Geology of the Lower Cretaceous in the Falkebjerg area, Wollaston Forland, northern East Greenland

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New data on the Lower Cretaceous Falskebugt Member (Palnatokes Bjerg Formation) and Stratumbjerg Formation in easternmost Wollaston Forland, northern East Greenland, are interpreted here. The type locality of the Falskebugt Member on the north-west corner of the Falkebjerg ridge has been revisited, and additional new good exposures were found in a riverbed just north of Falkebjerg and more in river beds on the plain further to the north, where both the Falskebugt Member and the Stratumbjerg Formation are exposed. Previously, only a limited marine fauna was reported providing a restricted middle Valanginian age of the Falskebugt Member. New fossil faunas in other parts of the Falskebugt Member suggest an early Valanginian – Hauterivian age and confirm lateral correlation with the Albrechts Bugt and Rødryggen Members of the Palnatokes Bjerg Formation. However, in places where the Falskebugt Member is exposed in contact with the lower Stratumbjerg Formation, dinoflagellate cysts from these units indicate Barremian and late Barremian ages, respectively. The stratigraphic range of the combined biostratigraphic data from the Falskebugt Member indicates an early Valanginian – late Barremian age. Dinoflagellate cysts from part of the assemblage in the Stratumbjerg Formation suggest a marginal marine/brackish water depositional environment. Comparable depositional environments are also recorded in upper Barremian sediments on Store Koldewey and in the Ladegårdsåen Formation on Peary Land much farther to the north in Greenland. The dark mudstones of the Stratumbjerg Formation show no potential for generation of liquid hydrocarbons, and the immature and poorly sorted sediments of the Falskebugt Member have little potential as a petroleum reservoir.

Keywords: Stratigraphy, ammonites, dinoflagellate cysts, geochemistry, Falskebugt Member, Stratumbjerg Formation, Cretaceous, East Greenland

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The Cretaceous basins in East Greenland contain a sedimentary succession up to several kilometres in thickness. The basins extend for more than 500 km from south to north and are exposed in a number of fault blocks (Maync 1949; Bütler 1957; Donovan 1957). The Wollaston Forland area was heavily rifted, starting in the Middle Jurassic and culminating in the Middle Volgian when fault blocks were tilted and half-grabens subsided rapidly (Vischer 1943; Surlyk 1978). The Middle Volgian – Ryazanian basin infill of coarse clastic rift deposits were draped by thin, fine-grained Valanginian–Hauterivian late syn-rift/early post-rift deposits as the block crests were submerged. These sediments are referred to the Palnatokes Bjerg Formation (Surlyk 1978).

Petroleum-geological studies of the Wollaston Forland half-grabens in 2006 and 2010 included two fully cored drill holes. A 234 m deep core was drilled at Rødryggen (Hovikoski *et al.* 2010) and another 225 m deep, cored borehole was drilled on the south-western side of Bern Plateau, Brorson Halvø (Hovikoski *et al.* 2011) (Fig. 1). The two holes penetrated the fine-grained members of Palnatokes Bjerg Formation, Albrechts Bugt and Rødryggen Members which are stratigraphically correlated with the Falskebugt Member farther towards the east. The Brorson Halvø core includes the lowermost Stratumbjerg Formation which everywhere rests on the Palnatokes Bjerg Formation, e.g. on the Rødryggen Member at Rødryggen and south-west Brorson Halvø, and on the

Falskebugt Member in the Falkebjerg area. Both cores provide detailed stratigraphic analyses for correlation.

Encouraged by the better age constrains on the sedimentary rocks from the drilling of the Brorson Halvø-1 core in 2010, this study of the equivalent sediments was undertaken in the Falkebjerg area approximately 10 km away from the drill site. The study area represents the most easterly distribution of the Palnatokes Bjerg Formation at the eastern limit of a half-graben basin, where the crest of the tilted fault block is exposed (Fig. 1). The objective of the study was to investigate the eastern margin of the Wollaston Forland Subbasin and to interpret the ages and depositional environments in a petroleum geological context.

Geological setting and history of investigation

The Falskebugt Member of the Palnatokes Bjerg Formation (Surlyk 1978) was first described as the Falskebugt Beds by Maync (1949), accompanied by a sketch of the valley north of Falskebugt (west of Falkebjerg), which indicates sediment exposures of Valanginian and Aptian age as well as Tertiary basalts (Maync 1949, fig. 14, p. 57). Maync (1949) dated the Falskebugt Beds to the middle Valanginian (now early Valanginian) based on a relatively rich fauna, which he recognised throughout the region (Fig. 2). Surlyk (1978) selected the same locality on the western flank of Falkebjerg as type locality for the Falskebugt Member (Fig. 3A). The Falskebugt Member comprises coarse, siliclastic rocks and seems to constitute an isolated occurrence in the basin, its counterpart to the west being the likewise coarse, siliciclastic Young Sund Member (Surlyk 1978). Despite their apparent similarities, the Falskebugt and Young Sund Members differ in their tectonic setting (Surlyk 1978). Falskebugt Member was apparently sourced from the crest of the eastern boundary fault and was deposited westwards down-slope from the basement ridge, whereas the Young Sund Member originated from the block crest of the western boundary fault and the adjacent hinterland and was deposited eastwards (Surlyk & Korstgård 2013). The Albrechts Bugt Member is the fine-grained age equivalent to the two mentioned coarse-grained members on each side of the basin (Surlyk 1978). The Albrechts Bugt Member is overlain by the Rødryggen Member (Surlyk 1978), which was accordingly considered to be the youngest of the four members of the Palnatokes Bjerg Formation (Fig. 2). The boundary between the Albrechts Bugt and Rødryggen Members appears also to represent the boundary between the Valanginian and Hauterivian in Wollaston Forland (Alsen & Mutterlose 2009; Pauly *et al.* 2010). Surlyk (1978, plate 9) indicated the presence of mudstones referred to the Upper Jurassic Bernbjerg Formation in the southern part of the valley, suggesting that such rocks could underlie the Falskebugt Member.

The northern extension of the valley between Falkebjerg (to the east) and Bern Plateau, (the plateau with Eocene basalts to the west, Fig. 1) runs subparallel to Claveringstrædet ('stræde' is Danish for strait) to the east, from which it is separated by the Falkebjerg ridge, a narrow ridge of Caledonian basement rocks referred to the Nathorst Land Group (e.g. Pedersen *et al.* 2013). To the west, the valley is bordered by steep slopes of Lower Cretaceous shales referred to the Stratumbjerg Formation by Bjerager *et al.* (2020), capped by Eocene basalts (Larsen *et al.* 2014). The Falkebjerg ridge is S–N oriented, c. 3 km long, extending from Falskebugt and to the north, where it terminates and the valley opens in a broad low-lying plain stretching from the slopes of the Bern Plateau to the coast along Claveringstrædet (Fig. 1C). The plain is incised by shallow rivers running generally in west-to-east direction from the steep hillsides towards the sea. The bay Falskebugt cuts the basement ridge and the valley towards the south (Fig. 1B).

The valley west of the Falkebjerg ridge is referred to as 'the valley' and the plain north of Falkebjerg is referred to as 'the plain' in the following text.

Field work

The area on the eastern side of Brorson Halvø has not been much visited by geologists, probably due to its remoteness and the few, mainly poor, exposures. During field work in 2010, two of the authors (SP and JBK) studied the area around the valley west of Falkebjerg and north of Falskebugt (Fig. 1). 'Falkebjerg' is Danish for falcon mountain and 'Falskebugt' is 'false bay'. The limited exposures are widely scattered throughout the valley and in the plain north of the valley, mainly in stream cuts. The continuation of the valley on the southern side of Falskebugt was not visited, but Maync (1949) reports similar strata with a relatively rich fauna there. Further field work in 2018 (PAL) at the type locality of Falskebugt Member added a new collection of marine fossils despite extensive snow cover in the area.

Stratigraphy

Caledonian basement rocks

The basement ridge forming the summit of Falkebjerg and the eastern margin of the valley consists of weathered metasediments and gneiss (Fig. 3A). The metasediments are conglomeratic with well-

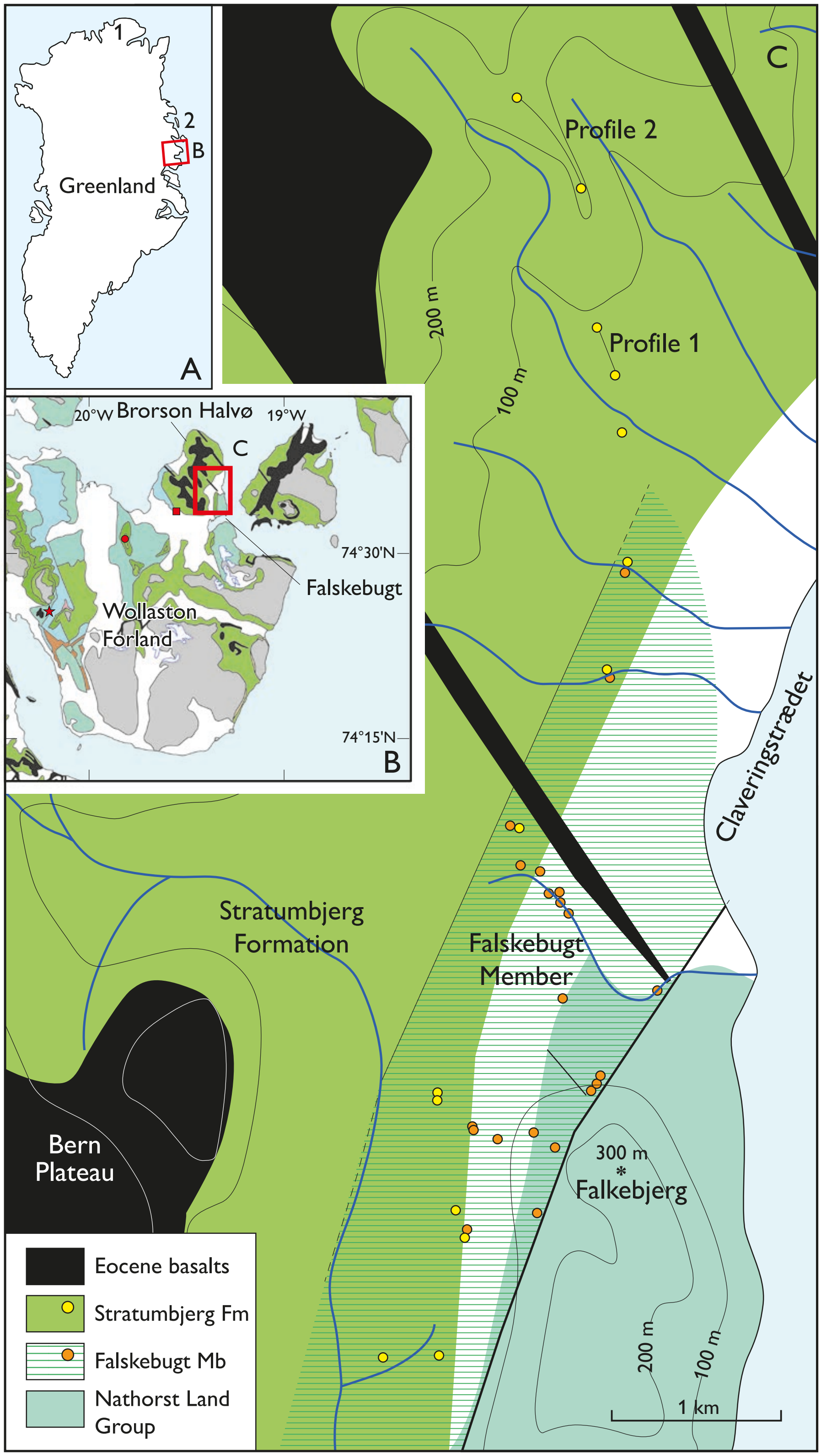

Fig. 1. A: Simplified map of Greenland showing the position of Wollaston Forland in northern East Greenland (Map B). Number 1 indicates the position of Peary Land and number 2 the island Store Koldewey. **B**: Geological map of Wollaston Forland (Pedersen *et al.* 2013); C indicates the study area. The Brorson Halvø-1 drill site is marked with a red square, the Rødryggen-1 drill site with a red circle and Stratumbjerg with a red star. **C**: Geological map of the Falkebjerg region with samples/localities of Falskebugt Member (orange) and Stratumbjerg Formation (yellow). Profile 1 and 2 are marked by top and bottom samples connected by thin lines. The green hatching shows the recorded extent of the Falskebugt Member; the type locality at Falkebjerg is indicated with a thin black line.

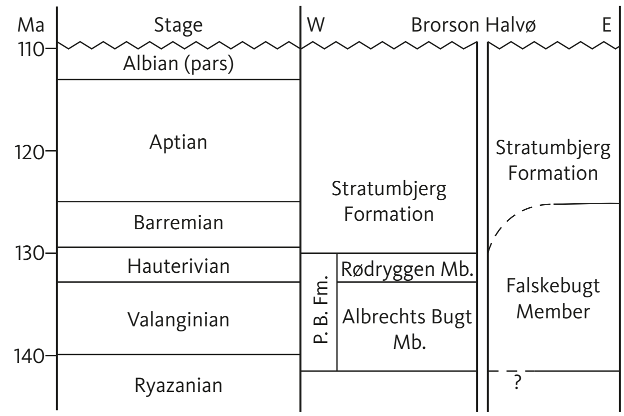

Fig. 2. Stratigraphic scheme of the Lower Cretaceous of Brorson Halvø, from the Brorson Halvø-1 core drilling site in the west to the Falskebugt area in the east. International Commission on Stratigraphy 2019 time-scale. P.B. Fm: Palnatokes Bjerg Formation.

rounded clasts of quartzite generally up to 20 cm in size and also clasts of other lithologies. Weathered metasediments can be recognised at a distance on the hillside of Falkebjerg by a strong yellowish colour and are at first sight indistinguishable from the conglomerates of Falskebugt Member. However, the conglomerates are buff rather than yellowish in colour, and a close inspection of the two contrasting lithologies using a handlens reveals a clearly metamorphic cement texture with intergrown quartz grains in the metasediments, whereas the Falskebugt Member conglomerates show a clear sedimentary cement texture with individual rounded quartz grains cemented by a whitish cement of unknown composition. Similar reworked quartzitic clasts are reported from Devonian to Cretaceous sediments in East and North-East Greenland Basins (e.g. Bütler 1957).

Alleged Bernbjerg Formation

Pyritic, laminated mudstone referred to the Jurassic Bernbjerg Formation by Surlyk (1978) occurs in several 1–2 m high erosional cuts in the banks of shallow streams in the southern valley floor. The mudstone is exposed only 20 m from where the slope of the basement ridge meets the valley floor, but the sedimentary contact was not observed. However, all collected mudstone samples were of Early Cretaceous age and are accordingly referred to the Stratumbjerg Formation (Figs 2 and 4E–F).

Falskebugt Member, Palnatokes Bjerg Formation

Outcrops of the Falskebugt Member are prominent on the north-western flank of the basement ridge in the northern part of the valley and continue into the basin north and west of the ridge (Fig. 1).

The sediments on the ridge include coarse conglomerates with a matrix of unsorted, angular gravel, sand and apparently kaolinised material (Fig. 3E). The clasts comprise well-rounded quartzite cobbles up to 20 cm derived directly from the underlying metasediments. Locally, trough-, cross- and planar-bedding appear in gravel and coarse-grained sand (Fig. 3C–D). The sediments can be followed up the basement flank, and a saddle-shaped erosional platform between sediments and basement marks the top of the exposures (Fig. 4A). The highest-lying sediments consist of fine-grained sand with bright red and yellow colours, very similar to the weathering colours of the partly contemporaneous Albrechts Bugt and Rødryggen Members (Fig. 4A).

A roughly NW–SE transect through the Falskebugt Member is exposed in a shallow riverbed north of the most prominent part of the basement ridge, where the ridge decreases in height from approximately 300 m to a few tens of metres above sea level. Beds of coarse-grained sandstone are well exposed. Mudstones are locally present and mobile due to solifluction, hence their stratigraphic position in relation to the sandstones is not always clear (Fig. 4C–D).

Towards the west, Cretaceous mudstones of the Stratumbjerg Formation overlie the Falskebugt Member and cover the westernmost exposures of Falskebugt Member sandstone. Due to heavy solifluction, fluvial erosion and redeposition, details of the distribution of mudstone is somewhat uncertain.

The most distal facies of the Falskebugt Member towards the west consists of planar-bedded, fine-grained, well-sorted sandstone with angular grains. The beds strike 54–60° and dip 9–11° NW. Horizontal burrows are common together with clay flasers (Fig. 3B–C). Towards the east, conglomerates with a matrix of immature gravel and with pebble-sized clasts suggest more proximal facies. Trough-cross-bedded conglomerates with beds more than 1 m thick, and with foresets 5–10 cm thick, appear a short distance farther east (Fig. 3D). Some of the clasts are larger than the thickness of the foresets, approximately 10–20 cm (Fig. 3E).

Clast-supported conglomerates with quartzitic clasts consistently 10–20 cm large become the dominant lithology towards the east and may be the basal strata of Falskebugt Member (Fig. 4C). In addition, a few clasts occur that consist of other rock types, including dark carbonate and gneiss. Near the base

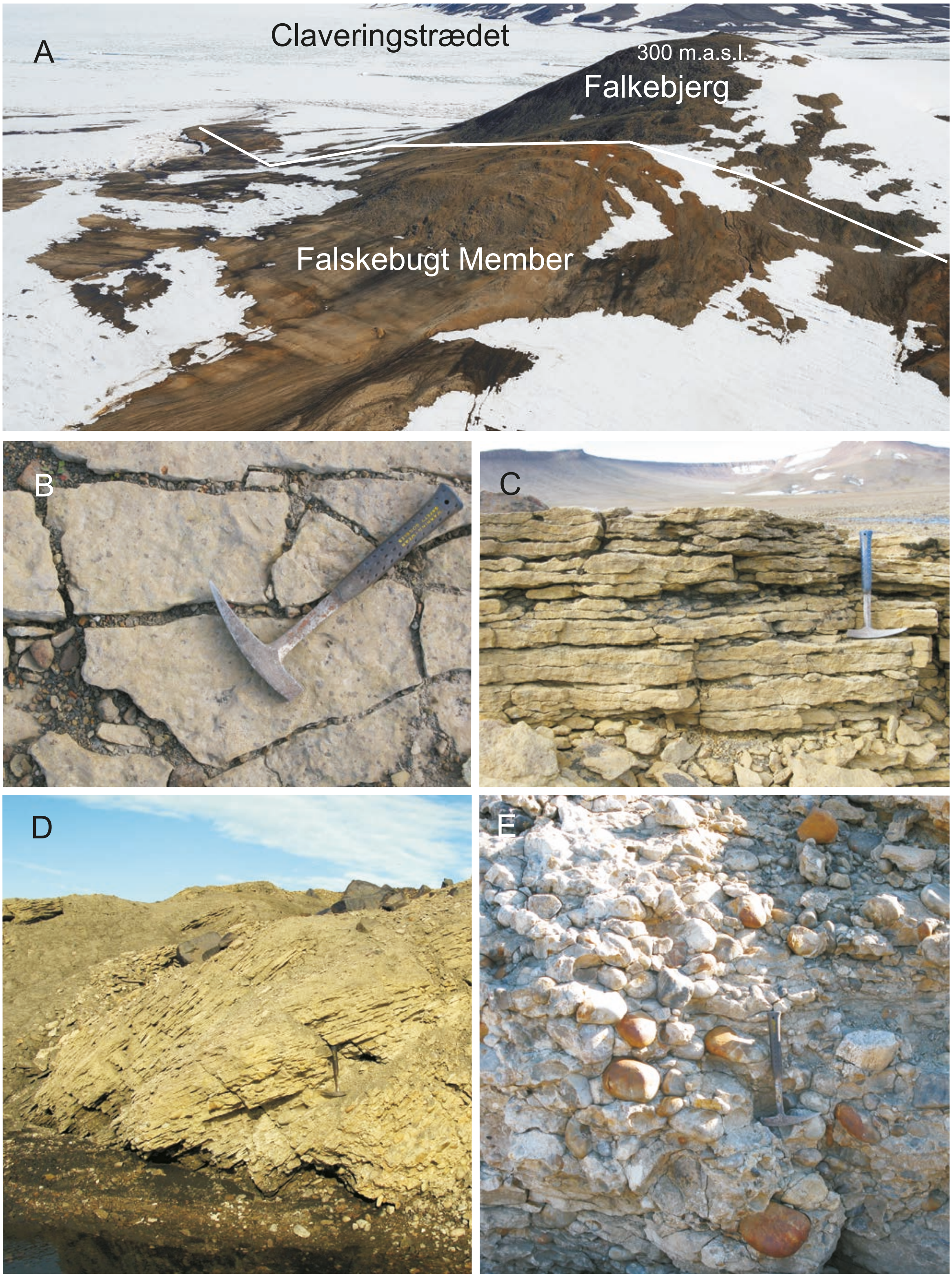

Fig. 3. A: Aerial view of the western flank of mount Falkebjerg with the onlapping Falskebugt Member: the type locality of the member. The approximate basis of Falskebugt Member is marked with a white line. **B** to **F**: Photographs of the Falskebugt Member at the stream north of the type locality. Hammer 32 cm long for scale. **B**: Distally deposited Falskebugt Member sandstone bed, few centimetres thick, on Stratumbjerg Formation mudstone (not visible on the photo). **C**: Distally deposited, stacked thin sandstone beds of Falskebugt Member. **D**: Large-scale, cross-bedded, pebbly sandstone of Falskebugt Member. **E**: Proximally deposited, clast-supported conglomerate of Falskebugt Member.

of the member, a few deformed mudstone rip-up clasts appear in medium-grained sandstone between conglomerates (Fig. 4D). At another locality, three successive, dark mudstone beds of approximately 0.5 m thickness, and laterally thinning, appear to be *in situ.*

The contact with the basement is exposed downstream along the stream banks. The basement is weathered and shows strong yellow colours similar to those observed on the flank of Falkebjerg. The outcrops terminate at a minor, roughly SE–NW trending dyke, 2–4 m across. Farther downstream, the riverbed and banks are covered by ice.

Due to the scattered nature of the outcrops it was not possible to carry out reliable measurements of palaeocurrent directions, but a general assessment suggests overall directions towards the west and north-west.

Macroscopic marine fossils are found in the Falskebugt Member on the north-west flank of the Falkebjerg ridge and in the northernmost Falskebugt Member on the plain. Silicified tree trunks with branches occur in conglomerates in an approximately 30 m thick succession on the northern flank of the ridge (Fig. 4B). Coalified branches and abundant leaves are accumulated in the top layers of some mudstones.

Stratumbjerg Formation

The type section of the Stratumbjerg Formation is located on mount Stratumbjerg in south-western Wollaston Forland (Fig. 1B), where the lower boundary is well exposed. Dark grey, silty to sandy mudstones with common sideritic concretions dominate the formation (Bjerager *et al.* 2020) and occur widely in the coastal regions of East and North-East Greenland (Donovan 1957; Bjerager *et al.* 2020). The Brorson Halvø-1 core was drilled in the lower Stratumbjerg Formation *c.*10 km west of the Falkebjerg area (Hovikoski *et al.* 2011). Here, the Albrechts Bugt and Rødryggen Members of respectively Ryazanian – Valanginian and Hauterivian ages are overlain by the basal Stratumbjerg Formation of late Hauterivian – Barremian age based on dinoflagellate cysts (Fig. 2) (Hovikoski *et al.* 2011).

West of the Falkebjerg area, cliffs more than 300 m high are preserved against erosion beneath a top cover of sills or plateau basalts. The mudstone in most of the cliffs, in the valley floor and on the plain towards the Falkebjerg ridge and the coast are referred to the Stratumbjerg Formation (Figs 1 and 4E–F). Shallow streams cut into the plain between the cliffs and the coast and expose mudstone and sandstone. These mudstones have somewhat blocky weathering forms and seem to be richer in sand and silt compared to the shales of the Bernbjerg Formation found further to the west on Wollaston Forland. Conspicuous yellow concretions often pave low-angle surfaces of weathered mudstone. However, discrimination between Bernbjerg Formation and Stratumbjerg Formation relies mostly on biostratigraphy because the units cannot be unambiguously distinguished in the field. Hence, a number of mudstone samples were collected for dating (Fig. 4E).

The most accessible, continuous exposure of the Stratumbjerg Formation in the study area is present in the northern part of the plain along its western margin, where selected parts of the succession were sampled for stratigraphical and geochemical analyses (Figs 1 and 4E–F).

Material and methods

Forty-two fine-grained samples were collected in the Stratumbjerg Formation in the valley floor west of Falkebjerg and on the plain north of Falkebjerg, for palynological and geochemical analyses of the mudstones (Fig. 1C). A further 21 samples were collected in conglomerates, sandstones and mudstones of the Falskebugt Member exposed on the north-west corner of Falkebjerg and north of Falkebjerg (Fig. 1C). Macrofossils were recovered from some of these samples.

The fossiliferous material was prepared manually, and the fossils were identified. Fine-grained material was prepared palynologically and analysed for dinoflagellate cysts.

The palynology samples were prepared following a standard protocol including treatment with hydrochloric acid (HCl), hydrofluoric acid (HF), oxidation with nitric acid (HNO3) and heavy liquid separation. At each preparation step, a slide was inspected to follow the process closely, and finally the organic residue was passed through a 21 μm filter, and for some samples 30 μm, to concentrate palynomorphs in samples poor in dinoflagellate cysts. The residue was swirled and mounted on glass slides using a glycerine jelly medium. The dinoflagellate cyst content was analysed using a normal light microscope. The dinoflagellate assemblages are referred to the dinoflagellate stratigraphy of Nøhr-Hansen *et al.* (2019). The illustrated fossils are deposited at the Natural History Museum of Denmark and identified by MGUH numbers.

Total Carbon (TC, wt%), Total Organic Carbon (TOC, wt%) and Total Sulphur (TS, wt%) were determined by combustion in a LECO CS-200 induction furnace. TOC was measured after elimination of carbonate-bonded carbon by prolonged HCl treatment. Rock-Eval-type pyrolysis was carried out using a Source Rock Analyzer (SRA) instrument, manufactured by Humble Instruments and Services. Calibration was done using

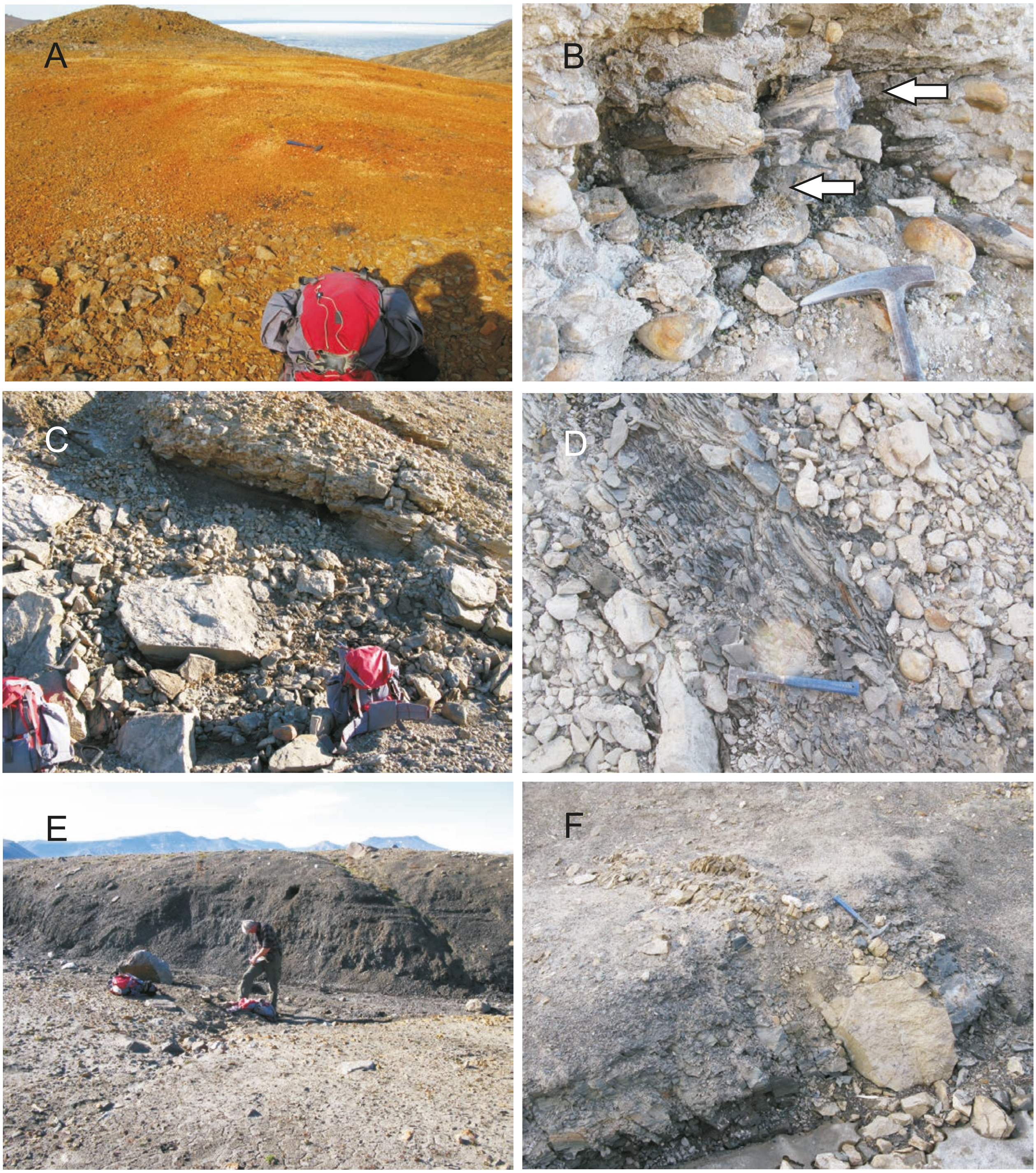

Fig. 4. Photographs of the Falskebugt Member (A–D) and the Stratumbjerg Formation (E–F). Hammer 32 cm long for scale. **A**: The topographically highest exposure of Falskebugt Member at Falkebjerg: fine-grained sandstone with vivid colours. **B**: Cobble conglomerate with silicified tree trunks marked by arrows. **C–D**: Dark mudstone and sand interbedded with conglomerates, probably large mudstone rip-up clast. **E**: Dark mudstone of the lower Stratumbjerg Formation north of Falkebjerg. **F**: Sandstone dyke in dark mudstone of the Stratumbjerg Formation in the valley floor west of Falkebjerg.

the IFP-160000 standard with sets of one blank and one in-house control standard being run for every 10 samples to ensure instrument stability.

Results

Palynology

Fossil dinoflagellate cysts are recorded in two samples of fine-grained sandstone from the Falskebugt Member, whereas all other samples are barren or only contain degraded sporomorphs together with black woody material. Sample no. 523259 is from the valley north-west of Falkebjerg where the most distal part of Falskebugt Member interfingers with black mudstone of the Stratumbjerg Formation (Fig. 3B). Sample no. 523254 is from the plain north of Falkebjerg where Falskebugt Member occurs associated with dark mudstone of the Stratumbjerg Formation.

The valley and the area north-west of Falkebjerg

Sample 523259. The Falskebugt Member is characterised by an *Oligosphaeridium complex*, *Pseudoceratium pelliferum* and *Stephanelytron membranoidea* dominated assemblage with *Chlamydophorella nyei*, *Circulodinium distinctum*, *Gardodinium trabeculosum*, *Hystrichodinium pulchum*, *H. voigtii*, *Muderongia simplex*, *Odontochitina operculata* and *Phoberocysta neocomica* (Fig. 5). The assemblage cannot be easily referred to the East Greenland zonation of Nøhr-Hansen *et al.* (2019) due to the absence of zonal and subzonal stratigraphical marker species, but the earlier reported FO (First Occurrence) of *Odontochitina operculata* in the lower Barremian of East Greenland (Nøhr-Hansen 1993; Piasecki *et al.* 2012; Nøhr-Hansen *et al.* 2019) suggests an age not older than early Barremian. The assemblage appears slightly restricted with respect to a fully marine assemblage, and therefore differs in composition from the assemblages in the correlative Stratumbjerg Formation.

Samples of Stratumbjerg Formation from the valley area contain assemblages with abundant *Vesperopsis longicornis*, *Fromea xantha* and *Wallodinium krutzschii* and common *Oligosphaeridium* spp., *Odontochitina* spp., *Circulodinium* spp., *Chlamydophorella* spp., *Batioladinium* spp. and *Gardodinium trabeculosum* (Fig. 6). *Odontochitina operculata* has FO in the lower Barremian and *Vesperopsis longicornis* has FO in the mid–upper Barremian (Nøhr-Hansen 1993; Aarhus *et al.* 1986). The assemblage is therefore referred to the *Pseudoceratium toveae* (3) Subzone of the *Batioladinium longicornutum* (I) Zone, of Nøhr-Hansen *et al.* (2019), and the age of the Stratumbjerg Formation in the valley area is suggested to be late Barremian.

The abundance of species of like *Vesperopsis*, *Fromea* and *Wallodinium* in combination with a limited occurrence of common marine dinoflagellate cysts may suggest an overall brackish depositional environment (e.g. Batten & Lister 1988). However, this assemblage is mixed with common marine dinoflagellate cysts and may suggest transition or mixing of two different assemblages.

The plain north of Falkebjerg

Sample 523254. A poor assemblage is recorded in the second sample from Falskebugt Member. The assemblage contains *Apteodinium reticulatum*, *Cribroperidinium edwardsii*, *Gardodinium trabeculosum*, *Odontochitina operculata*, *Odontichitina nuda*, *Oligosphaeridium complex* and *O. totum* (Fig. 5). *Apteodinium reticulatum*, *C. edwardsii* and *O. nuda* are all reported with FO in lower to uppermost lower Barremian (Nøhr-Hansen 1993; Aarhus *et al.* 1986).

A sample from the closely overlying Stratumbjerg Formation contains a much more diverse and abundant, marine assemblage dominated by *Ciculodinium attalicum* with very rare *Fromea xantha*, *Vesperopsis longicornuta* and *Wallodinium krutzschii* (Fig. 6). The assemblage is basically similar to the assemblage in the underlying Falskebugt Member sandstone but includes *Batioladinium longicornutum* and *Pseudoceratiun tovae* that refer the assemblage to the upper Barremian *Pseudoceratium toveae* (3) Subzone of the *Batioladinium longicornutum* (I) Zone (Nøhr-Hansen *et al.* 2019).

The dinoflagellate cyst assemblages in these samples from the Falskebugt Member and Stratumbjerg Formation thus suggest a Barremian to late Barremian age of this part of the succession. However, not all parts of the Falskebugt Member were deposited in a marine environment. Some parts of the member are interpreted to be deposited in a terrestrial environment indicated by the presence of abundant wood and leaves and an absence of marine dinoflagellate cysts in mudstones. The lower Stratumbjerg Formation was deposited partly in brackish and partly in marine environments.

Fauna

Macrofossils were reported from the Falskebugt Member at Falkebjerg by Maync (1949), including buchiid bivalves and crinoid fragments. They were collected at two levels, one at 50–60 m a.s.l. and one relatively high, at 155 m a.s.l., on the western flank of Falkebjerg. The latter level is stratigraphically below the former level due to the dip of the bedding. We did not succeed in finding macrofossils at Maync's level at 155 m a.s.l. However, two new fossil assemblages

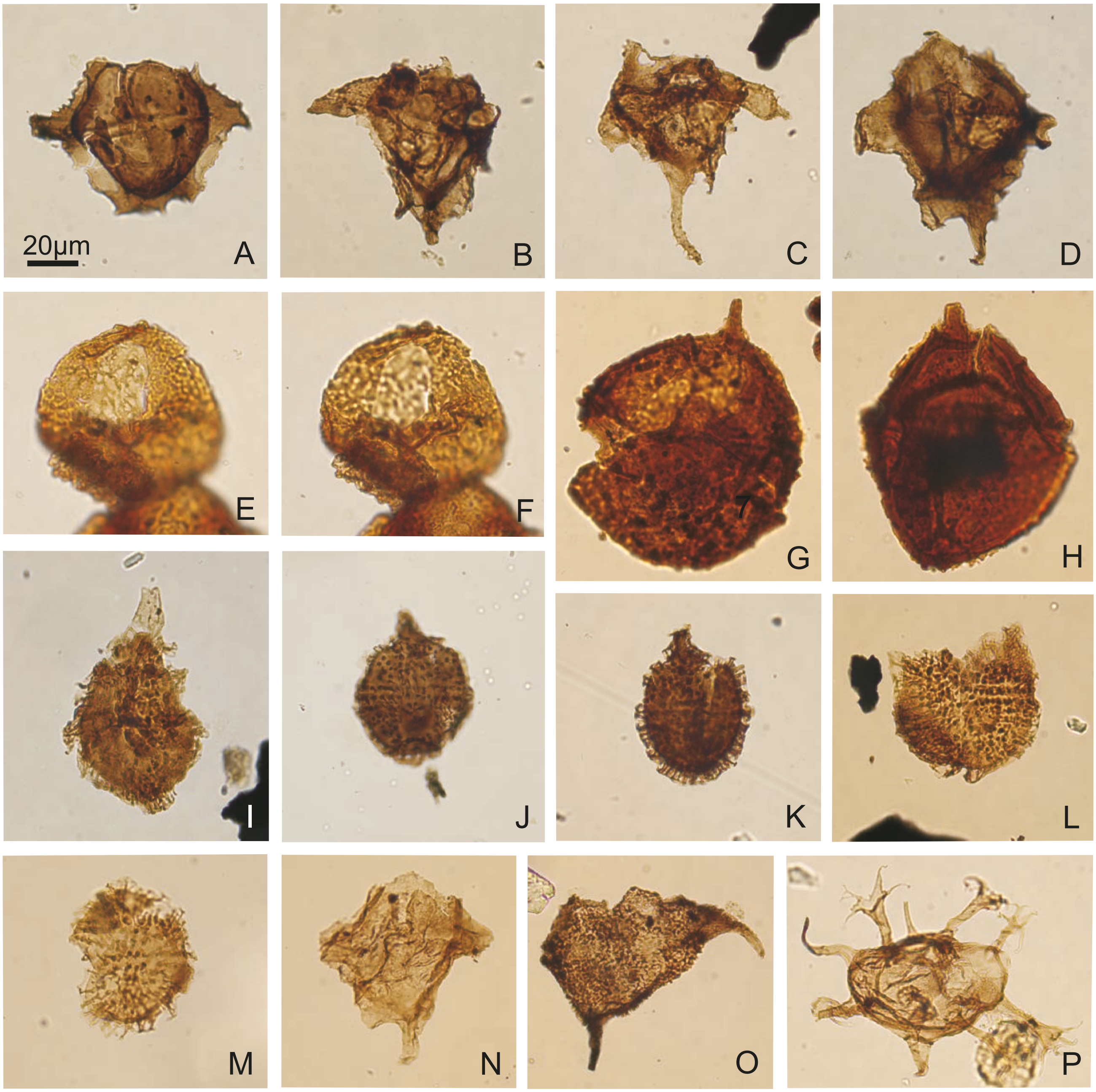

Fig. 5. Barremian dinoflagellate cysts from the Falskebugt Member, magnification ×400. The 20 μm bar in figure A is representative for all illustrations. **A–D**: *Phoberocysta neocomica* with variable morphology, MGUH 33409, 33410, 33411 and 33412. **E–F**: *Apteodinium reticulatum*, MGUH 33413. **G–H**: *Cribroperidinium edwardsii*, MGUH 33414 and 33415. **I**: *Gardodinium trabeculosum*, MGUH 33416. **J–K**: *Chlamydophorella nyei*, MGUH 33417 and 33418. **L**: *Stephanelytron membranoideum*, MGUH 33419. **M**: *Chlamydophorella* spp., MGUH 33420. **N**: *Muderongia simplex*, MGUH 33421. **O**: *Pseudoceratium pelliferum*, MGUH 33422. **P**: *Oligosphaeridium complex*, MGUH 33423.

were encountered in strata poorly exposed on the low plain immediately west of Falkebjerg (Fig. 3A), possibly identical to Maync's 50–60 m a.s.l. level. They include ammonites – the first reported from Falskebugt Member – buchiid bivalves and poorly preserved brachiopods and belemnites.

One assemblage includes numerous small shells of buchiid bivalves, in places lying in clusters, with a few nuclei or juveniles of ammonites (Fig. 7). The assemblage contains the bivalve *Buchia keyserlingi* (Trautschold) (Fig. 7K), which is the most commonly occurring species of *Buchia* in North-East Greenland

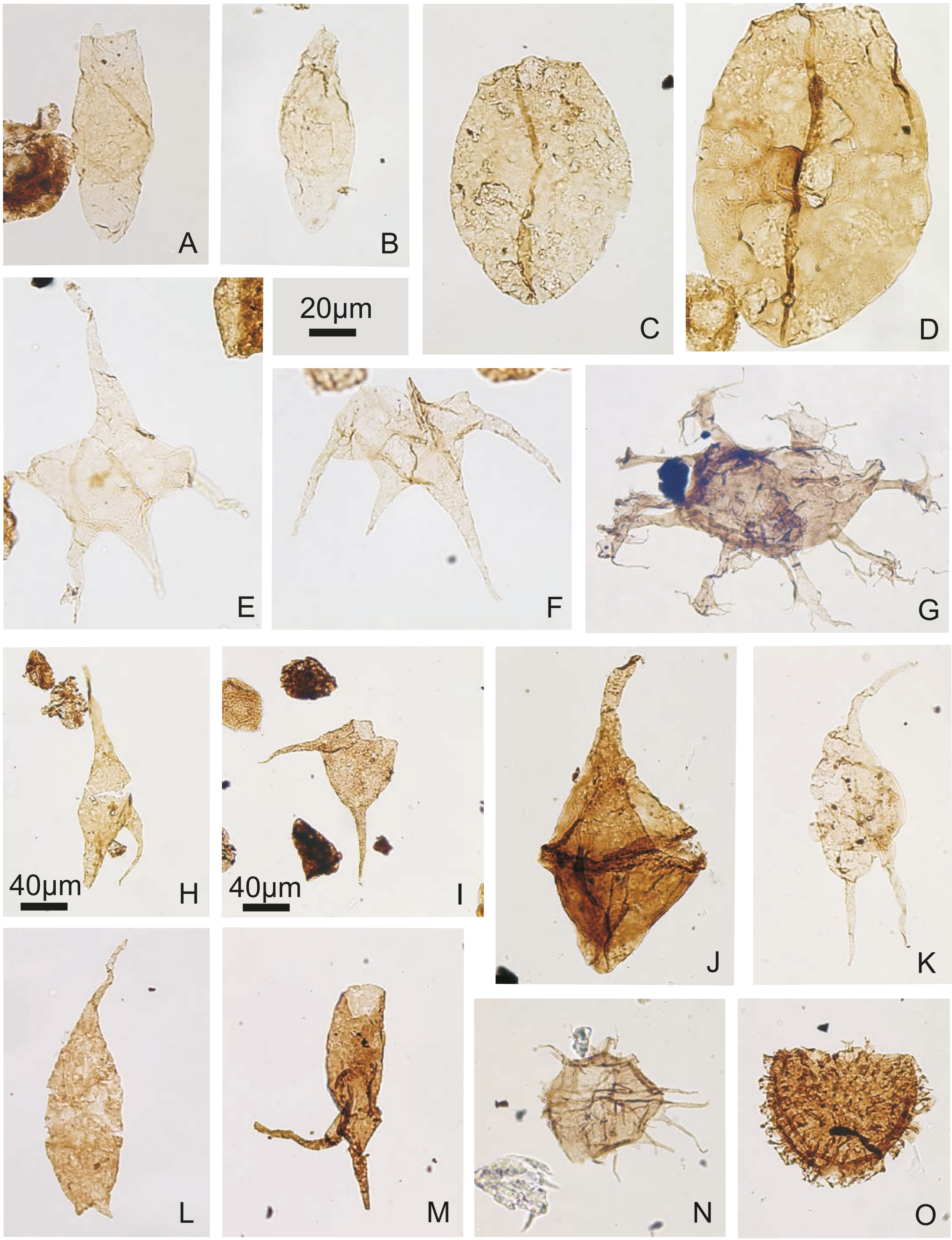

Fig. 6. Barremian acritarchs and dinoflagellate cysts from the Stratumbjerg Formation. The 20 µm bar is representative for all figures except H and I, which show 40 µm bars. **A–B**: *Wallodinium krutzschii*, MGUH 33424 and 33425. **C–D**: *Fromea xantha*, MGUH 33426 and 33427. **E–F**: *Vesperopsis longicornuta*, MGUH 33428 and 33429. **G**: *Oligosphaeridium complex*, MGUH 33430. **H**: *Odontochitina operculate*, MGUH 33431. **I**: *Pseudoceratium toveae*, MGUH 33432. **J**: *Scriniodinium pharo*, MGUH 33433. **K**: *Odontochitina nuda*, MGUH 33434. **L**: *Batioladinium jaegeri*, MGUH 33435. **M**: *Batioladinium longicornutum*, MGUH 33436. **N**: *Hystrichodinium voigtii*, MGUH 33437. **O**: *Ciculodinium attalicum*, MGUH 33438.

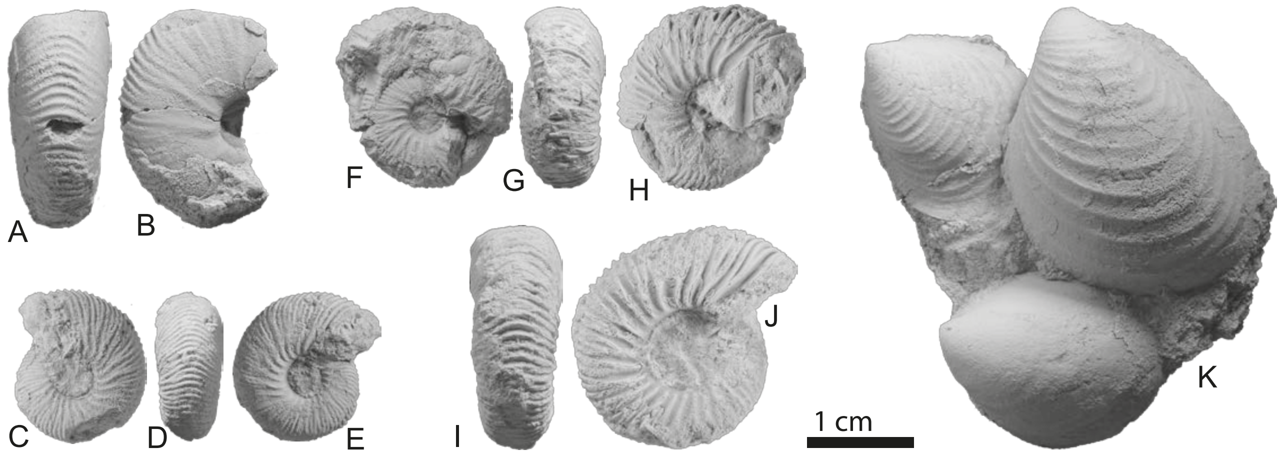

Fig. 7. Early Valanginian molluscs from conglomeratic facies of the Falskebugt Member. Figs A–J, nuclei of polyptychitid ammonites. **A**–**B**: *Polyptychites (Siberiptychites)* cf. *stubendorffi*, MGUH 33439 (from sample 543914). **C**–**E**: *Polyptychites (Siberiptychites)* cf. *stubendorffi*, MGUH 33440 (from sample 592404_2). **F**–**H**: *Propolyptychites* sp., MGUH 33441 (from sample 592404_3). **I**–**J**: *Propolyptychites* sp., MGUH 33442 (from sample 592404_1). **K**: Cluster of bivalves, *Buchia keyserlingi*, MGUH 33443 (from sample 543914).

and has a range from the lower to the lower upper Valanginian (Surlyk 1978; Surlyk & Zakharov 1982). The ammonite nuclei are polyptychitids. Two specimens are referred to *Propolyptychites* sp. (Figs 7F–J) and resemble specimens reported from the lowermost? Valanginian in England (Casey 1973). Two other specimens are referred to *Polyptychites* (*Siberiptychites*) cf. *stubendorffi* (Schmidt) (Figs 7A–E), which is a relatively long-ranging polyptychitid species, indicating lower, but not the lowermost Valanginian (Jeletzky & Kemper 1988; Bogomolov 1989; Alsen 2006). Taken together, the assemblage indicates the lower Valanginian.

Fig. 8. Poorly preserved specimen of a crioceratid heteromorph ammonite, *Aegocrioceras*? from Falskebugt Member, probably of Hauterivian age. MGUH 33444 (from sample 592405).

The other assemblage contains poorly preserved, worn fossils of which the most interesting find is a heteromorph ammonite (Fig. 8). The fossil and pebbles and clasts in the sediment have a greenish appearance from glauconite coating, suggesting that deposition of the Falskebugt Member conglomerates in this area was followed by sediment starvation. The locality is situated at the westernmost extent of the Falskebugt Member, only a few metres from black, fine-grained mudstones of the Stratumbjerg Formation farther to the west. The Stratumbjerg Formation probably onlapped the Falskebugt Member after a depositional break. Heteromorphs are rarely reported from the Lower Cretaceous of North-East Greenland. They include Barremian–Aptian *Ancyloceras, Audouliceras, 'Crioceras', Hamites* and *Tonohamites* (Donovan 1957; Kelly *et al.* 2000). The specimen from the Falskebugt Member is crioconic, with whorls clearly coiled in a loose spiral, and with ornamentation that appears to consist of simple, strong, coarse, non-furcating ribs, resembling those of *Aegocrioceras*. This taxon would indicate a Hauterivian age, but as its identification is ambiguous, the age indication remains tentative. It is, however, in accordance with the age of the base of the overlying Stratumbjerg Formation (Nøhr-Hansen *et al.* 2019; Bjerager *et al.* 2020).

Organic geochemistry

All analysed samples are from the Stratumbjerg Formation and comprise three groups of samples:

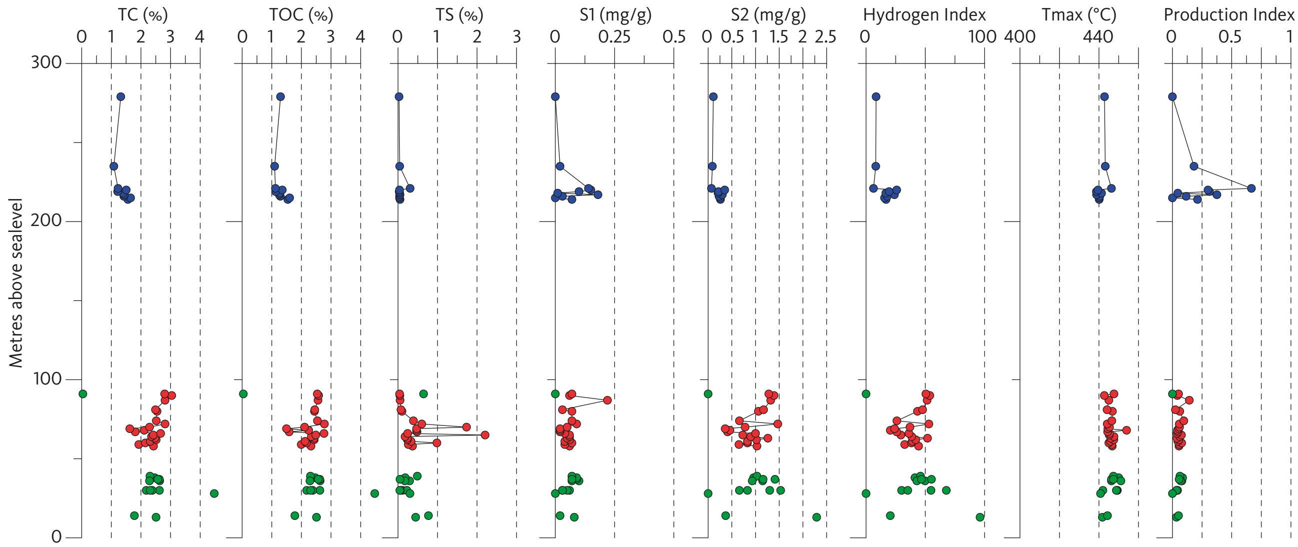

Fig. 9. Rock-Eval pyrolysis data of samples from the Stratumbjerg Formation. Green: Distributed samples from the lower formation. Red: Profile 1 from the lower formation. Blue: Profile 2 from the mid- to upper formation. TC: Total Carbon (wt%); TOC: Total Organic Carbon (wt%); TS: Total Sulphur (wt%); S1: free hydrocarbons (mg HC/g sample); S2: pyrolytic hydrocarbons (mg HC/g sample).

samples from scattered localities distributed all over the valley and the plain areas; samples from the lower Stratumbjerg Formation north of the plain (profile 1); and samples from the upper part of the formation north of the plain (Profile 2) (Fig. 1). A summary plot of the analytical results is shown in Fig. 9 and analytical data are listed in Table 1.

All samples show very low levels of carbonate, with total carbon (TC) and total organic carbon (TOC) being almost identical. The TOC mainly falls in the range 2–3 wt% in the lower part of the sampled succession, decreasing markedly to 1–1.5 wt% in the upper part of the sampled succession. Sulphur levels are generally low, mostly close to 0.5 wt%, decreasing upwards, although a few samples yield higher values. Pyrolysis yields are low, with S1 consistently being less than 0.25 mg/g and S2 ranging from nearly zero to close to 3 mg/g, with a clear decrease upwards through the succession. The pattern shown by TOC and S2 is mirrored in the Hydrogen Index, which is consistently low but shows a marked decrease from a maximum value close to 100 near the base of the succession to values mainly less than 25 at the top. Tmax is generally close to 445°C, suggesting a level of thermal maturity approaching the main phase of petroleum generation. However, due to the overall inert or poor gas-prone nature of the kerogen, this is not reflected by the production index, which remains low except for a few kicks towards higher values near the top of the succession. The succession does not include deposits showing even marginal petroleum generation potential. However, the thick mudrock succession of Stratumbjerg Formation may perhaps have caprock potential.

Conclusions

The Falskebugt Member extends much farther north of Falkebjerg than previously known.

The coarse-grained deposits near the steep flank of the Falkebjerg ridge apparently become more fine-grained basinwards to the west and the beds thin out in basinal mudstone of the Stratumbjerg Formation. It is now clear that the Falskebugt Member is not only a lateral equivalent of the Albrecths Bugt and Rødryggen Members of the Palnatokes Bjerg Formation but also of the lower Stratumbjerg Formation (Fig. 2).

Despite earlier suggestions, the Bernbjerg Formation and the Albrecths Bugt and Rødryggen Members have not been recorded anywhere in the Falkebjerg area. The nearest known exposure of these units is 8–10 km towards the west. The brightly coloured red/yellow deposits of Falskebugt Member high on Falkebjerg are possibly a local equivalent of the colourful Albrechts Bugt and Rødryggen Members. Sedimentary contacts have only been observed between Falskebugt Member, the underlying Nathorst Land Group, and the Stratumbjerg Formation.

Table 1. Geochemically analysed samples and analytical data from the Stratumbjerg Formation.

Sample	North (Deg.Min.)	West (Deg.Min.)	Altitude (m a.s.l.)	Type	TC (wt-%)	TOC (wt-%)	TS (wt-%)	Tmax (°C)	S1 (mg/g)	S2 (mg/g)	HI	PI	PC (wt-%)
523247	74 34.315	19 21.544	30	Distributed	2.62	2.26	0.12	442	0.06	1.53	68	0.04	0.13
523248	74 34.315	19 21.544	30	Distributed	2.38	2.37	0.22	449	0.05	1.30	55	0.04	0.11
523249	74 34.297	19 22.211	13	Distributed	2.51	2.38	0.45	442	0.08	2.29	96	0.03	0.20
523250	74 34.297	19 22.211	14	Distributed	1.78	1.81	0.77	444	0.02	0.37	20	0.05	0.03
523251	74 34.676	19 20.711	91	Distributed	0.04	0.05	0.65	343	0.00	0.00	0	0.00	0.00
523253	74 34.786	19 21.474	30	Distributed	2.18	2.20	0.06	449	0.03	0.66	30	0.04	0.06
523256	74 34.702	19 21.343	30	Distributed	2.31	2.36	0.05	449	0.03	0.83	35	0.03	0.07
523257	74 35.159	19 21.794	36	Distributed	2.29	2.17	0.17	451	0.07	0.93	43	0.07	0.08
523258	74 35.133	19 21.777	37	Distributed	2.57	2.48	0.05	447	0.07	1.16	47	0.06	0.10
523259	74 35.796	19 20.488	28	Distributed	4.48	0.04	0.30	441	0.00	0.00	0	0.00	0.00
523312	74 37.322	19 20.160	36	Distributed	2.63	2.31	0.29	446	0.10	1.15	50	0.08	0.10
523313	74 37.322	19 20.160	37	Distributed	2.62	2.55	0.06	446	0.09	1.41	55	0.06	0.12
523314	74 37.322	19 20.160	38	Distributed	2.47	2.33	0.18	450	0.09	0.96	41	0.09	0.09
523315	74 37.322	19 20.160	39	Distributed	2.30	2.24	0.49	447	0.07	1.03	46	0.06	0.09
523316	74 37.501	19 20.288	58	Profile 1	2.42	2.32	0.37	447	0.06	1.03	44	0.06	0.09
523317	74 37.501	19 20.288	59	Profile 1	1.93	1.99	0.26	447	0.04	0.65	33	0.06	0.06
523318	74 37.501	19 20.288	60	Profile 1	2.15	2.17	0.98	445	0.07	0.83	38	0.08	0.07
523319	74 37.501	19 20.288	61	Profile 1	2.32	2.12	0.33	446	0.04	0.83	39	0.05	0.07
523320	74 37.501	19 20.288	62	Profile 1	2.52	2.43	0.24	448	0.06	1.02	42	0.06	0.09
523321	74 37.501	19 20.288	63	Profile 1	2.47	2.43	0.24	446	0.05	1.26	52	0.04	0.11
523322	74 37.501	19 20.288	64	Profile 1	2.36	2.34	0.18	448	0.06	0.90	39	0.06	0.08
523323	74 37.501	19 20.288	65	Profile 1	2.42	2.49	2.21	445	0.06	0.73	29	0.08	0.07
523324	74 37.501	19 20.288	66	Profile 1	2.67	2.76	0.24	445	0.04	1.00	36	0.04	0.09
523325	74 37.501	19 20.288	67	Profile 1	1.81	1.59	0.48	444	0.02	0.41	26	0.05	0.04
523326	74 37.501	19 20.288	68	Profile 1	2.11	2.25	0.47	454	0.02	0.46	20	0.04	0.04
523327	74 37.501	19 20.288	69	Profile 1	1.62	1.49	0.47	445	0.02	0.36	24	0.05	0.03
523328	74 37.501	19 20.288	70	Profile 1	2.29	2.11	1.74	445	0.05	0.78	37	0.06	0.07
523329	74 37.501	19 20.288	72	Profile 1	2.81	2.78	0.60	444	0.09	1.47	53	0.06	0.13
523330	74 37.501	19 20.288	74	Profile 1	2.52	2.54	0.39	447	0.07	0.66	26	0.10	0.06
523331	74 37.501	19 20.288	80	Profile 1	2.54	2.44	0.10	447	0.07	1.06	43	0.06	0.09
523332	74 37.501	19 20.288	81	Profile 1	2.49	2.45	0.07	444	0.03	1.17	48	0.03	0.10
523333	74 37.501	19 20.288	87	Profile 1	2.81	2.56	0.05	445	0.22	1.32	52	0.14	0.13
523334	74 37.501	19 20.288	90	Profile 1	3.04	2.58	0.05	443	0.06	1.39	54	0.04	0.12
523335	74 37.501	19 20.288	91	Profile 1	2.80	2.53	0.04	448	0.07	1.28	50	0.05	0.11
523337	74 38.296	19 21.333	214	Profile 2	1.56	1.54	0.05	440	0.07	0.26	17	0.21	0.03
523338	74 38.296	19 21.333	215	Profile 2	1.65	1.60	0.04	440	0.00	0.25	16	0.00	0.02
523339	74 38.296	19 21.333	216	Profile 2	1.42	1.29	0.04	440	0.03	0.23	18	0.12	0.02
523340	74 38.296	19 21.333	217	Profile 2	1.43	1.25	0.05	439	0.18	0.30	24	0.38	0.04
523341	74 38.296	19 21.333	218	Profile 2	1.39	1.26	0.04	441	0.01	0.21	17	0.05	0.02
523342	74 38.296	19 21.333	219	Profile 2	1.21	1.13	0.03	439	0.10	0.22	19	0.31	0.03
523343	74 38.296	19 21.333	220	Profile 2	1.50	1.35	0.04	440	0.15	0.35	26	0.30	0.04
523344	74 38.296	19 21.333	221	Profile 2	1.23	1.12	0.31	446	0.14	0.07	6	0.67	0.02
523345	74 38.296	19 21.333	235	Profile 2	1.09	1.09	0.04	443	0.02	0.09	8	0.18	0.01
523346	74 38.296	19 21.333	279	Profile 2	1.32	1.30	0.03	443	0.00	0.11	8	0.00	0.01

TC: Total Carbon (wt%); TOC: Total Organic Carbon (wt%); TS: Total Sulphur (wt%); S1: free hydrocarbons (mg HC/g sample); S2: pyrolytic hydrocarbons (mg HC/g sample); HI: Hydrogen Index; PI: Production Index; PC: Pyrolyzable Carbon.

Three levels in the Falskebugt Member have been dated by their fossil content as Valanginian, Hauterivian and Barremian. The dinoflagellate cyst assemblages in the Stratumbjerg Formation indicate a late Barremian age where the formation is correlative with the Falskebugt Member. In comparison, the dinoflagellate cyst stratigraphy of the lowermost Stratumbjerg Formation in the Brorson Halvø-1 core indicates a late Hauterivian to early Barremian age (Hovikoski *et al.* 2011).

The Falskebugt Member was deposited directly on the basement, as indicated by the common character of the sedimentary material in the member and in the underlying basement. The Falskebugt Member has a steeply dipping gradient towards north-west; the oldest strata (Valanginian) are located near the basement surface towards the south-east, and successively younger strata occur towards north-west (Hauterivian) and west (Barremian).

Part of the dinoflagellate cyst assemblage in the upper Barremian Stratumbjerg Formation indicates deposition in a marginal marine to brackish? environment, comparable to similar observations of dinoflagellate cyst assemblages suggesting brackish depositional environments in contemporaneous sediments at Store Koldewey and Peary Land, North Greenland (Piasecki *et al.* 2012; unpublished data).

Dinoflagellate cysts have not been recorded in any mudstone samples of Falskebugt Member. Some of the mudstone samples are from an interval with common tree trunks, branches and leaves. Despite new records of marine fauna in the Falskebugt succession, part of the succession was probably terrestrially deposited.

The Stratumbjerg Formation in the Falkebjerg area does not include deposits showing any petroleum generation potential. However, this thick mudstone succession may have cap-rock potential. The coarse-grained Falskebugt Member is situated in a lateral and up-dip position relative to the prolific oil-prone source rock of the Upper Jurassic Bernbjerg Formation, and overlain by mudstones of the Stratumbjerg Formation; this basin margin position corresponds to a classic, half-graben, play type. However, the source of the coarse-grained Falskebugt Member sediments is a strongly kaolinised metasediment, and the short transportation distance has resulted in an immature and poorly sorted sediment that probably has little reservoir potential.

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