The K–T boundary strata north of Korsnæb, Stevns Klint, Denmark – evolution and geometry revealed in a long, horizontal profile

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A 460 m long profile of the Cretaceous–Paleogene (K–T) boundary strata at Stevns Klint was measured by the late Professor A. Rosenkrantz probably in 1944. The measured profile was inherited by Finn Surlyk around 1974 together with other original boundary data. This material was dug up in a long-forgotten drawer in connection with detailed field work by the co-authors on the boundary succession in the late spring and summer of 2021. The profile illustrates the stratigraphy, geometry and palaeotopography of the boundary strata in unprecedented detail. The part of the cliff illustrated in the profile is today partly covered by beach ridges composed of flint rubble but is situated below the finest section of the lower Danian bryozoan mounds exposed at Stevns Klint. This coastal section is situated immediately adjacent to a large limestone quarry and was planned to be quarried away around 1937, but was saved by A. Rosenkrantz who demonstrated its great scientific and educational value to the authorities.

Keywords: Cretaceous–Paleogene boundary, K–T, K–Pg, Fiskeler Member, Cerithium Limestone Member, palaeotopography, Korsnæb.

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A full description, including a new lithostratigraphy of the Maastrichtian–Danian succession exposed in the 14.5 km long coastal cliff, Stevns Klint (Fig. 1) based on stereo-photogrammetric mapping was provided by Surlyk *et al.* (2006). The nature of the Cretaceous–Paleogene (K–T, K–Pg) boundary which is well exposed in the cliff has a long history of investigation. The boundary succession is rather complex partly due to the development of low bryozoan chalk mounds in the uppermost Maastrichtian Højerup Member. The boundary clay, the Fiskeler Member was only deposited in the small basins between the mounds. It passes upwards into the Cerithium Limestone Member and an erosion surface truncates the top of the Cerithium Limestone and the intervening crests of the Maastrichtian mounds. The layers beneath the erosion surface were lithified to form a complex hardground, comprising the Cerithium Limestone and the top of the Maastrichtian mounds. The true stratigraphic nature of the boundary was first unravelled in a short, seminal paper by Alfred Rosenkrantz in 1924, who in contrast to previous workers distinguished carefully between lithified topmost Maastrichtian and similarly lithified lowermost Danian Cerithium Limestone during fossil collection. He discovered that the two superficially similar rock types contained remarkably different faunas (e.g. Rosenkrantz 1939, 1966) – an early indication of the K–T boundary mass extinction, first clearly recognized many years later (e.g. Alvarez *et al.* 1980, 1984a, b, c and references therein).

A field sketch book inherited by FS after the death of A. Rosenkrantz in 1974 was dug up in a long-forgot-

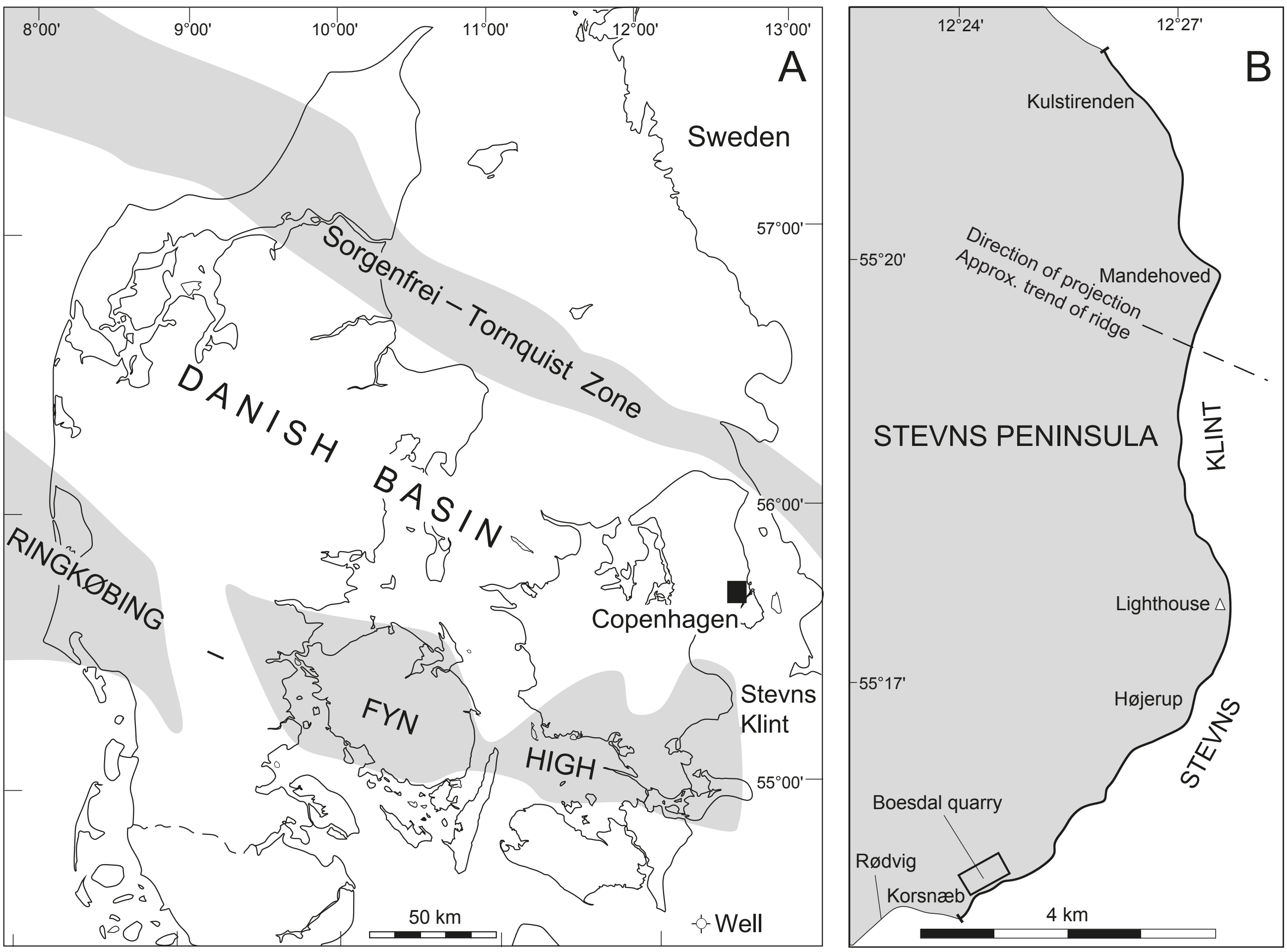


Fig. 1. A: Map of Denmark, showing the major structural elements. From Lykke-Andersen & Surlyk (2004) and Surlyk *et al.* (2006). B. Map of the Stevns peninsula showing important localities along the cliff. The profile measured by Rosenkrantz was measured along the cliff N of Korsnæb. Dashed line indicates the approximate orientation of late Maastrichtian sea floor ridges and valleys identified on seismic data by Lykke-Andersen & Surlyk (2004) and shown in cross section in figure 6.

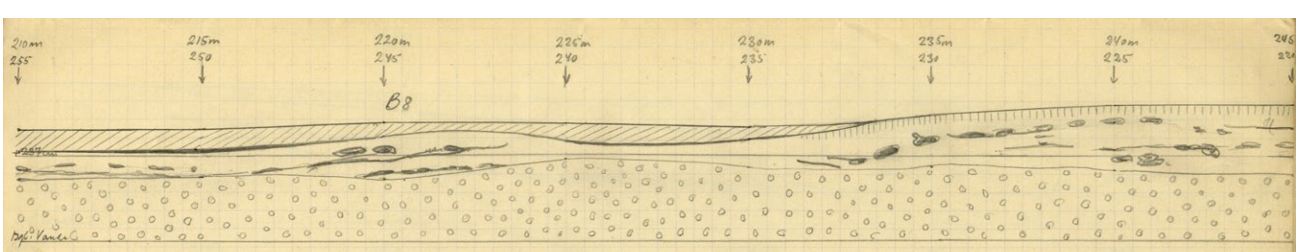
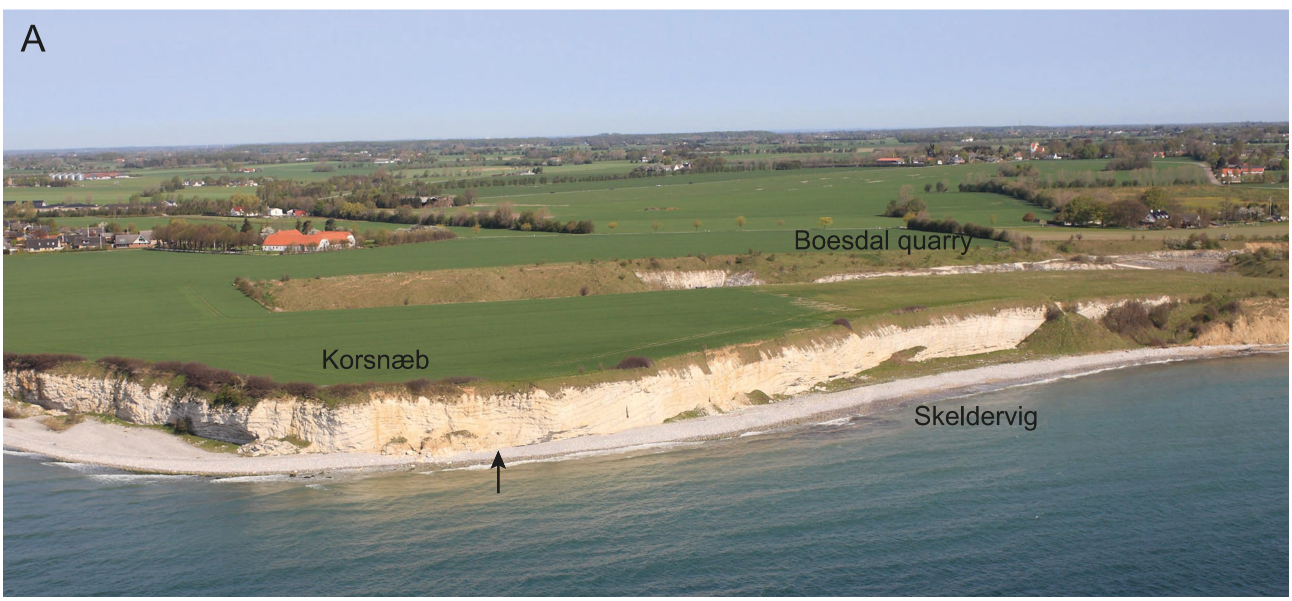


Fig. 2. Example of part of the profile measured by A. Rosenkrantz, probably in 1944.

ten drawer in connection with detailed field work on the boundary strata by the co-authors of to this article (Fig. 2). It contains a 460 m long horizontal profile of the boundary strata measured in great detail by A. Rosenkrantz in a stretch of the cliff from Korsnæb and farther north (Figs 1, 3). It is not indicated in the note book when the profile was measured but the best guess is 1944 where a large block indicated on the profile was excavated for exhibition at the Geological Museum of the University of Copenhagen. Today, the boundary strata are mostly covered by beach ridges composed of flint rubble along the measured stretch of the cliff. The succession is overlain by some of the most well exposed, and easily accessible lower Danian bryozoan mounds exposed along the 14.5 km long cliff (Surlyk 1997) and is visited by numerous researchers, student field trips, amateur palaeontologists and tourists every year. This coastal exposure is situated immediately adjacent to the large Boesdal limestone quarry, and it was only through a thorough demonstration to the authorities by A. Rosenkrantz of the great scientific value of the profile that it was saved from being quarried away.

Stevns Klint became a UNESCO World Heritage Site in 2014 (Damholt & Surlyk 2012), and the exhibition centre highlighting the significance of the boundary strata is at the time of writing under construction in the now abandoned quarry.

The boundary succession has been studied by a large number of workers focusing on foraminifers (Schmitz *et al.* 1992; Hart *et al.* 2005; Rasmussen *et al.* 2005), organic-walled dinocysts (Hansen 1977, 1979; Kjellström & Hansen 1981; FitzPatrick *et al.* 2018), calcareous dinocysts (Leighton *et al.* 2011), coccoliths (Thomsen 1975; Perch-Nielsen 1979a, b, c), bivalves (Heinberg 1976, 1978, 1979a, b, 1989, 1993, 1999b),



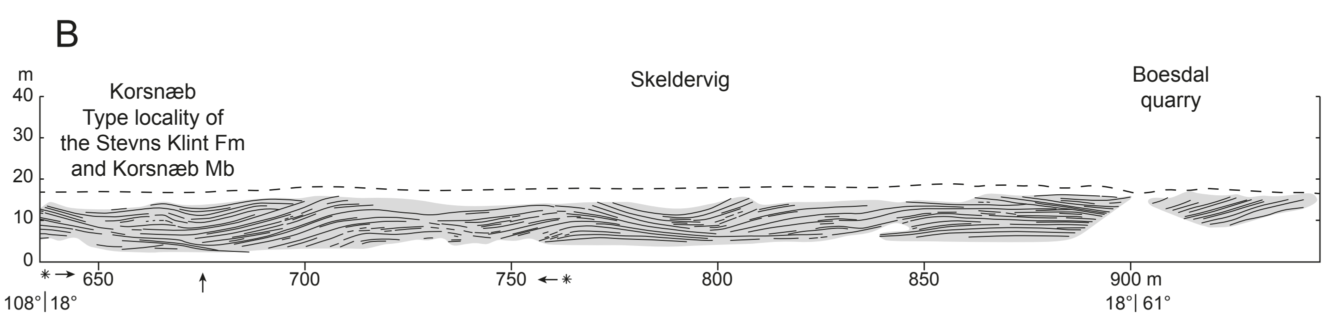


Fig. 3. A: Aerial photograph of the southern part of Stevns Klint showing the position of Korsnæb and the bay Skeldervig where the profile shown in figures 5–7 was measured by A. Rosenkrantz, probably in 1944. The 0 m starting point of the profile is immediately below the word 'Korsnæb'. The K–T boundary strata are exposed at the arrow. It is mainly covered by the beach ridge in the rest of the profile. Photo from Pedersen (2011). **B:** Photogrammetric profile of the part of Stevns Klint where the profile was measured. The southern starting point indicated with an arrow. The profile extends northwards over 460 m, but northern end of the profile is today covered by scree or quarried away.

gastropods (Hansen 2019), brachiopods Surlyk (1979, 1984), ammonites (Birkelund 1993; Surlyk & Nielsen 1999; Machalski & Heinberg 2005), trace fossils (Ekdale & Bromley 1984), inorganic geochemistry including stable isotopes (Christensen *et al.* 1973; Alvarez *et al.* 1980; Schmitz 1985; Schmitz *et al.* 1988, 1992; Elliot *et al.* 1989; Frei & Frei 2002; Hart *et al.* 2004; Drits *et al.* 2004; Gilleaudeau *et al.* 2018) and organic geochemistry (Sepúlveda *et al.* 2009). However, it is remarkable that only very few precise and detailed sections through the succession have been published. Many are misleading or outright wrong and Rosenkrantz' old profile and sections are in our opinion the most precise yet produced and records the nature of the K–T boundary over a long stretch of the cliff in unprecedented detail.

We have thus felt it highly relevant and timely to publish Rosenkrantz' old profile documented with photographs and comments.

Geological setting and stratigraphy

The coastal cliff, Stevns Klint is 14.5 km long, up to 41 m high, and roughly N–S-oriented with an E–W-bend at the southern end from Rødvig to Korsnæb. It is situated over the eastern end of the Ringkøbing–Fyn High which forms the southern border of the Danish Basin (Fig. 1). It was described and illustrated along its length based on stereo-photogrammetric mapping accompanied by a new lithostratigraphic subdivision by Surlyk *et al.* (2006). The Tor Formation of that paper was subsequently changed to the Møns Klint Formation based on a fully cored borehole by Surlyk *et al.* (2013). The stratigraphic evolution across the K–T boundary was unravelled by Rosenkrantz (1924). A detailed subdivision of the boundary clay, the Fiskeler Member of the Rødvig Formation was first established by Christensen *et al.* (1973). Sequence stratigraphic analyses of the succession were presented first by Thomsen (1995) and in more detail by Surlyk (1997).

The succession exposed in the cliff encompasses the following units and key surfaces from below (Figs 4–6; Surlyk 1997; Surlyk *et al.* 2006, 2013):

1. Gently mound-bedded upper Maastrichtian chalk (Surlyk *et al.* 2006; Anderskouv *et al.* 2007), passing upwards into horizontally bedded chalk, both belonging to the Sigerslev Member (Møns Klint Formation) with about 32 m exposed in the cliff.

3. Two incipient hardgrounds 10–25 cm apart, the upper one defining the top of the Sigerslev Member. A prominent band of large black flint nodules occurs 30–50 cm below the upper hardground and forms a clearly visible marker bed along the whole length of the cliff.

4. Up to 4–5 m of bryozoan chalk deposited in low, asymmetric mounds forming the uppermost Maastrichtian Højerup Member, Møns Klint Formation (Svendsen 1975; Surlyk 1997; Larsen & Håkansson 2000). The member thins towards the north and is only about 1 m thick at Kulstirenden at the northern end of the cliff (Fig. 1B).

5. The basal Danian Fiskeler Member (Rødvig Formation) is a mainly 5–10 cm thick clay-marl layer, comprising at least three sublayers (Christensen *et al.* 1973; Ekdale & Bromley 1984; Surlyk *et al.* 2006). It reaches a maximum thickness of 30–45 cm to the north at Kulstirenden. The sublayer of black clay at the base contains the famous iridium anomaly discovered by Alvarez *et al.* (1980). The Fiskeler Member is restricted to the central parts of the basins between the mound crests of the Højerup Member and wedges out towards the basin margins.

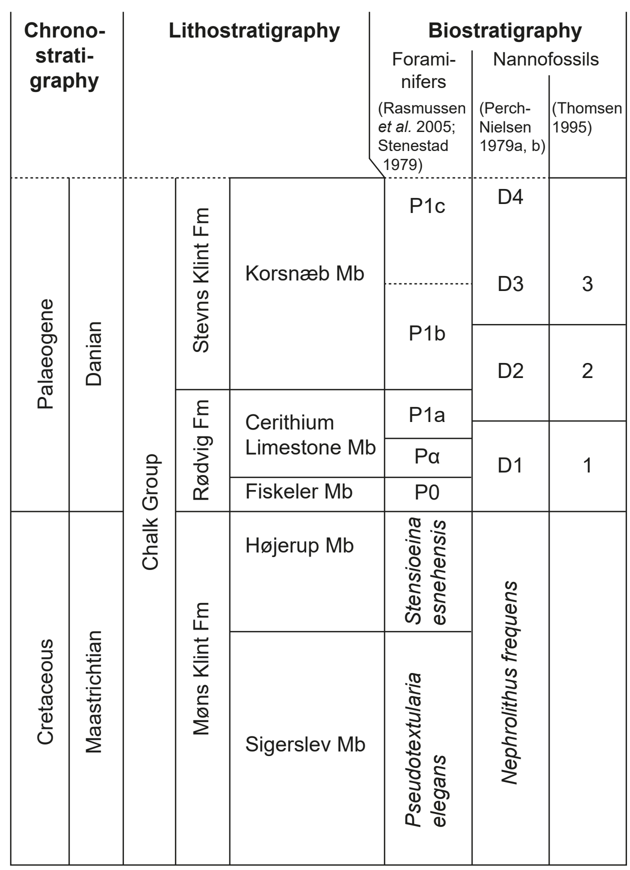


Fig. 4. Stratigraphic scheme of the Cretaceous–Paleogene (K–T) boundary strata at Stevns Klint. The profile measured by A. Rosenkrantz (Fig. 5) includes the top of the Højerup Member, the Rødvig Formation and the lowermost Korsnæb Member. NP 1–4 are standard nannoplankton zones, whereas coccolith zones 1–3 are local zones of Thomsen (1995).

6. The Fiskeler Member passes gradationally or in some case abruptly upwards into the partly cemented, strongly burrowed and up to mainly 30–60 cm thick lower Danian Cerithium Limestone Member, which, however, reaches 80 cm at some basins north of Rødvig and 120 cm at Kulstirenden (Hart *et al.* 2005; Surlyk *et al.* 2006). It oversteps the Fiskeler along the margins of the basins and onlap the basin margins along a shallow-dipping disconformity, separating it from the top of the Højerup Member.

7. The Cerithium Limestone and the intervening cemented crests of the topmost Maastrichtian mounds of the Højerup Member are truncated by a prominent erosion surface along the length of the cliff. The complex hardground topped by the erosion surface is double at the northernmost locality, Kulstirenden where a second minor hardground occurs about 10 cm above the main hardground (probably first recognised by C. Heinberg, quoted by Hart *et al.* (2005) as Heinberg (1999a) but not mentioned in the latter publication). The position of the erosion surface varies from about 5 m below to about 30 m above present-day sea level and forms a series of highs and lows which were earlier interpreted to represent anticlines and synclines formed by post-depositional folding (Rosenkrantz 1937). However, seismic data clearly show that the wavy relief represents the original sea-floor topography formed by persistent WNW-flowing bottom currents (Lykke-Andersen & Surlyk 2004; Surlyk & Lykke-Andersen 2007).

8. The top Cerithium Limestone hardground forms the basis for the growth of prominent lower Danian bryozoan mounds of the Korsnæb Member, Stevns Klint Formation (Figs 3B, 5, 6A) (e.g. Surlyk 1997; Surlyk *et al.* 2006; Bjerager & Surlyk 2007a, b).

Rosenkrantz' profile from Stevns Klint

A detailed 460 m long horizontal profile was measured by Alfred Rosenkrantz probably in 1944 from just north of Korsnæb and northwards along the bay, Skeldervig (Figs 1, 3, 7, 8). Stratigraphically, the profile comprises up to 5 m of Maastrichtian chalk (top Sigerslev Member overlain by the Højerup Member), measured from the daily mean sea level and upwards, but the lowest metres were covered by flint rubble at the time when the profile was measured. The exposed chalk belongs to the mound-bedded, bryozoan-rich Højerup Member. Up to three bands of large black flint nodules occur in the chalk and outlines the mounded geometries of the bryozoan chalk. The upper nodule band is the most prominent and is situated about 1 m below the top Cerithium Limestone erosion surface. In addition, scattered thin sheet flints occur along the length of the profile. The Højerup Member is overlain by the Fiskeler Member, the Cerithium Limestone Member and the lowest metre or so of the Korsnæb Member. The profile includes a total of 13 Fiskeler–Cerithium Limestone basins (B1–13; Fig. 7).

One of the basins, B7 was truncated along the basin margin where the Fiskeler is absent and only Ce-

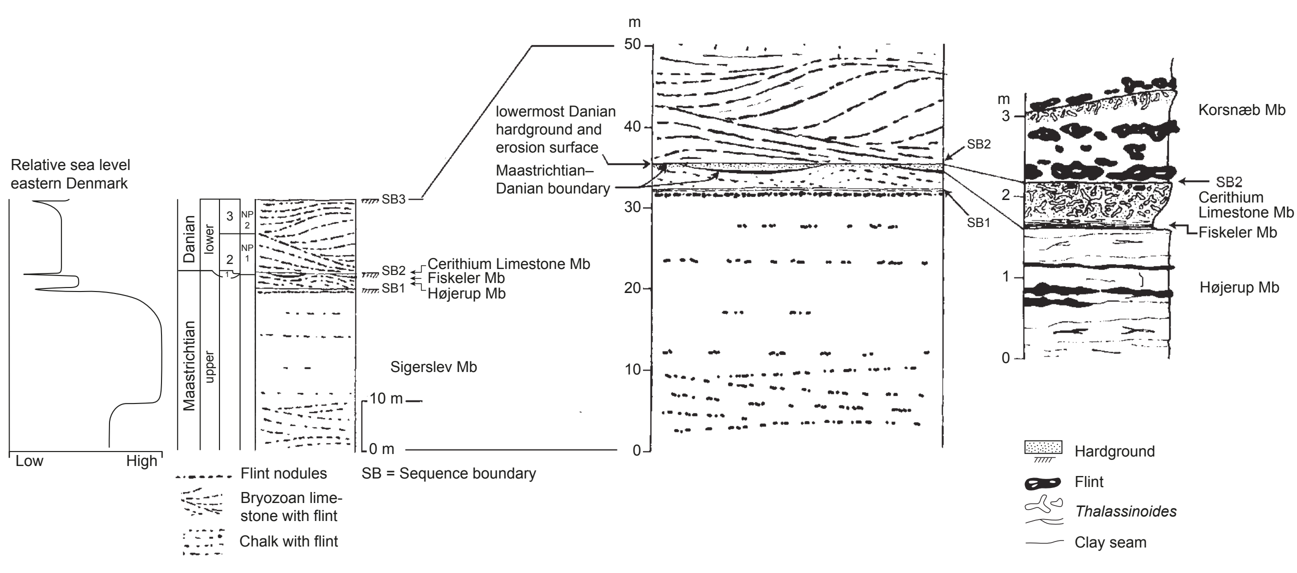


Fig. 5. Schematic sections showing the stratigraphic evolution, sequence boundaries and interpreted relative sea-level curve across the Maastrichtian–Danian boundary at Stevns Klint. The indicated sequence boundaries (SB1–3) are marked by erosion caused by relative sea-level falls. Partly after Surlyk (1997).

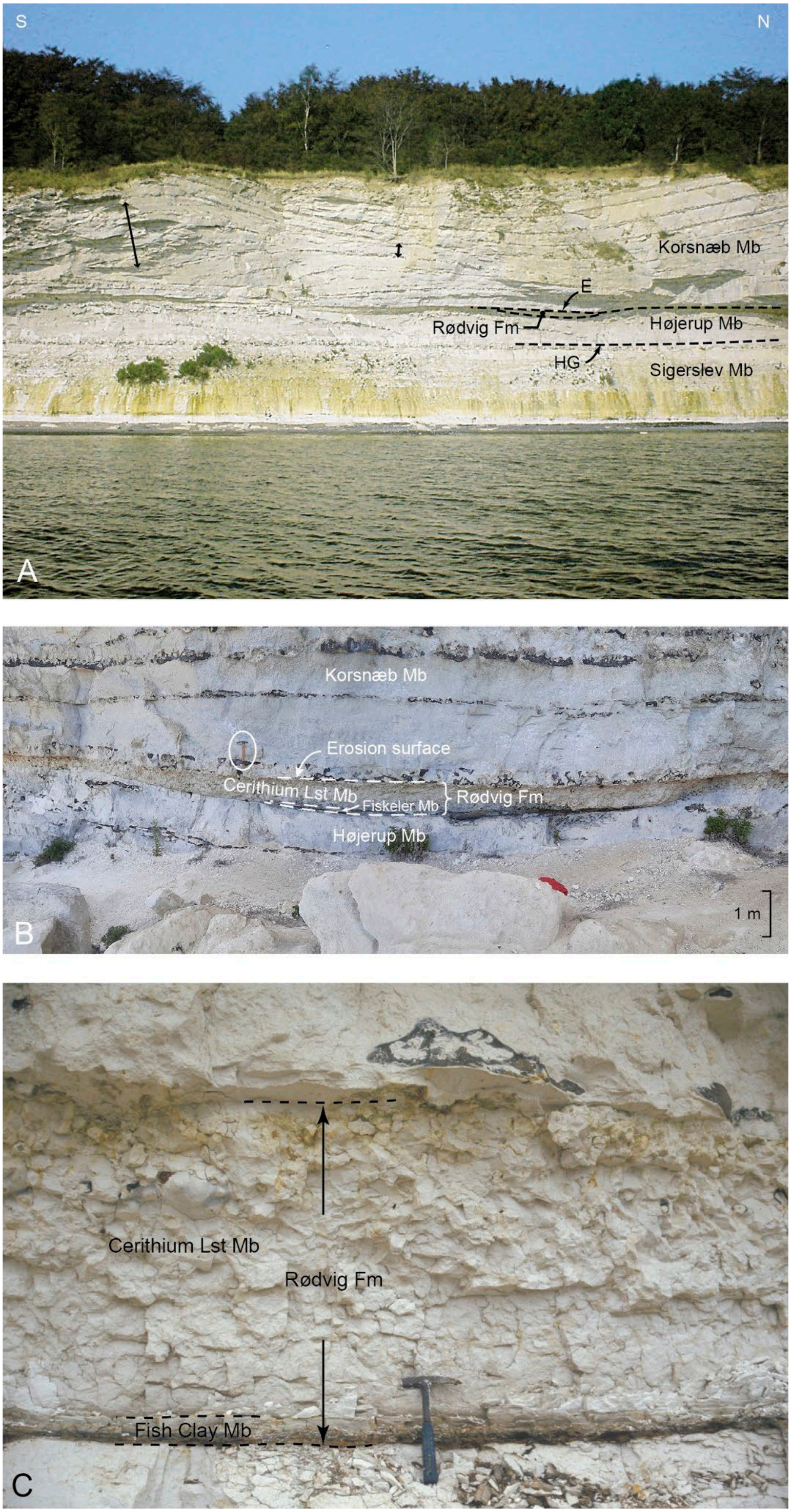
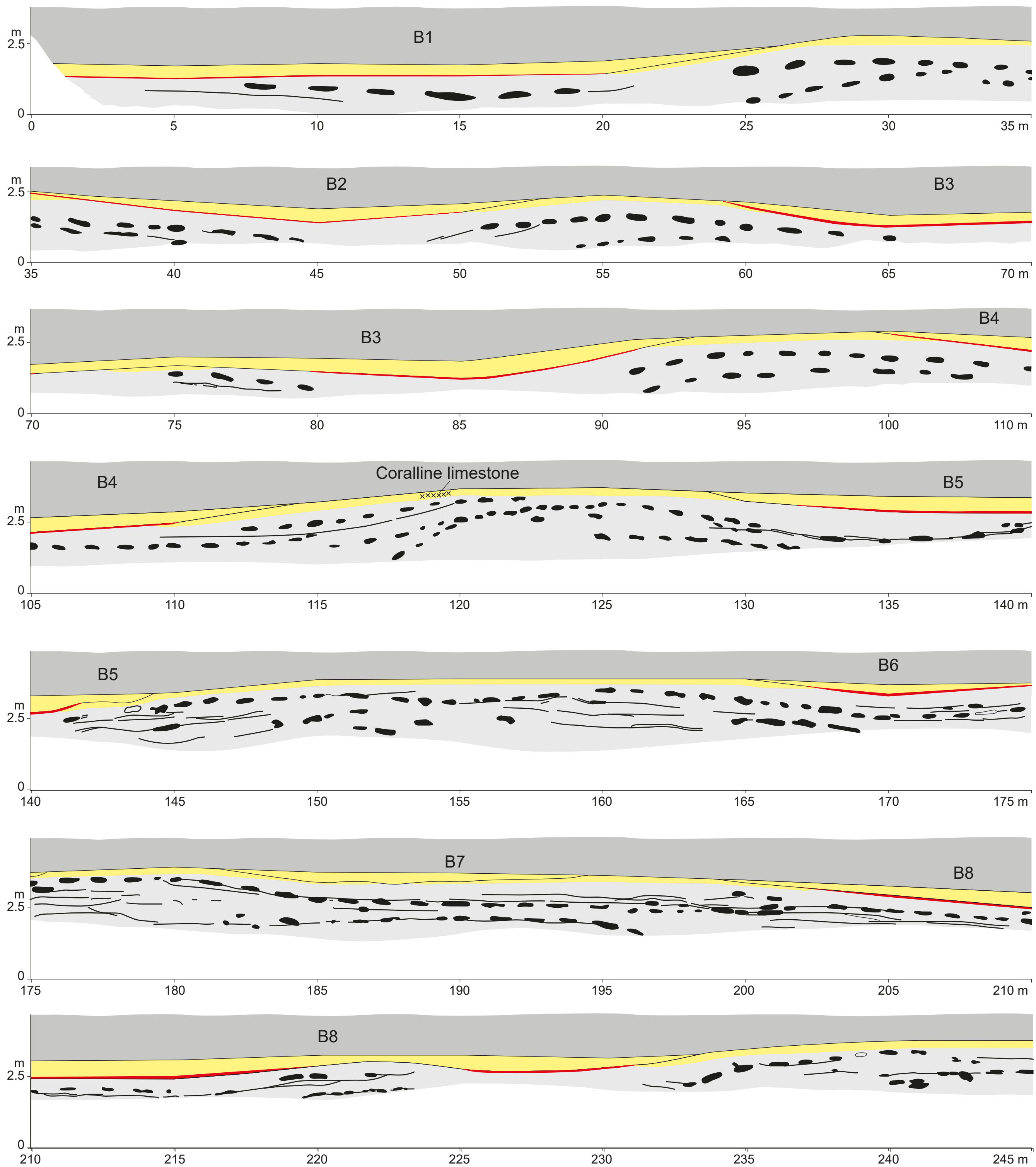


Fig. 6. Photographs of the K–T boundary strata at Stevns Klint (Fig. 1B). **A:** Cliff section showing the stratigraphic units across the K–T boundary north of the old church at Højerup. The Rødvig Formation was deposited in small basins formed between the mound crests of the uppermost Maastrichtian Højerup Member, and includes the lowermost Danian Fiskeler Member overlain by the Cerithium Limestone Member. E indicates the top Cerithium Limestone erosion surface. **B:** The boundary strata immediately south of the old church. Note that the Fiskeler Member wedges out towards the margins of the small basin. **C:** Type locality of the Rødvig Formation west of Korsnæb (Figs 1B, 3) immediately west of the profile measured by A. Rosenkrantz (Fig. 5). The yellow stained top of the Rødvig Formation is the top Cerithium Limestone hardground. Hammer is 33 cm long.



▲▼ **Fig. 7.** The 460 m long horizontal profile measured by A. Rosenkrantz, probably in 1944 in the area from Korsnæb and northwards along the Skeldervig bay (Fig. 1B). The complex hardground (yellow signature) includes the lithified lower Danian Cerithium Limestone and the intervening crests of the mounds in the uppermost Maastrichtian Højerup Member. The erosion surface topping the hardground has a slightly wavy geometry, being lower over the Cerithium Limestone than over the adjacent top Maastrichtian mounds, partly reflecting compaction of the Fiskeler Member.

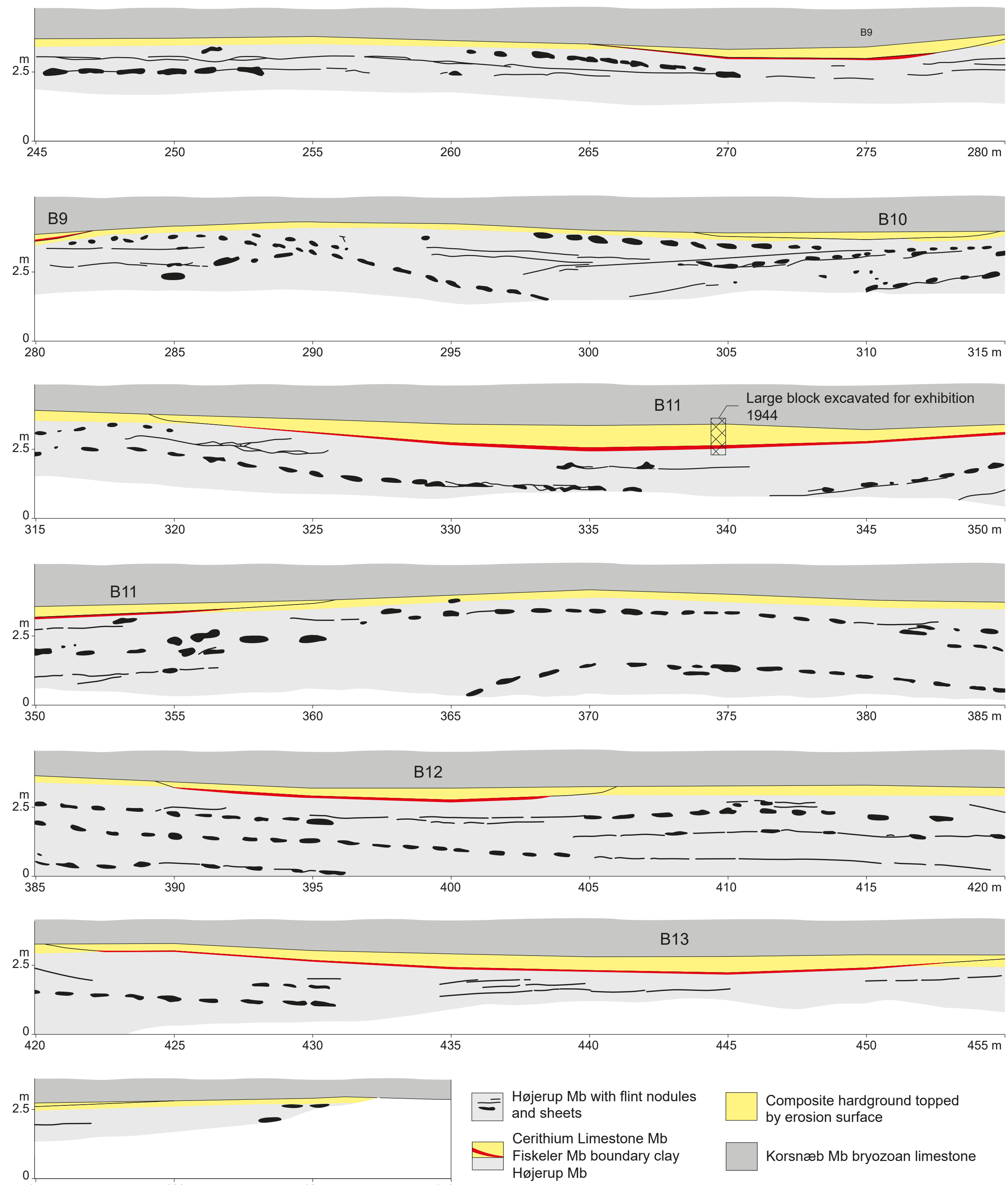


Fig. 7. Continued from previous page.

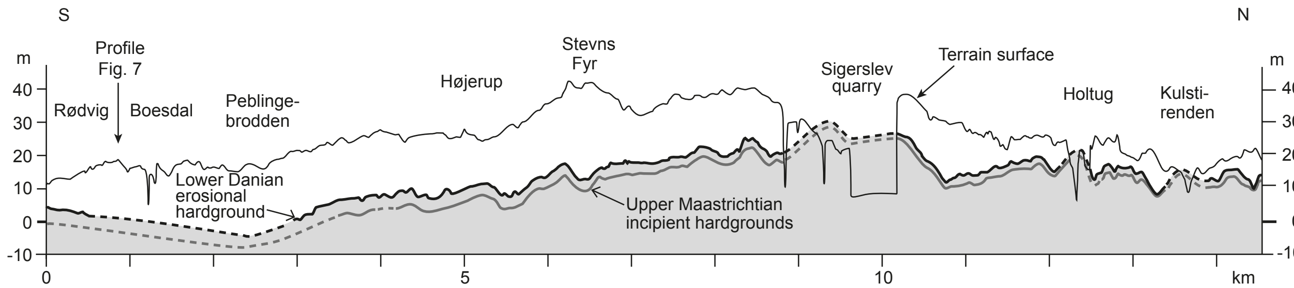


Fig. 8. Profile of Stevns Klint showing the present-day land surface and the position of top Cerithium Limestone erosion surface. The location of the profile described here (Fig. 7) is indicated with an arrow. Modified from Surlyk *et al.* (2006).

rithium Limestone is exposed in this section. Another basin, B8 is subdivided into two sub-basins by a low bryozoan mound, which probably was cut laterally to the culmination of the crest.

The height of the base of the Fiskeler varies between 1.3 and 2.5 m above daily sea level and the top of the erosion surface truncating the Cerithium Limestone and the top of the Maastrichtian mounds varies in height between 1.8 and 3.9 m. The erosion surface reaches its lowest position at 1.8 m above sea level at the 5 m mark at the southern start of the profile and the highest at the 370 m mark in the northern end (Fig. 7). It is in general situated at a lower level above the Cerithium Limestone than above the bryozoan chalk of the Højerup Member, probably reflecting the greater erodibility of the Cerithium Limestone than the cemented crests of the Maastrichtian chalk mounds and compaction of the Fiskeler Member. The amplitude of the erosion surface reaches 2.1 m even over the relatively short distance of 460 m. This should be compared with the maximum amplitude of about 35 m along the 14.5 km long cliff as seen in the long profile of Surlyk *et al.* (2006). The erosion surface in the present profile occupies a position close to the main valley formed by bottom currents in the top Maastrichtian chalk surface (Fig. 8). The profile of Rosenkranz (Fig. 7) thus illustrates important aspects of the K–T boundary at Stevns Klint and is in our opinion the most detailed section measured at the whole length of the cliff. It is thus not only of historical interest but shows the nature of the boundary over a long stretch in unprecedented detail.

Conclusions

- A detailed, 460 m long profile covering the K–T boundary strata north of Korsnæb in the southern part of Stevns Klint was measured by the late Alfred Rosenkrantz probably in 1944.
- The boundary strata include mounded bryozoan chalk of the uppermost Maastrichtian Højerup Member, the lowermost Danian Fiskeler and Cerithium Limestone Members and the mounded bryozoan limestone of the lower Danian Korsnæb Member.
- The profile shows 13 Fiskeler basins and intervening cemented mound crests of the Højerup Member.
- One basin is exposed in a basin margin position, where the Fiskeler is absent and the section thus only exposes the Cerithium Limestone.
- Another basin is double as it is subdivided into two by a mound which appears to have been cut marginal to the crest in the measured profile.
- The amplitude of the erosion surface truncating the Cerithium Limestone and the intervening mound crests is 2.1 m with the lowest position at the southern end of the profile.
- The erosion surface cuts deeper into the Cerithium Limestone than over the Højerup Member.
- The amplitude of the erosion surface along the whole 14.5 km length of the cliff is about 35 m, reflecting the action of a persistent WNW-flowing bottom current system which sculpted the top Maastrichtian surface into large valleys and ridges.
- The profile occupies a position in the deepest valley formed by late Maastrichtian bottom currents.

Acknowledgements

This paper is dedicated to the memory of the eminent geologist and palaeontologist Alfred Rosenkrantz, who in 1924 was the first to unravel the complicated stratigraphic relations around the K–T boundary at Stevns Klint. We thank Jette Halskov for drafting and reviewers Anne Mehlin Sørensen and Henrik Tirsgaard for careful reading of the manuscript.

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