GEOLOGICAL GUIDES
7 - 2020

FESTNINGEN

A 300-million-year journey through shoreline exposures of the Carboniferous and Mesozoic in 7 kilometers

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The Festningen islet, giving name to the whole Festningen section

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The Festningen Section displays rocks ranging in age from the Early Carboniferous to Cenozoic (i.e. approximately 300 million years) in an easy accessible shore section in central Spitsbergen (Figs. 1 & 2).

Figure 1. Geological map showing the location of the Festningen section, named after the Festningen island (marked with the red circle)

The Festningen Section is easily accessible of the southern shore facing Isfjorden within the Cenozoic foldbelt occurring all along western Spitsbergen. While only scattered exposures display the Carboniferous and Lower Permian succession, the continuous exposure from the Upper Permian through the Mesozoic succession gives visitors a first-hand opportunity for understanding the geology of Svalbard. Not only for educational purposes, but also the simple pleasure of experiencing world class exposures for any interested persons wanting to learn more about the geology of Svalbard. The locality is a ***geotope*** and therefore protected by law. This protection ensure that future observers will be able to study an undamaged succession. In this respect, hammers are not welcome! Scientists may be granted sampling permission for specific purposes from **Sysselmannen** (the Governor of Svalbard), but any sampling should be conducted with care as to not hamper the experience for later visitors.

Figure 2. Infra-red satellite photo of the Festningen section. Key localities are marked with number that are also used in the guide.
R-Landing at Russekeila
S-Landing locality in Soloveckijbukta
F-Pick up place W of Festningen
1-Carboniferous conglomerates
2-Carboniferous dolomites
3-Carboniferous-Permian dissolution breccia
4-Permian – Vøringen Member initiate the Kapp Starostin Formation
5-Kapp Starostin Cape with the Kapp Starostin Formation
6-Permian – Triassic boundary
7-Lower Triassic Vardebukta and Tvillingodden formations
8-Middle Triassic Bravaisberget Formation
9-Upper Triassic De Geerdalen Formation
10-Upper Triassic-Middle Jurassic Wilhelmøya Subgroup
11-Jurassic – Cretaceous Janusfjellet Subgroup
12-Cretaceous—Helvetiafjellet Formation with the Festningen Sandstone
13-Lower Crataceous—Carolinefjellet Formation
14-Cretaceous – Cenozoic boundary and hiatus

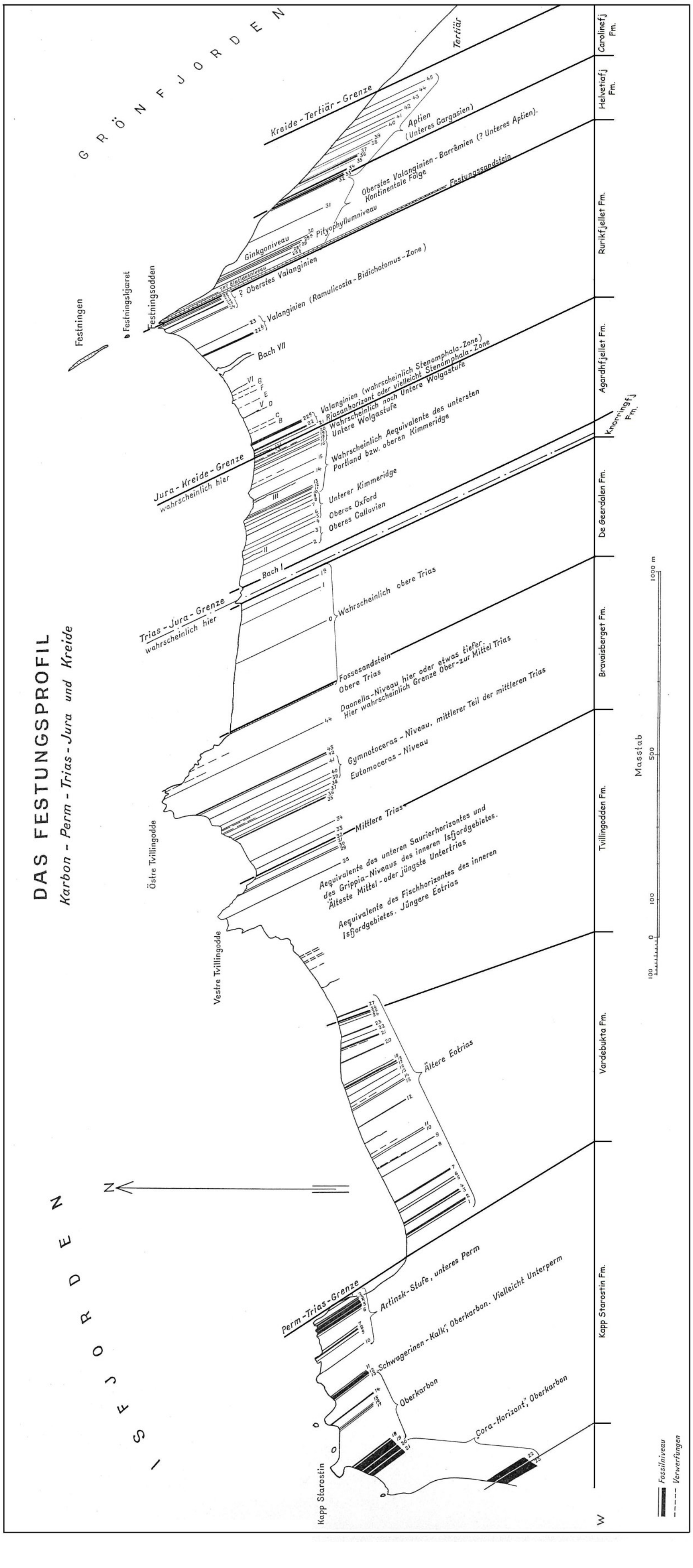


Figure 3. Map view of the Festningen section with fossil beds marked (Hoel & Orvin 1937).

Detailed bed-by-bed measurements, taken nearly 100 years ago by Hoel & Orvin (1937) resulted in a robust overview of the Festningen section that has served as a framework for all later studies (Figs. 3 & 4). An interpretative sedimentological overview of the Upper Permian throughout the Cretaceous section is presented in Figure 5.

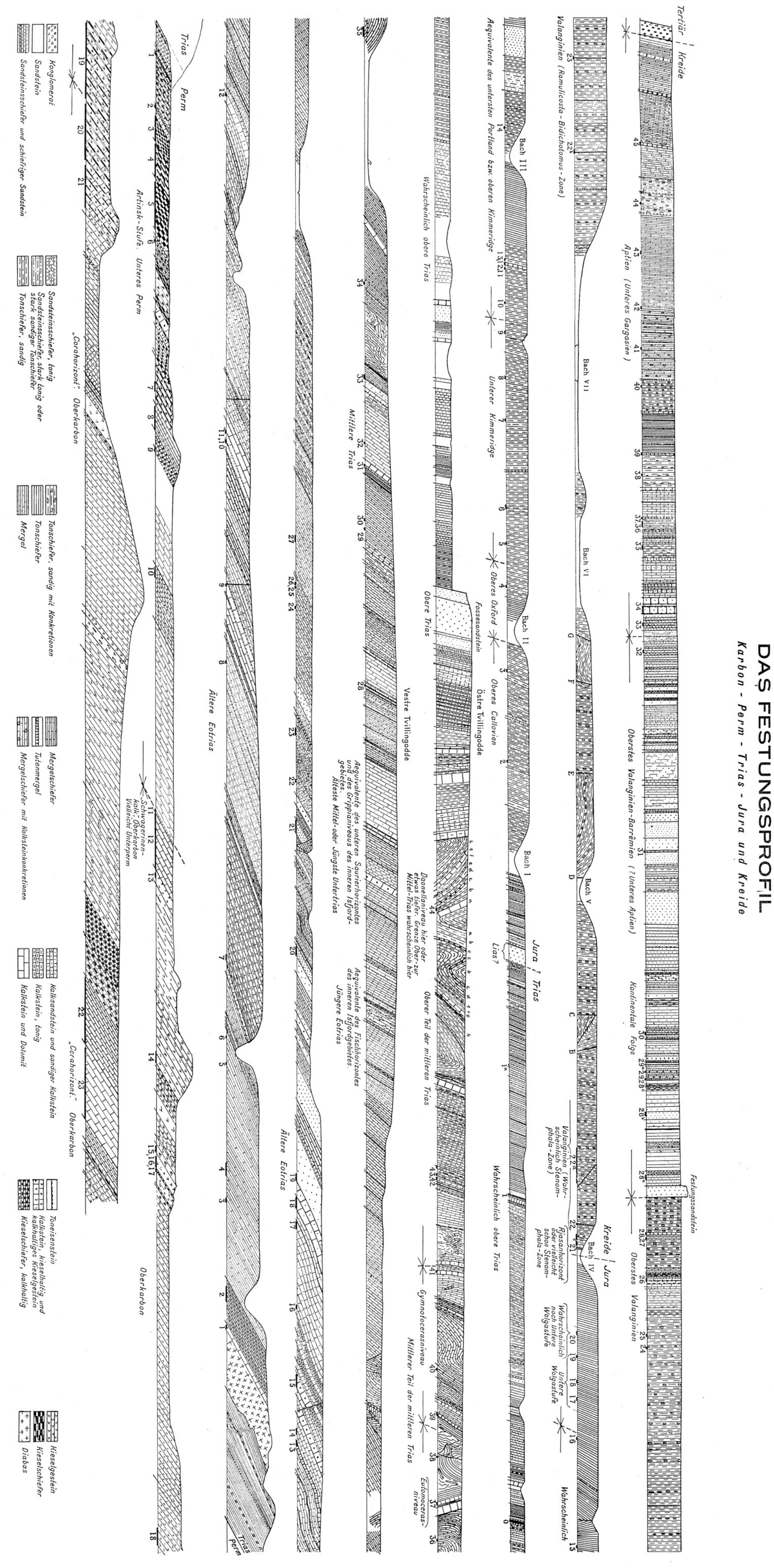
Palaeontological and stratigraphical studies along the Festningen section were typically prioritised first, whilst workers from the 1970s focused on detailed sedimentological studies. A selected reference list for these works is enclosed at the end of this guide. In the revision of the lithostratigraphical framework of Svalbard (Dallmann (ed.) 1999), the Festningen section was selected as the type section for the Upper Permian Kapp Starostin and the Lower Triassic Vardebukta and Tvillingodden formations, as well as the uppermost Triassic to middle Jurassic Knorringfjellet Formation (the latter presently being under revision). The section is also renowned for containing Cretaceous dinosaur foot prints. The cast of a large dinosaur footprint, taken in the early 1960s, can be viewed at the museums in Longyearbyen and on Natural History Museum in Oslo. The original traces have unfortunately collapsed due to weathering.

Boat landing sites - Practical information

Along the 4 km long coastline, approximately 2.5 km of geological succession occurs with steep to vertically dipping beds. The folding is a result of the Eurekan Orogeny during the Cenozoic.

Festningen (the castle, see photo on front page) itself is a small island in the easternmost and stratigraphically upper part of the section described within this guide, and 40 km west of Longyearbyen.

Figure 4. Drawn section of the Festningen section ("Das Festungsprofil") as seen from the sea (Hoel & Orvin 1937).



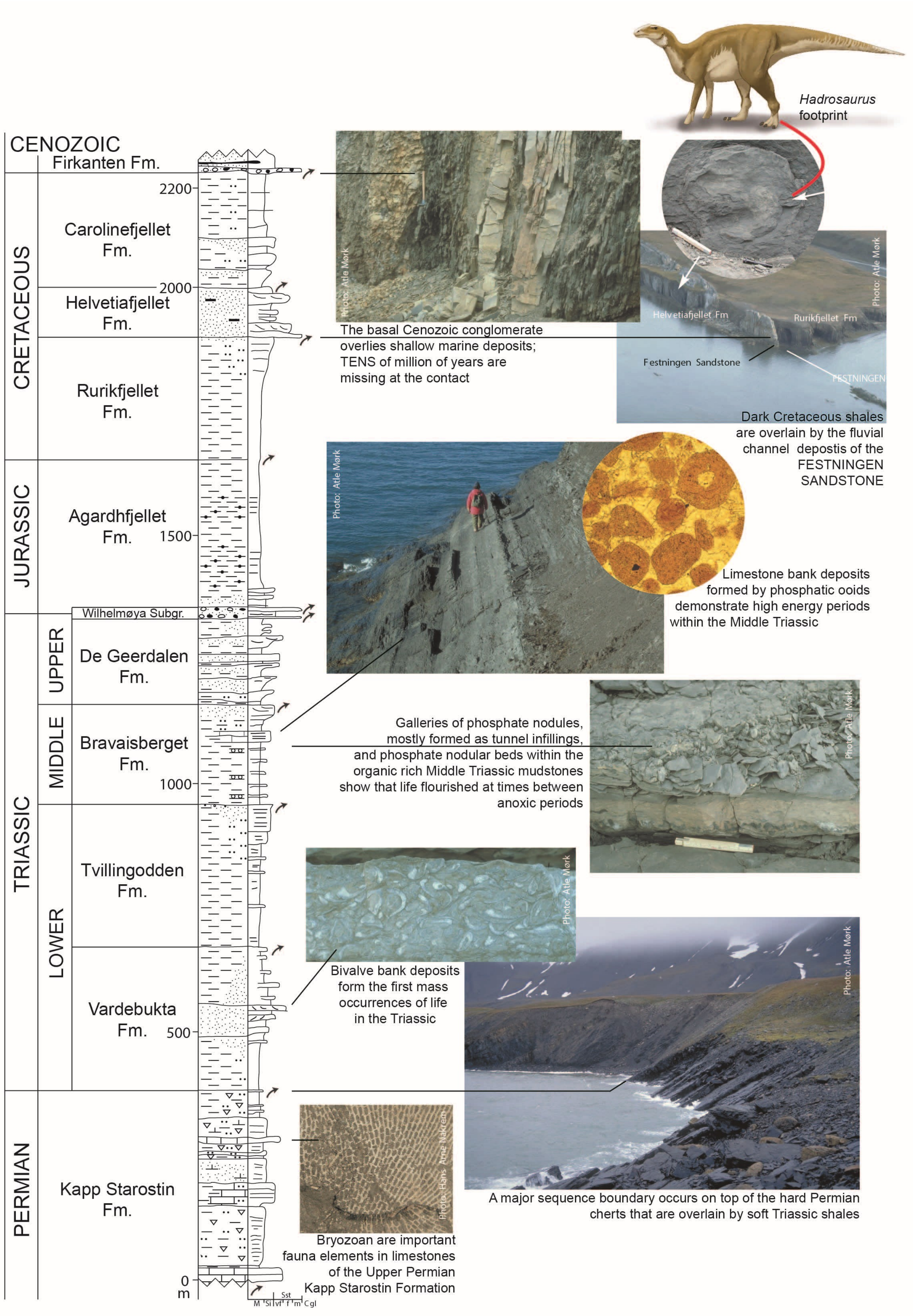


Figure 5. Schematic overview of the Upper Permian and Mesozoic part of the Festningen section.

Accessibility: Names used below are found on the geological map "*Isfjorden*" B9G 1:100 000. The shore section is easily accessible by small boat. However, care must be taken with the numerous skerries formed by vertically dipping chert and sandstone ridges that restrict landing sites. We therefore recommend going ashore in any of the wide bays, here described from W to E. If a mothership is used and an excursion along the entire coastline is planned; we recommend to land in one of the westernmost bays (*Russekeila or Soloveckijbukta)* and return from the bay west of Festningsodden at the mouth of Festningselva. See notations on Figure 2.

Russekeila: Go on land below the huts in the west of the bay. At high tide it may be possible to sail small boats into the small estuary where the river from Linnevannet enters the fiord. Starting at this location also gives the possibility of visiting an outcrop of conglomerate beds of the Billefjorden Group that are present in this area (Fig. 6).

Soloveckijbukta : Most visitors to the Festningen section start here. Dependent on wave conditions at the shore (there may be some drag) you may go on land central in the bay (a river valley occurs behind the gravelly shore) or on one of the sides. The water is deep until reaching the shore making landing with small boats safe.

Vardebukta: The best landing is found on the west side of the bay, where a small river enters the fjord. At low tide, access may be difficult, and attention should be paid to shallow rocks.

The Bay at Tvillingoddane, between Austre and Vestre Tvillingodde: This locality is suitable for landing at both high and low tide. This landing site is recommended if workers plan to arrive by boat that will be taken onshore with the intention of returning from the same place, as it is located central in the study area.

Figure 6A. Billlefjorden Group conglomerates. Fluvial conglomerates at the point East of Russekeila.

Figure 6B. Billefjorden Group conglomerates. Conglomerates showing imbrications of pebbles and gravels of the braided streams.

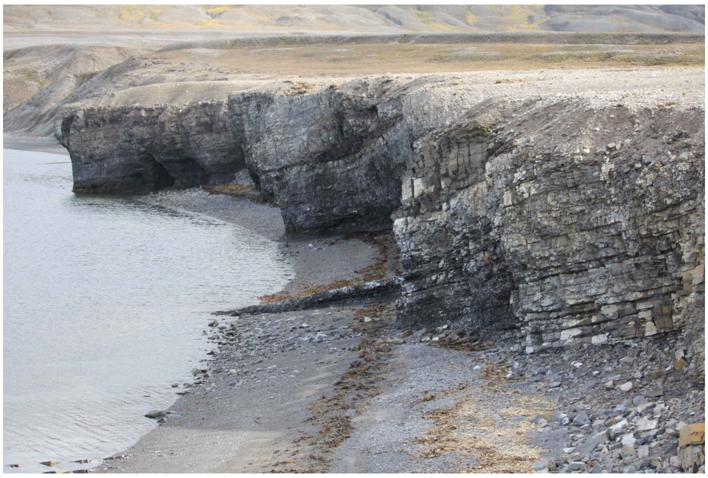


Figure 7. Dolomites from the Gipsdalen Group.

The long bay from Austre Tvillingodde to Festningen: In this bay numerous sandstone ridges protrude from land and into the shallow fiord. At high tide landing is possible along the shore, however, at low tide we recommend landing at the easternmost part of the bay, between Festningselva and Festningen itself. It is recommended that watercraft navigate along the strike of the outcrop dip (i.e. parallel to the Festningen islet) in order to avoid hitting the sandstone ridges.

East of Festningen: Access by small boat is typically only possible at high tide, therfore landing west of Festningen is recommended.

Walking information W to E up-section

Normal clothing suitable for fieldwork on Svalbard should be used, and most places you can walk along dry shoreline in mountain boots.

Starting at Russekeila (Fig. 2 "R"), you can study the Billefjorden Group conglomerates (Fig. 6) at the eastern part of the bay and at the point. On the western shore of Soloveckijbukta exposures of dolomites from the Gipsdalen Group are only accessible at low tide (Fig. 7).

Starting in the central part of Solovjetskibukta (Fig. 2 "S"), a small exposure of dolomites representing a dissolution breccia occurs a few meters up on the eastern side of the valley (Fig. 8A). These same rocks can be found as eroded material along the shore. Dissolved anhydrite nodules in the dolomites of the Gipsdalen Group also occur in the scree (Fig. 8B), whilst, silicified algal laminations are seen to occur in the upper part of the Gipshuken Formation (Fig. 8C).

The *Festningen section proper* (Fig. 2 "5") starts with a series of brachiopod coquina beds formed at the base of the Kapp Starostin Formation. The lower part of this formation can be studied here, but access around the point is not possible. It is recommended to climb the section just west of the coquina beds and follow the cliff to the NE, here you will find a discrete path that is largely maintained by visiting geologists and reindeer. When passing a small ridge, note the presence of meso-scale clinoform geometries present in the bedding on the opposite steep rock cliff. From here, walk down to the shore, and proceed along the shoreline.

At the top of the Kapp Starostin Formation (on the eastern side of Kapp Starostin), a small path works its way down to the Permian-Triassic boundary. If the tide is to high an alternative is to climb up the cliff (at the P-T boundary, Fig. 2 "6"), cross inland and go down to the shore at the first river to the East then back-track towards the boundary beds.

Western (*Vestre*) Tvillingodde passes directly into the sea, but you may walk down to the shore at its NE corner to visit a spectacular example of trace fossils. Return back up to the top of the cliff and continue to the next river that enters between the two Tvillingodde points which provides access down to the sea.

Walk westwards along bay to where the well-exposed transition from Tvillingodden to Bravaisberget formations occurs (here a brachiopod-bivalve conglomerate marks the boundary). At very low tide it is possible to follow the shore to the western side of Eastern (*Austre*) Tvillingodde. Here laminae of ooides are exposed. This locality can also be accessed from above.

Continue walking across the point to the exposures that form the easternmost point. This point is formed by vertically dipping sandstone and dolomite beds, which display excellent sedimentary structures and trace fossils. Usually, these can only be studied at low tide. East of Tvillingoddane the shoreline exposures can be followed to Festningen. Only at high tide it may be required to climb up the cliff to pass some small points.

Festningselva, the river just west of Festningen can be problematic to cross early in the summer. Therefore, waders, survival suits, or the use of a boat is recommended. The river is deepest at its mouth on the beach, if the water-level is high it is possible to cross further up the valley. In late summer it is a short jump to cross. Alternatively, tree trunks found along the shore can be used as a rudimentary bridge.

At low tide, there is an excellent exposure of the characteristic sandstones of the Festningen Member, and at very low tide it is possible to pass around the sandstone itself and observe the boundary with the underlying Rurikfjellet Formation. The cliff sections just above the Festningen Sandstone Member can be accessed by descending just south of the northernmost sandstone, however, to follow the section upwards through stratigraphy low tide is required. It is possible to access the section a few places, however the safest route to the beach can be found at the boundary to the base Cenozoic conglomerate. This occurs just North of the ruins of an old hut and is the point at which the classical Festningen section described in this guide ends.

Walk back to the boat or pick-up location (Fig. 2 "F"). If returning to Russekeila, it is possible to cross the lower mountain ridge of Starostinaksla in the area of the parabolic antenna.

Permian

The Permian succession consist of two formations, the Gipshuken Formation of Early Permian age (Sakmarian–Artinskian) and the Kapp Starostin Formation of Middle to Late Permian age (late (Artinskian – Changhsingian). The Gipshuken Formation represents the upper part of the Upper Carboniferous to Lower Permian Gipsdalen Group whereas the Kapp Starostin Formation is assigned to the Tempel-fjorden Group. The Festningen section is the type locality for the Kapp Starostin Formation.

The Lower Permian succession is mostly scree-covered in the Festningen section and an exact thickness estimate is therefore problematic. In other locations in central Spitsbergen, the formation is up to 280 m thick. Based on the stratigraphic dip, a similar thickness seems reasonable for the unit in the Festningen section. Some few meters of

Figure 8A. Collapse-breccia where gypsum has been dissolved and a muddy dolomite occur in the valley side of a dried out river.

Figure 8B. Dissolved anhydrite nodules in the dolomites of the Gipsdalen Group

Figure 8C. Silicified algal lamination in the upper part of the Gipshuken Formation. Picture is ca. 10 cm across.

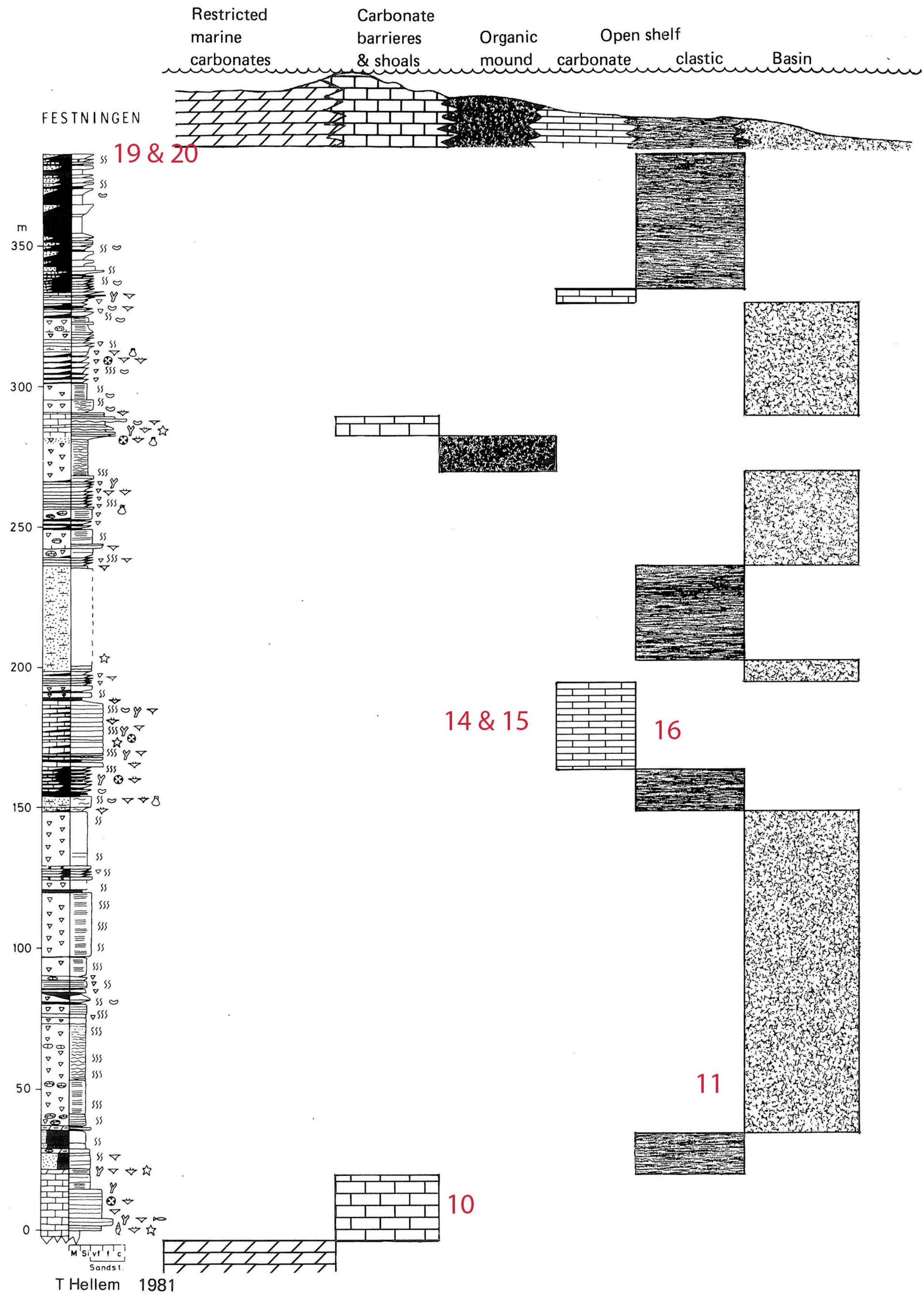


Figure 9. Interpretative log from the Kapp Starostin Formation logged by Terje Hellem in 1978. The location of photos is marked with numbers in red.

outcropping rock occur in a small creek in the central part of Soloveckijbukta (possibly marking the basal part of the unit). The uppermost few meters of the succession are poorly exposed immediately below the cliff-forming, brachiopod-dominated Vøringen Member (which is the basal unit of the Kapp Starostin Formation).

At Festningen, the Gipsdalen Group consists mostly of intensely fractured dolomitic mudstones (Fig. 7). Algal laminations (Fig. 8C), occasionally displaying poorly developed mounded geometries (i.e. stromatolites), ripple cross-lamination and partly dissolved anhydrite nodules occur sporadically within these rocks (Fig. 8C). Some of these features are best observed in loose blocks on the talus slope below the friable cliff. A dissolution breccia is also seen to occur in the upper part of the exposure (Fig. 8A). The Gipshuken Formation has been interpreted to represent deposition on a shallow, warm-water and periodically emerged carbonate platform under arid to semi-arid climatic conditions (Hüneke et al., 2001; Sorento et al., 2019).

The dolomitic mudstones of the Gipshuken Formation are sharply overlain by the Vøringen Member, the base of which marks a regional hiatus. This unit initiates the Middle to Upper Permian Kapp Starostin Formation. At the Festningen section, the Kapp Starostin Formation is ca. 380 m thick (Fig. 9; Hellem, 1980), exceeding 460 m at locations further to the south and thinning to less than 100 m to the NE. This variation reflects a regional deepening of the basin southwards (Steel & Worsley 1984; Blomeier et al., 2013; Bond et al., 2016).

The Vøringen Member of late Artinskian to Kungurian age, represents the basal unit (Fig. 10A) of the Kapp Starostin Formation. The unit forms a prominent, grey-colored limestone cliff on the eastern shore of Solovjetskibukta and is readily recognizable in the field. The unit has a stratigraphic thickness of ca. 25 m and is dominated by thick beds consisting of broken brachiopod shells (brachiopod grainstone/floatstone to rudstone; Fig. 10B). Note that some of the bed boundaries are not true depositional boundaries and are

Figure 10A. Overview of the Vøringen Member that forms the base of the Kapp Starostin Formation.

Figure 10B. Abundant brachiopod shells forming thick beds interpreted to represent migrating banks, that are dominated by fractured *Productus* sp.

Figure 11. Spiculitic chert with abundant *Thalassinoides* trace fossils giving rise to nodular fabric that forms the lower part of the Kapp Starostin Formation above the basal Vøringen Member.

Figure 12. Walking across the spiculitic cherts on the western side of the Kapp Starostin promontory. A well-trodden path hold open by reindeer and geologists takes you across the plateau.

Figure 13. The erosion resistant mountain Starostinaksla continues from the point Kapp Starostin as both the cape and the mountain consist of resistant cherts and carbonates.

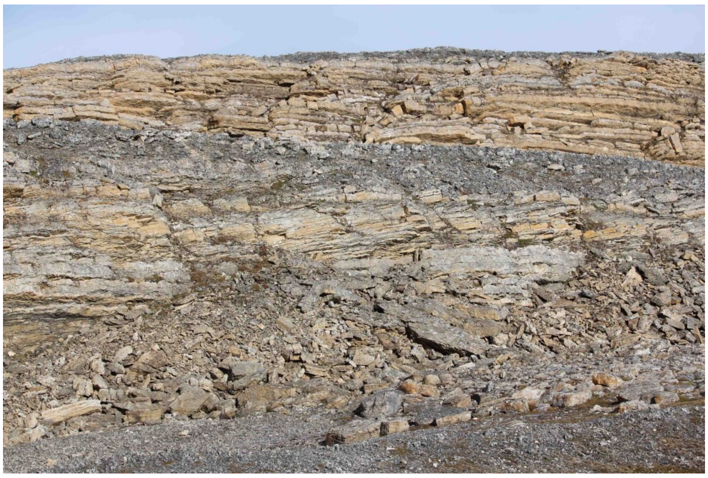


Figure 14. Clinoforms (i.e. dipping depositional surfaces) representing migrating offshore banks in carbonate grainstones in the middle of the Kapp Starostin Formation.

instead defined by the occurrence of stylolites (pressure solution fronts). Crinoids and bryozoans occur in varying amounts, particularly in the upper part of the unit. On some bed surfaces, the characteristic lobate trace fossil *Zoophycos* may be observed.

Collectively, the faunal elements found in the Vøringen Member reflect deeper and colder waters than those of the underlying Gipshuken Formation. Thus, the Vøringen Member is interpreted to represent a transgressive shallow marine deposit of regional extent (Steel & Worsley 1984; Uchman et al., 2016). The basal unconformity developed following a long-lasting subaerial exposure of the shelf that left parts of the Artinskian missing (e.g. Blomeier et al., 2013; Uchman et al., 2016; Sorento et al., 2019). The coarse-grained brachiopod coquinas and the lack of fine-grained material further indicate frequent storm-reworking and winnowing, together pointing to deposition above storm wave base.

Further east along the coastal cliff, the grey-colored carbonates of the Vøringen Member are gradually replaced (across an interval of a few meters) by dark-colored, silicified shale with a characteristic nodular appearance (Fig. 11). These shale deposits are heavily cemented by biogenic silica derived from disintegrated spicules, composed of silica, found on sponges and are thus referred to as spiculites. Locally, some well-preserved sponges may be observed, but for the most part, they are fully disintegrated and form thick stacks of well-defined beds. The remaining, accessible part of the exposures on the western side of the Kapp Starostin promontory consists of similar lithologies. Trace fossils such as *Thalassinoides* and *Nereites missourensis* occur within the spiculites. The fauna elements of the dark-colored spiculites and the relatively abrupt transition from the Vøringen Member indicate continued transgression and gradual deepening of the basin. This trend is observed throughout the basin (Ehrenberg et al., 2001; Blomeier et al., 2013; Bond et al., 2016).

It is not possible to make a compete traverse of the shoreline to the eastern side of Kapp Starostin. It is therefore advised to ascend the gentle slope west of the Vøringen Member to continue up the section along a path close to the cliff (Fig. 12). When following this path, some bed packages exhibit low-angle dipping surfaces (i.e. meso-scale clinoforms), which indicate the lateral migration or progradation of larger bars (Figs. 13 & 14). In the middle of the formation, the dark-coloured spiculites intercalate with a series of beige- to yellowish-coloured fossiliferous and silicified carbonate units (Fig. 15). These units form prominent benches in the terrain and offer excellent outcrops for closer inspection.

Various bryzoans, both fenestrae and trepostome (Fig. 16) are abundant, whereas the occurrence of brachiopods and sponges is more sporadic. *Thalassinoides* burrows, commonly silica-cemented, may be observed at several bed surfaces. At regional-scale, these upward-shoaling carbonate units represent a prograding carbonate ramp system (Steel & Worsley 1984; Eherenberg et al., 2001; Blomeier et al., 2013).

The upper part of the Kapp Starostin Formation consists of dark-grey silicified mudstones. This in contrast to sections further E and NE in Spitsbergen, which display a more sandstone-dominated development in the upper part, reflecting proximity to a structural high defined as the Nordfjorden High (Ehrenberg et al., 2001; Blomeier et al., 2011; Bond et al., 2016). *Zoophycos* trace fossils are abundant in these uppermost silicified mudstones. The very uppermost mudstone beds exposed on the eastern side of the Kapp Starostin promontory are intensively bioturbated and in this regard a strong contrast to the overlying basal shales of the Lower Triassic Vardebukta Formation, which is devoid of trace fossils. Here, the Permian–Triassic boundary (Figs. 18 & 19) and its mass-extinction event also marks the end of the Paleozoic carbonate platform development and the onset of the shallow siliciclastic shelf environment of the Mesozoic (Wignall et al., 1998; Worsley, 2008; Uchman et al., 2016).

Triassic

The Triassic succession is approximately 1100 m thick (Fig. 17) and consists of five formations all separated by pronounced regional unconformities, that can be followed throughout Svalbard and most of them also to other Arctic and global regions (Mørk et al., 1989; Mørk & Smelror, 2001).

Figure 15. A classical stop on the tour, the outer point of the Kapp Starostin promontory. The light-coloured beds consists of fossiliferous and partly silicified carbonates. Bryozoans are one of the dominant fossil groups in these units.

Figure 16. Fossils occur abundant in the yellow weathering carbonate beds (Fig. 15). The photo show large Bryozooan colonies

The Lower Triassic (Fig. 20) Forms two major coarsening up-ward sequences, the Vardebukta Formation of Induan age and the Tvillingodden Formation of Olenekian age. The lithostratigraphic base of the Vardebukta Formation is found at the top of the silica cemented mudstone forming the top of the Kapp Starostin Formation (Figs. 18 & 19), this also coincides with the Westernmost end of Vardebukta bay (named after the *varde* meaning cairn in Norwegian seen on top of the cliff midway through the formation).

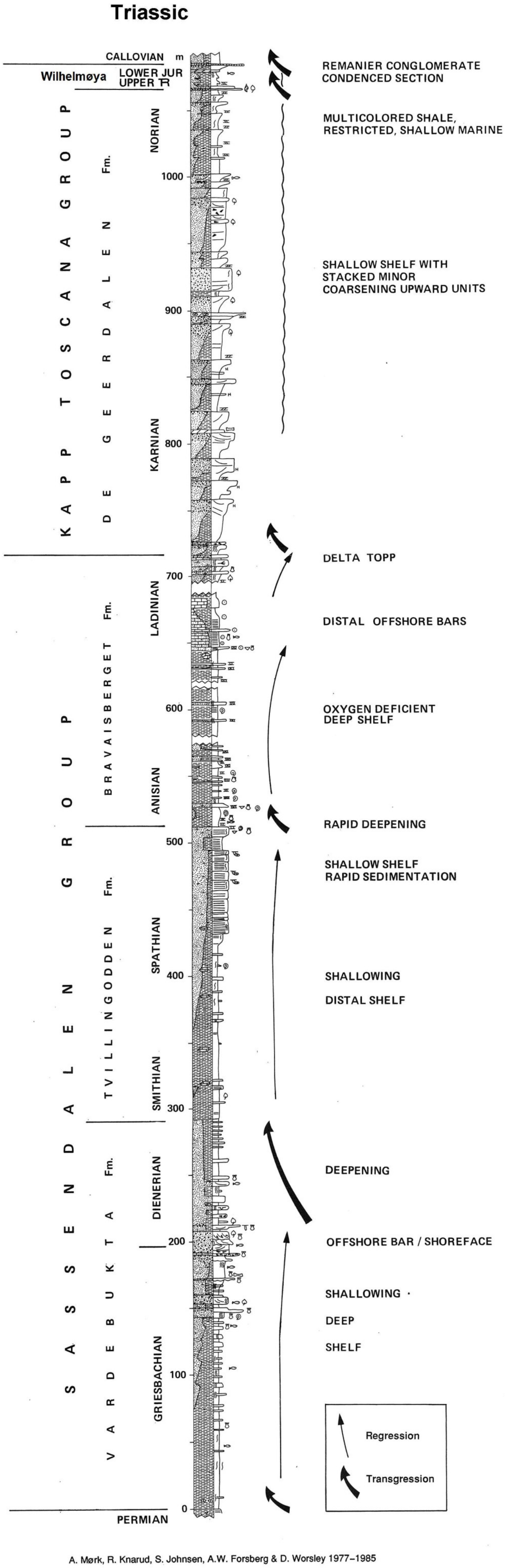


Figure 17. A composite log of the Triassic succession.

Figure 18. Photo of the boundary of the Vardebukta Formation on top of the cherts of the Kapp Satrostin Formation marked with V/KS, while T/P marks the Permian-Triassic boundary. Legends to sections in Fig. 52

Figure 19. The students sit on the lithostratigraphic boundary between the Kapp Starostin (Upper Permian) and Vardebukta (Triassic) formations, while the Permian – Triassic boundary is located in the upper left part of the photo.

Figure 20. A section with suggested facies interpretation for the Lower Triassic section. Locations of photos are indicated in red.

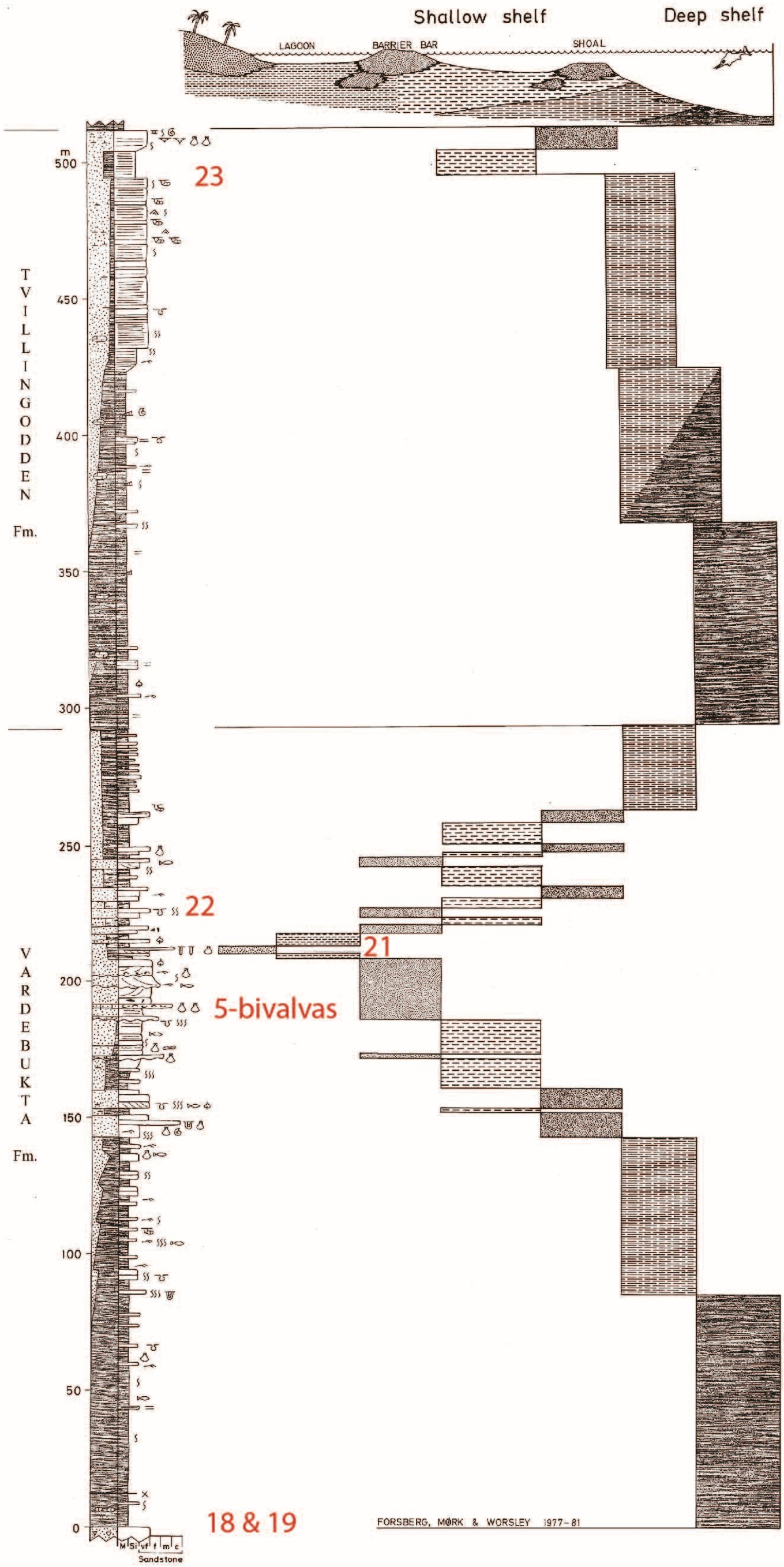


Figure 21. The protective burrows of *Skolithos* forms a "piperock" in the shallow bank deposits in the Vardebukta Formation.

Figure 22. Large-scale ball-and-pillow structures in the upper part of the Vardebukta Formation.

Figure 23. Vestre Tvillingodde (Western Twin Point) is formed by fine-grained sandstone and host a special *Rhizocorallium jenense* fauna at the marked position (*R*)

The boundary between the Permian Kapp Starostin Formation and the Triassic Vardebukta Formation is shown in Figures 18 & 19.

The chronostratigraphic P-T boundary, as indicated by the occurrence of the ammonoid *Otoceras boreale* is found a few meters higher up section, close to the ca 10 m thick diabase sill of Early Cretaceous age. (Figs. 18 & 19). Palynology in addition to a fungal peak and an isotope peak also support this interpretation.

Vardebukta Formation. Basal shales in the lowermost part are gradually replaced by storm derived sandstone beds increasing in thickness and abundance upwards. Note that there is no bioturbation in the basal part of the Vardebukta Formation. However, traces become progressively more abundant upwards, where they finally form a piperock of *Skolithos* (Fig. 21) in the barrier bar section just above 200 m. This interval passes upwards into coal bearing beds that mark the shallowest part of the succession. Figure 20 shows a sedimentological interpretation. Also note that the bivalve (*Promyalina* sp.) is more abundant upwards and can be seen to form coquina beds (see photo in Fig. 5).

A transgression represented by a fining upwards unit occurs at the top of the barrier bar, starting with a plant and coal debris probably representing lagoonal deposits. Rapid deposition of this faint transgressive succession is evidenced by abundant large ball and pillow structures (Fig. 22).

Tvillingodden Formation. The boundary, as most of the other formation boundaries in the Festningen section, occurs in a river. Along the coast, the boundary is covered by pebbles, but up-creek you may see a transition from mudstone to the platy silty-shale of the Tvillingodden Formation.

The formation forms a single coarsening upward succession following the basal Olenekian transgression (a world-wide transgression). Fossils are sparse, as are sedimentary structures. The upper part of the formation is formed of a very fine-grained sandstone with thin lamination (Fig. 23). This resistant sandstone body forms the point Vestre Tvillingodde. On the steeply dipping sandstone beds that form the eastern part of the point, a unique occurrence of trace fossils can be seen in the upper part of the formation. Here the trace fossil *Rhizocorallium jenense* are observed to increase in size and abundance upwards through the succession and the orientation indicates dwelling traces of suspension feeding animals (Worsley & Mørk 2001). This is a strong contrast to the mud-feeding *Rhizocorallium irregulare* that are abundant in the overlying Bravaisberget Formation.

The Middle Triassic in western Spitsbergen is represented by the *Bravaisberget Formation* (Fig. 24). The base is marked by a brachiopod and bivalve conglomerate overlying the platy sandstones at the of the Tvillingodden Formation (Fig. 24A). Due to the rich mudstone content of this formation tectonic activity has resulted in extensive folding and thrusting within this unit at Festningen. Consequently, a complete, or reliable section cannot be accurately measured, thus readers are referred to the bed-by-bed measurements in Figure 4 and the interpretative section in Figure 25.

In the lower part (West of the creek in the bay) large silt/sandstone surfaces feature phosphatised ammonoids and a web of interconnected nodular phosphate cemented sediments (Fig. 25B). These nodular webs have been mapped (Fig. 26) and interpreted as tunnel network of the ichnogenus *Thalassionides* and the infillings have subsequent been phosphatized (Mørk & Bromley 2008). Such nodular beds have often been eroded, probably by heavy storms, and often form conglomerates at base of siltstone beds (see photo in Fig. 5). The lower part of the section which is dominated by mudstone and abundant phosphate nodules represents the Passhatten Member.

Starting at the western side of Austre Tvillingodde, lamellar dark beds consisting of phosphatised oolites are present, representing high energy environments (Fig. 25D and photos in Fig. 5). At the point, extensive folding makes stratigraphic interpretation difficult (see Fig. 4). This part of the succession is included within the Somovbreen Member, which further south of this locality forms a major siltstone body. A regressive development occurs throughout West Spitsbergen due to sediment influx from the West (potentially Greenland).

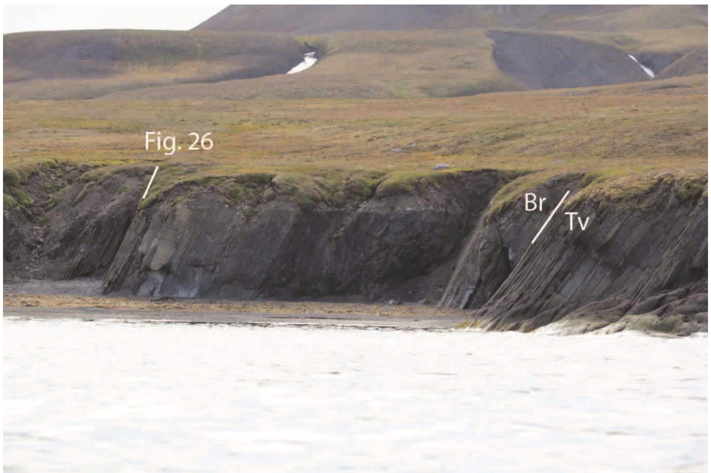


Figure 24A. The uppermost part of the Tvillingodden Formation and the lower part of the Bravaisberget Formation. Boundary is marked by Br/Tv, and the fossiliferous surface interpreted in Figure 26 is marked by (26).

Figure 24B. The lower part of the Bravaisberget Formation, East of the small river in the middle of the bay between Tvillingoddane.

The upper 25 m of the Formation is well-exposed as vertical sandstone beds which form the Eastern part of the point (Austre Tvillingodde)(Figs. 27 & 28). This sandstone is defined as the Van Keulenfjorden Member and can be followed along the entire western area of Spitsbergen. The unit represents a clear and final regressive stage of basin infilling during deposition of the Bravaisberget Formation.

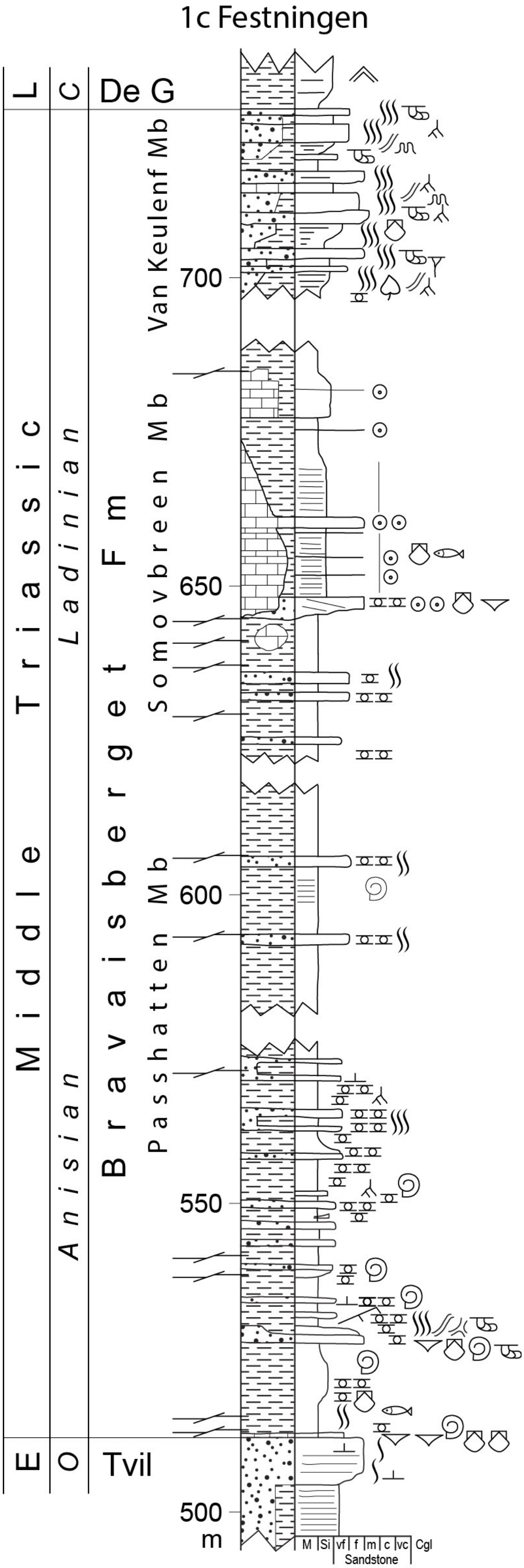


Figure 25A (left side). Measured sections from the Middle Triassic Bravaisberget Formation. A continuous section has not been made due to the complicated tectonics.

Figure 25B. Thick siltstone bed with a phosphate conglomerate at base (ca 550 m)

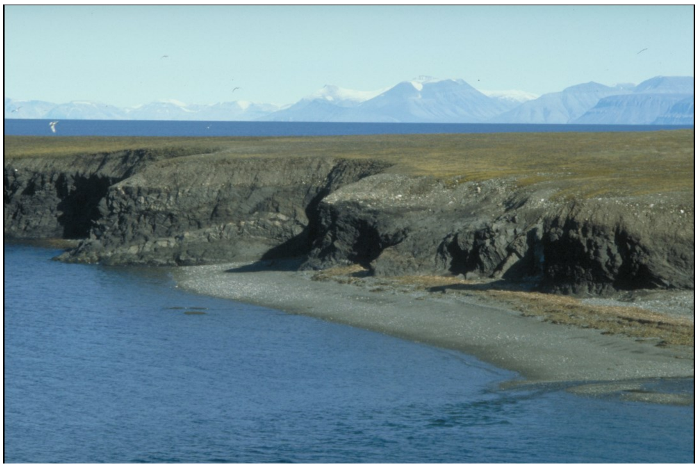


Figure 25C. The strongly folded section below 650 m.

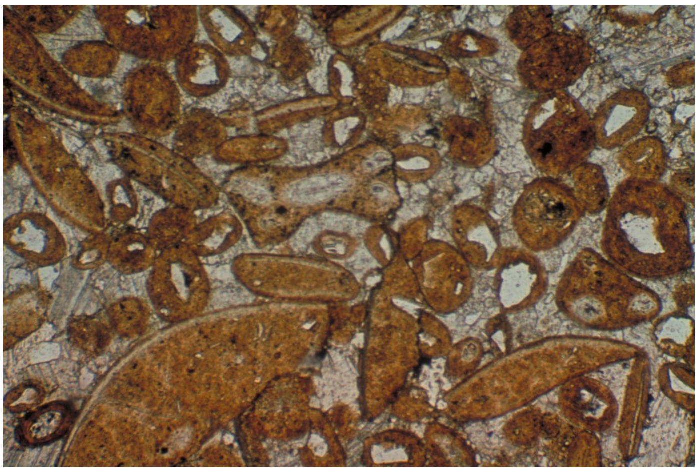


Figure 25D. Phosphatic oolites and phosphate occuring below small bivalve shells in a soparite matrix (from the oolite bank at 650 m).

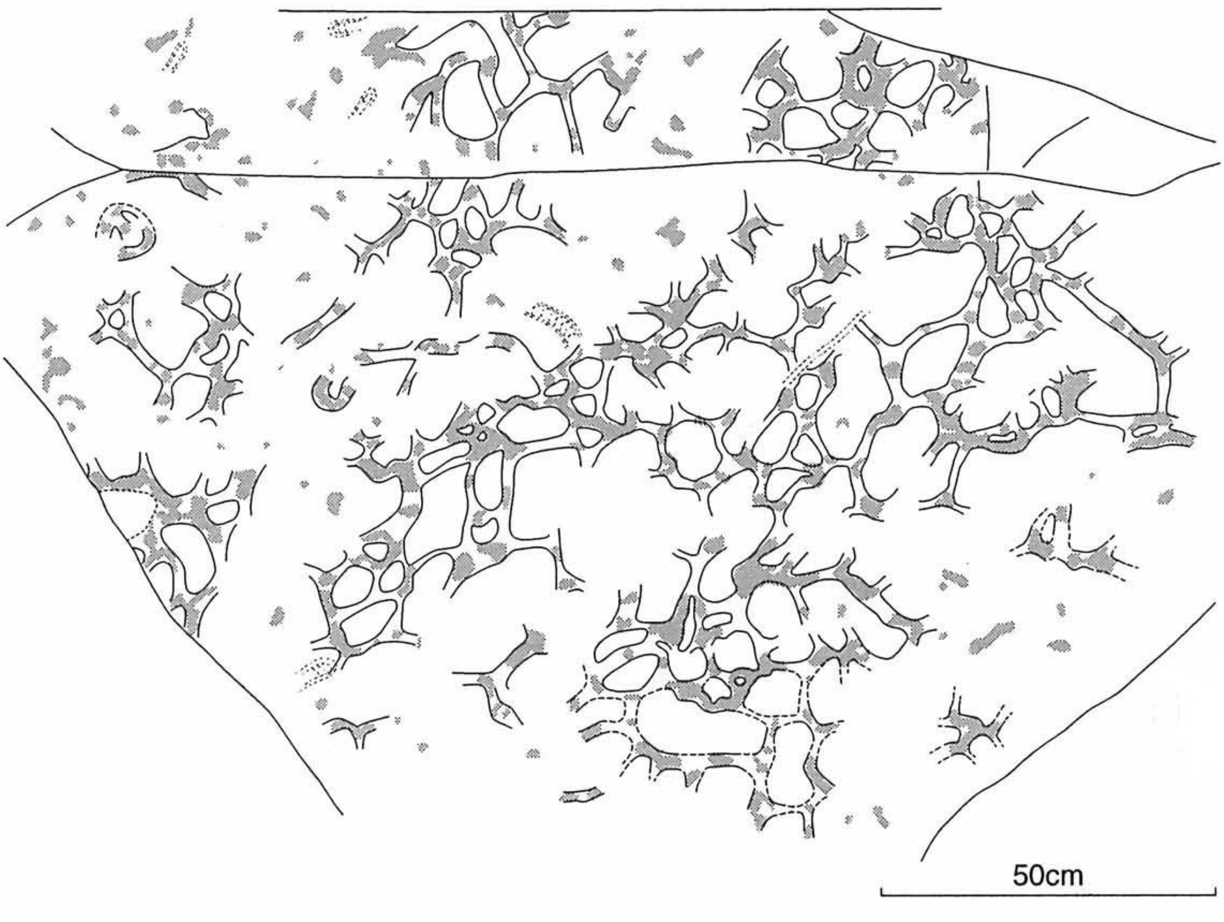


Figure 26. Bedding surface with *Thalassinoides* trace fossils and a suggested interptretation by Mørk & Bromley (2008). This surface is marked at Figure 24.

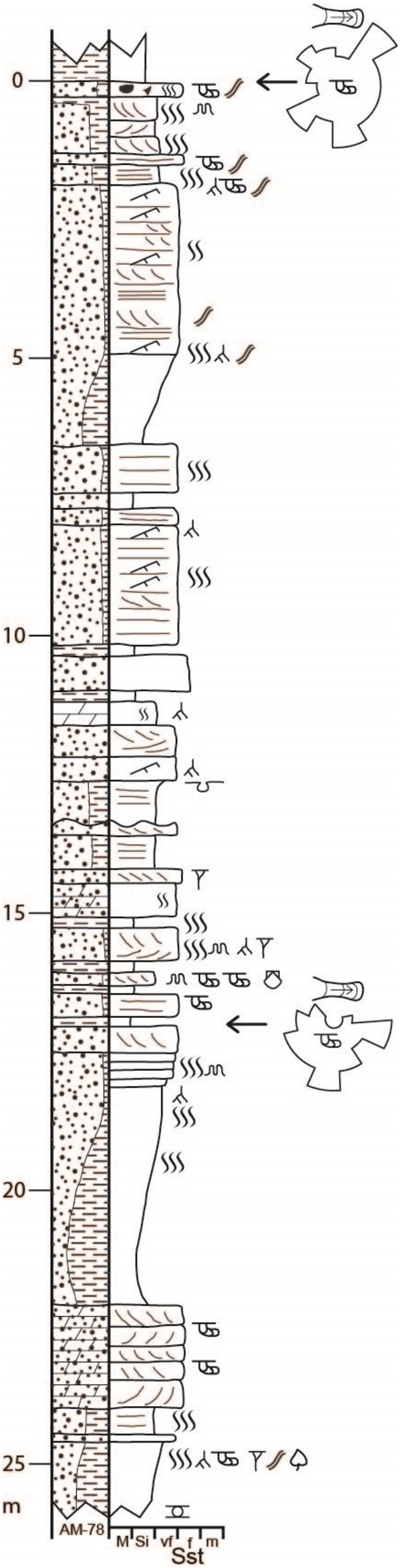


Figure 27. Log and photos (Figure 28) of Van Keulenfjorden Member which form the uppermost part of the Bravaisberget Formation. Note the abundance of trace fossils, and that the *Rhizocorallium* at level 17 is orientated, but not on the top surface.

Figure 28A. The uppermost part of the Van Keulenfjorden Member. On top of the cliff the Tschermakfjellet Formation may be represented by the few metres of shale on top of the cliff forming sandstone

Fig. 28B. A very large trace fossil of *Rhizocorallium*, occuring between the two rose-diagrams.

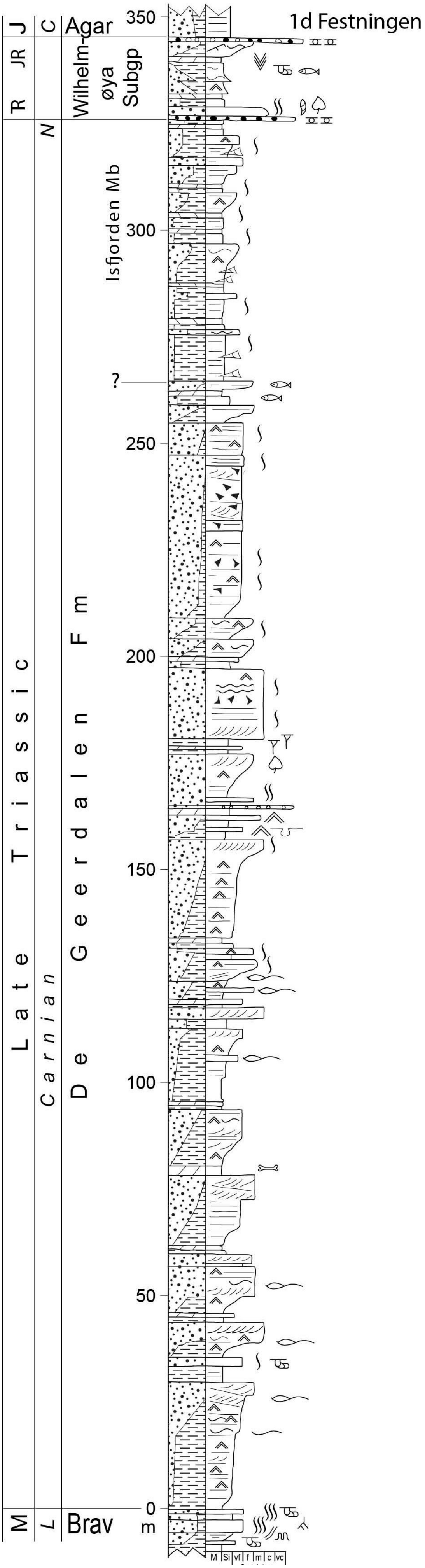


Figure 29. View of the Upper Triassic De Geerdalen Formation.

Figure 30 (left). Sedimentological log of the De Geerdalen Formation and the Wilhelmøya Subgroup.

Figure 31. A cross-bedded sandstone unit in the Upper Triassic De Geerdalen Formation.

The sandstones show abundant wave ripples and a fauna of clearly protective trace fossils like *Polyklacichnus* and *Rhizocorallium*. The *Rhizocorallium* show a clear trend of orientation in the lower part, while their orientation is totally arbitrary in the top bed (see rose diagram in Fig. 27).

The Upper Triassic consists of a structurally missing and thinned Tschermakfjellet Formation and De Geerdalen Formation overlain by the Knorringfjellet Formation of the Wilhelmøya Subgroup at this locality (Figs. 29 & 30).

The Tschermakfjellet Formation is not formally recognised in western Spitsbergen and this may be attributed to structural thinning resulting from Cenozic deformation. The unit consists of the lowermost shales and siltstone beds that immediately overly the Bravaisberget Formation and features abundant pyrite nodules. In eastern areas the formation can reach ca. 100 m in thickness and is composed of shale and siltstone with thin interbeds of fine-grained sandstone and siderite nodules. The Tschermakfjellet Formation represents pro-delta shales to the paralic De Geerdalen Formation.

The De Geerdalen Formation is exposed in the bay West of Tvillingoddane. The boundary with the Bravaisberget Formation (representing a lateral equivalent of the Tschermakfjellet Formation in this area) and this sandstone dominated unit is shown in Figures 28 & 29. Active erosion of the sandstone and shale beds has resulted in a relatively wide shoreline separating the sea from outcrop, thus exposure is not as high quality as more resistant units. The formation consists of nearly 20 coarsening upward sequences (Fig. 30) ranging between a few to maximum 50 m in thickness. Many of these sequences are capped by 0.5-2 m thick carbonate beds. Mud flakes are abundant and several beds in the lower half of the succession exhibit hummocky cross-lamination. The succession is interpreted as representing shallow marine shelf sedimentation.

The upper part of the formation has red and green weathering mudstone beds (Fig. 32) and is defined as the *Isfjorden Member*. These mudstones represent palaeosoil horizons developed during a regional regression, marking a shift from shallow marine and paralic deltaic facies to a mature delta top environment. At Festningen, paleosols have not been observed.

The *Wilhelmøya Subgroup* is only 24 m thick at Festningen (Fig. 30). However, the regionally extensive phosphate conglomerate of the *Slottet Bed* is well exposed at the base of this unit (Fig. 33). Earlier dating indicated that the Triassic – Jurassic boundary was situated in the middle part of this unit

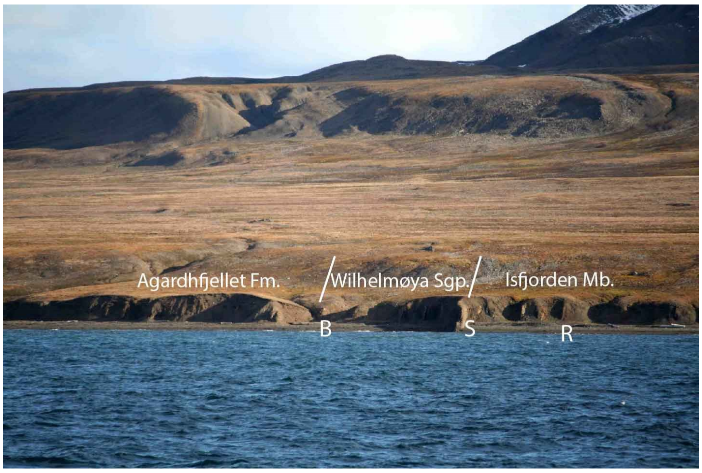


Figure 32. The upper part of the De Geerdalen Formation with the red shales of the Isfjorden Member. The Wilhelmøya Subgroup starts with the Slottet Bed (S) and have the Brentskardhaugen Bed (B – scree covered) at top. To the left a basal bioturbated sandstone with fissile dark shale belong to the Agardhfjellet Formation (Jurassic).

Figure 33. The Slotted Bed consists of grey rounded phosphate nodules.

Figure 34. The middle part of the Wilhelmøya Subgroup which is only 24 m thick at this locality.

(Mørk et al., 1982, 1999). However, new palynological evidence indicates that the entirety of the unit at Festningen was deposited during the Triassic (Fig. 34, Rismyhr et al, 2018). In light of this new data, the stratigraphic nomenclature, notably the Knorringfjellet Formation and Tverrbekken member is being reconsidered and the whole unit is regarded as correlating with the *Flatsalen Formation* as elsewhere on Svalbard. In 1978, the section was excavated with phosphate nodules being observed in the creek ca. 24 m above the Slottet Bed. (Bach 1 in Figs. 3 & 4). This established the presence of *Brentskardhaugen Bed* and is regarded as marking the onset of the Jurassic succession at Festningen. Unfortunately, this bed is again covered by gravel and scree, however it may occur as a small exposure, just below the mud rich and bioturbated sandstone bed just west of the creek.

Jurassic – Lower Cretaceous and Paleogene

From the top of the condensed strata of the Wilhelmøya Subgroup, the succeeding Middle Jurassic to Lower Cretaceous succession is readily accessible along the beach towards Festningsodden. However, the degree of exposure is variable, with folding and thrust faults occurring at several places (See Fig. 4). The succession is approximately 1000 m thick, and lithostratigraphically belongs to the *Adventdalen Group*, which is comprised of the Agardhfjellet, Rurikfjellet, Helvetiafjellet and Carolinefjellet formations.

The *Agardhfjellet Formation* of Middle Jurassic (Bathonian) to lowermost Cretaceous (Ryazanian) age is ca. 330 m thick. The unit is dominated by finely laminated, black 'paper' shale and silty mudstones (Figs. 35-37), occasionally intersected by carbonate-cemented mudstone and sandstone beds. Belemnites, bivalves and gastropods occur locally (Fig. 38), and by closer inspection, *Phycosiphon* and *Chondrites* burrows are present in some shale horizons. The dark colour of these shales relates to the high concentration of organic material, with a total organic carbon content up to 10–12% (Koevoets et al., 2016). Collectively, the laminated character of the shale and trace fossil assemblages point to deposition of the unit on a relatively deep shelf environment under oxygen deficient conditions (i.e. anoxic to dysoxic bottom waters).

Figure 35. Examples of the vertically-tilted, finely-laminated black shales of the Jurassic Agardhfjellet Formation.

Figure 36. The typical shale-dominated character of the Agardhfjellet Formation. Note thrust faults cutting the carbonate-cemented layer. Photo: Terje Solbakk.

Figure 38. Large bivalve shell fragments and gastropods on the top surface of a prominent, beige to yellow-colored, sandy carbonate bed in the lower part of the Oppdalssåta Member (ca. 181 m above the base of the Agardhfjellet Formation, see Figure 37 for stratigraphic position of the bed).

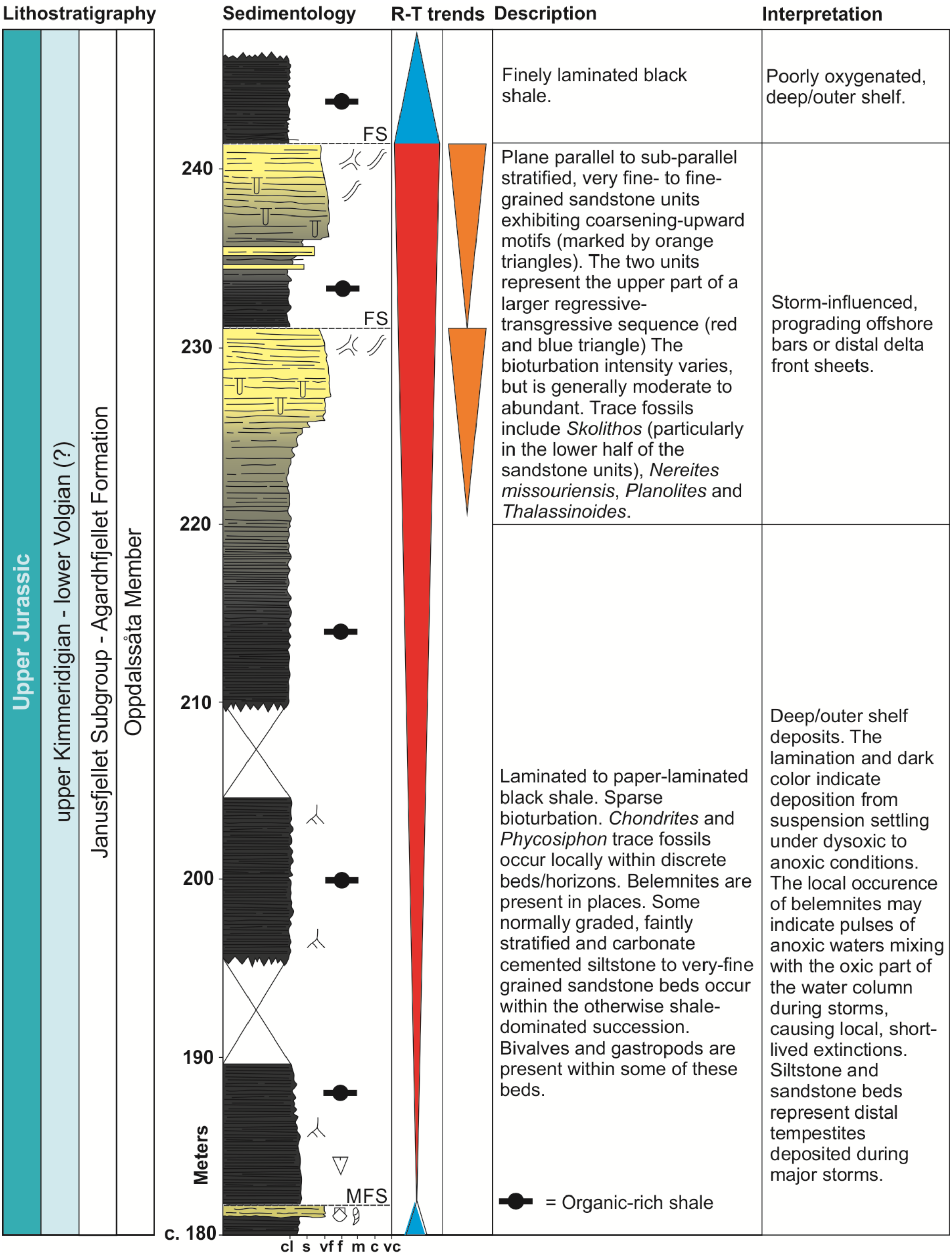


Figure 37. Examples of sedimentary succession of organic rich shales of the Agardhfjellet Formation deposited under anoxic conditions that are interrupted by strongly bioturbated sandstones as offshore bars entered the basin.

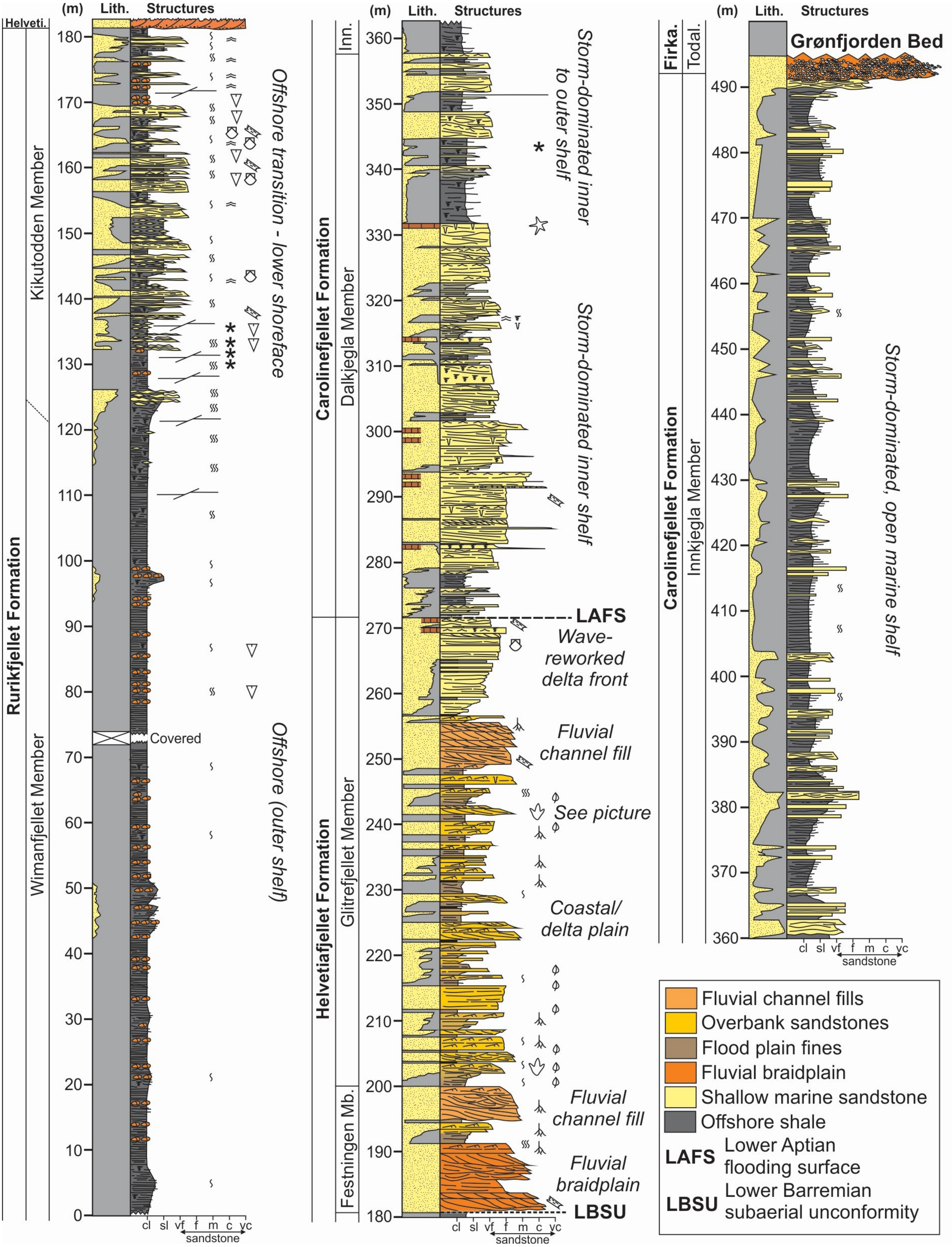


Figure 39. Sedimentological log of the Rurikfjellet, through Helvetiafjellet into the Carolinefjellet formations.

Figure 40. Randomly distributed or strata-bound, 'canon-ball' siderite concretions are commonly occurring features in the upper part of the Rurikfjellet Formation (lens caps for scale).

Figure 41. Tempestite beds (i.e. storm-deposits) with hummocky cross-stratification occur commonly in the Kikutodden Member in the uppermost part of the Rurikfjellet Formation below the Barremian unconformity at base of the Festningen Member.

Figure 42. The base of the cross-bedded sandstones of the Festningen Member marks an early Barremian unconformity of regional extent. Note the heterolithic character of the uppermost Rurikfjellet Formation (stratigraphic-up is to the left in the picture).

Two vertically stacked, coarsening-upwards sandstone units, each 5–6 m thick occur ca. 220 to 240 m above the base of the formation. These sandstones units are horizontally stratified and contain trace fossils such as *Skolithos*, *Thalassinoides* and *Nereites*, pointing to deposition in open marine shelf environments. The coarsening upward trend suggest progradation of offshore bars or distal delta front sheets (e.g. Koevoets et al., 2018). The succeeding part of the formation is dominated by black shale and mudstones similar to the lowermost part. In the Barents Shelf, the time equivalent Hekkingen Formation of similar facies forms an important source rock for oil and gas.

The boundary between the Jurassic Agardhfjellet Formation and the Cretaceous aged Rurikfjellet Formation is in other locations marked by the up to 10 m thick plastic clay unit defined as the Myklegardfjellet Bed (Dypvik et al., 1991; Jelby et al., 2020a). In the Festningen section, a small creek 200 m west of Festningselva (named 'Bach IV' in Figure 4) separates the dark paper shales of the Agardhfjellet Formation from prismatic fracturing grey shales of the Rurikfjellet Formation. The creek itself features a slippery yellow weathering product which may represent the Myklegardfjellet Bed in this area. These two formations are both dominated by dark shale and are collectively referred to as the Janusfjellet Subgroup (Mørk et al., 1999).

A sedimentological log with the upper part of the Rurikfjellet Formation, the Helvetiafjellet Formation the lower part of the Carolinefjellet Formation is presented in Figure 39. At Festningen, the Rurikfjellet Formation is much thicker than in most other sections in central Spitsbergen where it usually measures up to 220 m thick (Dypvik et al., 1991). This is due to the presence of several thrust faults and folds within the shale-dominated part of the unit (see Fig. 4).

The *Rurikfjellet Formation* (Valanginian to earliest Barremian age; see Sliwinska et al., 2020) is ca. 380 m thick. Its lower part is dominated by silty mudstones, which grade upwards into bioturbated siltstones and alternating sandstone beds to form a large-scale upwards-coarsening unit (Fig. 39; Jelby et al., 2020b). The trace fossils *Nereites missourenis* and *Chondrites* occur abundantly in the siltstones, and 'Canon-ball' siderite concretions (Fig. 40), glendonites, belemnites, and fossil wood fragments occur sporadically throughout the unit. The sandstone beds in the upper part are sharp-based, exhibiting hummocky cross-stratification and wave-rippled bed tops (Fig. 41). Vertical escape burrows are also observed to penetrate some of the sandstone beds. Collectively, this suggest deposition by short-lived storm events (Jelby et al., 2020b). The deposits of the Rurikfjellet Formation are interpreted to have accumulated on a relatively shallow, storm-dominated, open marine shelf. The coarsening upwards trend indicate progressive shallowing and progradation of the nearshore environment (Dypvik et al.,1991; Grundvåg et al., 2019; Jelby et al., 2020b).

The sandstones in the upper part of the Rurikfjellet Formation can only be studied at low tide when it is possible to access the steep cliffs forming the very point of Festningsodden (Fig. 42). The lower and middle part of the units is however accessible at high tide. If access cannot be made around the point, ascend the mossy, flat plateau west of Festningsodden and continue towards the prominent cliffs of the Festningen Member (Figs. 42-48), which represent the basal unit of the overlying Helvetiafjellet Formation. From a distance, these cliffs protruding from a relatively flat landscape resemble the walls of a fortress, and provide the etymology for the Festningen locality name.

The *Helvetiafjellet Formation* is ca. 90 m thick and is of Barremian to early Aptian age (Fig. 39). The basal *Festningen Member* consists of two vertically stacked cross-bedded sand-stone bodies, forming a ca. 20 m thick sequence (Steel et al., 1978). This very prominent sandstone unit forms a laterally extensive sheet that can be recognised across most of the Lower Cretaceous outcrop belt (Midtkandal & Nystuen, 2009; Grundvåg et al., 2017). The cross-bedding in combination with its lateral extent suggest deposition in a fluvial braidplain setting (Nemec, 1992). The base of the member is an

Figure 43. Roots occur abundant between the two lower sandstones of the Festningen Memner

Figure 44. Panoramic view of Festningsodden and Fest-ningsskjeret. The whitish, vertically-tilted sandstones is the Festningen Member of the Helvetiafjellet Formation. This locality have given name to the Festningen section, meaning the fortress.

Figure 45. The vertically-tilted, cross-bedded sandstones of the Festningen Member represent a lateral-extensive fluvial braidplain deposit. The base of the unit marks a regional unconformity formed during uplift and exposure of the Svalbard platform during the early Barremian (stratigraphic-up is to the right in the picture).

Figure 46. Large-scale (epsilon-type) cross-bedding in the upper fluvial sandstone body of the Festningen Member. This type of large-scale cross-bedding is attributed to lateral accretion of side-channel bars/point bars in active river channels.

unconformity that marks a period of regional uplift and juxtapose shelf deposits of the Rurikfjellet Formation abruptly against the overlying fluvial sandstones. The unconformity is easy to observe at the base of the vertically tilted sandstones of the Festningen Member (Fig. 42) and may be studied in greater detail at low tide.

Rootlets occur in several horizons in the Helvetiafjellet Formation, and locally the sediments are thoroughly disturbed (bioturbated) by these plant roots. The rootlets are preserved as simple, vertical sandstone-filled tubes (occasionally with a black carbonaceous-lining) or as black, carbonaceous, branches extending downwards from thin coal or coaly shale beds into the underlying deposits, commonly fluvial channel fills or inter-channel sandstone sheets (Fig. 43). The overlying Glitrefjellet Member consists of alternating sandstones, mudstones and thin coal beds, forming a ca. 70 m thick heterolithic succession (Figs. 39 & 49). The unit is best observed at low tide, care should be taken to avoid becoming trapped in some of the bays during rising tide. The sandstones commonly display trough cross-bedding and current-ripple cross-lamination. Plant material and rootlets occur frequently

Figure 47. A dinosaur footprint (outlined) at the base of a fluvial overbank sandstone in the upper part of the Glitre-fjellet Member of the Helvetiafjellet Formation. Although the footprint is often covered by beach gravel and seaweed, the observant eye will usually spot it right away. Photo: Malte Jochmann.

Figure 48. A ca. 10 m thick, coarsening- and thickening-upwards delta front (?) sandstone unit is present in the uppermost part of the Helvetiafjellet Formation (He). The boundary to the overlying Carolinefjellet Formation (Ca) occur on top of this unit, and is marked by a regional extensive lower Aptian flooding surface (LAFS). Stratigraphic up is to the left in the picture.

throughout the unit. The Glitrefjellet Member accumulated in a low-lying coastal plain or paralic environment, influenced by both fluvial and marine processes.

The classical well-preserved dinosaur footprints documented by earlier studies (e.g. Lapparent, 1962; Heintz, 1963) are unfortunately no longer present due to recent erosion. However, a series of footprints reside inside a narrow cave halfway up the succession (Hurum et al., 2006). In addition, a cast occurs underneath a sandstone bed in the upper part (sometimes covered by beach gravel and seaweed). (Fig. 47) Casts of a footprint can be seen in the Svalbard Museum in Longyearbyen.

The overlying lower Aptian to Albian aged *Carolinefjellet Formation* is ca. 220 m thick and consists of sandstones and alternating mudstones arranged in a large-scale fining-upward succession. The entire succession is easily accessible along the shore from the eastern side of Festningsodden towards the wooden hut 700 m to the SE. If time is short, it is possible to traverse the top of the cliffs and descend to out-crops of interest along the way.

The basal boundary of the Carolinefjellet Formation is placed on top of a 10 m thick coarsening upward unit in the uppermost part of the Helvetiafjellet Formation (Figs. 48 & 49). This unit is capped by ca. 5 m thick dark-colored heterolithic shale package deposited during an early Aptian flooding event, which transgressed the entire Helvetiafjellet Formation coastal plain (Midtkandal et al., 2016; Grundvåg et al., 2019). The lower 50 m of the unit is sand-stone-dominated and referred to the Dalkjegla Member, whereas the succeeding Innkjegla Member is finer-grained and heterolithic (Fig. 38).

The sandstone beds of the Carolinefjellet Formation commonly exhibit hummocky cross-stratification and wave-rippled tops (Fig. 50) with trace fossils such as *Skolithos*, *Rosselia*, *Diplocraterion* and *Thalassinoides* occurring frequently.

Fragmented remains for starfish and bivalves are also

Figure 49. A sandy shale packaged of early Aptian ages separates the paralic Helvetiafjellet Formation from the open marine shelf deposits of the Carolinefjellet Formation (stratigraphic up is to the left in the picture).

Figure 50. Open marine, inner-shelf storm deposits of the Carolinefjellet Formation. Wave-ripples with straight crests and wave ripples with multiple-directed crests occur commonly throughout the sandstone-dominated parts of the formation.

present. These features collectively point to deposition on a storm-dominated, open-marine shelf (Grundvåg et al., 2019). The fining-upward trend indicates a progressive deepening of the basin.

A spectacular conglomerate, referred to as the Grønfjorden Bed, occurs in the cliff below the wooden hut (Figs. 51 & 52). This bed ends the classical Festningen section and the base initiates the Cenozoic, marking a regional hiatus where Paleocene rocks sit directly on top of Lower Cretaceous strata. Thus, the entire Upper Cretaceous is missing as else-

Figure 51. The Grønfjorden Bed (next photo) is present in the coastal cliff just below the cabin ruins.

Figure 52. The conglomerates of the Grønfjorden Bed marks the Mesozoic-Cenozoic transition and represent a significant regional hiatus with Paleocene strata sitting directly atop of Lower Cretaceous strata (between the dark shale and the conglomerate bed, stratigraphic up is to the left).

where in Svalbard. The conglomerate consists of sub-rounded gravel to boulder-sized clasts embedded in a coarse-grained sandy matrix. The clasts display slight imbrication and transported plant material occurs locally. The Grønfjorden Bed is of fluvial origin and is interpreted to have accumulated during a period of fluvial rejuvenation resulting from the exhumation and exposure of the Svalbard Platform. Here the classical Festningen section ends. Return to pick-up point.

Acknowledgement

This guide is an extended and modified version of guide-books by David Worsley and Atle Mørk based on fieldwork from 1978 until now. Many geologists and geology-students have during the last decades contributed to our understanding of the geology of the Festningen sections, often as part of more regional studies. SAG received funding from the ARCEx project which is supported by the Research Council of Norway (grant number 228107). Gareth S. Lord has improved the English text. Constructive recommenda-tion from the reviewers Malte M. Jochmann and Morten Bergan improved the guide.

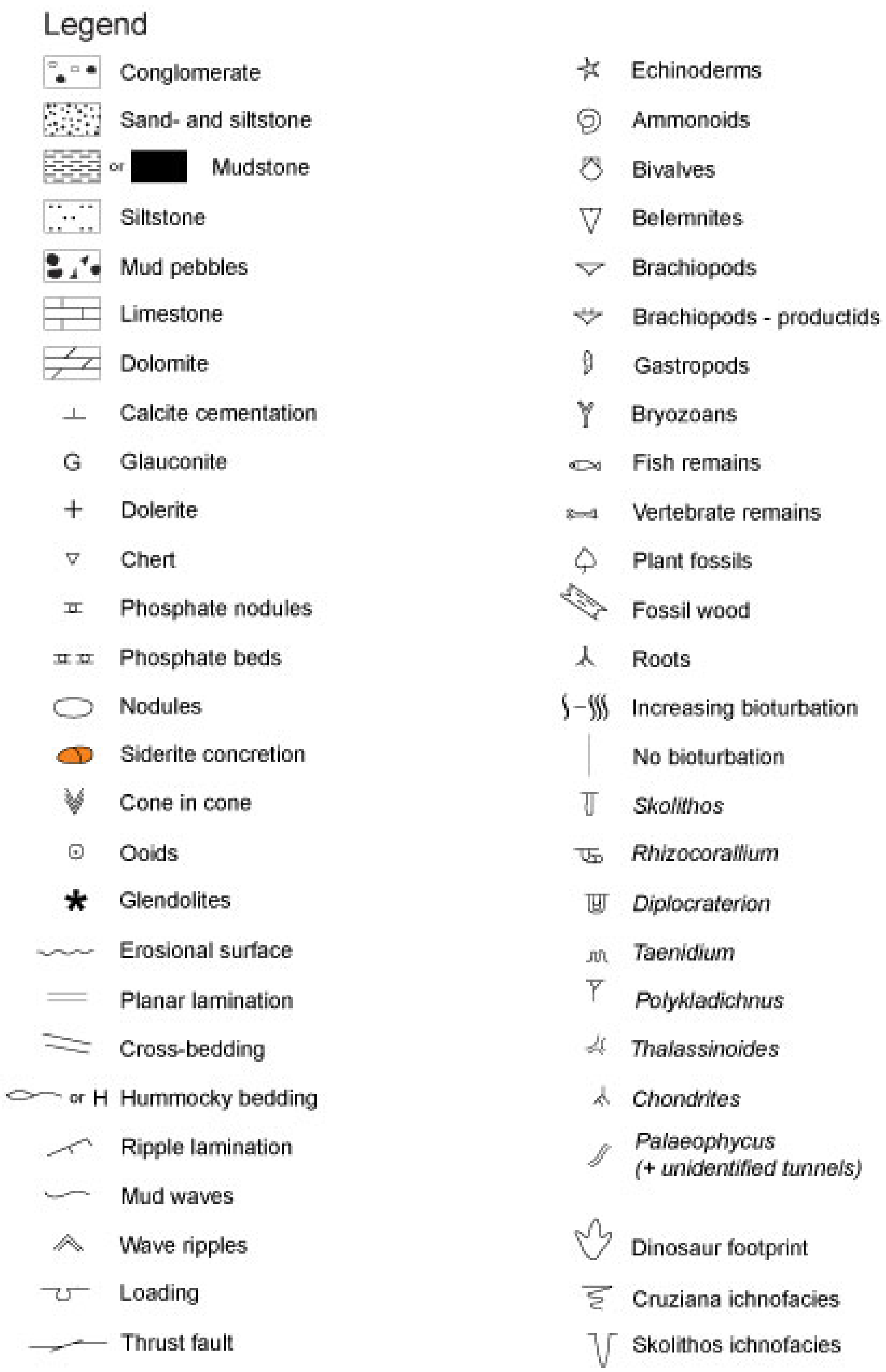


Figure 52. Legend.

Festningen References

Blomeier, D., Dustira, A.M., Forke, H. & Scheibner, C., 2013: Facies analysis and depositional enviro ments of a storm-dominated, temperate to cold, mixed siliceous-carbonate ramp: the Permian Kapp Starostin Formation in NE Svalbard. *Norwegian Journal of Geology* 93, 75-94.

Bond, D.P., Blomeier, D., Dustira, A., Wignall, P., Collins, D., Goode, T., Groen, R., Buggisch, W., Grasby, S., 2017: Sequence stratigraphy, basin morphology and sea-level history for the Permian Kapp Starostin Formation of Svalbard, Norway. *Geological Magazine*, 1-17.

Dallmann, W.K. (ed.) 1999: *Lithostratigraphic lexicon of Svalbard. Review and recommendations for nomenclature use. Upper Palaeozoic to Quaternary bedrock.* Norsk Polarinstitutt, Tromsø. 318 pp.

Dypvik, H., Eikeland, T.A., Backer-Owe, K., Andresen, A., Johanen, H., Elverhøi, A., Nagy, J., Haremo, P. & Bjærke, T., 1991: The Janusfjellet Subgroup (Bathonian to Hauterivian) on central Spitsbergen: a revised lithostratigraphy. *Polar Research* 9, 21-44.

Ehrenberg, S., Pickard, N.A.H., Henriksen, L.B., Svånå, T.A., Gutteridge, P. & Macdonald, D., 2001: A depositional and sequence stratigraphic model for cold-water, spiculitic strata based on the Kapp Starostin Formation (Permian) of Spitsbergen and equivalent deposits from the Barents Sea. *Ameri can Association of Petroleum Geologists, Bulletin* 85, 2061-2087.

Grundvåg, S.-A., Marin, D., Kairanov, B., Śliwińska, K.K., Nøhr-Hansen, H., Jelby, M.E., Escalona, A. & Olaussen, S., 2017: The Lower Cretaceous successsion of the northwestern Barents Shelf: Onshore and offshore correlations. *Mar. Petrol. Geol*., 86, 834–857.

Grundvåg, S.-A., Jelby, M.E., Śliwińska, K.K., Nøhr-Hansen, H., Aadland, T., Sandvik, S.E., Tennvassås, T. & Olaussen, S., 2019: Sedimentology and palynology of the Lower Cretaceous succession of central Spitsbergen: integration of subsurface and outcrop data. *Norwegian Journal of Geology*, 99, 1–32. https://dx.doi.org/10.17850/njg006.

Heintz, N. 1963: Dinosaur-footprints and polar wandering. Norsk Polarinstitutt, Årbok 1962, 35-43.

Hellem; T. 1980, Personal communication.

Hoel, A. & Orvin, A., 1937: Das Festungsprofil auf Spitzbergen, Karnon – Kreide I. Vermessungsresiltate. *Svalbard og Ishavet, Skrifter*, 18.

Hüneke, H., Joachimski, M., Buggisch, W. & Lützner, H., 2001: Marine Carbonate Facies in Response to Climate and Nutrient Level: The Upper Carboniferous and Permian of Central Spitsbergen (Svalbard). *Facies* 45, 93–136.

Hurum, J.H., Mila`n, J., Hammer, Ø., Midtkandal, I., Amundsen, H. & Sæther, B., 2006: Tracking polar dinosaurs – new finds from the Lower Cretaceous of Svalbard. *Norwegian Journal of Geology*, 86, 397–402.

Jelby, M.E. Śliwińska, K.K., Koevoets, M.J., Alsen, P., Vickers, M., Olaussen, S. & Stemmerik, L. (2020a) Arctic reappraisal of global carbon-cycle dynamics across the Jurassic–Cretaceous boundary and Valanginian Weissert Event. Palaeogeography, Palaeoclimatology, Palaeoecology 555, https://doi.org/10.1016/j.palaeo.2020.109847.

Jelby, M.E., Grundvåg, S.-A., Helland-Hansen, W., Olaussen, S. & Stemmerik, L., 2020: Tempestite facies variability and storm-depositional processes across a wide ramp: Towards a polygenetic model for hummocky cross-stratification. *Sedimentology* 67, 742-781.

Koevoets, M., Abay, T.B., Hammer, Ø. & Olaussen, S., 2016: High resolution organic carbon-isotope stratigraphy of the Middle Jurassic–Lower Cretaceous Agardhfjellet Formation of central Spitsbergen, Svalbard. *Palaeogeography, Palaeoclimatology, Palaeoecology* 449, 266–274. https://doi.org/10.1016/j.palaeo.2016.02.029.

Koevoets, M.J., Hammer, Ø., Olaussen, S., Senger, K. & Smelror, M., 2018: Integrating subsurface and outcrop data of the Middle Jurassic to Lower Cretaceous Agardhfjellet Formation in central Spitsbergen. Norwegian Journal of Geology 98, 1–34.

Lapparent, A.F. de. 1962: Footprints of Dinosaur in the Lower Cretaceous of Vestspitsbergen - Svalbard. Norsk Polarinstitutt, Årbok 1960, 14-21.

Midtkandal, I. & Nystuen, J., 2009: Depositional architecture of a low-gradient ramp shelf in an epicontinental sea: the lower Cretaceous of Svalbard. *Basin Research*, 21, 655–675, https://doi.org/10.1111/j.1365-2117.2009.00399.x

Midtkandal, I., Svensen, H., Planke, S., Corfu, F., Polteau, S., Torsvik, T., Faleide, J.I., Grundvåg, S.-A., Selnes, H. & Olaussen, S., 2016: The Aptian oceanic anoxic event (OAE1a) in Svalbard and the age of the Barremian-Aptian boundary. *Palaeogeogra., Palaeoclimatol, Palaeoecol*., 463, 126–135.

Mørk, A., Dallmann, W.K, Dypvik, H., Johannessen, E.P., Larssen, G.B., Nagy, J., Nøttvedt, A., Olaussen, S., Pchelina, T.M. & Worsley, D., 1999: Mesozoic lithostratigraphy. In: Dallmann, W.K. (ed.), *Lithostratigraphic lexicon of Svalbard. Review and recommendations for nomenclature use. Upper Palaeozoic to Quaternary bedrock*. 127—214. Norsk Polarinstitutt, Tromsø.

Mørk, A. & Smelror, M., 2001: Correlation and Non-correlation of High Order Circum-Arctic Mesozoic Sequences. *Polarforschung*, 69, 65-72.

Mørk, A., Embry, A.F. & Weitschat, W., 1989: Triassic transgressive--regressive cycles in the Sverdrup Basin, Svalbard and the Barents Shelf. In: Collinson, J.D. (ed.), *Correlation in Hydrocarbon Exploration, Norwegian Petroleum Society*, Graham & Trotman, 113-130.

Mørk, A., Knarud, R. & Worsley, D., 1982: Depositional and diagenetic environments of the Triassic and Lower Jurassic succession of Svalbard. In: Embry, A.F. & Balkwill, H.R. (eds.), *Arctic Geology and Geophysics, Canadian Society of Petroleum Geologists Memoir* 8, 371-398.

Nemec, W., 1992: Depositional controls on plant growth and peat accumulation in a braidplain delta environment: Helvetiafjellet Formation (Barremian–Aptian), Svalbard. In: McCabe, P.J. & Totman Parrish, J. (eds) Controls on the Distribution and Quality of Cretaceous Coals. *Geological Society of America, Special Papers*, 267, 209–226, https://doi.org/10.1130/SPE267-p209

Rismyhr, B., Bjærke, T., Olaussen, S., Mulrooney, M. J. & Senger K., 2018., Facies, palynostratigraphy and sequence stratigraphy of the Wilhelmøya Subgroup (Upper Triassic–Middle Jurassic) in western central Spitsbergen, Svalbard. Norwegian Journal of Geology, 99, 189-218. https://dx.doi.org/10/17850/njg001

Śliwińska, K.K., Jelby, M.E., Grundvåg, S.-A., Nøhr-Hansen, H. and Olaussen, S., 2020: Dinocyst stratigraphy of the Valanginian–Aptian Rurikfjellet and Helvetiafjellet formations on Spitsbergen, Arctic Norway. *Geol. Mag.*

Sorento, T., Olaussen, S. & Stemmerik, L., 2020: Controls on deposition of shallow marine carbonates and evaporites–lower Permian Gipshuken Formation, central Spitsbergen, Arctic Norway. SedimentoloGy 67, 207-238.

Steel, R.J., Gjelberg, J. & Haarr, G., 1978: Helvetiafjellet Formation (Barremian) at Festningen, Spitsbergen – a field guide. *Norsk Polarinstitutt Årbok 1978*, 111-128.

Steel R.J. & Worsley D., 1984: Svalbard's post-Caledonian strata—an atlas of sedimentational patterns and palaeogeographic evolution. In A.M. Spencer et al. (eds.): *Habitat of hydrocarbons on the Norwegian continental margin*. 109–135. London: Graham & Trotman.

Uchman, A., Hanken, N.-M., Nielsen, J. K., Grundvåg, S.-A. & Piasecki, S., 2016: Depositional environment, ichnological features and oxygenation of Permian to earliest Triassic marine sediments in central Spitsbergen, Svalbard. *Polar Research*, 35, https://doi.org/10.3402/polar.v35.24782

Wignall P.B., Morante R. & Newton R., 1998: The Permo-Triassic transition in Spitsbergen: d13Corg chemostratigraphy, Fe and S geochemistry, facies, fauna and trace fossils. *Geological Magazine* 135, 47-62.

Worsley, D., 2008: The post-Caledonian development of Svalbard and the western Barents Sea. *Polar Research* 27, 298-317.

Worsley, D. & Mørk, A., 2001: The environmental signifycance of the trace fossil *Rhizocorallium jenense* in the Lower Triassic of western Spitsbergen. *Polar Research*, 20, 37-48

Net addresses of relevance

https://lovdata.no/dokument/SF/forskrift/2003-09-26-1190?q=festningen

https://toposvalbard.npolar.no/

https://geokart.npolar.no/Html5Viewer/index.html?viewer=Svalbardkartet

http://www.svalbox.no/

https://data.npolar.no/dataset/eafafbb7-b3df-4c71-a2df-316e80a7992e

https://www.researchinsvalbard.no/

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