle *Arcoscalpellum*, and small phosphatic fragments of decapod crustaceans (Sørensen & Surlyk 2008; Iqbal 2013; Einarsson et al. this thesis). Elasmobranchs are represented by 38 species (Siverson 1993a; McLoughlin et al. this thesis) with the hybodont shark *Polyacrodus siversoni* (Rees 1999), the squatiniforms *Squatina*

lundegreni and *Squatina fortemordeo* (Siversson et al. 2016), the heterodontiform *Heterodontus* of *H. portusjacksoni*-type (Siverson 1993a; McLoughlin et al. this thesis), the orectolobid *Cederstroemia nilsi* (Siverson 1995), the lamniforms such as '*Carcharias*' *latus*, *Squalicorax lindstromi, Scapanorhynchus perssoni*, *Anomotodon hermani*, *Archaeolamna kopingensis* (Siverson 1992a), *Cretalamna borealis* and *Cretalamna sarcoportheta* (Siversson et al. 2015), the carcharhiniforms *Galeorhinus*, *Palaeogaleus* and *Paratriakis*, the synechodontiform palaeospinacid *Synechodus filipi* (Siversson et al. 2016), the rhinobatids *Rhinobatos casieri* and *Squatirhina* (Siverson 1993a). Chimaeroids are represented by four species including *Ischyodus bifurcatus*, *Edaphodon* sp., *Amylodon* sp. and *Elasmodus* sp. (McLoughlin et al. this thesis; M. Siversson pers. comm. 2018). Actinopterygians are represented by lepisosteids, pycnodontids and the teleosts ichthyodectids, pachycormiform *Protosphyraena* sp., elopiform *Pachyrhizodus* sp. and enchodontid *Enchodus* cf. *gladiolus* (Bazzi et al. 2016). Dermal scutes from a large acipenseriform (sturgeon) are also represented (McLoughlin et al. this thesis). Cheloniid sea turtle remains have recently been identified (unpublished data). Polycotylid plesiosaurian propodials and teeth (Einarsson et al. 2010; unpublished data), as well as non-aristonectine elasmosaurid cranial elements (Sachs et al. 2016) and teeth referred to *Scanisaurus* have also been found (Kear et al. 2017; Einarsson et al. this thesis). Identifiable mosasaurid taxa include *Eonatator stenbergii* (Lindgren & Siverson 2005), *Clidastes propython* (Lindgren & Siverson 2004), *Prognathodon* sp., *Tylosaurus ivoensis* and *Hainosaurus* sp. (Lindgren & Siverson 2002; Lindgren 2005a, 2005b) and *Platecarpus* sp. (Lindgren 1998). Lindgren & Siverson (2004) suggested that the sheltered drowned valley might even have been a nursery area for *Clidastes* individuals. Terrestrial vertebrates are represented by pterosaurs bone fragments (unpublished data), together with teeth and phalanges from both neoceratopsians similar to the North American *Leptoceratops* (Lindgren et al. 2007; Poropat et al. 2016) and phalanges from small ornithopods similar to the North American *Thescelosaurus* and *Hypsilophodon* (Poropat et al 2016).

Maltesholm

Reference data. Lundgren (1895), Hennig (1910), Grönwall (1915), Lundegren (1934), Christensen (1975), Sandström (2001).

Belemnite index taxa. Belemnellocamax mammillatus, Belemnitella mucronata.

Stratigraphic position. Uppermost lower Campanian.

Lithology. Maltesholm is an abandoned quarry situated close to the Linderödsåsen horst ridge. It is the southernmost locality within the Kristianstad Basin (Sandström 2001). A 13 m section incorporates six different facies: calcirudites and calcarenites, calcirudite with pebbles, a coarse-shelled calcirudite, pebbly conglomerates and a shell fragment conglomerate. The calcirudites and calcarenites yield abundant rudists and were deposited by tidal currents with intermittent storm accumulations comprising pebbles and shell fragments with scour and fill structures, and hummocky cross-bedding. The shell fragment conglomerate facies indicates a northwesterly or southeasterly prevailing current running parallel to the coastline. Coarse carbonates near Linderödsåsen have yielded coralline algae and lack micrite, which is suggestive of a nearshore, high-energy environment (Sandström 2001).

Documented fossils. The fossil assemblage is dominated by rudists, calacareous algae, foraminifers, and belemnites; whereas brachiopods and bivalves are rare but evident in all beds (Christensen 1975; Grönwall 1915; Christodoulou 1993). Rudists predominate up to the level of the conglomerates; belemnites are numerically abundant within, and above the pebbly conglomerates (Sandström 2001). Rare lamniform sharks include *Squalicorax lindstromi* (listed as *S. kaupi* by Siverson 1992a), '*Carcharias*' *latus* (Siverson 1993a) and *Cretalamna sarcoportheta* (Siverson 1993a; Siversson et al. 2015). Other elasmobranchs include *Heterodontus* aff. *H. rugosus*, *Squatina* sp., *Pararhincodon* sp., *Chiloscyllium* sp, *Paratriakis* sp., *Scyliorhinus* sp. (sensu lato) and *Squatirhina* sp. (Siverson 1993a). Mosasaurids include *Prognathodon* sp., *Hainosaurus* sp. (Lindgren 2005a, 2005b) and *Platecarpus* sp. (Lindgren 1998). Finally, Persson (1959) reported an articulated cheloniid turtle carpace.

Lowermost upper Campanian (*Belemnellocamax balsvikensis* zone)

This biozone is here recognized at the localities Åsen and Balsvik, but is also present at the studied locality Ballingslöv 2 (Fig. 8). Based on unpublished biometric analysis of belemnite guards by the late Walter Kegel Christensen, the Åsen population is probably the oldest within the *B. balsvikensis* zone (Siversson et al. 2016).

Åsen

Reference data. Lindgren & Siverson (2002, 2004), Iqbal (2013), Siversson et al. (2016), Einarsson et al. (this thesis).

Belemnite index taxa. *Belemnellocamax balsvikensis*, *Belemnitella mucronata* but see Siversson et al. 2016.

Stratigraphic position. Lowermost upper Campanian.

Lithology. The *B. mammillatus–B. balsvikensis* zone boundary is marked by an erosional discontinuity with burrows and reworked *B. mammillatus* (Lindgren &

Siverson 2002, 2004; Siversson et al. 2016). At Åsen, the *B. balsvikensis* zone consists of an up to 2.8 m thick marine sand divided into the facies beds: 'balsvikensis green' and 'balsvikensis yellow' (Einarsson et al. this thesis) both included in 'bed 4' by Siversson et al. (2016). The subdivision into 'balsvikensis green' and 'balsvikensis yellow' is partially a result of weathering when green coloured sediments became yellow. 'Balsvikensis green' comprises 1.2 m of coarse grained calcareous quartz sand with green quartz colored by glauconite or copper. The lowermost part of the bed contains reworked *B. mammillatus* from the 'oysterbank', and is overlain by abundant *B. balsvikensis*, together with fragmented corals, oysters, echinoids, and marine vertebrate bones. 'Balsvikensis yellow' includes 1.6 m of fine-grained calcareous quartz sand with carbonate-cemented nodules containing chelipeds from decapod crustaceans. A basal lens of 'balsvikensis white' comprises a higher component of calcareous material (Einarsson et al. 2016; Einarsson et al. this thesis). Quaternary deposits cap the *B. balsvikensis* zone and reveal glaciotectonic cross-cutting of Quaternay clay within the Cretaceous marine sands (Siversson et al. 2016; Einarsson et al. this thesis).

Documented fossils. The macroinvertebrates are dominated by belemnites and bivalves, but also include solitary corals *Micrabacia*, echinoderms (echinoids, asteroids, and crinoids), arthropods (dominated by barnacles in 'balsvikensis green' and by decapod crustaceans *Protocallianassa faujasi* in 'balsvikensis yellow'), bryozoans and polychaete worm tubes. A smaller amount of charcoal, coprolites and microcoprolites from decapods are also present (Einarsson et al. 2016; Einarsson et al. this thesis). Actinopterygians are represented by pycnodontids e.g. *Anomoeodus subclavatus* (only present in 'balsvikensis green') and the teleosts ichthyodectids, elopiform *Pachyrhizodus* sp. and enchodontid *Enchodus* cf. *gladiolus* (Bazzi et al. 2016). The elasmobranchs include e.g. the lamniform *Squaliocorax lindstromi*, the heterodontiform *Heterodontus*, and rhinobatids (only present in 'balsvikensis green') (Einarsson et al. this thesis; unpublished data). Chimaeroids are also present. The mosasaurids *Eonatator stenbergii* (Lindgren & Siverson 2005; Einarsson et al. this thesis), *Clidastes propython* (Lindgren & Siverson 2004) and *Tylosarus ivoensis* (Lindgren & Siverson 2002), as well as the elasmosaurid *Scanisaurus* sp. have also been found (Einarsson et al. this thesis).

Balsvik

Reference data. Lowenstam & Epstein (1954), Brotzen (1960), Christensen (1975), Siverson (1993a).

Belemnite index taxa. Belemnellocamax balsvikensis, Belemnitella mucronata.

Stratigraphic position. Lowermost upper Campanian.

Lithology. A greensand (Brotzen 1960) overlain by a conglomerate rich in belemnites (Christensen 1975).

Documented fossils. Slender morphotype variants of *B. mucronata*, commonly with borings from encrusting epifauna (Christensen 1975). Large lamniform teeth are represented by e.g. *Anomotodon hermani*, *Cretoxyrhina mantelli*, *Pseudoscapanorhynchus* sp., *Pseudocorax laevis*, *Paranomotodon*. Other elasmobranchs are also represented by the paraorthacodontids *Paraorthacodus conicus*, *P. anderssoni* and *P.* n. sp. and the heterodontiform *Heterodontus* aff. *H. rugosus* (unpublished data P. Cederström collection).

Lower upper Campanian (*Belemnitella mucronata* zone)

This biozone is here represented at the studied localities Hanaskog and Balsvik, but is also present at the studied locality Kjuge (Fig. 8).

Hanaskog

Reference data. De Geer (1881, 1889), de Morgan (1882), Hennig (1895), Lundgren (1895), Grönwall (1915), Lundegren (1934), Brotzen (1960), Christensen (1975).

Belemnite index taxa. *Belemnitella mucronata.*

Stratigraphic position. Lower upper Campanian.

Lithology. Presently this is an abandoned quarry overgrown by vegetation. The previously exposed succession includes a thick section of fine-grained limestone (calcisiltites) with flint layers and nodules. Basal limestones are grey, trending to yellow-white at the top of the sequence (Christensen 1975).

Documented fossils. Lanceolate morphotype of *B. mucronata,* occasionally referred to *Belemnitella lundgreni* (Christensen 1975). Bivalves *Ostrea haliotoidea*, *Pycnodonte vesicularis*, *Ostrea semiplana* and *Pecten undulatus* are also represented (Lundegren 1934; Brotzen 1960). Persson (1962) described vertebrae and a propodial from large elasmosaurids, as well as a mosasaurid tooth. Undescribed chondricthyans (surface collected by the late Per-Ove Persson) include *Squalicorax lindstromi* (dentally advanced forms approaching *S. pristodontus* in tooth-shape and tooth-size), *Cretalamna borealis* and *Elasmodus* sp. (mandibular plate).

Balsvik

Reference data. Lundegren (1934), Christensen (1975).

Belemnite index taxa. Belemnitella mucronata.

Stratigraphic position. Lower upper Campanian.

Lithology. A conglomerate with 6 m of overlying fine-grained yellow to greyish calcisilitites (Lundegren

1934; Christensen 1975). A silty layer (1–2 cm thick) comprising about 50% fragmented gravel is dominated by muscovite and biotite and a discontinuity surface with burrows caps the *B. mucronata* zone (Christensen 1975).

Documented fossils. The bivalves *Pycnodonte vesicularis*, *Pecten subaraturs* and *Lima semisulcata* (Lundegren 1934).

Upper upper Campanian (*Belemnella lanceolata* zone)

This biozone is here represented at the localities Balsvik, Bjärlången, Ballingslöv 1 and Ballingslöv 2 (Fig. 8). The biozone previously defined the base of the Maastrichtian stage but is revised to the upper upper Campanian according to Niebuhr et al. (2011). The *B. lanceolata* population at Balsvik is considered the most primitive morphotype, and marks the base of the *B. lanceolata* zone (Schulz 1979; Siverson 1993a).

Balsvik

Reference data. Brotzen (1960), Christensen (1975, 1998), Siverson & Cappetta (2001).

Belemnite index taxa. *Belemnella lanceolata, Belemnitella mucronata, Belemnitella minor.*

Stratigraphic position. Upper upper Campanian.

Lithology. Discontinuity overlain by 3 m of calcisiltite and fine-grained calcarenite incorporating a basal clastic quartz layer with two upper levels containing flint nodules, belemnites and the oyster *Pycnodonte vesicularis* (Christensen 1975, 1998).

Documented fossils. The elasmobranch assemblage is dominated by deeper water squaloids including *Proetmopterus hemmooriensis*, *Squalus balsvikensis, S. ballingsloeviensis, Centroscymnus schmidi, Eoetmopterus supracretaceus* and the rajid *Walteraja exigua* Siverson 1993b; Siverson & Cappetta 2001). The elasmobranchs are also represented by the squatiniform *Squatina* sp., the orectolobiforms including the hemiscyllids *Acanthoscyllium* sp., *Chiloscyllium gaemersi, Hemiscyllium hermani,* and the parascyllids *Pararhincodon* spp., the carcharhiniforms such as *Scyliorhinus moosi* and *Paratriakis*, the synechodontiforms *Synechodus* spp., and *Parasquatina* sp. and the rhinobatids. Lamniform sharks include '*Carcharias*' sp. and *Archaeolamna kopingensis* (Siverson 1993a). Mosasaurid remains occur at the base of the calcisiltite (Brotzen 1960), represented by a partial right quadrate of the mosasaur *Plioplatecarpus* sp. (Lindgren 2004).

Bjärlången

Reference data. Hennig (1892), Lundegren (1934), Siverson (1993b).

Belemnite index taxa. *Belemnella lanceolata, Belemnitella mucronata, Belemnitella minor.*

Stratigraphic position. Upper upper Campanian.

Lithology. A muddy and sandy light grey to white, fine-grained calcisiltite (Lundegren 1934).

Documented fossils. The benthic macroinvertebrates are represented by the bivalve *Pycnodonte vesicularis* and the brachiopods *Rhynchonella* sp. and *Terebratula carnea* (Lundegren 1934). The bryozoans are represented by the *Cheilostomata* (Hennig 1892). The scyliorhinids and orectolobids sharks are dominant, whereas squaloids e.g. *Proetmopterus hemmooriensis*, *Squalus balsvikensis, S. ballingsloeviensis* are relatively rare (Siverson 1993b). Other elasmobranchs are represented by the squatiniform *Squatina*, the hemiscyllid *Acanthoscyllium* sp., the parascyllid *Pararhincodon* spp., carcharhiniforms such as *Scyliorhinus moosi*, the synechodontiform *Synechodus,* rhinobatids and the lamniform *Carcharias* sp. The elasmobranch fauna indicates cooler water temperatures. Abundant (about 40%) planktic foraminifers characterize an offshore setting (Siverson 1993a).

Ballingslöv 1

Reference data. Siverson (1993a, 1993b).

Belemnite index taxa. *Belemnella lanceolata, Belemnitella* sp.

Stratigraphic position. Upper upper Campanian.

Lithology. Calcisiltite with glauconite and quartz sand (Siverson 1993a).

Documented fossils. Belemnella lanceolata and *Pycnodonte vesicularis* are the dominant macroinvertebrate species. The sediment also contains a diverse assemblage of undescribed micromorph brachiopods. The elasmobranch fauna is numerically dominated by squaloid and orectolobiform taxa, including *Proetmopterus hemmooriensis*, *Squalus balsvikensis, S. ballingsloeviensis, Acanthoscyllium* sp., *Chiloscyllium gaemersi, Hemiscyllium hermani*, *Pararhincodon* spp. and several undescribed orectolobid forms (Siverson 1993a, 1993b). The dominated shark fauna (and especially *Proetmopterus hemmooriensis)* indicate a deep water setting with water depth of more than 50 m. Well worn teeth from sharks living in shallow waters e.g. *Heterodontus* sp. and quartz sand transported to deeper waters during storms indicate closeness to the shore.

Ballingslöv 2

Reference data. Siverson (1993a, 1993b).

Belemnite index taxa. *Belemnella lanceolata, Belemnitella* sp.

Stratigraphic position. Upper upper Campanian.

Fig. 8. Field photographs of selected localities with Santonian to Campanian rocks exposed within the Kristianstad Basin. **A.** Ullstorp. **B.** Maltesholm. **C.** Bjärlången. **D.** Ballingslöv 2. **E.** Ivö Klack. **F.** Ringeleslätt. **G.** Kjuge. **H.** Ugnsmunnarna**. I.** Ignaberga. **J.** Ballingslöv 1. **K.** Balsvik**. L.** Åsen.

Lithology. Calcisiltite (Siverson 1993a).

Documented fossils. Foraminifers imply an offshore setting. Elasmobranchs include the squatiniform *Squatina*, the heterodontiform *Heterodontus* sp., the orectolobiforms including the hemiscyllids *Acanthoscyllium* sp., *Chiloscyllium gaemersi, Hemiscyllium hermani* and the parascyllids *Pararhincodon* spp., the lamniform *Carcharias* sp., the carcharhiniforms such as *Scyliorhinus moosi* and *Paratriakis*, the synechodontiform *Synechodus,* the squaloids such as *Proetmopterus hemmooriensis*, *Squalus balsvikensis* and *S. ballingsloeviensis* and the rhinobatids (Siverson 1993a, 1993b).

Discussion

Palaeoenvironments

The Late Cretaceous depositional succession within the Kristianstad Basin records several late Santonian – late Campanian transgression and regression cycles establishing the archipelago including different living environments for the diverse fauna. The basal-most non-marine kaolin clay is overlain by a Santonian transgressive sequence evidenced by calcarenite and conglomerate at Ringeleslätt, with quartz-arenite sandstone at Ignaberga and fluviatile sandy and lacustrine argillaceous clays representing an adjacent delta at Åsen (e.g. Christensen 1975; Friis & Skarby 1981). The lowermost Campanian *G. granulataquadrata* zone indicating a shallow nearshore tropical to subtropical marine setting with sandy biocalcarenite in Bed B, and conglomerate in Bed C at Ullstorp (Erlström & Gabrielson 1985; Andersson Medhaine 2017). The *G. quadrata quadrata* zone is represented by conglomerate in Bed E at Ullstorp (M. Siversson pers. comm. 2017).

The latest early Campanian *B. mammillatus* zone records near-shore high-energy environments, with rocky shore, beaches and a drowned river valley. The near-shore high energy environments are successively recognized by calcarenites represented at Ignaberga (Erlström & Gabrielson 1992) and Maltesholm (Sandström 2001) and the rocky shore built up around the island of Ivö Klack with lithology of clacirudites (Surlyk & Christensen 1974). Beaches associated with topographic highs (e.g. Ryssberget), are evidenced by the Ryedal and Holma quartz-sandstones (Holst 1888; Lundegren 1934). The drowned river valley at Åsen constituted a transition area with fluvial input (Siversson et al. 2016). Lithologically this includes loosely consolidated green quartz sand with conifer driftwood and charcoal debris washed out to sea by strong currents during flood events; mangroves do not appear to have been present contra Sørensen & Surlyk (2008) (McLoughlin et al. this thesis).

The earliest late Campanian *B. balsvikensis* zone at Åsen, ('balsvikensis green' and 'balsvikensis yellow' local facies) bioturbation of the yellowish quartz sand is evidenced by decapod crustacean burrows, whose living chambers are preserved as calcified nodules. The bioturbation makes the sediment more prone to weathering explaining the yellowish colour of the sediments (Einarsson et al. 2016). Late Campanian *B. mucronata* zone fine-grained

calcarenites and calcisiltites with flint layers found at Hanaskog and Balsvik and the *B. lanceolata* zone at Balsvik, Bjärlången, Ballingslöv 1 and Ballingslöv 2 (Lundegren 1934; Christensen 1975; Siverson & Cappetta 2001) indicate deeper water conditions, both offshore and closer to the shore, and cooler water temperatures (Christensen 1975; Siverson 1993a, 1993b). Basin outliers and boulders with encrusting epifauna suggest that the coastline was further north than the current boundary of the Kristianstad Basin (Lundegren 1934).

The Campanian sea temperatures of the Kristianstad Basin were undoubtedly influenced by local sea-level fluctuations, palaeolatitude, global climate trends and depth within the water column (van Hinsbergen et al. 2015; Linnert et al. 2016). The distribution of marine crocodilians, and both *Squalus*-type and sclerorhynchid sharks indicate a subtropical climate in the basal Campanian *G. granulataquadrata* zone followed by cooling throughout the remainder of the Campanian (M. Siversson pers. comm. 2017). Isotopic palaeotemperature estimates from Ivö klack, Åsen and Maltesholm indicate an average temperature of 12.5ºC for the younger part of the *B. mammillatus* zone (Sørensen et al. 2015), whereas Surlyk & Christensen (1974) proposed a 17ºC–18ºC range for the older part of the *B. mammillatus* zone at Ugnsmunnarna, Ivö klack and Ignaberga based on scleractinian corals. Specific site palaeotemperature measurements include 15.5 ºC ± 2.0 ºC at Ignaberga (*B. mammillatus* zone), 13.9ºC ± 1.3ºC at Åsen (*B. mammillatus* zone) and 12.5ºC ± 1.9ºC at Balsvik (*B. lanceolata* zone; Ljungberg 2004). This records a weak trend towards decreasing temperatures during the latest early Campanian (Ugnsmunnarna, Ivö klack, Ignaberga and Åsen) to the late late Campanian (Balsvik). Declining temperature could also be detected within the *B. mammillatus* zone by comparing the older sediments at the localities Ugnsmunnarna, Ivö klack and Ignaberga with the younger sediments at Åsen.

Declining temperatures might be reflected in the faunal successions by the following examples. 1. Between the *G. granulataquadrata* zone and *B. mammillatus* zone, record the transition from abundant crocodilians and tropical to subtropical sclerorhynchids, to rare crocodilians (with only one specimen from Ivö Klack) and the complete absence of sclerorhynchids, together with *Pseudoscapanorhynchus compressidens* and *Acrolamna* sp. (Persson 1959; M. Siversson pers comm. 2017).

2. The upper section of the *B. mammillatus* zone also reveals the disappearance of both *G. quadrata scaniensis* (Christensen 1975) and marine crocodilians (Persson 1959) despite the persistence of near shore strata at Maltesholm and Åsen (Siversson et al. 2016; Einarsson et al. this thesis; McLoughlin et al. this thesis), which are otherwise rich in plesiosaurs and mosasaurs.

3. Within the *B. mammillatus* zone belemnite and lamniform shark abundance show positive correlation. Both groups are very abundant at Åsen and Ugnsmunnarna, moderately common in relative terms at Ignaberga and Ivö Klack and comparatively rare at Maltesholm (Siverson 1992a; 1993a). The *Cretoxyrhina mantelli* was abundant in the earliest early Campanian (*G. granulataquadrata* zone), fairly rare in the latest early Campanian (*B. mammillatus* zone) and only represented by one tooth from the earliest early Campanian (*B. balsvikensis* zone) indicating a decrease in abundance through the Campanian (Siverson 1992a).

4. Tropical to subtropical rudists found at Ullstorp (*G. granulataquadrata* zone) and Maltesholm (*B. mammillatus* zone) disappear (Sandström 2001; Andersson Medhaine 2017), together with several mosasaur genera across the lower – upper Campanian boundary described as a major biotic turnover especially amongst mosasaur taxa (Lindgren & Siverson 2002; Lindgren 2004). Fossils from sea turtles and hybodont sharks are also restricted to the early Campanian (Persson 1959; Siversson 1992b, 1993a, 1993b; Rees 1999; Siversson et al. 2016).

5. The belemnites of the Kristianstad Basin demonstrate a gradual decline of generic diversity through the first half of the Campanian stage. Four genera (*Belemnitella*, *Gonioteuthis Belemnellocamax* and *Actinocamax*) were present during the earliest early Campanian, three genera (*Belemnitella*, *Gonioteuthis* and *Belemnellocamax*) during latest early Campanian, two genera (*Belemnitella* and *Belemnellocamax*) during the earliest late Campanian, a single genus (*Belemnitella*) during early late Campanian (Christensen 1975; M. Siversson pers. comm. 2017). Diversity subsequently increased to two genera (*Belemnitella* and *Belemnella*) during late late Campanian (Christensen 1975; Niebuhr et al. 2011). *Belemnellocamax*, represented by the successive species *B. grossouvrei*, *B. mammillatus* and *B. balsvikensis*, was adapted to subtropical shallow waters (Christensen 1975), possibly explaining its disappearance at the transition to cooler water conditions during the *B. mucronata* zone time.

6. The transition from the *B. mucronata* to *B. lanceolata* zone is characterised by reduced abundance of warm-water rajiforms, such as *Rhinobatos* and *Squatirhina*, and the appearance of the cold-water resistant genus *Walteraja*, as well as the appearance of large numbers of 'deep-water' sqauloids (e.g. *Proetmopterus hemmooriensis*) in the *B. lanceolata* zone (Siverson 1993a; Siverson & Cappetta 2001).

Palaeoecology

The interpreted marine food web of the Kristianstad Basin includes multiple trophic levels (Fig. 9; Sørensen et al. 2013). Primary producers (photosynthetic organisms) are

represented by red algae (Andersson Medhaine 2017) and dinoflagellates (V. Vajda pers. comm. 2018; unpublished data). Foraminifera (McLoughlin et al. this thesis) and benthic macroinvertebrates, including bivalves (e.g. oysters), gastropods, echinoderms (echinoids, crinoids and asteroids), bryozoans, brachiopods, corals, polychaetes, barnacles and decapod crustaceans constitute benthic detritivores and filterfeeders representing the primary level consumers (Einarsson et al. this thesis). Rudists are especially common at Ullstorp (*G. granulataquadrata* zone) and Maltesholm (*B. mammillatus* zone), with oysters predominating at Ignaberga, Ivö klack, and in the Åsen 'oysterbank' (*B. mammillatus* zone); decapods are frequent in the 'balsvikensis yellow' bed at Åsen (*B. balsvikensis* zone; e.g. Erlström & Gabrielson 1992; Sandström 2001; Sørensen et al. 2012; Einarsson et al. 2016; Einarsson et al. this thesis; unpublished data). The high abundance of decapods and drop in abundance of bivalves within the 'balsvikensis yellow' bed at Åsen (*B. balsvikensis* zone) could be explained by decapods feeding on bivalve larval stages during bioturbation of the sediments (Einarsson et al. 2016). The bivalve *Pycnodonte vesicularis* seems to have preferentially inhabited offshore calcisiltites during the latest Campanian *Belemnella lanceolata* zone (M. Siversson pers. comm. 2017).

The benthic macroinvertebrates provided an important food resource for the secondary-level consumers of durophagous vertebrates including the pycnodontid fish *Anomoeodus subclavatus* (Bazzi et al. 2016), the chimaeroids *Ischyodus bifurcates*, *Elasmodus* and *Edaphodon* (Davis 1890; McLoughlin et al. this thesis), rays such as *Rhinobatos*, the galeomorph sharks *Heterodontus,* and orectolobiforms including *Parascyllium* and *Chiloscyllium* (Siversson et al. 2016; McLoughlin et al. this thesis). Cretaceous sea turtles are also known to have preyed upon benthic invertebrates (Kear 2006), and indeed, the Kristianstad Basin specimens are consistent with stem-cheloniid *Euclastes* (sensu Paraham 2005, but referred to *Osteopygis* by Persson 1959), which was likely a durophagous omnivore based on its broad secondary palate (Parham & Pyenson 2010). The rhinobatids probably fed predominantly on decapods (Siversson et al. 2016), while the pycnodontids may have fed upon oysters (Bazzi et al. 2016). Other secondary consumers could have included small bony fish but these are extremely rare, likely because of taphonomic and sampling biases (Bazzi et al. 2016).

Ammonites and belemnites (Christensen 1975; Kennedy & Christensen 1997), together with larger actinopterygians such as lepisosteids, *Protosphyraena*, ichthyodectids, *Pachyrhizodus* and *Enchodus* (Bazzi et al. 2016) the orectolobiform *Cederstroemia nilsi*, carcharhiniforms and synechodontiforms (Siverson 1993a; Siversson et al. 2015, 2016) represent pelagic macrocarnivores and the tertiary level consumers.

Cephalopods, bony fish and small sharks, in turn, probably supported the quaternary-level consumers including nektonic sharks such as hybodonts, paraorthacodontids, squaliforms, squatiniforms and lamniforms including *Carcharias*, *Pseudoscapanorhynchus*, *Scapanorhynchus* and *Anomotodon* (e.g. Siversson 1992a, 1992b, 1993a; Rees 1999), as well as smaller-bodied mosasaurs *Clidastes propython*, *Eonatator* (*Halisaurus*) *sternbergii* and *Platecarpus somenensis* and *Platecarpus* sp. (Lindgren 1998; 2004; Lindgren & Siverson 2004; 2005), the marine crocodilian *Aigialosuchus villandensis* (Persson 1959), flightless diving birds *Hesperornis rossicus*, *Hesperornis* and *Baptornis*, and polycotylid and elasmosaurid plesiosaurs (Persson 1959; Sachs et al. 2016); note that Kear et al. (2017) interpreted *Scanisaurus* as a middle trophic-level predator capable of feeding both on the sea floor and within the water column. The narrow snouted marine crocodile *Aigialosuchus villandensis* (Persson 1959) was adapted for feeding upon larger fishes e.g. *Enchodus* (Rees & Lindgren 2005) and benthic macroinvertebrates demonstrated by its quite robust teeth.

Apex predators, the fifth-level consumers, are represented by the large-bodied mosasaurs *Tylosaurus ivoensis*, *Hainosaurus minor* and *Prognathodon* (Lindgren 2004, 2005a, 2005b; Lindgren & Siverson 2002; Gren & Lindgren 2014), together with the nektonic lamniform sharks 3.8 m long (Bazzi et al. 2017) *Squalicorax lindstromi*, *Archaeolamna kopingensis*, *Cretalamna borealis, Cretalamna sarcoportheta* and 5 m long (Shimada 1997) *Cretoxyrhina mantelli* (Siverson 1992a, 1993a; Siversson et al. 2015, 2016). These may have preyed upon juvenile marine reptiles and sharks. For example, Åsen seems to have been a nursery area for the Sand tiger shark '*Carcharias*' *latus* (McLoughlin et al., this thesis), and mosasaur *Clidastes propython* based on the high abundance of juvenile teeth (Lindgren & Siverson 2004). Osteologically immature plesiosaur remains are also prolific at Åsen, Ivö Klack and Ignaberga (Einarsson et al. 2010; Nordén 2011). Similar patterns with higher abundance of juvenile plesiosaur bones in more sheltered environments have been presented from coeval deposits from New Zealand, Mangahouanga (Vajda & Raine 2010) and interpreted as nurseries. Plesiosaurs were viviparous (O'Keefe 2011), and their frequency might be indicative of juvenile mortality (Nordén 2011).

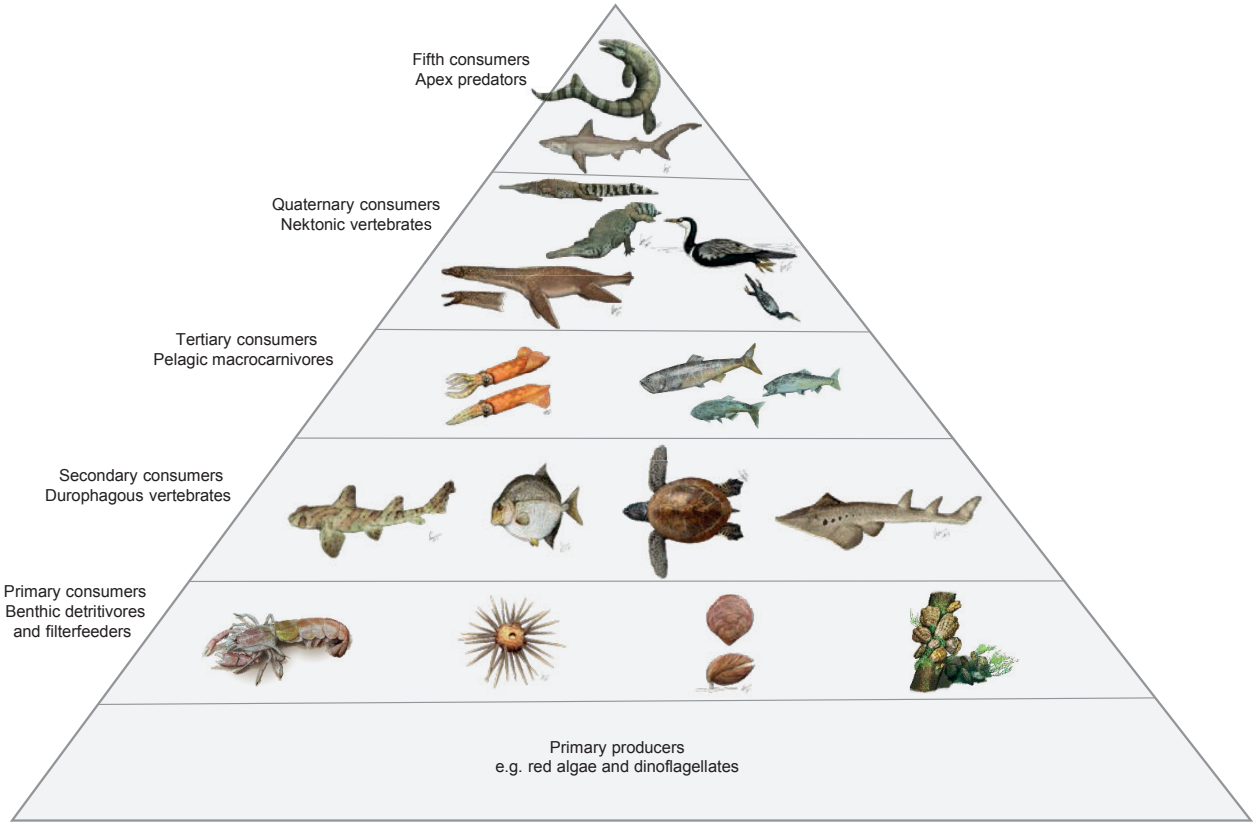

Fig. 9. The ecological pyramid illustrates examples of animals included within the different trophic levels of the marine Campanian ecosystem and food web of the Kristianstad Basin based on identified fossils. The primary producers are represented by red algae and dinoflagellates. The primary consumers are represented by ghost shrimps, the echinoid *Salenia*, brachiopod *Terebratula* and oysters *Acutostrea incurva*. The secondary consumers are represented by *Heterodontus*, pycnodontid fish, *Euclastes* and *Rhinobatos*. The tertiary consumers are represented by *Belemnellocamax mammillatus* and *Enchodus*. The quaternary consumers are represented by *Scanisaurus*, *Aigialosuchus* and *Hesperornis*. The fifth-level consumers (apex predators) are represented by *Prognathodon* and *Squalicorax*. Illustrations: Gabriel Ugueto.

Feeding traces from lamniform sharks are relatively common on marine reptile bones (especially plesiosaurs) from Åsen and Ivö klack (Persson 1959; 1962; Einarsson et al. 2010). Einarsson et al. (2010) also described mosasaur (*Prognathodon*) bite marks (a result of either predation or scavenging) on an isolated propodial of a juvenile polycotylid plesiosaur from the *B. mammillatus* zone at Åsen. Mosasaurs bite traces are otherwise known on ammonites (Kase et al. 1998; Kauffman & Kesling 1960; Kauffman 2004; Klompmaker et al. 2009), which are rare in the Kristianstad Basin (Kennedy & Christensen 1997). The terrestrial, probably island, ecosystems reconstructed from Kristianstad Basin included ferns, conifers, and low-growing flowering plants (Friis & Skarby 1981, 1982; Halamski et al. 2016), which would have provided a food source for small (body length of less than 3 m) herbivorous neoceratopsian (resembling *Leptoceratops*) and ornithopod dinosaurs (resembling *Thescelosaurus* and *Hypsilophodon*), with non-avian theropods (compared with *Australovenator*) as the apex carnivores (Poropat et al. 2016). Non-marine aquatic vertebrates, such as the trionychid turtle (Scheyer et al. 2012) probably fed on small fish and decapods; these also likely supported pterosaurs (unpublished data). Possible scincomorph lizards resembling *Araeosaurus* found in the near shore environment of *G. granulataquadrata* zone of Ullstorp (unpublished data) may have fed on insects.

Palaeobiogeography

The palaeobiogeographical interrerelationships of local assemblages within the Kristianstad Basin would have been directly influenced by fluctuating sea levels, which affected habitat availability via relative water depth, and connectivity between adjacent basins, in particular the Båstad Basin in northwestern Skåne (Gabrielson & Holland 1984). During the lowermost Campanian *Gonioteuthis granulataquadrata* zone interval, the estimated sea levels within the Kristianstad Basin reached a maximum depth of about 20 m (Fig. 10 A), as evidenced by the nearshore environment at Ullstorp Bed B which underwent continuous sedimentation throughout the *G. granulataquadrata* zone Bed C timeframe. This potentially persisted up until bed E, or deacreased with a hiatus between Beds C and E, and a transgression in Bed E (unpublished data). A depositional hiatus is also marked between the *G. quadrata quadrata* and *B. mammillatus* zones. The next transgressive event during the uppermost

lower Campanian *Belemnellocamax mammillatus* zone produced water depths that probably reached 40–50 m (Fig. 10 B; Van der Zwaan et al. 1990) as suggested by the predominance of coastal benthic communities at Åsen, Ignaberga, Ivö klack, Ugnsmunnarna and Maltesholm. The high abundance of planktonic foraminifers in Ullstorp Bed G and the overlying biocalcarenite correlates with peak water depths in the *B. mammillatus* zone (Erlström & Gabrielson 1985). Palaeocurrent indicators reveal a prevailing northwesterly directional flow parallel to the Nävlingeåsen horst ridge, and could imply the opening of a seaway connection with the Båstad Basin (Bruun-Petersen 1975; Erlström & Gabrielson 1992; Sandström 2001). Similar conditions persisted intermittently into the lowermost upper Campanian *Belemnellocamax balsvikensis* zone, delimited by the belemnite conglomerate separating the *B. mammillatus* and *B. balsvikensis* zones at Åsen. The subsequent *Belemnitella mucronata* zone transgression marked by conglomerates at Balsvik, created deeper water conditions in the Kristianstad basin area with finer-grained calcisiltite deposited at Hanaskog and other localities. Water depths might have reached as much as 75 m (Fig. 10 C) during this interval (Lundegren 1932; Christensen 1975). Identification of *Belemnitella* aff. *langei* at Svenstorp and Köpinge Mölla in the Vomb Trough correlates beds at those sites with strata in the Malen quarry and Gropemöllan in the Båstad Basin, and represents a timeframe with depositional hiatus in the Kristianstad Basin (Christensen 1986). The last transgressive pulse in the latest Campanian *Belemnella lanceolata* zone raised sea levels to 100–200 m above present (Fig. 10 D-F; Gabrielson & Holland 1984).

Post-Cretaceous uplift of the south Småland Peneplain, including northern Skåne (with e.g. Ballingslöv, Bjärlången and Bjärnum presently elevated to 125–175 m above sea level) and re-exposure of the Cretaceous hilly relief reveals some of the Campanian topography of Skåne (Japsen et al. 2016.). The uplift is evidenced by outliers of Cretaceous sediments and irregular flint deposits in the area between the present dermacations of the Kristianstad Basin and Båstad Basin margins (Norling & Bergström 1987; Japsen et al. 2016). The topographical information could reveal a possible seaway between the Kristianstad Basin and Båstad Basin and/or an open shelf across Skåne with distant links to the proto-Atlantic.

Marine vertebrate dispersals occurred between Europe and North America during the early Campanian (Lindgren & Siverson 2004; Bazzi et al. 2016). This is evidenced by actinopterygian (Bazzi et al. 2016), selachian and mosasaurid assemblages (Lindgren & Siverson 2004). Late Cretaceous global homogeneity is otherwise characteristic amongst these clades, with compositional resemblance to assemblages from the Western Interior Seaway of North America supporting pelagic faunal connectivity across the Boreal proto-Atlantic Ocean (Lindgren & Siverson 2004; Cumbaa et al. 2010; Bazzi et al. 2016). Terrestrial vertebrates, such as trionychid turtles and neoceratopsians, probably arrived from Asia at least by the Santonian–early Campanian, and may have used the Fennoscandian island archipelagos as a Laurasian migration route towards North America before the late Campanian (Lindgren et al. 2007; Scheyer et al. 2012; Poropat et al. 2016).

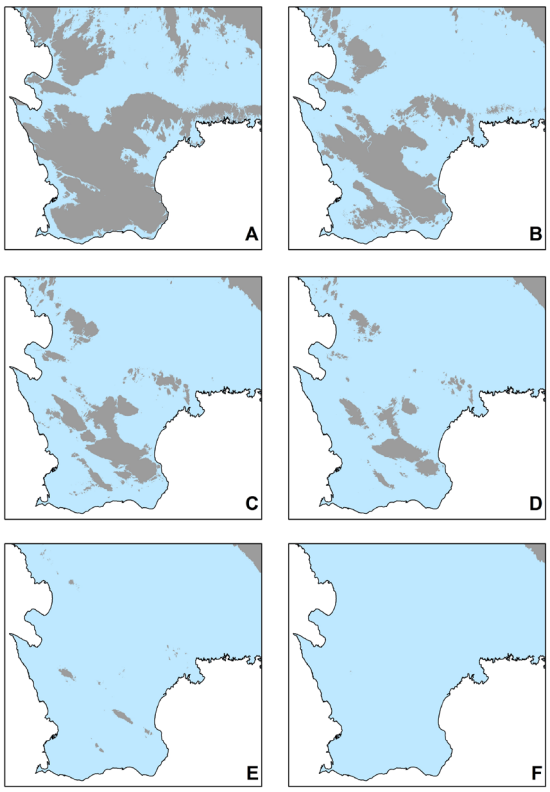

Figure 10. The Campanian archipelago of the Kristianstad Basin illustrated by maps showing the distribution of landmass/islands and sea at different hypothetical sea levels and with Campanian topography by lowering the southern Småland Peneplain by 150 m (according to Japsen et al. 2016). A. +20 m sea level representing the earliest early Campanian (*G. granulataquadrata* zone). B. +50 m sea level representing the latest early Campanian (*B. mammillatus* zone). C. +75 m sea level representing the early late Campanian (*B. mucronata* zone). D. +100 m sea level representing the lowermost calculated sea level during the late late Campanian (*B. lanceolata* zone). E. +150 m sea level representing the intermediate calculated sea level during late late Campanian (*B. lanceolata* zone). F. +200 m sea level representing the maximum calculated sea level during late late Campanian (*B. lanceolata* zone). GIS Illustrations: Nils Wallin.

Future research

Substantial work remains to be undertaken on the Upper Cretaceous succession within the Kristianstad Basin. Key projects are listed below, and are either planned for the immediate future, or are already underway.

- Descriptive reassessment of marine reptile occurrences from the Kristianstad Basin, especially the elasmosaurid and polycotylid plesiosaurian material, cheloniid sea turtles (to be combined

with newly identified remains from the lower Campanian of northwestern Germany), and the northernmost palaeolatitudinal exemplars of the marine crocodilian taxa *Aigialosuchus* and *Thoracosaurus* from the Campanian, and Danian of Skåne respectively (see Kear et al. 2016).

- Palaeoecological and palaeoenvironmental assessment of the Santonian invertebrate assemblage at Ignaberga and Ringeleslätt. This will include biometric analyses of belemnites to refine biostratigraphy within the lowermost exposed section of Kristianstad Basin succession.
- Documentation of new discoveries from Ullstorp, Bed B, which incorporate terrestrial lizard, and neoceratopsian dinosaur remains. New elasmobranch occurrences will also be presented, such as the sclerorhynchids. In addition, elasmobranch microdental fossils will be used for novel age calibrations with beds C, D and F, and provide a site correlative stratigraphical log relative to belemnite data derived from biometrics and CT tomography.
- Evaluation of elasmobranch dental microremains from the *Belemnellocamax mammillatus* zone collected at Ivö klack. Redescription of chimeroids originally documented by Davis (1890). Description of new elasmobranch teeth and scale occurrences from Balsvik, which include scyliorhinids, triakids, squalids and paleospinacids. Parascyllid carpet sharks have also been recovered from various Campanian and Danian deposits in Skåne; a new occurrence of the orectolobiform *Pararhincodon* will be described from Ballingslöv 1.
- Actinopterygian and elasmobranch microremains will be used to correlate between the Kristianstad Basin, Vomb Trough and Båstad Basin to refine regional palaeobiogeography and biostratigraphy.

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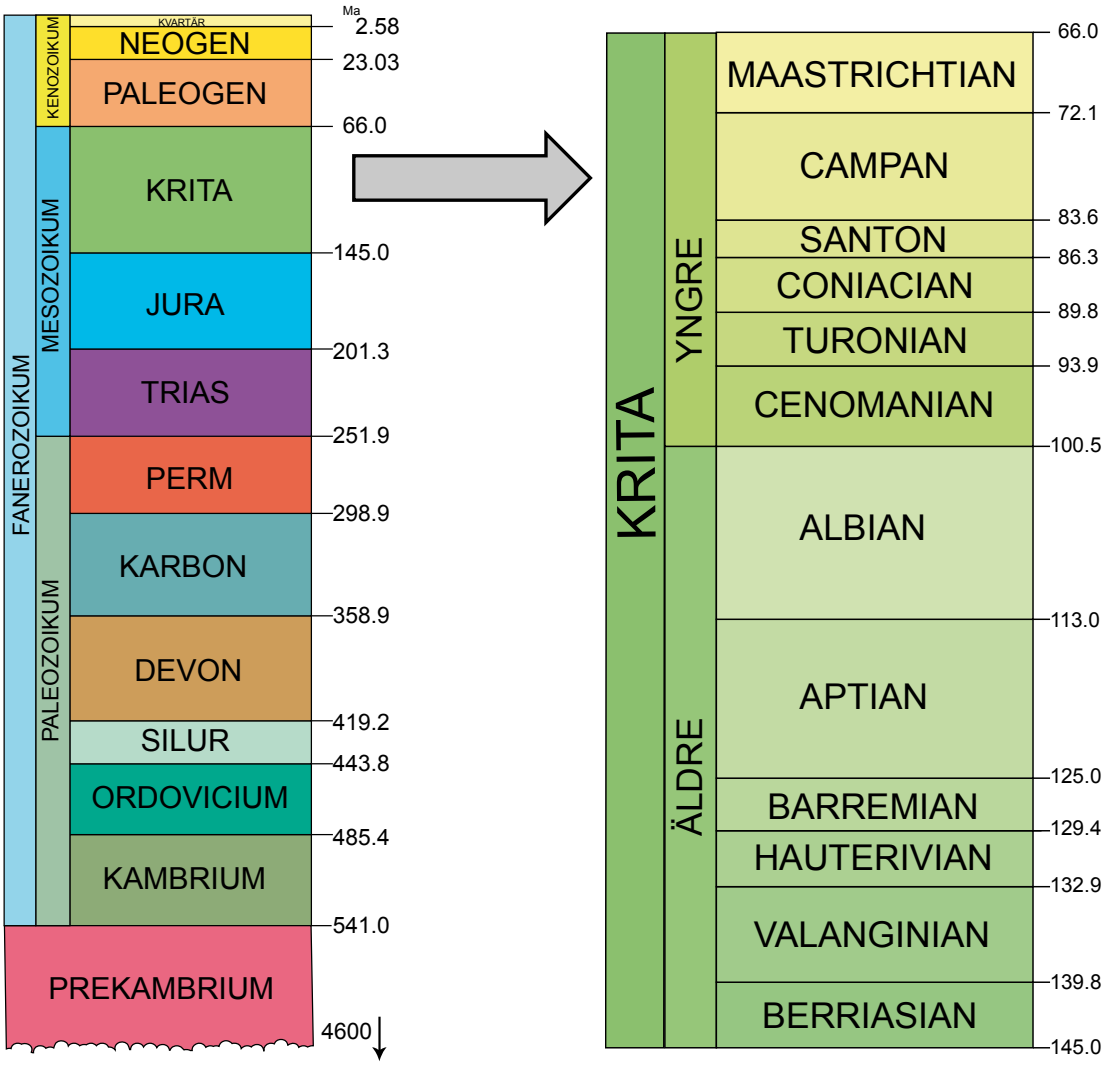
Part II

Pedagogiska och didaktiska tillämpningar av forskningsresultat för användning i undervisning från förskola till gymnasieskola

Introduktion – vad berättar fossil från Kristianstadsområdet?

I denna del av avhandlingen introduceras några konkreta förslag på tillämpningar av paleontologisk kunskap generellt, och forskningsresultat om fossil från Kristianstadsområdet specifikt, som kan användas i undervisning från förskola till gymnasieskola. Delen inleds med en populärvetenskaplig sammanfattning av del 1 för att sedan presentera undervisningsförslag inom de tre områdena; fossil och dinosaurier i förskolan, tidslinjer för utveckling av tidsmedvetenhet samt geovetenskapens ämnesövergripande karaktär i skolan.

Min forskning som presenteras i del 1 behandlar ekosystemet i nordöstra Skåne under slutet av dinosauriernas tid, sen kritaperiod (campan), för 83.6 till 72.1 miljoner år sedan (figur 1).



Figur 1. Den geologisk tidsskalan representerar tiden från jordens bildande fram tills idag. Tidsperioden campan finns inom den övre delen av kritaperioden (ICS 2017).

Studien fokuserar geografiskt på Kristianstadsbassängen som sträcker sig från Hässleholm till Åhus samt från Listerlandet till Maglehem (figur 2). Under tidsperioden campan utgjordes området av ett grundhav med skärgårdsmiljö som bildades i samband med fluktuerande lokala havsnivåförändringar som bland annat innebar en havsnivå på cirka 50 meter över dagens nivå för ungefär 80 miljoner år sedan (Christensen 1975; Kornfält et al. 1978; Gabrielson & Holland 1984).

Figur 2. Karta över Skåne där Kristianstadsbassängen är markerad. Denna del av avhandlingen handlar om hur man kan konkretisera forskningen om Kristianstadsbassängen för barn och elever genom olika övningar om fossil från närmiljön som kan berätta om Skåne under dinosauriernas tid.

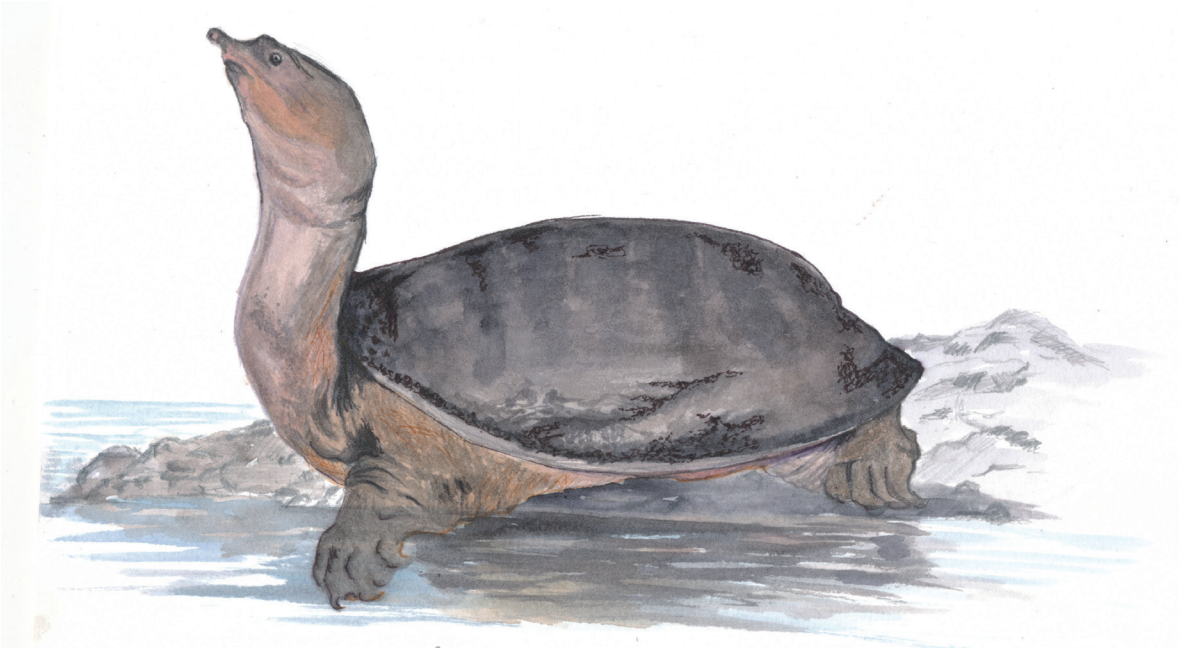
Genom att studera sediment och berggrund från campan bestående av lera, sand och kalksten som överlagrar urberget kan den dåtida miljön i Kristianstadsområdet rekonstrueras. Under de perioder när havsnivån var låg och inte täckte urberget utsattes graniten för vittring vilket fick till följd att fältspat omvandlades till kaolinlera medan erosion av granit bildade kvartssand. När havet sedan steg omlagrades en del av kaolinleran genom att det fördes ut till deltaområden och floddalar, medan sanden transporterades ut till grundhavet men kunde även sedimentera i de översvämmade floddalarna. Kalkstenen vittnar om en hög diversitet av skalbärande organismer som levde i ett varmt grundhav. Kalkstenen består av fragmenterade rester från dessa skalbärande djur där fragmentens storlek delar in kalkstenen i den finkorniga skalstoftkalken bildad i lugnare vatten, den lite grövre skalgruskalken bildad nära kusten i grundhavet samt den grovkorniga skalkalken bildad i en energirik kustmiljö med mycket vågpåverkan. Det mindre vittrade urberget utgjorde skärgårdens öar och halvöar som idag gör sig påminda som bergknallar i landskapet, som exempelvis Fjälkingebacke, Kjugekull, Västanåberget, Listerlandets klackar, Ivö Klack, Oppmannaberget, Vångaberget och Ryssberget (Lundegren 1934; Christensen 1975; Kornfält et al. 1978). Marken var täckt av barrväxter, lövfällande träd, ormbunkar och lågt växande blommande växter (Friis & Skarby 1981, 1982; Halamski et al. 2016). I skogarna levde fyrbenta växtätande dinosaurier som med sin halskrage och näbbliknande mun påminner om *Leptoceratops* (figur 3) (Lindgren et al. 2007; Poropat et al. 2016), men det fanns även tvåbenta växtätande ornithopoder (figur 4) samt köttätande theropoder (figur 5). Samtliga identifierade dinosaurier var mindre än 3 m långa och har kunnat beskrivas med hjälp av fragmenterade fossilfynd av tänder, fingerben samt ett skenben (Poropat et al. 2016).

Figur 3. Dinosaurien *Leptoceratops gracilis* som påminner om de ceratopsider som levde på öarna och halvöarna i Kristianstadsområdets skärgård under campan. Illustration: Gabriel Ugueto

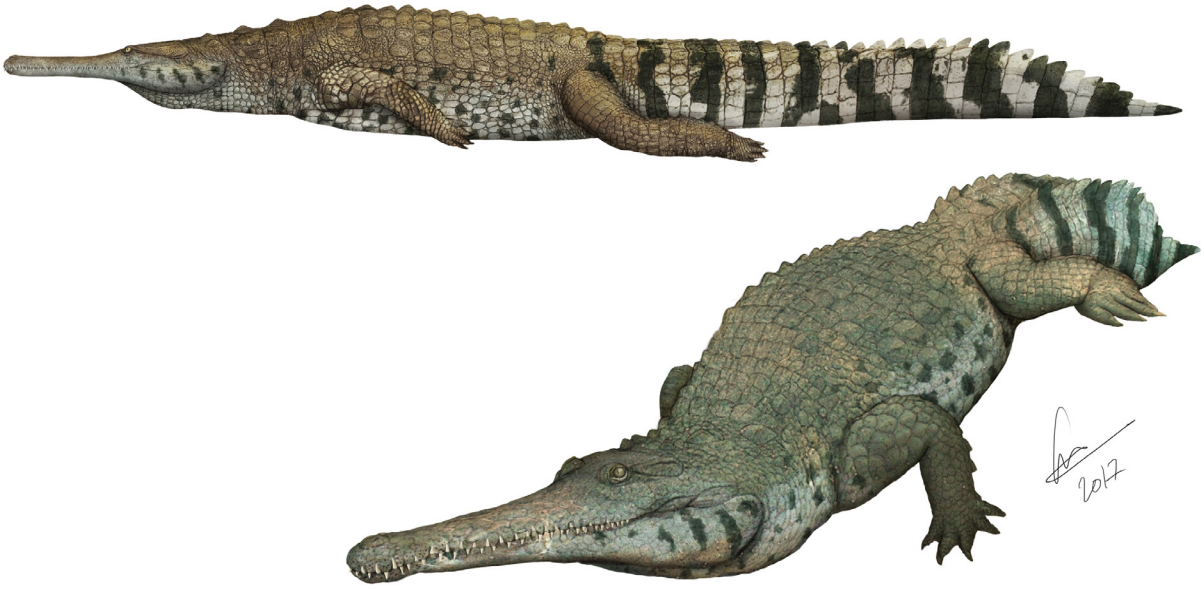
Figur 4. Dinosaurien *Parkosaurus* som påminner om de ornithopoder som levde i Kristianstadsområdet under campan. Illustration: Gabriel Ugueto.

Figur 5. Dinosaurien *Australovenator wintonensis* som har använts som jämförelsematerial vid beskrivning av de köttätande (theropod) dinosaurierna från Kristianstadsbassängen. Illustration: Gabriel Ugueto.

Vid den steniga strandkanten på Ivö Klack levde landlevande läderköldpaddor (figur 6), marina krokodiler (*Aigialosuchus villandensis*) (figur 7) samt vattenlevande fåglar, så kallade hesperorner (figur 8) representerade av *Hesperornis* och *Baptornis*. De vattenlevande fåglarna levde både på land (där de ruvade sina ägg) och i vatten (där de fångade fisk) (Rees & Lindgren 2005). De marina krokodilerna hade ett långsmalt käkparti, vilket tyder på att de föredrog att äta fisk, men de robusta tänderna antyder även en diet av skalbärande organismer samt eventuellt större bytesdjur. Fynd av krokodilernas osteoderm (benplattor som bäddats in i huden) liknar fynd av läderköldpaddans skal, men skiljs åt genom den yttre strukturens gropar i osteodermet eller genom histologi då man studerar den inre benstrukturen med hjälp av mikroskop (Persson 1959; Scheyer et al. 2012). De marina krokodilerna levde även vid stränderna utmed förkastningshorstar (Nävlingeåsen) tillsammans med små, landlevande ödlor (figur 9; opublicerat material).



Figur 6. Den landlevande läderköldpaddan som levde vid den steniga strandkanten på Ivö Klack i Kristianstadsområdet. Illustration: Katarina Månsson.

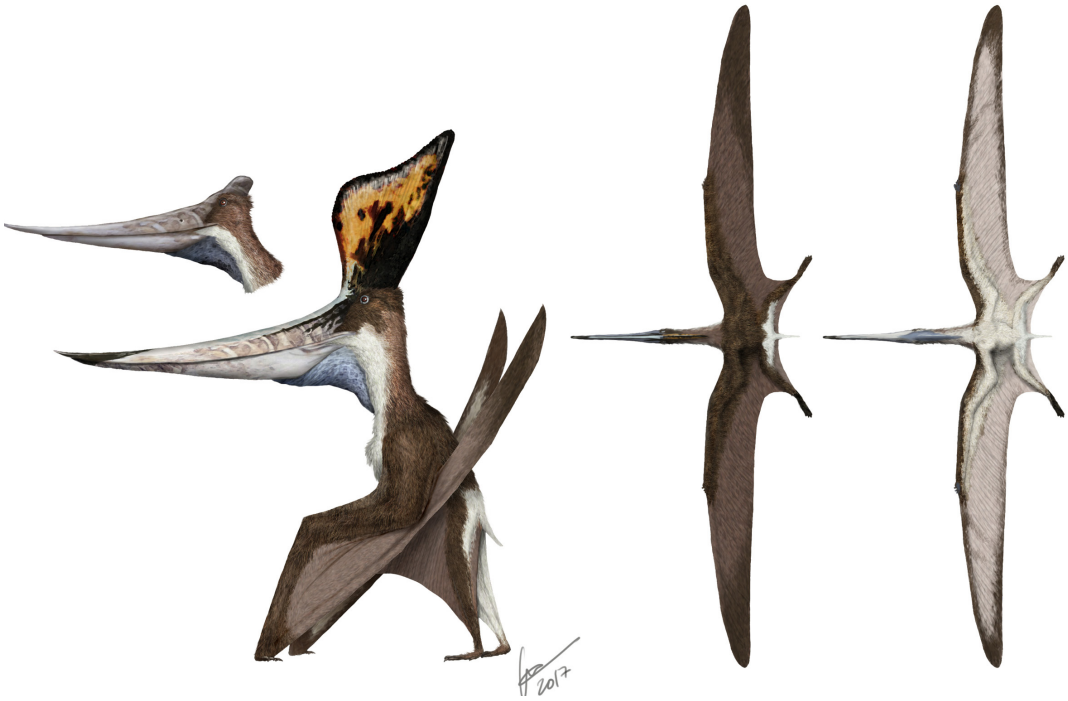


Figur 7. Den marina krokodilen *Aigialosuchus villandensis* som endast är känd ifrån Kristianstadsbassängen. Illustration: Gabriel Ugueto.

Figur 8. Den vattenlevande fågeln *Hesperornis regalis* som utgjorde jämförelse- och typmaterialet för bestämning och identifikation av *Hesperornis rossicus* och *Hesperornis* sp. från Kristianstadsbassängen. Illustration: Gabriel Ugueto.

Figur 9. En liten ödla inom gruppen Scincomorpha som påminner om *Araeosaurus*. Illustration: Gabriel Ugueto

Flygödlor (pterosaurier) har kunnat konstateras med hjälp av små benfragment. Däremot är det mycket svårt att avgöra vilken typ av flygödla som fanns representerad. Exempel på flygödlor från samma tid är *Pteranodon* (figur 10), men den har endast hittats i Nordamerika.



Figur 10. Flygödlan *Pteranodon sternbergi* från Nordamerika som ett exempel på en flygödla från sen kritaperiod (ca 83-82 miljoner år sedan) Illustration: Gabriel Ugueto.

I det varma, grunda havet levde mosasaurier, plesiosaurier, broskfiskar, marina sköldpaddor samt strålfeniga fiskar. De minsta mosasaurierna representerades av *Clidastes* och *Eonatator* som kunde bli 2-4 meter långa. De större mosasaurierna representerades av *Platecarpus*, *Hainosaurus,* den ca 8 meter långa *Prognathodon* (*Dollosaurus*) (figur 11) och den över 10 meter långa *Tylosaurus*. Fossila fynd av tänder visar att de största tänderna från *Hainosaurus* är 35 mm långa, medan tänderna från den betydligt vanligare *Tylosaurus* är 60 mm långa (Lindgren 2004, 2005; Lindgren & Siverson 2004, 2005; M. Siversson pers. kom. 2018).

Figur 11. Mosasaurien *Prognathodon* (*Dollosaurus*) som kunde bli ca 8 meter lång. Illustration: Gabriel Ugueto.

Den andra gruppen av stora marina reptiler utgjordes av svanhalsödlor (plesiosaurier) vilka är uppdelade i de två grupperna A. långhalsade Elasmosauridae som bland annat representeras av den 4-5 m långa *Scanisaurus* (figur 12) samt B. korthalsade Polycotylidae (figur 13) (Persson 1959; Sachs et al. 2015; Kear et al. 2017) som påminner om *Dolichorhynchops*.

Figur 12. En elasmosaurid plesiosaurie inom släktet *Scanisaurus* (Skåneödla) från campan som endast har hittats i Kristianstadsområdet. Illustration: Gabriel Ugueto.

Figur 13. En yngre individ av en korthalsad polycotylid plesiosaurie. Illustration: Gabriel Ugueto.

Tänder från broskfiskar i form av hajar, rockor och havsmusfiskar utgör de allra vanligaste fossilfynden i Kristianstadsbassängen. Hajar fanns representerade genom hybodonter, Squalomorphii och Galeomorphii. Hybodonthajarna *Polyacrodus* och *Meristodon* (Rees 1999; opublicerat material) hade ett kort huvud med långa käkar samt fentaggar framför varje ryggfena (Rees 1999). De försvann från Kristianstadsbassängen under tidig campan. Squalomorphii innefattade kamtandhajartade hajar, pigghajartade hajar samt havsänglar som troligtvis livnärde sig på benfiskar, bläckfiskar och kräftdjur. Galeomorphii utgjordes av tjurhuvudhajar som till exempel *Heterodontus* (figur 14), wobbegongartade hajar, håbrandsartade hajar som till exempel *Squalicorax* (figur 15), gråhajartade hajar samt Synechodontiformes. De mindre hajarna livnärde sig troligtvis på småfisk, kräftdjur, bläckfisk, musslor och snäckor, medan de håbrandsartade jättehajarna torde aven ha inkluderat plesiosaurier, andra hajar, marina sköldpaddor och mindre mosasaurier i sin diet (Siverson 1989, 1992, 1993a, 1993b, 1995; Siversson et al. 2016).

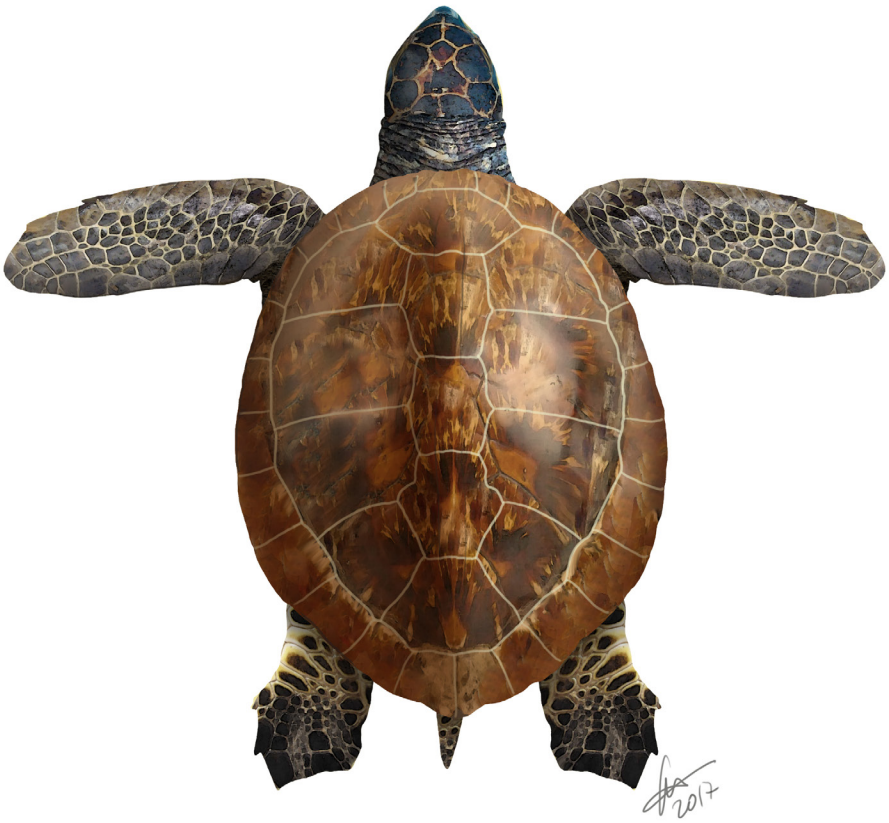
Figur 14. Tjurhuvudhajen *Heterodontus* hade platta krossartänder anpassade för att äta skalbärande organismer. Illustration: Gabriel Ugueto.

Figur 15. *Squalicorax* är ett exempel på en av de håbrandsartade jättehajarna som levde i Kristianstadsområdet för ungefär 80 miljoner år sedan. Illustration: Gabriel Ugueto.

Rockorna omfattade hajrockor (*Rhinobatos* (figur 16) och *Squatirhina*), egentliga rockor (*Walteraja*) samt sågfiskar. Sågfiskar var vanliga i det varma grunda havet under tidig campan tillsammans med hajrockor som fanns i hög andel fram till början av sen campan. De egentliga rockorna som var anpassade till lite kallare vatten utgjorde de vanligaste rockorna under senare delen av campan (Siverson 1993a; Siverson & Capetta 2001; Siversson et al. 2016).

Figur 16. Hajrockan *Rhinobatos casieri* som levde i Kristianstadsområdet under campan. Illustration: Gabreil Ugueto.

Havsmusfiskarna representerades av *Ischyodus, Edaphodon, Amylodon* och *Elasmodus* vars tänder utvecklats till krossande tandplattor anpassade till att äta skalbärande organismer. *Ischyodus* var det vanligaste släktet medan fynd från *Edaphodon* indikerar mycket stora individer (Davis 1890; McLoughlin et al ms; M. Siversson pers. kom. 2018). De marina sköldpaddorna tillhör troligtvis *Euclastes* (figur 17), men den tidigare benämningen *Osteopygis* (Persson 1959) har ännu inte reviderats. Detta innebär att de marina sköldpaddorna från Kristianstadsbassängen antagligen utgör en av de första härstamningarna till de nutida marina sköldpaddorna. De livnärde sig troligtvis på skalbärande organismer.



Figur 17. Den marina sköldpaddan *Euclastes* som levde i Kristianstadsområdet under sen kritaperiod. Illustration: Gabriel Ugueto.

Med hjälp av fossilfynd av tänder, kotor och fiskfjäll har de olika benfiskarna tillhörande gruppen strålfeniga fiskar kunnat beskrivas. Denna grupp bestod av bengäddor, pycnodontider som t.ex. *Anomoeodus* (figur 18), störartade fiskar samt äkta benfiskar. De äkta benfiskarna representerades bland annat av den svärdfiskliknande *Protosphyraena,* den tarponartade fisken *Pachyrhizodus* som påminner om tonfisk med hög stjärtfena samt laxtobisartade fisken *Enchodus* (figur 19) med långa smala tänder. *Enchodus* smala tänder hade mycket tunn emalj, vilket får till följd att de fossila tänderna oftast hittas utan emalj då denna inte bevarats. Pycnodontiderna kunde med hjälp av sina platta krossartänder livnära sig på skalbärande organismer medan övriga strålfeniga fiskar åt andra mindre fiskar förutom *Protosphyraena* som även var lämpad till att äta större bytesdjur (Bazzi et al. 2016; McLoughlin et al. ms).

Figur 18. En pycnodontid fisk med krossartänder anpassade för födoval av skalbärande organismer. Illustration: Gabriel Ugueto.

Figur 19. De vanligaste fynden av strålfeniga fiskar utgörs av de långa smala tänderna från *Enchodus*. Illustration: Gabriel Ugueto.

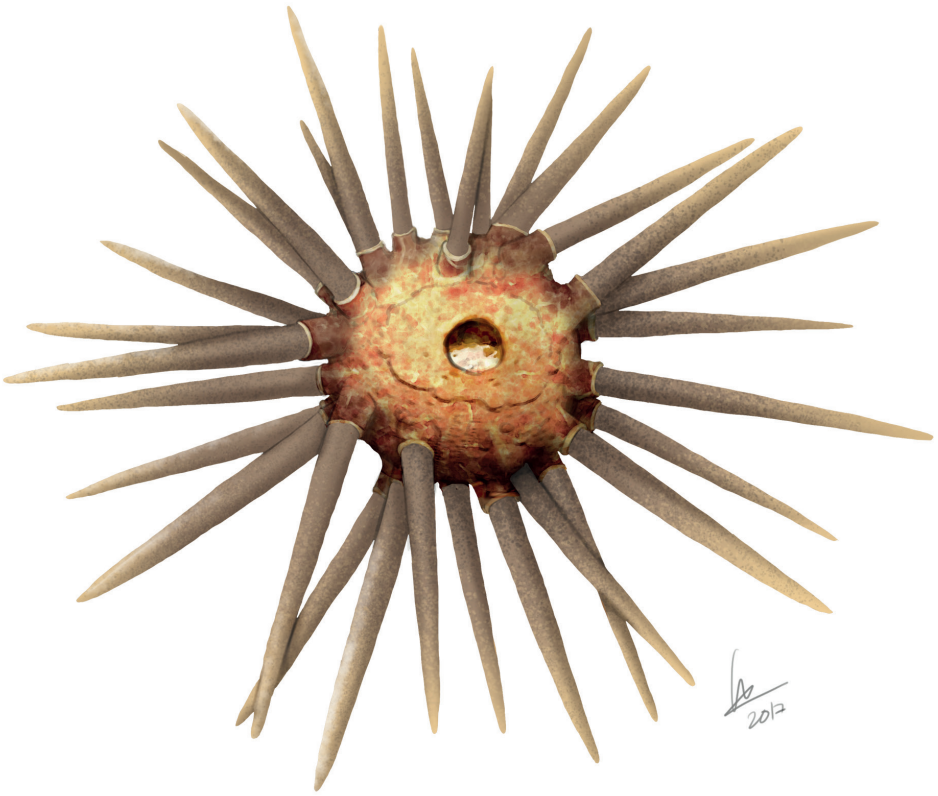
Havets botten, klippor, stenblock, vedrester som förts ut till havs samt i vissa fall skalbärande organismer och benrester efter döda djur täcktes av en rik fauna av ryggradslösa djur som framförallt utgjordes av musslor, snäckor, armfotingar, mossdjur, tagghudingar, koraller, havsborstmaskar samt kräftdjur. Musslor dominerades av ostron (figur 20), inoceramider, kammusslor (som exempelvis *Pecten*) samt *Spondylus*.

Figur 20. Ostron som sitter fastväxta på vedrester från träd som spolats ut till havs. Illustration: Gabriel Ugueto.

Fossila snäckor (gastropoder) är mycket sällsynta, vilket antagligen beror att deras skal av aragonit lättare bryts ned än skal som är uppbyggt av kalcit. Exempel på gastropodsläkten från Kristianstadsområdet är *Nerita, Patella* och *Campanile*. Armfotingar (brachiopoder) representerades av *Rhynchonella*, *Terebratula* (figur 21), *Magas*, *Crania* samt Discinida brachiopoder. Armfotingen är ett djur som påminner om en mussla, men består av två asymmetriska skalhalvor med en pedikel från bukskalet för fäste på hårda underlag eller för nedgrävning i bottensediment.

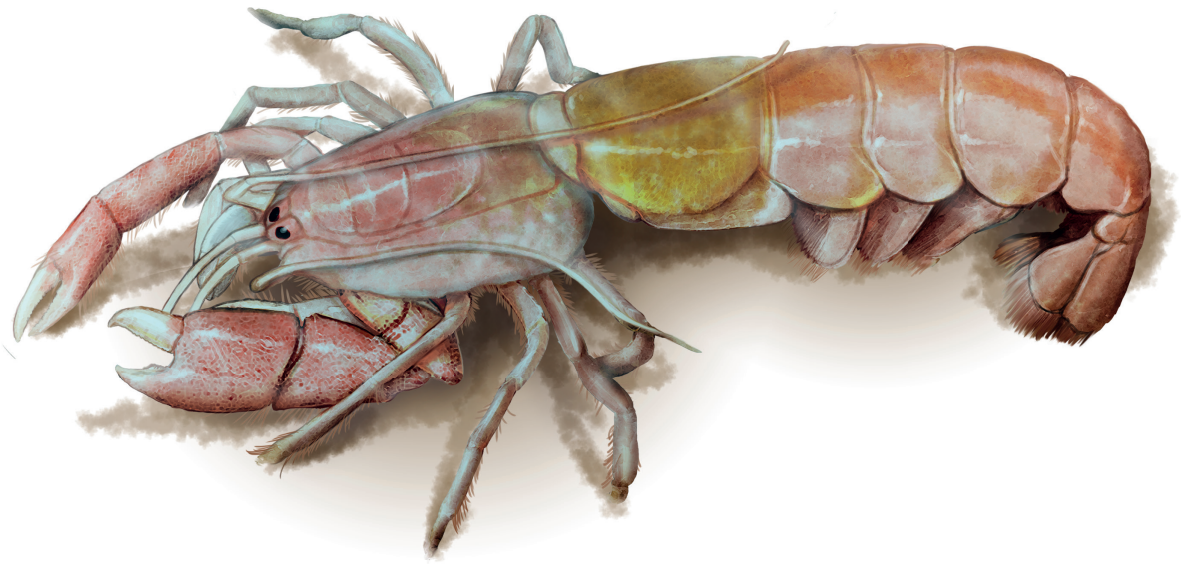
Figur 21. Armfotingen (brachiopoden) *Terebratula* från campan i Kristianstadsbassängen. Illustration: Gabriel Ugueto.

Tagghudingar (sjöborrar, sjöstjärnor samt sjöliljor) dominerades av de irreguljära sjöborrarna *Echinocorys, Micraster, Holaster* och *Caratomus* samt reguljära sjöborrarna *Cidaris, Phymosoma* och *Salenia* (figur 22).



Figur 22. Ett exempel på en tagghuding från Kristianstadsområdets campan representerat av sjöborren *Salenia*. Illustration: Gabriel Ugueto.

Koraller representerades främst av enkelkorallerna *Micrabacia, Leptophyllia* samt *Parasmilila.* Fynd från havsborstmaskar görs i form av grävspår i bottensedimenten som bevaras som enkelrör eller som flera sammansatta rör. Kräftdjuren utgjordes av rankfotingar i form av havstulpaner samt tiofotade kräftdjur (figur 23) som representerades av grävande spökräkor (*Calianassa* och *Protocallianassa*) (Einarsson et al., 2016). Spökräkorna hittas oftast i kalkkonkretioner som är igenfyllda, fossiliserade grävgångar och bon. Det är framförallt klorna som återfinns i form av stenkärnor eftersom de bevaras lättare än kräftornas övriga exoskelett (Einarsson et al. 2016 och referenser däri).



Figur 23. Kräftdjuret den grävande spökräkan *Protocallianassa faujasi* vars klor hittas som stenkärnor i kalkkonkretioner. Illustration: Gabriel Ugueto.

Bläckfiskar bestod av de mycket vanliga belemniterna och de mindre vanliga ammoniterna. Belemniterna representerades av *Gonioteuthis, Belemnitella, Actinocamax, Belemnellocamax* (figur 24) och *Belemnella*. Eftersom varje släkte och därinom varje art levde under ett begränsat tidsintervall används belemniterna som ledfossil vid åldersbestämning av samtida sedimentära bergarter och fossil från Kristianstadsbassängen (Christensen 1975). Belemniterna bildade en grundläggande del i näringsväven eftersom de sannolikt var föda åt flera av de havslevande vertebraterna som exempelvis hajar, svanhalsödlor (plesiosaurier) och mosasaurier.

Figur 24. Bläckfisken (belemniten) *Belemnellocamax mammillatus* vars släkte nästintill endast återfinns i Kristianstadsbassängen. Illustration: Gabriel Ugueto.

Faunans samspel i ekosystemet mellan olika trofiska nivåer skapar en komplex näringsväv. Fossila fynd har gjorts som bevisar en interaktion mellan mosasaurien *Prognathodon* och en polycotylid plesiosaurie (se framsida samt Einarsson et al. 2010). Kristianstadsbassängens ekosystem och dess näringsväv kan rekonstrueras med hjälp av fossil. Fossil är ett avtryck eller en avgjutning av det dåtida djuret. De fossil som vi hittar i Kristianstadsbassängen är till största del fragmenterade vilket beror på upplösning av ämnen så som aragonit samt transport av det döda djuret i strömmar, vågor och stormar. För att kunna avgöra vilket djur som de fragmenterade fossilen kommer ifrån kan man studera speciella karaktärer som är avgränsande för bestämning av olika arter, jämföra med andra mer kompletta samtida fossil från andra delar av världen, jämföra med nutida djur samt undersöka fossilets histologi (benuppbyggnad) med hjälp av mikroskop. Vi som arbetar med att samla in fossil och rekonstruera djur, växter och miljö med hjälp av fossil kallas för paleontologer. Paleontologi är ett ämne som ingår i geologi som i sin tur ingår i geovetenskap. Här nedan följer konkreta exempel på hur man kan använda forskningsresultat om det ovan beskrivna marina ekosystemet i undervisning från förskola till gymnasieskola, men även diskussion om utveckling av tidsmedvetenhet samt geovetenskap i skolan.

Material och metod

I det pedagogiska och didaktiska utvecklingsarbetet med fokus på konkretisering av forskningsresultat om dinosauriernas värld i närmiljön har fokus legat på utveckling av nya metoder och konkret material, som bland annat baseras på barnintervjuer, formativa diskussioner

med pedagogerna, behovsanalys av kompetensutveckling samt övergripande arbete om geovetenskap på nationell och politisk nivå.

Undervisningsmaterial och ämnesfortbildning

Samtliga aktiviteter demonstrerades för barn/elever och pedagoger på förskolor och skolor i Kristianstads kommun i kombination med ämnesfortbildning för pedagoger där övningarna utvecklades i en formativ process (Einarsson ms, a, b). För att spegla variationen av barnens/elevernas olika erfarenheter och uppfattningar i form av uppmärksamhetsfokus inom de olika lärandeobjekteten (Elm Fristorp 2016) genomfördes både muntliga och skriftliga barn- och elevintervjuer. Intervjufrågorna utgjordes av frågorna Vad är ett fossil? samt Vad är en dinosaurie? Frågorna ställdes både inledningsvis samt avslutningsvis. Analysen bestod av en jämförelse mellan barnens/elevernas inledande och avslutande svar på intervjufrågorna (Einarsson ms, a).

För att synliggöra pedagogernas kunskapssyn kopplat till läroplanens mål samt deras och barnens/elevernas utveckling under projektets gång genomfördes diskussioner i pedagogernas arbetslag utifrån reflektions-, utvärderings- och formativa frågor.

Syfte/mål-tabell – ett planeringsverktyg

Syfte/mål-tabell är en metod som utvecklats för användning vid planering av tematiskt och ämnesövergripande arbete för konkretisering av forskningsresultat och skolans läroplan. Det övergripande syftet med syfte/mål-tabellen är att illustrera kopplingen mellan innehåll, undervisning och läroplanens mål för ett pågående tematiskt arbete. Tabellen består av syfte som antingen kan spegla innehållet i det tematiska arbetet (exempelvis i form av de tre lärandeobjekten fossil, dinosaurier och tidsperspektiv) eller arbetssätt som tränar förmågor i enlighet med syftestexten i Lgr 11 (se materialet Geologi i läroplanen). Syftet placerades i vänsterkolumnen i tabellen. Utvalda mål från läroplanen från avsnitten ”utveckling och lärande” samt ”barns inflytande” från förskolans läroplan (Lpfö/10) eller från kursplanernas centrala innehåll (Lgr 11) placerades i den översta raden i tabellen. I varje ruta där ett syfte möter ett mål finns förslag på en undervisningsaktivitet som kan genomföras tillsammans med barnen/eleverna. Syfte/mål-tabellen utgör därmed en form av pedagogisk planering som skapar en sammanfattning och överblick av det ämnesövergripande temaarbetet för både pedagoger och föräldrar (Einarsson ms, a).

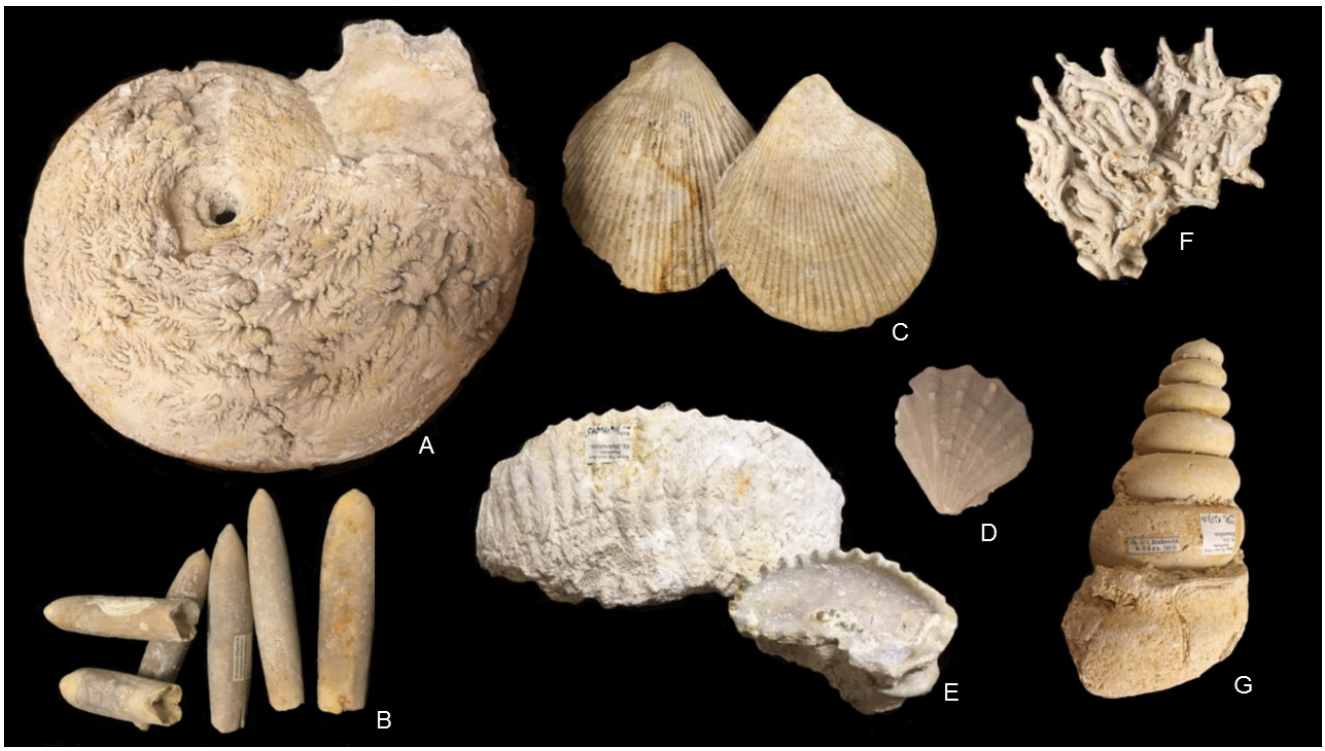
Enkätundersökningar

För att i framtiden kunna ge stöd i ämnesfortbildning för lärare som undervisar i geografi genomfördes tre olika enkätundersökningar som handlar om geologi i skolan, GIS i skolan samt geografiämnet i ett internationellt perspektiv. Orsaken till behovet av denna undersökning beror på omstrukturering av geologiinnehållet inom läroplanen för grundskola, förskoleklass och fritidshem (Lgr 11), där tidigare geologiinnehåll i åk 7–9 har flyttats till åk 4–6 samt att det uppkommit nya mål om GIS i gymnasieskolans geografiämne inom läroplan och ämnesplaner för gymnasieutbildningen (Gy 11). Varje enkätundersökning besvarades av 50–90 lärare. Studien, som inte är färdiganalyserad, kommer att fokusera på lärarnas behov av kompetensutveckling, vilken typ av kompetensutveckling som efterfrågas, hur man definierar GIS och geologi samt vad som begränsar geografiundervisningen. I den internationella studien analyseras likheter och skillnader mellan geografiämnet och geologins roll i geografi mellan länderna Storbritannien, Chile, Singapore, Portugal och Sverige.

Fossil och dinosaurier – ingångsport till naturvetenskap i närmiljön

De flesta skolor och förskolor i Kristianstads kommun har sand med fossil från kritahavet i sina sandlådor, vilket uppmärksammades i projektet ”Åhus under dinosauriernas tid” (Einarsson ms, a). Tillsammans med barnen och förskollärarna identifierades de tre lärandeobjekten (Gustavsson 2016; Hansson & Löfgren 2016); fossil, dinosaurier och tidsperspektiv som skulle utvecklas och fokuseras under projektets gång. Enligt Redfors (2016) gillar barn att undersöka sin omgivning och få svar på sina frågor. Fossilfynden (figur 25) i sandlådan och närmiljön uppmärksammades av både barn/elever och pedagoger genom frågorna: Vad är ett fossil? Hur har fossilen hamnat i sandlådan? samt Vilka djur representerar fossilen? Svaren på frågorna leder fram till en rekonstruktion av hur växter, djur och miljö såg ut för 80 miljoner år sedan. På så sätt ges det möjlighet att lära sig mer om närmiljöns spännande förhistoria. Projektet ”Åhus under dinosauriernas tid” blir ett exempel på hur aktuell naturvetenskaplig forskning om fossil, dinosaurier och tidsperspektiv kan användas och synliggöras i barnens närmiljö på förskolan med utgångspunkt i barnens intresse och nyfikenhet samt förskolans läroplan. Projektets struktur och innehåll tydliggörs med hjälp av en syfte/mål-tabell (Einarsson ms, a).

Förslag på konkret genomförande utifrån syfte/mål-tabellen är att inleda temat med att samla fossil från sandlådan på förskolan/skolan samt besöka fossillokaler (t.ex. Ivö Klack). En annan möjlighet är att besöka en sandlåda med fossilsand och tillhörande informationsskylt som ligger mitt i Kristianstad vid Sjöcronas gata som tagits fram i ett samarbete med Agenda 21 inom projektet ”Naturkul i stan”.



Figur 25. Exempel på fossil av några ryggradslösa djur från fyndlokalen Ivö Klack som även kan finnas representerade i förskolornas och skolornas sandlådor i form av fragment. A. ammonit (bläckfisk) B. belemniter (bläckfiskar) C. kammussla D. kammussla E. ostron F. maskrör G. gastropod (snäcka).

Fossil som barnen/eleverna har samlat in kan sedan undersökas genom att studera färg, form och antal. Förståelse för ekosystemets uppbyggnad kan erhållas genom att uppskatta mängden fossil från olika djurgrupper. Fossilen kan också studeras genom identifikationsövningar där barnen/eleverna parar ihop fossil med bilder eller beskrivningar. Fossilbildning kan illustreras genom en praktisk övning med gipsavgjutningar av musselavtryck i deltasand. (Einarsson ms, a).

För att ge både barn och vuxna en djupare inblick i ekosystemet som fanns i havet som täckte Kristianstadsområdet under slutet av kritaperioden har barnföreläsningen ”Fossiljakt” och vuxenföreläsningen ”Fossilens hemligheter” utvecklats. Under föreläsningarna får åhörarna aktivt delta i berättelsens gång antingen genom att praktiskt utföra fossilbildning eller med hjälp av ledtrådar gissa vilka djur som fossil från den lokala miljön representerar. På så sätt tar föreläsningarna även upp grundläggande geologi och paleontologi i form av hur identifikation, åldersbestämning, analyser, och fastställande av den förhistoriska miljön, ekologin och faunan går till. Kunskaper om det förhistoriska ekosystemet kan sedan vidareutvecklas till ekosystemets struktur och dynamik i form av trofisk struktur, näringskedjor och näringsväv. Ett exempel på detta är leken ”Vem äter vem i kritahavet?” (figur 26) som illustrerar en av näringskedjorna i kritahavet genom att barnen får vara fiskar, bläckfiskar, svanhalsödlor och mosasaurier i havet som jagar och ”äter upp varandra” genom att fånga och hålla varandra i händerna (Einarsson ms, a). Förhoppningen är att dessa grundläggande kunskaper om ekosystemets struktur med exempel från dinosauriernas tid kan göra barnen/eleverna uppmärksammade på liknande samband idag (Einarsson ms, a).

Figur 26. I leken ”Vem äter vem i kritahavet?” får barnen lära sig mer om det förhistoriska ekosystemet representerat av fiskar, belemniter, plesiosaurier och mosasaurier som ger grunden i kunskaperna om näringsväven genom start i näringskedjan. Illustration: Eminent Reklambyrå Sara Mazetti-Nissen, Vedran Besirevic och Oskar Lärn.

Projektet ”Åhus under dinosauriernas tid” har även utgångspunkt i barnens/elevernas stora intresse för dinosaurier. Eftersom dinosaurier och dinosauriernas värld ingår i ämnet naturvetenskap (Sjøberg 2010) kan barnens intresse för dinosaurier användas som en ingångsport till naturvetenskap genom konkreta övningar med utgångspunkt i det naturvetenskapliga arbetssättet. Förslagsvis kan ett tema om dinosaurier inledas med en inventering av befintliga dinosaurieböcker och dinosaurieleksaker på förskolan och skolan där barnen/eleverna ritar av eller fotograferar dinosaurieleksakerna. Leksakerna, bilderna och fotografierna kan sedan användas i olika konkreta övningar. I en övning möter barnen Simis havsreptil, Flygis flygödla samt Trampis dinosaurie (figur 27) för att få mer kunskap om hur man karakteriserar en dinosaurie. I en annan övning delas dinosaurierna in i växtätare och köttätare. I en tredje övning åker barnen iväg i en tidsmaskin för dinosauriesafari på förskolans gård. På utegården möter barnen de olika dinosaurierna som finns representerade som leksaker på förskolan genom att tillsammans mäta upp dem och på så sätt undersöka hur stora de var i verkligheten i jämförelse med saker som finns på utegården. Efter dinosaurieövningarna kan man tydligt se hur barnen använder sig av nya begrepp i de barninitierade lekarna som handlar om dinosaurier och dinosauriernas värld (Einarsson ms, a). Tidigare dokumenterade arbete om dinosaurietema med naturvetenskap som bas på förskola har gjorts på en Reggio Emilia skola som ett steg i utvecklandet av deras styrdokument (Rankin 1998). Efterfrågan av pedagogiskt och didaktiskt material om dinosaurier som vilar på naturvetenskaplig grund är efterfrågat i förskolan. Min förhoppning är att detta material kan komma till användning för de förskolor som vill arbeta med naturvetenskap utifrån ett dinosaurietema (Einarsson ms, a).

Figur 27. Genom barnens egna teckningar och fotografier av de befintliga dinosaurieleksakerna på förskolan kan man göra många olika övningar om dinosaurier. Denna teckning visar de tre stora grupperna av reptiler som levde under dinosauriernas tid representerade av Simis havsreptil, Trampis dinosaurie och Flygis flygödla. Illustration: Caspian Einarsson 5 år.

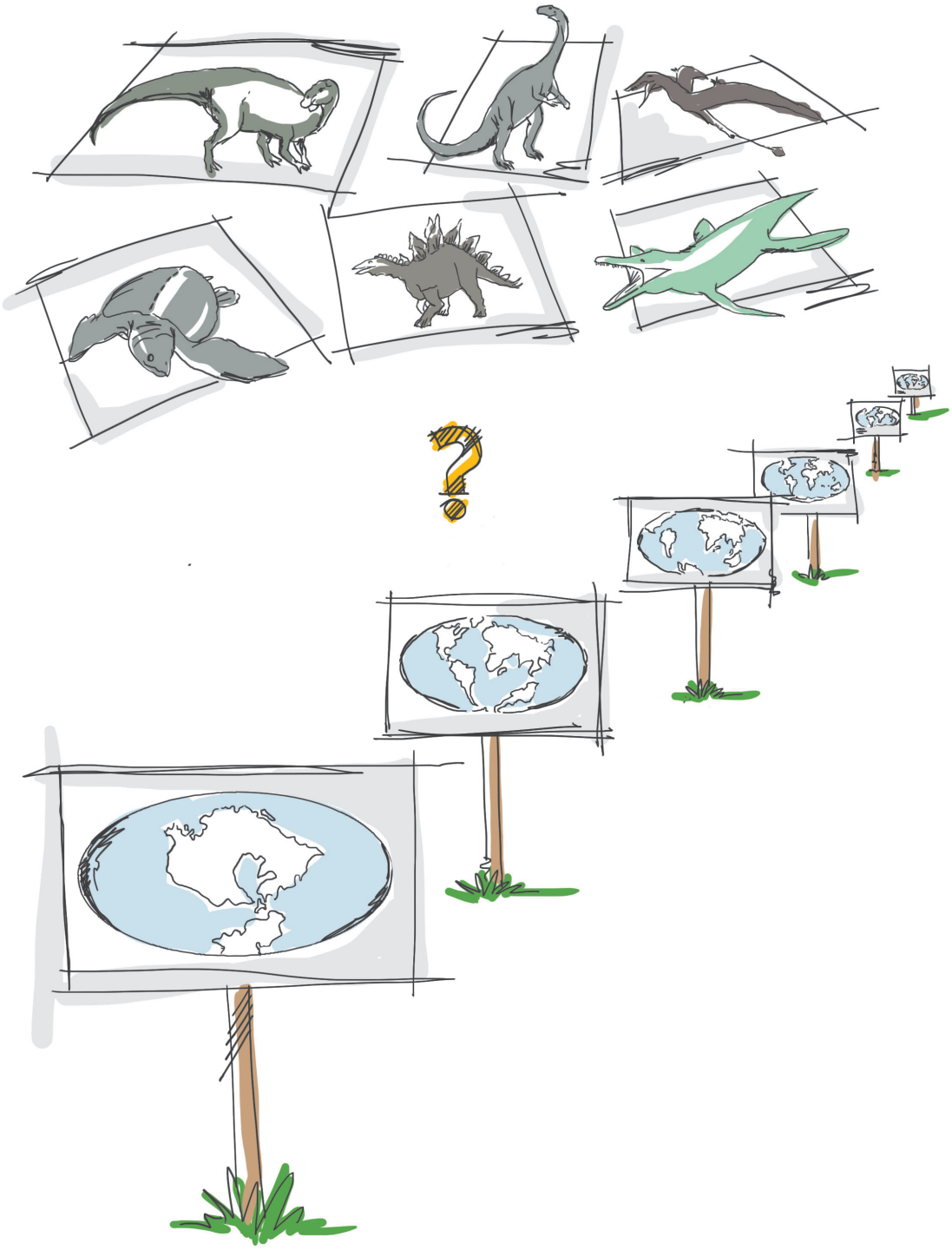
Tidsperspektiv - tidsmedvetenhet skapar omvärldsperspektiv

Det andra arbetet behandlar begreppen tid och tidsperspektiv samt förmågan tidsmedvetenhet. För att kunna utveckla tidsmedvetenhet behöver man bli uppmärksammad på de tre dimensionerna av tid som representeras av dåtid, nutid och framtid (Adler & Adler 1998) samt få möjlighet att träna olika tidsbegrepp på ett konkret sätt. Tidslinjer, oavsett tidsram, skapar uppfattning om de tre tidsdimensionerna (Hartsmar 1994; Adler & Adler 1998) som gör att man kan finna sin plats och sin historia i det långa tidsperspektivet. Det långa tidsperspektivet kallas även för det geologiska tidsperspektivet som utgör det grundläggande perspektivet inom geovetenskap (Kastens et al. 2009).

Begreppen tid och tidslinjer saknas i kurs- och ämnesplanerna för de naturvetenskapliga ämnena i grundskola och gymnasieskola, men finns med som implicita inslag inom biologi i form av evolution (Lgr11; Gy11). Varken historia eller geografi, där tidsperspektivet tas upp i förskoleklass, åk 1-3 samt gymnasiet, har någon progression gällande tid och tidslinjer (Lgr 11; Gy 11) som tar hänsyn till barnens/elevernas utveckling av tidsmedvetenhet från det konkreta till det abstrakta. Det är inte heller alla elever som läser geografi på gymnasiet (Gy 11) och därmed är det endast i förskola, förskoleklass samt åk 1-3 som eleverna blir uppmärksammade på tidsperspektiv, vilket är i de åldrarna då man har svårt att tänka abstrakt (Oakden & Sturt 192; Bradley 1947; Jahoda 1963; Hartsmar 1994, 2001; Alin-Åkerman 2003; Holst 2009; Holmberg & Eriksson 2013). Även om tid, tidslinjer och förmågan tidsmedvetenhet inte finns med på ett tydligt sätt i skolans styrdokument så finns uttalade behov av konkret material som har ett ämnesövergripande förhållningssätt inom både naturvetenskapliga och samhällsvetenskapliga ämnen. En viktig pusselbit som saknas i ämnesintegrationen mellan skolämnet geografi och de naturvetenskapliga ämnena i skolan är progression i arbetet med tid, tidslinjer och utveckling av barnens/elevernas tidsmedvetenhet (Einarsson ms, b).

Genom utveckling av tidslinjer som pedagogiskt material som illustrerar och fokuserar på det geologiska tidsperspektivet i olika övergripande perspektiv som jordens historia, dinosauriernas tidsålder samt växternas och djurens utveckling med miljontals år som skala ska detta arbete visa hur elevernas tidsmedvetenhet och kunskap om tid och tidsperspektiv kan utmanas och tränas i en tydlig progression från förskola till gymnasieskola (Einarsson ms, b). Detta har främst gjorts genom att konkretisera den abstrakta tiden i form av användning av tidslinjer där tid kan mätas som avstånd, hastighet eller ålder genom proportioner mellan olika

rekonstruktionsbilder på exempelvis världskartor och djur från olika geologiska tidsperioder (figur 28). Jordens och livets utveckling (med fokus på växter och djur) som konkreta helhetsperspektiv över den geologiska tidslinjen kan kompletteras med fördjupningsövningar inom varje tidsperiod för att lära sig den geologiska tidsskalan mer ingående. Detta har utarbetats som ett nytt förslag till upplägg av ”den förhistoriska tidslinjen” som ingår i montessoriförskolans pedagogiska material. De olika övningarna kan även utvecklas mot ett betydligt mer abstrakt förhållningssätt som utmanar de äldre elevernas abstrakta tänkande. (Einarsson ms, b).



Figur 28. Geologiska tidslinjen uppbyggd med hjälp av olika rekonstruktionskartor över hur världen har sett ut under olika geologiska tidsperioder. Rörliga bilder på tidslinjen utgörs av både nutida och förhistoriska djur som kan läggas ut på tidslinjen för att diskutera de olika djurgruppernas uppkomst och eventuella utdöende. Illustration: Eminent Reklambyrå Sara Mazetti-Nissen, Vedran Besirevic och Oskar Lärn.

Geovetenskap i skolan – den röda tråden mellan skolämnena

Det tredje arbetet fokuserar på geovetenskapens roll i skolan. Även om geologi inte är ett skolämne i Sverige, är det en grundläggande och bred vetenskap som genomsyrar andra skolämnen i både grund- och gymnasieskola. Den största delen av geologin i skolan ligger inom geografin i form av jordens inre processer, naturresurser, hållbar utveckling och klimatförändringar, men en del återfinns även inom de naturvetenskapliga ämnena (Lgr11; Gy 11; Einarsson & Örbring 2016). Genom en ämnesintegration mellan geografi och de naturvetenskapliga ämnena hade man kunnat få med de geologiska perspektiven (Einarsson & Örbring 2016; Geologi i läroplanen). Geovetenskap kan på så sätt visa på ett helhetsperspektiv genom att vara den röda tråden mellan skolämnena som behandlar aktuella samhällsfrågor och tidsperspektiv.

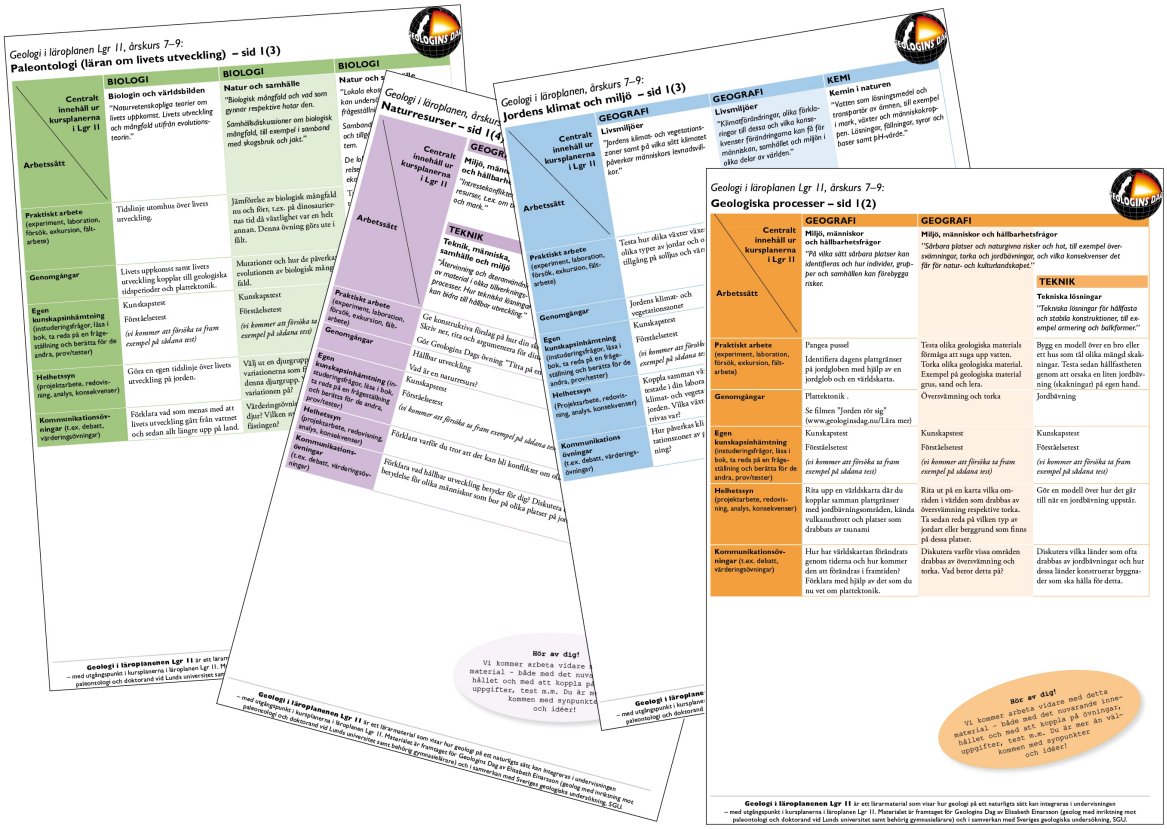
Övergripande arbete med geovetenskap i skolan på nationell och politisk nivå

I arbetet som ledamot i Kommittén för skolfrågor vid Kungliga Vetenskapsakademien (KVA), styrelsen för geologins dag samt geosektionen har en långsiktig utredning angående geologi i skolan med fyra utgångspunkter föreslagits.

- Definiera begreppet geovetenskap genom Svenska Nationalkommittén för geologi (SNKG) vid KVA.
- Identifiera det centrala innehållet med geologiskt innehåll i skolans kurs- och ämnesplaner.
- Urskilja orsaker till val av universitetsutbildning inom geologi genom enkätundersökning och fokusgrupper för geologistudenter.
- Specificera efterfrågade kunskaper och förmågor för nyblivna geologer definierade av geologernas arbetsmarknad.

Samtliga punkter har genomförts och bland annat resulterat i materialet ”Geologi i läroplanen” samt utvecklande och inrättande av resurscentrum för geologi i skolan.

Materialet ”geologi i läroplanen” som baseras på metoden syfte/mål-tabellen ger konkreta undervisningsexempel på hur man kan arbeta ämnesövergripande och tematiskt med geologi i åk 7-9 utifrån både syftesdelen och centrala innehållet i kursplanerna (Lgr 11). Materialet är uppdelat i fyra olika teman: Paleontologi (läran om livets utveckling), Naturresurser, Geologiska processer samt Jordens klimat och miljö (figur 29). Genom detta tematiska arbete är förhoppningen att synliggöra geovetenskapens framträdande roll i arbetet med de ämnesövergripande globala samhällsfrågorna i skolan.



Figur 29. Materialet ”Geologi i läroplanen” uppdelat i temaområdena paleontologi (läran om livets utveckling), naturresurser, geologiska processer samt jordens klimat och miljö.

För att ge ytterligare stöd i undervisning med fokus på globala samhällsfrågor t.ex. klimatförändringar, miljöförändringar, naturkatastrofer (allt från jordskred till tsunami), tillgång till grundvatten och naturresurser, men även om geologiska företeelser som skapar nyfikenhet och förundran som exempelvis dinosauriernas färg och utdöende, stora vulkanutbrott, istidens mammutar och människor samt jordens och livets utveckling inrättades utifrån lärares uttryckta behov resurscentrum för geologi i skolan. Genom geologilektioner, geologilådor, materialet geologi i läroplanen, fortbildningsdagar i geologi och geologididaktik som även kan presenteras av geologistudenter, som ett led i träning av populärvetenskaplig presentation, får skolor konkreta förslag på geovetenskaplig undervisning.

Sammantaget ledde ovanstående arbete via arbetsgruppen ”geovetenskap i skolan” fram till följande formulering i handlingsplanen för kommittén för skolfrågor vid Kungliga Vetenskapsakademien:

> ”Bevaka kunskapsläget för specifika ämnen i skolorna där det är särskilt påkallat, exempelvis geologi, nutrition, medicin och evolution”.

Materialet ”geologi i läroplanen” resulterade även i en inskrivning av geologi för samhället i näringsdepartementets mineralstrategi genom följande formulering för åtgärd nummer 14.

> ”öka kunskapen om geologins roll i samhället”.

Dessutom ledde arbetet med ”resurscentrum för geologi i skolan” fram till följande kommentar från Utbildningsminister Gustav Fridolin från utbildningsdepartementet den 2 december 2015.

> ”Jag kan också konstatera att det görs goda insatser på flera håll i landet i syfte att underlätta för skolorna att integrera området geologi i undervisningen. Som exempel kan jag nämna att den naturvetenskapliga fakulteten vid Lunds universitet har ett resurscentrum för geologi i skolan och via sin webbplats erbjuder de bland annat undervisningsmaterial, lärardagar och forskningsartiklar i geologididaktik.”

Fortsatt arbete med förtydligande av geovetenskap i skolan

Enligt Lgr 11 ska eleverna utveckla kunskaper i det naturvetenskapliga ämnets sammanhang. Detta skulle kunna göras genom att stärka geografiämnet som kan få en central roll i skolans tvärvetenskapliga arbete för att förtydliga geovetenskapen som en röd tråd mellan skolämnena. Därmed utgör nästkommande steg i arbetet med förtydligande av geovetenskap i skolan följande förslag presenterade i punktform nedan (Einarsson & Örbring 2016).

- Inkludera geografi som ett obligatoriskt ämne på det naturvetenskapliga programmet på gymnasiet, vilket innebär att geografi blir ett gymnasiegemensamt ämne (Einarsson & Örbring 2016).
- Inför tydliga geovetenskapliga exempel i skolämnena biologi, fysik, kemi och naturkunskap (Einarsson & Örbring 2016).
- Se över antagningskraven på geovetenskapliga program på universitetsnivå. De elever som idag läser naturvetenskapligt program studerar ingen geovetenskap om de inte har gjort ett tillval av ämnet geografi.
- Utvärdera möjligheterna att utöka den redan befintliga geografin i grundskolan genom att bredda den med mer geologiinnehåll som eventuellt skulle kunna omfatta fältstudier av närmiljön samt material om tidsperspektiv och tidslinjer (för utveckling av elevernas tidsmedvetenhet) framförallt för åk 4–9 (Einarsson ms, b).
- Se över kurs- och ämnesplaner inom geografi och de naturvetenskapliga ämnen för diskussion om integration av tid, tidslinjer och utveckling av förmågan tidsmedvetenhet som en progression från förskola till gymnasieskola baserat på barnens och elevernas förmåga att kunna tänka abstrakt som utvecklas i olika steg under dessa skolår (Einarsson ms, b).
- Fastställa behov av ämnesfortbildning i geologi för geografilärare genom att skapa ett nätverk av lärare och forskare som kan diskutera dessa frågor tillsammans (Einarsson & Örbring 2016). Ämnesfortbildningen som har en nära relation till ämnesdidaktiken kommer ofta i skymundan eftersom annan kompetensutveckling oftast går före (Åkerblom 2016). Undersökningar inkluderade i denna avhandling visar att förskollärare är i behov av samt har en stor efterfrågan av ämnesfortbildning inom det geovetenskapliga ämnesområdet (Einarsson ms, a).

Diskussion och slutsatser

Användningen av den nyutvecklade metoden syfte/mål-tabellen hjälper till att ge en tydlig övergripande struktur över det tematiska och ämnesövergripande arbetet, vilket

skapar trygghet och samsyn i arbetslaget samt tydlighet i dialogen med föräldrar och i samarbetet med förskole- och skolchefer. Syfte/mål-tabellen kan därmed ses som en pedagogisk planering eftersom man med dess hjälp kan dokumentera lärandeprocesser för varje specifikt tema i form av undervisningsmoment, koppling till läroplanen och temats lärandeinnehåll (Einarsson ms, a) där pedagogernas arbetslag tillsammans måste komma överens om vilka förklaringsmodeller och tolkningsramar som ska användas inom det utvalda temat. (Hansson & Löfgren 2016; Redfors 2016). Enligt pedagogerna som deltog i undersökningarna så representerar syfte/mål-tabellen en planeringsform som de gärna fortsätter att använda inom andra ämnesområden och som skulle kunna vara en bra utgångspunkt för förskolans kvalitetsredovisning (Einarsson ms, a).

Att våga lära tillsammans med barnen skapar en enklare väg till naturvetenskap

I de nyutvecklade undervisningsmomenten/aktiviteterna fick barnen möjlighet att på ett variationsrikt sätt möta den naturvetenskapliga forskningen om dinosaurier, fossil och tidsperspektiv men i en form som tar hänsyn till deras intresse och nyfikenhet, förskolans läroplan samt deras vardag och närmiljö. Repetition av övningarna användes för att öppna upp nya perspektiv genom att barnen uppmärksammade nya detaljer vid de olika repetitionstillfällena som vidare kunde byggas ihop till helheter. I de barninitierade lekarna testas de nya begreppen i sitt sammanhang. Barnen på förskolan engagerade även hemmet genom att ta med sig fossil, dinosaurieleksaker och dinosaurieböcker hemifrån vilket gjorde att föräldrarna visade intresse för förskolans temaarbete. Att både förskollärare och hemmet lyssnar in barnens intresse och engagerar sig skapar respekt för barnens nyfikenhet och intresse (Einarsson ms, a).

Förskollärarnas förhållningssätt till barnens intresse och nyfikenhet för dinosaurier förändrades under projektets gång. Genom att erkänna sin okunskap för barnen och istället lära sig ny fakta tillsammans med barnen, skapades nya möjligheter som förändrade förskollärarnas inställning till naturvetenskap. Detta möjliggör i sin tur att de naturvetenskapliga ämnena får en naturlig del i förskolans vardag eftersom de inte längre behöver väljas bort på grund av osäkerhet (Einarsson ms, a). Denna inställning kan vara avgörande för vilken syn barnen får på naturvetenskap i framtiden och vilken naturvetenskaplig grund de bär med sig från förskolan. På så sätt kan barnens intresse och nyfikenhet för dinosaurier som uppmärksammas av förskollärare öppna dörrar till naturvetenskapliga ämnen och arbetssätt, vilket kan göra att naturvetenskap i framtiden fortsättningsvis kan få utgöra något som är roligt, intressant och uppskattat (Tu 2006; Akerson et al. 2011; Eshach 2011).

Progression i utveckling av tidsmedveten för framtida beslutsfattare

En övergripande progression gällande utveckling av elevers tidsmedvetenhet som genomsyrar både de naturvetenskapliga och samhällsvetenskapliga skolämnena hade varit önskvärt (Einarsson & Örbring 2016; Einarsson ms, b). Det geologiska tidsperspektivet är viktigt eftersom mycket av det som förändrar jorden, klimatet och livets utveckling sker över långa tidsperioder där kunskaper om den geologiska tidsskalan spelar stor roll. Jorden är i ständig förändring och liknande scenarion som exempelvis naturkatastrofer, plattektonik, evolution och klimatförändringar återkommer ständigt i jordens historia och kommer även att göra så i framtiden. En överblick av den geologiska tidslinjen kan öka det allmänna ansvarstagandet i viktiga framtidsfrågor som rör klimatförändringar, naturresurser och hållbar utveckling (Einarsson ms, b). På så sätt kan beslutsfattare få upp ögonen för långsiktiga planeringar gällande exempelvis, grundvatten och exploatering av mineraler som inte bara sträcker sig några år framåt i tiden utan även några decennier till århundranden (Kastens et al. 2009). En utvecklad tidsmedvetenhet kan på så sätt leda fram till ökad beredskap, medvetenhet och trygghet om hur samhället och individen ska agera vid klimatförändringar, jordbävningar, tsunami och liknande återkommande händelser i jordens utveckling. Ett förslag är därmed att lägga in en progression gällande elevernas utveckling av tidsmedvetenhet i skolans kurs- och ämnesplaner som blir en ämnesintegration mellan geografiämnet och de naturvetenskapliga ämnena för att samtliga samhällsmedborgare ska få möjlighet att kunna fatta sina beslut utifrån ett omvärldsperspektiv (Einarsson & Örbring 2016; Einarsson ms, b).

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During the Campanian stage of the Late Cretaceous, the northeastern part of Skåne in southern Sweden, today forming the Kristianstad Basin, constituted a subtropical island archipelago inhabited by dinosaurs and pterosaurs, and surrounded by seas teeming with bony fish, sharks, plesiosaurs, mosasaurs, marine crocodiles, and aquatic birds, as well as cephalopods, oysters, sea urchins and crustaceans. This thesis includes ten papers thematically divided into two sections: Part 1 documenting palaeoenvironmental, palaeoecological and palaeobiogeographical aspects of the faunal assemblages; and Part 2 discussing the applications of palaeontological research for preschool to upper secondary school education.

The author, Elisabeth Einarsson, is a geologist specialized in palaeontology trained in the profession at Lund University. She is also a high school science teacher and lecturer in science education trained in the profession at Kristianstad University. She has led field expeditions and supervised master students. In 2016, Elisabeth was accepted as an Excellent Teaching Practitioner (ETP) in the Faculty of Science Teaching Academy.

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