The Hopen Member: A new member of the Triassic De Geerdalen Formation, Svalbard

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Hopen is a solitary island of Upper Triassic strata in the south-eastern most corner of the Svalbard archipelago. Outcrop studies throughout the island, supported by palynology, magnetostratigraphy and geological modelling have led to the identification of a new member unit within the upper part of the De Geerdalen Formation, the Hopen Member. Based on the distinctive visual properties of the strata observed in the mountain sides of Hopen, a recorded change in sediment style and an increase in the concentration of marine palynomorphs, the unit is well expressed. The Hopen Member represents an extensive, ~70 m thick succession of marine influenced shale and subordinate sandstones, distinguishing itself from the paralic and non-marine clastic sediment packages of the remaining part of the De Geerdalen Formation. The Hopen Member is traceable throughout the entire island, given its prominent darker colouration due to the lateral extent of its marine mudstones, unlike the bed packages below, which are laterally inextensive and more sandstone rich. Palynological and magnetostratigraphic studies have indicated an age of latest Carnian to earliest Norian for the member. With the age and stratigraphical position of the member being taken into account, it is possible to define this unit as a time equivalent to that of the Isfjorden Member of central Spitsbergen. However, its distinctively different lithological properties call for the creation of a new lithostratigraphic unit as opposed to simple correlation.

Key words: Hopen Member, Stratigraphy, Triassic, Svalbard.

Introduction

Expeditions organised by SINTEF Petroleum Research and the Norwegian Petroleum Directorate, have visited the island of Hopen in southeastern Svalbard regularly for the last six summers. Detailed lithological sections throughout the island have been measured (Klausen and Mørk, 2014; Mørk et al., 2013; Lord et al., 2014), in addition to biostratigraphic, palynological and magnetostratigraphic sampling. This has provided the basis for a considerable daraset, from which it has been possible to identify a new meber unit within the De Geerdalen Formation, the Hopen Member. In the construction of this member an interdisciplinary approach has been applied within its definition and this comprises primarily of; outcrop observation, sedimentology, magnetostratigraphy, palynology and photomosaic modelling.

Hopen is a narrow and elongate island consisting entirely of Late Triassic aged strata, which protrudes from the northern Barents Sea in the southeastern most corner of the Svalbard Archipelago (Fig. 1) (Mørk et al., 2013). At 32 km long and no wider than 2.5 km, Hopen features as somewhat of an oddity for the region, moreso given its relativley detatched position from the archipelago. The islands topographical expression is a result of the regional tectonic style, present in the eastern and southeastern areas of Svalbard, where the island represents the exposed tip of a tectonic high, within a fault system (Doré, 1995; Grogan et al., 1999). These faults trend northeast – southwest and extend throughout the offshore areas of south-eastern Svalbard and Kong Karls Land (Doré, 1995; Grogan et al., 1999), thus providing the basis for the islands axial orientation, with fault blocks down stepping to the southeast towards the Olga Basin.

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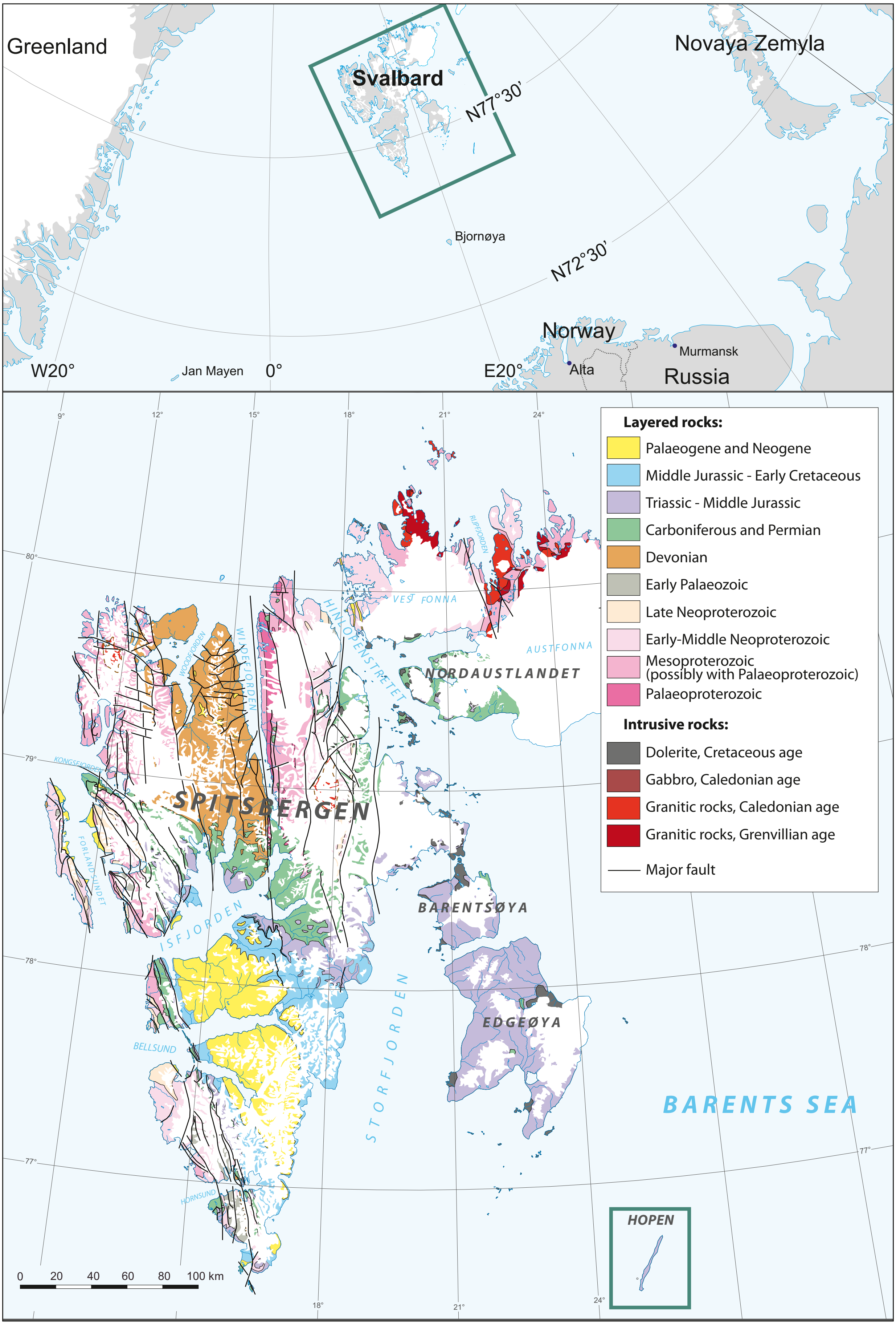

Figure 1. Overview areal map showing the position of Svalbard and basic bedrock geological map displaying the outcropping Mesozoic strata in purple with the position of Hopen denoted in the southeast. Map modified after Dallmann (in press).

The island is dissected by a series of NW-SE trending normal faults, which cut through the island at various intervals along its axis. Beds however are relatively horizontal with dips being in an order of no more than 1-2°, mainly to the NNE. The thickest exposures of the De Geerdalen Formation can be found at the southernmost mountain, Iversenfjellet, whilst in the north, the overlying Flatsalen and Svenskøya Formations are present (Mørk et al., 2013).

Pčelina (1972, 1983) noted the presence of her then defined Isfjorden 'Formation', from Central Spitsbergen, to represent the entirety of the De Geerdalen Formation on Hopen. She stated that the unit can be seen to extend over the entire archipelago, with the exception of Southern Spitsbergen. Her terminology included a much greater part of the succession within her Isfjorden 'suita' than in present nomenclature. Pčelina's Isfjorden 'Formation' and her Hahnfjella 'Formation' represented the Upper Triassic stratigraphic interval, which today is subdivided into the Tschermakfjellet and overlying De Geerdalen Formations. The revised lithostratigraphy of Mørk et al. (1999), have resulted in Pčelina's Isfjorden 'Formation' being downgraded to member status, within the De Geerdalen Formation, with its stratotype defined at Storfjellet in Sabine Land according to the section logged by Knarud (1980).

Mørk et al. (1999) (Fig. 2) did not recognise the Isfjorden Member outside of Spitsbergen, primarily due to poor constraints on stratigraphical thickness of the De Geerdalen Formation, its internal facies distributions and lithological variations in the eastern areas of Svalbard. Following a series of field studies and the creation of a computer based 3D geological model of Hopen, using photomosaics by Solvi (2013), the abrupt change in depositional style seen in the uppermost part of the De Geerdalen Formation became apparent. The 3D geological model of Hopen implemented a large photo dataset of the entire island (Solvi, 2013) and was made using Photomodeler™ software.

Mapping the lateral distribution of the base of the member, characterised by a notable colour change from light coloured yellow and grey, sands and shale to dark grey shale, was conducted using the 3D model, and this base could be followed all around the island. The surface was shown to be a more regional event unlike those more local facies variations of the stacked minor parasequences seen within the rest of the De Geerdalen Formation at Hopen (Klausen and Mørk, 2014; Lord et al., 2014). This also implies that the base of the Hopen Member may represent a major sequence stratigraphic boundary, expressing the onset of a marine transgression where the paralic deposits of the De Geerdalen Formation give way to more marine influenced deposition as a result of base level rise.

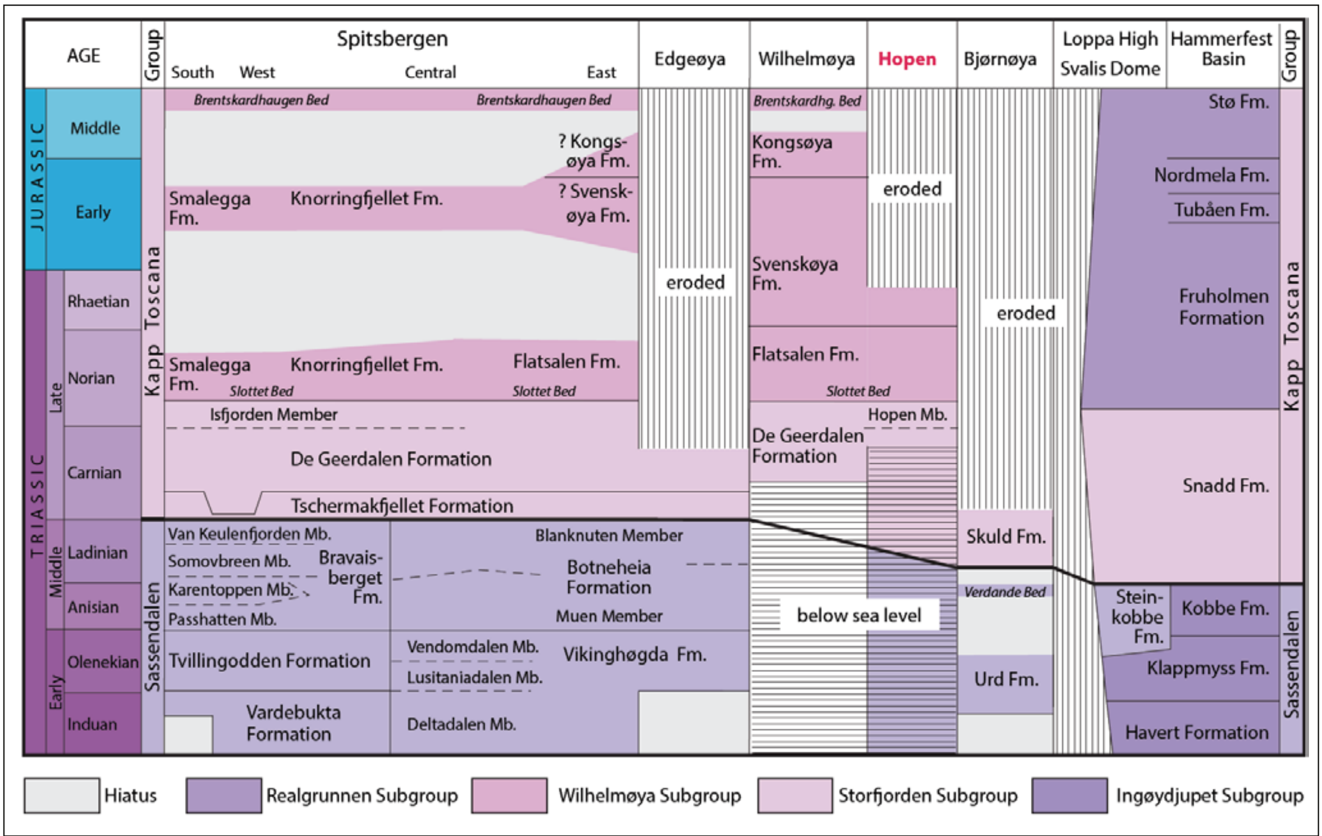

Figure 2. Stratigraphic subdivisions for the Triassic to mid-Jurassic succession of Svalbard and Barents Sea, with the Hopen Member included. Figure from Mørk et al. (2013).

Stratigraphy

Three formations are present on the island (Fig. 2) (Mørk et al., 2013). The thickest succession being the Carnian aged De Geerdalen Formation, deposited in a fluctuating deltaic environment close to an ancient shoreline (Klausen and Mørk, 2014). Overlying this is the Norian aged Flatsalen Formation, with the pronounced carbonate Slottet Bed at its base. Overlying this is the Svenskøya Formation of Norian to possibly Rhaetian age, a prominent, white and grey, cliff-forming succession of deltaic sandstones.

The De Geerdalen Formation in the region of Hopen is interpreted to be approximately 650 m thick based on data from the Hopen 2 well, an onshore well drilled by the Norsk Fina Group in 1973. A total of 165 m is exposed above sea level in the north of the island, while some 325 m (Smith et al., 1975) is exposed in the southern part of Hopen. This is in relatively strong contrast to the 200-300 m thickness of the entire formation seen in areas of central Spitsbergen; however, this is more akin to the development of the correlative Snadd Formation seen in the Barents Sea, which is considerably thicker (Worsley et al., 1988, Riis et al., 2008). The thickness of the De Geerdalen Formation on Edgeøya and Barentsøya is presently undefined, as the uppermost part of the formation is considered to have been significantly eroded during the Cenozoic.

Minor NW-SE trending normal faults on the island and the general dip of strata to the NNE have resulted in overlying units to the De Geerdalen Formation being exposed in some locations, most predominantly in the north of the island. The De Geerdalen Formation is overlain on Hopen, by the Norian aged marine mudstones of the Flatsalen Formation (Fig. 3). This formation consists entirely of dark marine shales, with a prominent hard carbonate bed at its base, the Slottet Bed (Mørk et al., 1999). The Flatsalen Formation represents a series of discrete, upwards-coarsening packages forming a 62 m thick, dark-shale dominated succession. The Flatsalen Formation's stratotype is also defined by Mørk et al. (1999) on the mountain of Flatsalen, in the northeast of Hopen.

The Flatsalen Formation is overlain with a low angle unconformity, by a thin ca. 45 m thick package of highly cross-stratified sandstones, featuring a coarse-grained erosive base. Interpreted as having been deposited in a fluvial to deltaic depositional environment; these prominent, cliff-forming, white and grey beds represent the Svenskøya Formation, as defined on Kong Karls Land (Smith et al., 1976; Mørk et al., 1999).

The island's underlying stratigraphic units at depth have been interpreted from information provided by the Hopen 2 well log. The base of the Kapp Toscana Group is at present suggested to be approximately 685 m below sea level. The deeper underlying units are un-interpreted, but are suggested to represent the Sassendalen Group. The base Triassic is interpreted in the well log to be at a depth of 1050 m below sea level (-1325 m on well log), where marine shales abruptly change to hard, silicified shale and sandstone of the Permian Kapp Starostin Formation. The proposed Hopen Member represents the upper ~70 m of the De Geerdalen Formation (Fig. 3) where it's notable, dark, cliff forming succession can be seen at numerous locations throughout the entire island. The thickness of the member is also seen to be relatively uniform, as measured in both in field sections and the Photomodeler™ 3D geological model.

Sedimentology

The base of the Hopen Member is marked by clear indication of marine facies being dominant in this interval, at all locations in northern Hopen where sedimentological logs (Figs. 3 and 4) have recorded the Hopen Member. Several logs document the nature of sediments and although facies types are seen to vary, they are all associated with marine deposition. There is seen to be a notable change in lithological type where stacked heterolithic packages are observed to become more mud rich, with a loss of any plant fragments, fossil leaves, root beds, palaeosols and minor coal beds, as seen in the underlying strata. A greater increases in the presence and intensity of bioturbation is observed in the basal beds of the Hopen Member.

The sedimentological logs have been acquired by various geologists, throughout successive visits to the island since 1995 and include sections at Blåfjellet, Lyngefjellet, Binnedalen and Nørdstefjellet (Fig. 4). Additional logs of the southern part of the island are presented by Mørk et al. (2013) and Lord et al. (2014). Alike the rest of the De Geerdalen Formation, the Hopen Member is composed of layered, heterolithic clastic rocks, in beds of varying lateral continuity and facies (Fig. 5). However, unlike the underlying strata, the facies are genetically related over the entirety of the island; whereas those lower in the succession are laterally discontinuous and facies types vary considerably over relatively short distances, at the same stratigraphic level. The member consists predominantly of minor upwards coarsening packages dominated by dark mudstones that are interspersed with thin sandstone beds.

The base of the member is most prominently seen from a distance (Fig. 5) due to the overall, highly heterolithic nature of the De Geerdalen Formation. Its base is defined where the presence of root structures and subordinate coal beds with associated palaeosols become absent, approximately 70 m below the Slottet Bed. A notable change in the colour of strata is observed at this level where the underlying heterolithic packages of light coloured sand and shale give way to a much darker,

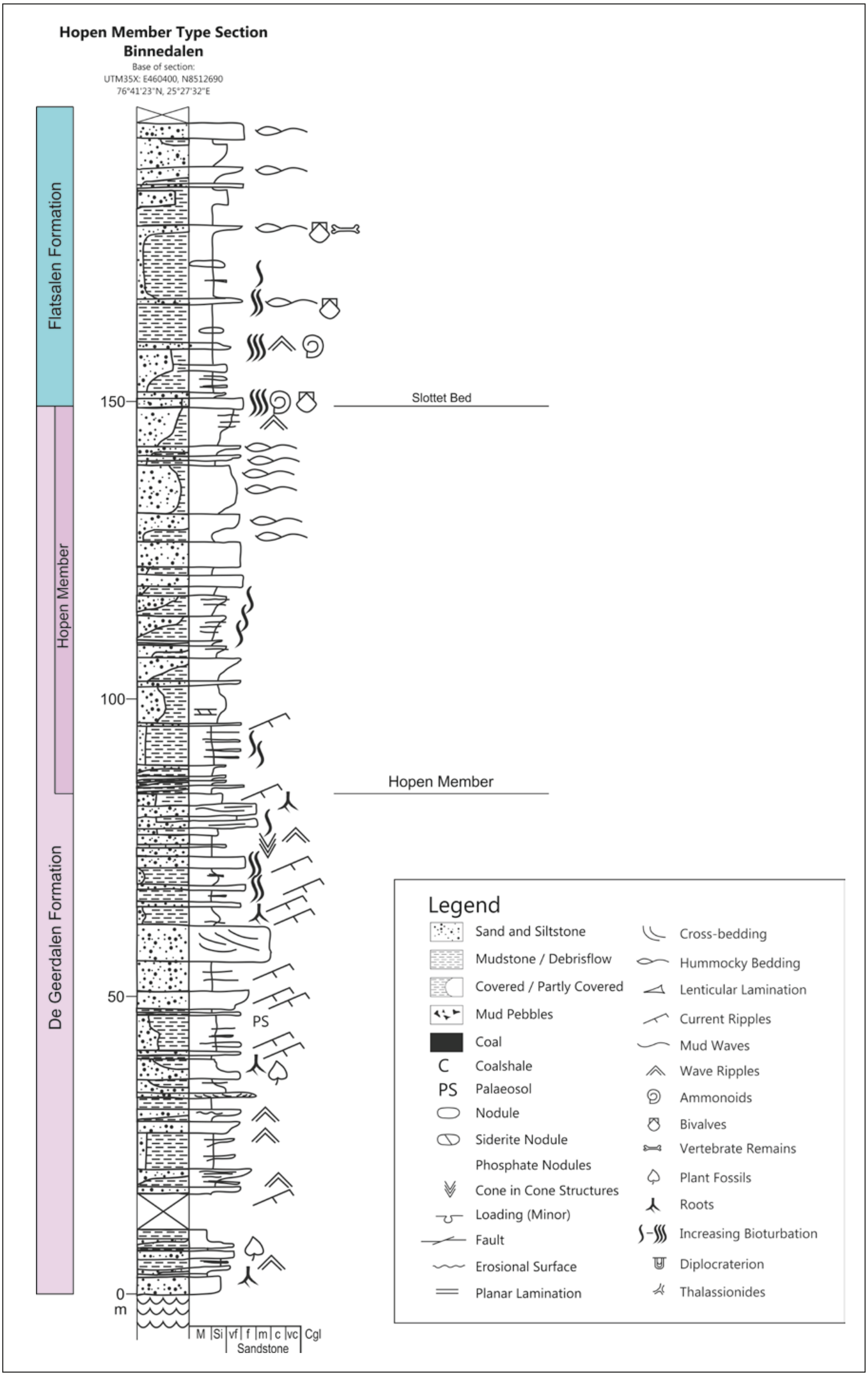

Figure 3. *Stratigraphic and sedimentological log of the Hopen Member type section, Binnedalen, eastern face of Lyngefjellet, northern Hopen.*

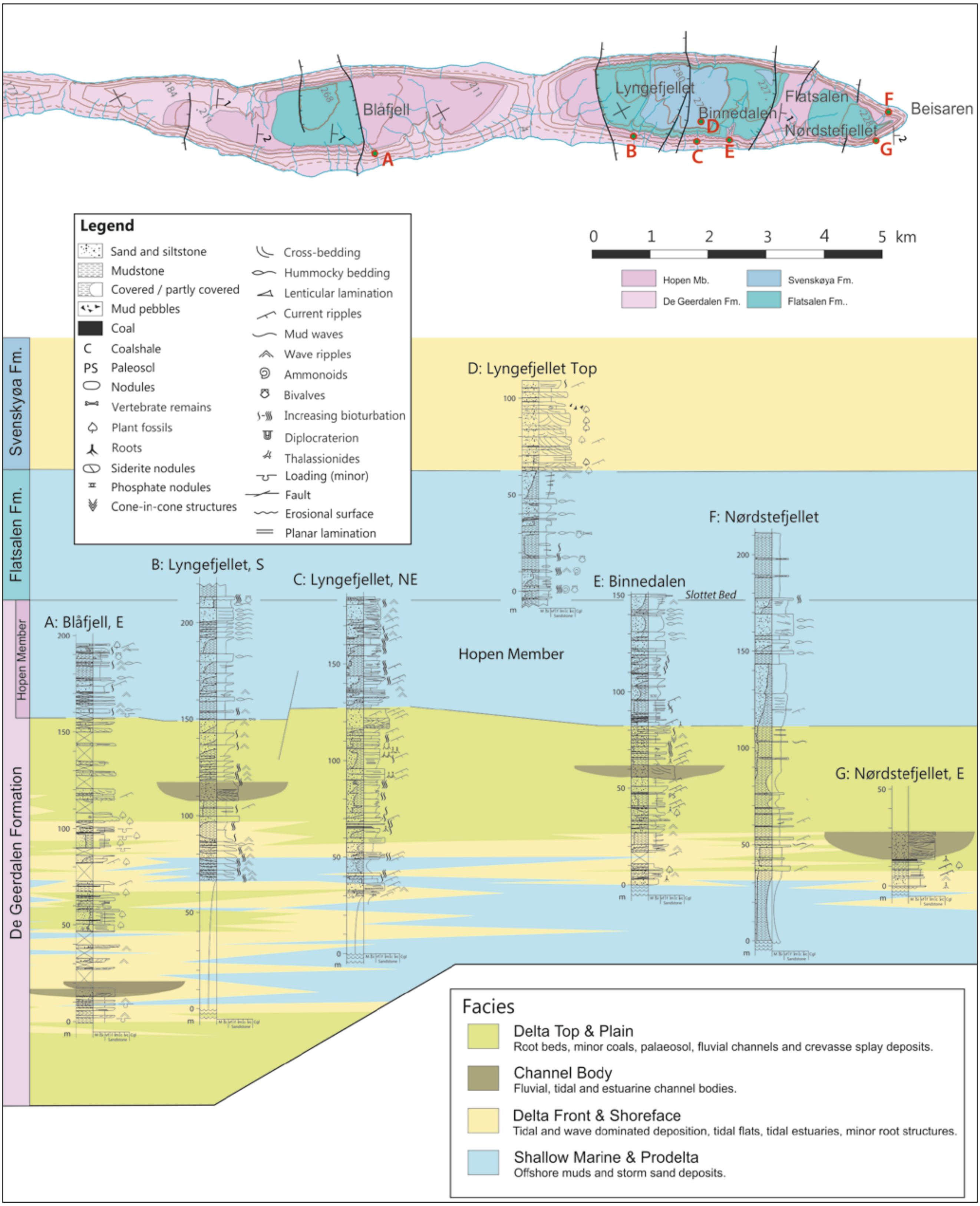

Figure 4. Facies association diagram throughout sections seen at Lyngefjellet in northern Hopen. Note the highly variable facies distribution in the De Geerdalen Formation below the base of the Hopen Member. A minor amendment has been made following the inclusion of palynological data, where the base of the Hopen Member has been set slightly lower in the Lyngefjellet NE log than previously shown in Mørk et al. (2013).

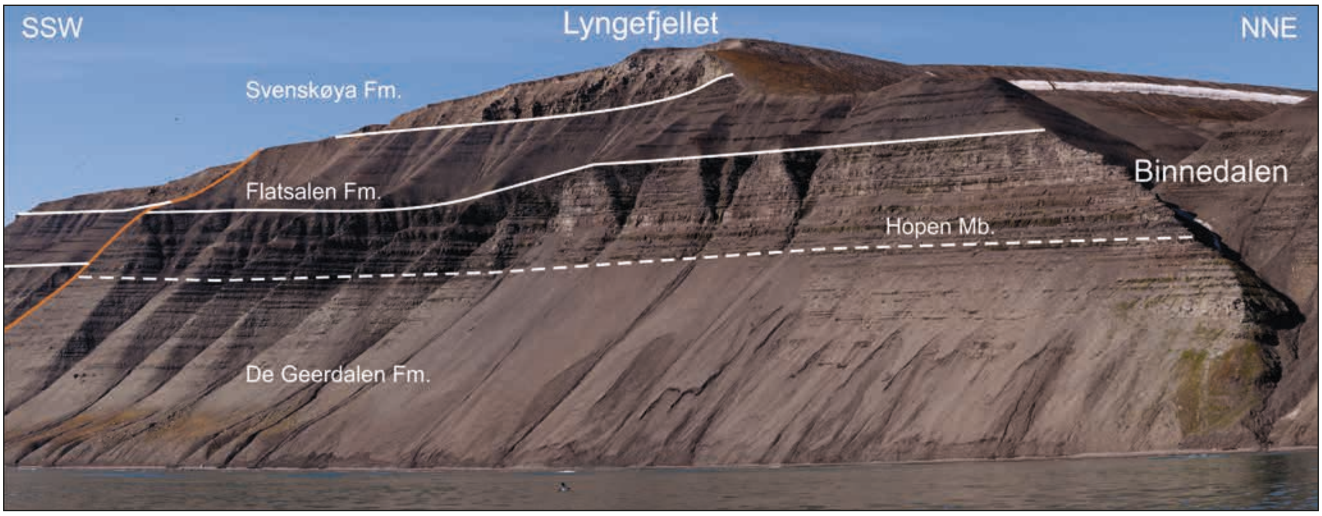

Figure 5. *A panoramic view of Lyngefjellet displaying the stratigraphic subdivision of the Mesozoic strata on Hopen. The base of the Hopen Member is defined where the De Geerdalen Formation becomes notably darker in colour, in the upper cliffs of the formation. The type section is measured within the valley of Binnedalen in the right half of the picture. Photo: Terje Hellem.*

laterally extensive succession (Figs. 5, 6, 7) that is visible in the Photomodeler™ 3D geological model. These lower beds, rich in mud and bioturbation, feature thin sandstones with both current and wave ripple structures, suggesting a relatively low energy environment of deposition. They most probably represent an inter delta lobe bay with fine grained sediments being deposited within the sub-tidal zone, with lamina and thin beds of sand representing reworked storm disrupted deposits.

Hummocky cross stratification is prolific throughout the sandstones within this interval, often being confined to more heterolithic sediment packages or thin sand beds in the uppermost part of the member. Wave and current ripples are also in abundance both in monolithic and heterolithic beds. In the case of Nørdstefjellet, a minor component of hummocky bedding is observed, in a more sandstone dominated package. Bioturbation is common and minor occurrences of bivalves are present. This suggests a slightly nearshore depositonal environment

Figure 6. *Photograph showing the nature of the Hopen Member at the type section within Binnedalen, Lyngefjellet. Note the darker colouration of this interval, with bioturbated shales hosting subordinate, rippled, sandstone laminae.*

Figure 7. *Photograph depicting the nature of the shale within the Hopen Member. This is the dominant lithology throughout the unit and is seen to be highly bioturbated with the presence of minor sandstone laminations featuring wave and current ripples. Larger sandstone beds are also apparent and feature hummocky cross stratification.*

for the upper part of the member, below or just within the range of normal wave base, but still within the depth for storm wave energy to both re-work and introduce sediments into the environment.

The northern most exposures of the Hopen Member at Binnedalen and Nørdstefjellet (Figs. 3, 4) are seen to feature larger proportions of sandstone in comparison to the sections logged in the southern part of the island at Russevika and Iversenfjellet (Mørk et al., 2013; Lord et al., 2014). This may suggest a very subtle, lateral facies change along the islands axis, where the Hopen Member represents more deeper facies in the southwest, gently shallowing to the northeast.

Based on the sedimentological logs (Figs. 3, 4), the facies within the Hopen Member are interpreted as being indicative of an extensive, yet fluctuating, storm influenced shallow marine environment. This is most probably an inter delta lobe bay or a very large scale inter distributary bay, formed as a result of delta lobe switch due to the avulsuion of primary channels on the delta flood plain. In this setting, calm periods have allowed for the deposition of dark marine mud and shales, below tidal range and normal wave base. The presence of disturbed sands, interspersed within the succession, suggests the influence of wave action below wave base, aggravating the sediments during storms or periods of higher energy. These become more abundant in the upper part of the member, suggesting a relative shallowing of the depositional environment, from deeper and calmer deposition offshore, to more wave and storm disturbed sedimentation in the upper part of the member.

Distribution and geometry

The clear, dark colouration of the Hopen Member allows for its visual profile to be traced throughout the entire island and by following the base of the boundary with the Photomodeler™ 3D geological model its distribution is seen to be widespread. The member also appears at a stratigraphically consistent level, with a similarly consistent thickness between 68-72 m. The basal surface is considered to be flat without evidence for underlying topography,

The member is present on nearly all of the major topographical highs of the island (Fig. 8). Due to the nature of faulting on the island the base of the Hopen Member has been used in order to reconstruct the islands stratigraphy, where erosion has removed significant proportions of the overlying formations, proving itself as a useable marker horizon. The most prominent locations for the change can be seen on the mountains of Iversenfjellet in the southwest and on the southern flank of Lyngefjellet in the northeast of Hopen.

The unit has been included in the Norwegian Polar Institute's geological map of Hopen (Mørk at al., 2013), due to its visual profile and pronounced continuous exposure on the island (Fig. 8).

Ammonoid biostratigraphy

Ammonoids from the Flatsalen Formation are determined to be sirenitid ammonoids, largely of the genus *Neosirenites* (now *Norosirenites*; Bragin et al., 2012), which were previously also named as *Argosirenites*).

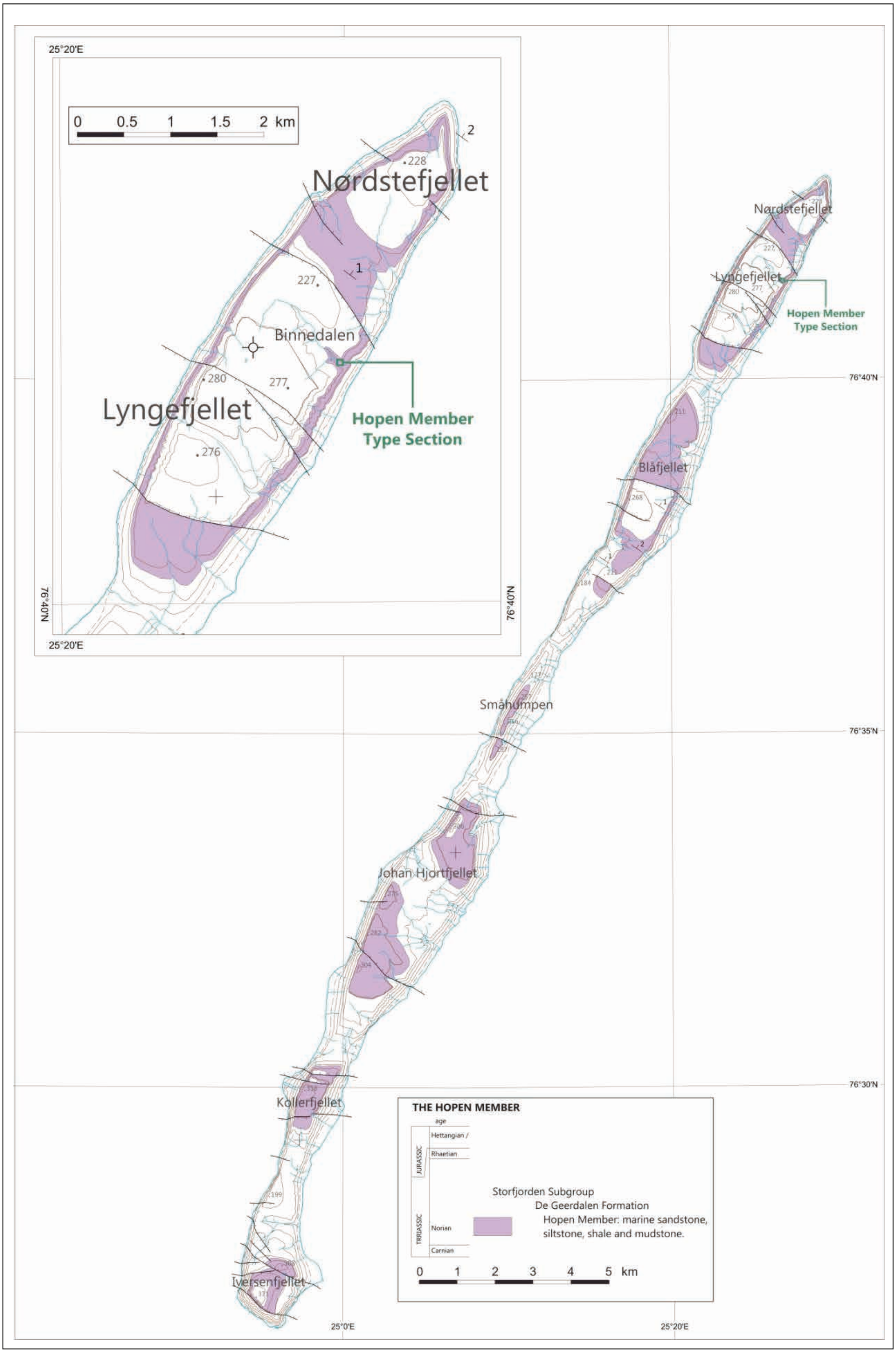

Figure 8. *Geological map of Hopen displaying the overall distribution of the Hopen Member throughout the island. The type section location is marked in Binnedalen on eastern Lyngefjellet. Map modified after Mørk et al. (2013).*

Sirenitid genera largely occur in Siberia and NE Asia, but do have representatives in Canada. They range in age, through the Boreal lower Norian with the last sirenitid ammonoids being either in the oldest parts of the NE Asian mid-Norian (within boreal ammonoid zone *Otapiria ussuriensis*; Zacharov 1997) or Siberian latest early-Norian (Konstantinov, 2008).

Korčinskaja (1980) describes *N. nelgehensis*, *N. obruchevi* and "Sirenites" *nabeshi* from the Flatsalen Formation on Hopen, which in NE Asia occurs in the *Pinacoceras verchojanicum* Zone. Bragin et al. (2012) and Konstantinov and Klets (2009) correlate this zone with the mid parts of the early Norian. The occurrence of the conodont *Norigondolella navicula* in the same beds bearing the *P. verchojanicum* Zone ammonoid fauna in NE Asia (Bragin et al., 2012), suggests much the same correlation, with *N. navicula* corresponding to the interval approximately from near the base of Lacian-I (Tethyan Jandianus Zone), to mid parts of Lacian-2 (Tethyan *Paulckei* Zone), of Krystyn et al. (2009) Norian sub-stage divisions (Orshard, 2010). This suggests the Hopen Member is at the very least, earliest Norian or older.

Palynological Age and Characteristics

Palynological investigation of the sedimentary succession on Hopen was initiated in the early 1970s. The first study was conducted by Smith (1974) who proposed that Rhaetian and possibly Norian to Hettangian aged strata are represented on Hopen, an age which was maintained by Smith et al. (1975). However based upon further palynological investigation, Bjærke and Manum (1977) supported the Rhaetian age assignment proposed by Smith et al. (1975); however, no palynological evidence supporting either a Norian or Hettangian age was found during their study. Recently, Hopen has been the subject of renewed palynological studies (Ask, 2013; Vigran et al., 2014), and below we present preliminary data from these ongoing studies.

In general, assemblages recovered from the lower part of the De Geerdalen Formation are dominated by spore taxa, while those from the Hopen Member are more pollen-rich. Marine palynomorphs are consistently present but become more abundant in samples from the Hopen Member. Many samples contain acritarchs assigned to *Michrystridium* and *Veryhachium* spp. Dinoflagellate cysts belonging to *Rhaetogonyaulax arctica* and *R. rhaetica* are also present in samples from the De Geerdalen Formation, but are exceptionally rare. Freshwater algae *Botryococcus* spp. and *Plaesiodictyon moesellaneum* are also present, with the latter becoming particularly abundant in samples from the Hopen Member.

Based upon semi-quantitative palynology, two distinct palynological zones are recognised in samples from the De Geerdalen Formation on Hopen (Fig. 9); these are the lower *Leschikisporis aduncus* Acme Zone and the upper *Protodiploxypinus* spp. Acme Zone. The transition between the two zones closely approximates the base of the Hopen Member.

Assemblages of the *Leschikisporis aduncus* Acme Zone have been recovered in samples from the lower portion of the De Geerdalen Formation on Hopen from the three sections investigated. The assemblages from this zone are characterised by the dominance *L. aduncus*. Other spore taxa present in this interval include: *Aratrisporites* spp., *Aulisporites astigmosus*, *Calamospora tener*, *Camerozonosporites rudis*, *Conbaculatisporites* spp., *Deltoidospora* spp., *Dictyophyllidites mortonii*, *Duplexisporites problematicus*, *Porcellispora longdonensis* and *Zebrasporites interscriptus*. Pollen comprises a relatively minor component of assemblages in this zone. Species recorded include: *Araucariacites australis*, *Chasmatosporites* spp., *Cycadopites* spp., *Eucommiidites* spp., *Illinites chitinoides*, *Ovalipollis ovalis*, *Triadispora verrucata* and *Vesicaspora fuscus*.

The *Protodiploxypinus* spp. Acme Zone is recognised in samples from the Hopen Member from Binnedalen, Blåfjell and Lyngefjellet. The diversity of assemblages from this zone is markedly higher than from those below. Assemblages from this zone are characterised by the dominance of pollen, particularly of *Protodiploxypinus* spp. Other pollen taxa present include: *Araucariacites australis*, *Chasmatosporites* spp., *Cycadopites* spp., *Eucommiidites* spp., *Illinites chitinoides*, *Ovalipollis ovalis*, *Triadispora verrucata* and *Vesicaspora fuscus*. *Leschikisporis aduncus* still occurs in assemblages from this zone but in significantly reduced numbers. The spore assemblage includes: *Annulispora folliculosa*, *Aratrisporites* spp., *Cingulizonates rhaeticus*, *Deltoidospora* spp., *Kyrtomisporis gracilis*, *K. laevigatus*, *K. speciosus*, *Ricciisporites tuberculatus*, *R. umbonatus*, *Rogalskaisporites cicatricosus*, *Semiretisporis gothae*, *Striatella seebergensis*, *Uvaesporites* spp., *Velosporites cavatus* and *Zebrasporites interscriptus*. Assemblages from the *Protodiploxypinus* spp. Acme Zone are also rich in freshwater algae, particularly *Plaesiodictyon moesellaneum*. Marine palynomorphs including the acritarchs *Michrystridium* and *Veryhachium* spp. and foraminifera test-linings are a consistent feature of this zone.

Bjærke and Manum (1977) reported the dominance of *Leschikisporis aduncus* in a coal sample from the lower De Geerdalen Formation near Iversenfjellet on the south of Hopen. Common to abundant *L. aduncus* is also a characteristic feature of the early to mid Carnian *Aulisporites astigmosus* Composite Assemblage Zone of Vigran et al. (2014). Those authors also report common bisaccate pollen with an abundance peak of *Protodiploxypinus* spp. in the upper part of the zone. These observations are consistent with the *Leschikisporis aduncus* Acme Zone and the *Protodiploxypinus* spp. Acme Zone as recognised here.

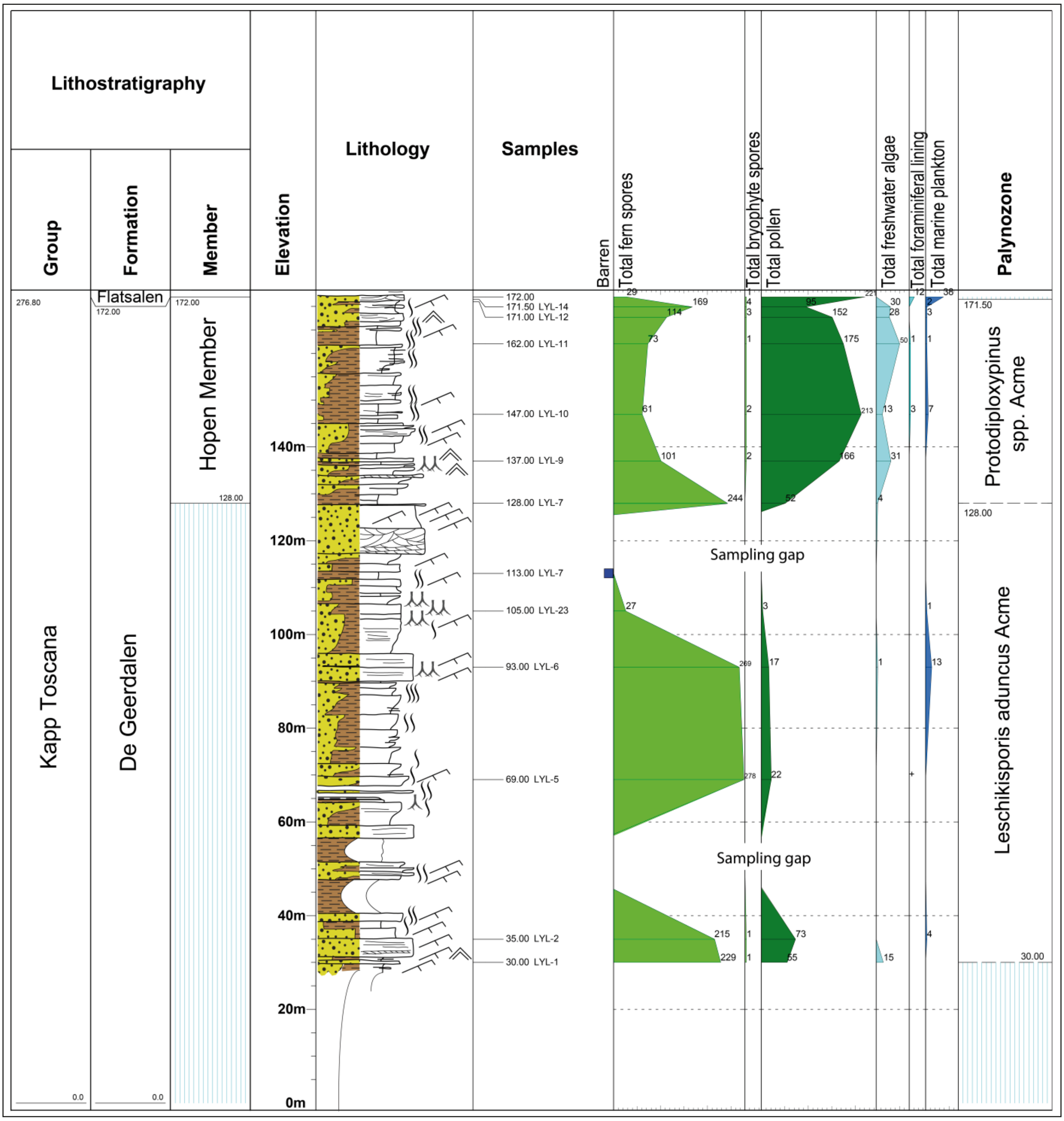

Figure 9. Relative abundances of main palynomorph groups from the De Geerdalen Formation, Lyngefjellet, Hopen. Samples and log from "Letesamarbeidet 1995".

The occurrence of *Triadispora verrucata* in assemblages assigned to the *Protodiploxypinus* spp. Acme Zone in the current study is indicative of a late Carnian age for the assemblage (Hochuli et al., 1989). Additionally, the common occurrence of the freshwater alga *Plaesiodictyon moesellaneum* within this zone is indicative of an age no younger than Norian (Hochuli et al., 1989). Combining ammonoid and palynology data we suggest that the Hopen Member is of late Carnian age, possibly continuing into the earliest Norian.

The Hopen Member coincides with a major transition in the composition of palynomorph assemblages on Hopen. Assemblages from lower De Geerdalen Formation are dominated fern spore taxa such as *Leschikisporis aduncus*. However, assemblages from the Hopen Member are dominated by conifer pollen (Fig. 9). This trend has been noted elsewhere in the region (Hochuli and Vigran, 2010; Hochuli et al., 1989). *L. aduncus* was produced by plants growing under humid conditions (Hochuli and Vigran, 2010) in a near-shore, deltaic environment (Pott, 2014; Launis et al., 2014). In general, high abundances of fern spores in palynomorph assemblages signify a close proximity to the fluvio-deltaic source, rapid deposition close to their provenance and humid climatic conditions to allow significant pteridophyte growth (Tyson, 1995).

The transition to the conifer pollen dominated assemblages of the Hopen Member may reflect a change to coastal vegetation dominated by conifers, possibly due to cooler or more arid conditions in the region during the latest Carnian. Alternatively, the increased relatively abundance of gymnosperm pollen in palynomorph assemblages may also signify more distal deposition from the fluvio-deltaic source (Tyson, 1995), the so-called "Neves effect "of Chaloner and Muir (1968). The latter interpretation would be consistent with deposition of the Hopen Member in a more distal marine environment.

Coinciding with the increased abundance of conifer pollen, the alga *Plaesiodictyon moesellaneum* also increases in relative abundance in the Hopen Member. Modern coenobial algae are common constituents in freshwater environments but are typically transported by rivers into marine settings (Brenner and Foster, 1994). *P. mosellanum* has been reported fluvial-lacustrine, marginal marine and offshore marine facies from ?Anisian-Norian-?Rhaetian age strata (Wood and Benson, 2000). The increased abundance of *P. mosellanum* in the Hopen Member probably indicates redeposition from areas of freshwater input (Tyson, 1995). Marine palynomorphs such as acritarchs are slightly more common in the Hopen Member but are still relatively rare due to the dominance of terrestrial organic matter in the assemblages. The low abundance and diversity of acritarchs in the Hopen Member is consistent with reduced salinities and freshwater input from a fluvio-deltaic source.

Magnetostratigraphy

The magnetostratigraphy on Hopen was constructed by sampling from the Binnedalen and Nørdstefjellet sections in northern Hopen. The sample-level data from these two sections were merged using a photo and log-based intersection correlation of the cliff sections. Data from the Nørdstefjellet section extends to slightly older intervals than that in the Binnedalen section. These data define parts of 8 major R-N magnetozone couplets, with 22 separate R plus N magnetozones plus sub-magnetozones (Fig. 10).

The reverse-polarity dominated interval HO3r to HO5r (Fig. 10) is one of the keys to understanding how the polarity may match the geomagnetic polarity timescale (GPTS). There are two intervals in the Late Triassic which have a reverse-dominated polarity pattern with three briefer normal polarity magnetozones within it. These are within the early Norian and across the Norian-Rhaetian boundary (Hounslow and Muttoni, 2010). This later possibility is implausible, since it would push the Flatsalen Formation *Norosirenites* fauna into the late Rhaetian. A third possibility using the ammonoid-age of the Flatsalen Formation in the middle parts of the early Norian pushes all of the De Geerdalen Formation on Hopen into the Carnian. This option, preferred here, fully satisfies the age constraints from the *Norosirenites* fauna in the Flatsalen Formation as well as the palynology, which should correspond to the upper part of Lacian-1 and lower part of the Lacian-2 sub-stage divisions (Fig. 10). The magnetostratigraphic match to the GPTS is broadly satisfactory for the interval HO3n to HO8n, but less so below HO3n- some sub-magnetozones have a match in the GPTS and some not. The GPTS of Hounslow and Muttoni (2010) through the mid Carnian is derived only from the non-marine Stockton Formation of the Newark Super-group, so the validity of the GPTS remains uncertain in this interval. We have chosen to remove the Stockton Formation data from our GPTS composite. Our preferred age option places the De Geerdalen Formation all within the Carnian, and the Slottet Bed on Hopen corresponds closely to the Carnian-Norian boundary.

The magnetostratigraphic data from the Isfjorden Member in central Spitsbergen (Hounslow et al., 2007) can now be considered in the light of this new data, since this unit is widely thought to correlate to the units on Hopen. The best magnetostratigraphic match is with the interval over the base of the Hopen Member and into its lower parts (Fig. 10). The relative stratigraphic thicknesses in metres of these two intervals are also quite similar.

Relationship to Isfjorden Member

The Hopen Member is prevalent on the island at which it is defined, Hopen in the southeast of the Svalbard archipelago. However, its notable similarity in stratigraphical position and thickness lends itself well to correlation with Triassic units elsewhere in the archipelago, most notably central and eastern Spitsbergen. In these regions the uppermost part of the De Geerdalen Formation is dominated by sediments of a marginal marine to lagoonal nature defined as the Isfjorden Member. These feature stacked heterolithic deposits of sandstone and shale as well as subordinate thin carbonates, nodular beds of siderite and phosphatic nodules (Mørk et al., 1999, Vigran et al., 2014). The most prominent features within the Isfjorden Member relate to its coloured, green and red beds, which are frequent in the upper strata of the member, below the Slottet Bed.

The Slottet Bed represents either a metre-scale hard carbonate bed in eastern Spitsbergen or a decimetre-scale bed of nodular phosphatic pebbles in central and western Spitsbergen (see logs in Vigran et al., 2014).

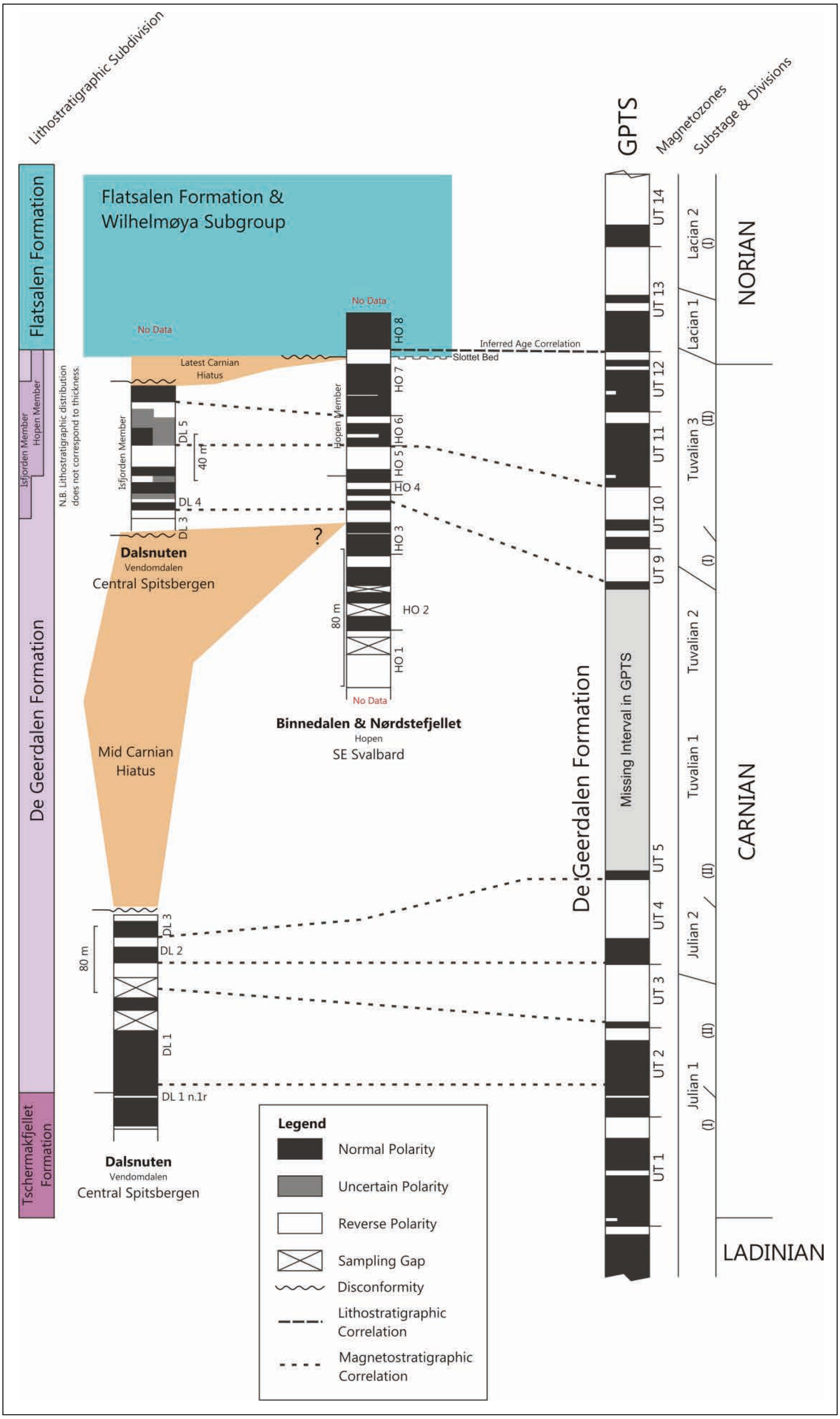

Figure 10. *Summary of lithostratigraphy, age and magnetostratigraphy of the late Triassic of Svalbard based on data from Nørdstefjellet at Hopen (HO) and Dalsnuten (DL) in central Spitsbergen.*

Palynology and magnetostratigraphy indicate that both member units represents the same period in time however it is unclear if the base of Isfjorden Member is synchronous to that of the Hopen Member as it is not directly observed or defined. The Isfjorden Member represents the onset of a lagoonal environment overlying a distal deltaic setting. The Hopen Member represents a dominantly shallow marine setting with inherently different lithological properties and facies, overlying a more proximal and paralic deltaic setting. This abrupt alteration seen in the De Geerdalen Formation shows a clear break and change in sediment style to marine facies, prior to the onset of a marine transgression, displayed by the Flatsalen Formation at Hopen and the Knorringfjellet Formation, in Spitsbergen.

Neither of these member units are reported to be present in the eastern areas of Svalbard, on either Barentsøya or Edgeøya, primarily due to the fact that considerable erosion has occurred into the De Geerdalen and the overall stratigraphic thickness is unascertained. On the island of Wilhelmøya, the upper part of the De Geerdalen Formation features bivalve coquina beds and consists of dark shale, resembling the Hopen Member.

The Hopen Member may be equivalent to the upper "Carnian clinoform unit" reported from seismic studies by Riis et al. (2008), Glørstad-Clark (2010, 2011), Høy and Lundschien (2011) and Lundschien et al. (2014).

The Hopen Member has not been extended to eastern islands of the archipelago, e.g. Edgeøya and Barentsøya, but may occur on the island of Wilhelmøya, indicating that the member is an extensive marine equivalent to the more lagoonal sediments of the Isfjorden Member defined on Spitsbergen. The marine transgression resulting in the Hopen and Isfjorden members may be equivalent to the uppermost transgression of the Snadd Formation, that initiate the uppermost clinoform unit seen within Snadd Formation on the Barents Shelf. We further argue for a separate definition of this unit, aside from the Isfjorden Member (instead of simple stratigraphic correlation), as the presence of green and red beds, nodular sideritic beds and carbonate beds used in the definition of the Isfjorden Member in central Spitsbergen are not observed on Hopen, where the lithologies are predominantly dark grey clastic shales.

Conclusions

The Hopen Member represents a widespread and abrupt variation in the depositional environment of the upper part of the De Geerdalen Formation on Hopen. Lithological changes and sedimentary structures suggest that the member has been deposited in a marine environment of variable energy and biota. Slow and relatively low energy depositional processes define the lowermost of the member, whilst offshore muds and storm deposits dominate the uppermost bed packages. The stratigraphical thickness of the member is relatively uniform throughout the entire island, at approximately 68-72 m.

The prominent change from the lower, paralic facies of the De Geerdalen Formation to those deposited in a more extensive marine and lagoonal setting (as shown by the occurrences of the Hopen and Isfjorden Members), suggests that both of these member units represent a response to a regime change at their time of deposition. This can arguably represent a surface that may be traceable into the Barents Sea. This is also reflected in the nature of palynomorphs seen at the onset of this interval, where the presence of marine algae becomes apparent.

Ammonoid stratigraphy shows that the overlying Flatsalen Formation of the Hopen Member is at its earliest Norian in age and magnetostratigraphic correlation with sections in central Spitsbergen, show that the base of the member correlates well to an interval of reverse polarity at the same period in time. Palynological studies show a clear increase in the presence of marine palynomorphs within the Hopen Member. This also co-incides with an increase in the abundance of terrestrial palynomorphs and algaes, interpreted as being flushed into the marine environment, palynological dating also defines the Hopen Member as being Carnian in age and possibly earliest Norian but no younger.

Acknowledgements.
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Formal Definition Hopen Member	
STATUS OF UNIT:	Formal
FIRST USE OF NAME:	Geological map of Hopen, Mørk et al., 2013.
CURRENT DEFINITION:	Here
SYNONYM:	None
ORIGIN OF NAME:	The island Hopen where the member is defined.
TYPE SECTION:	Stratotype Binnedalen – UTM 35X E460400, N8512690 – 76° 41′ 23″N, 25° 27′ 32″E.
DEPOSITIONAL AGE:	latest Carnian possibly lowermost Norian.
REFERENCES FOR AGE:	Here; Vigran et al., 2014, overlying and underlying beds dated by Korčinskaja, 1980.
OVERLYING UNIT:	Flatsalen Formation
UNDERLYING UNIT:	Un-named; remainder part of De Geerdalen Formation
SUPERIOR UNIT:	De Geerdalen Formation
OTHER USE OF NAME:	None
THICKNESS:	68-72 m, Type section is 68 m
MAIN LITHOLOGIES:	Dark shale and fine-grained sandstones
LOWER BOUNDARY DEFINITION:	Where grey shale and fine-grained sandstones are overlain by dark grey shales with fine-grained sandstones
DESCRIPTION:	Dark grey shale with subordinate fine grained sandstones. The unit represent marine sediments deposited in a fluctuating energy environment.
The Hopen Member has been approved by the Norwegian Committee on Stratigraphy, April 2014.	

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