Triassic channel bodies on Hopen, Svalbard: Their facies, stratigraphic significance and spatial distribution

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Channelized deposits are observed in the steep cliff sections on the island of Hopen in SE Svalbard. This presents a unique opportunity to study the geometry and spatial distribution of these channel bodies within the paralic depositional environment of the Carnian aged De Geerdalen Formation.

In this study we have combined field observations with a 3D geological model of the island. Utilising PhotoModeler™ software, with an extensive photo database of the study area, it has been possible to identify the presence of 25 channel bodies on the island. 12 have been observed directly in the field, with the remainder being identified with photo mosaics and by implementing the 3D geological model. Analysis has shown that the channels were deposited in three different depositional environments; fluvial, tidal and estuarine. Channel deposits that have not been observed in the field are interpreted based on their geometries and visible internal architectures seen within high resolution outcrop photographs. Channel bodies are seen to be confined to discrete stratigraphical intervals within the De Geerdalen Formation, defined as channel zones. Three zones are described, based upon the concentration of channels within each interval. These intervals are categorised as a lower fluvial zone, a middle tidal zone and an upper fluvial zone. These zones are subsequently overlain by a marine flooding event represented by the Hopen Member. An overall paralic depositional environment for the De Geerdalen Formation on Hopen is maintained, however the nature of channels clearly shows a greater influence of fluvial deposition for the formation in this region of Svalbard. This indicates deposition in a more proximal position relative to the source area, than elsewhere on Svalbard.

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

Introduction

The presence of cliff forming sandstone bodies, initially deposited in a continental fluvial environment, have long been known to form the island of Hopen, in the SE part of the Svalbard archipelago (Flood et al., 1971; Smith et al., 1975; Mørk et al., 2013). Economic interests in the northern Barents Sea have also increased scientific activity in the Upper-Triassic succession of Svalbard. Recent expeditions to Hopen have thus placed a greater interest in the understanding of these sandstone bodies, due to their potential as hydrocarbon reservoirs (Johansen et al., 1993; Riis et al., 2008; Lundschien et al., 2014). The sandstone bodies are laterally extensive, often seen in cross section and in some instances can be observed on both sides of the island. These represent ancient fluvial and estuarine channel systems which can be considered analogous to the upper part of the Snadd Formation in the Barents Sea (Klausen and Mørk, 2014).

Multiple short geological expeditions to Hopen have been conducted by SINTEF Petroleum Research, NPD and participant companies of production licences in the Barents Sea (PL438, PL533, PL609 and PL611),
The objective of this paper is to add further documentation of these channel features seen on the island of Hopen. By positioning them accurately within the stratigraphy of the De Geerdalen Formation, it is possible to understand their spatial distribution in relation to the paralic environment which characterises the De Geerdalen Formation on Hopen. This is achieved through the combination of geological modelling and outcrop studies. This is intended to provide a firm basis of geological understanding and support future studies with onshore-offshore correlation of the Late-Triassic sediments, into the northern Barents Sea.

Geological Setting and Stratigraphy of Hopen

The island of Hopen lies in the SE corner of the Svalbard archipelago (Fig. 1) at approximately N76°35’ E25°20’ in the Norwegian high arctic. It is a small island of only 34 km in length and 0.5-2.5 km in width consisting entirely of Triassic aged strata, which protrude to a maximum height of 371 m above sea level. Its origin probably relates to the nature of deep rooted faulting in NE region of the Barents Sea (Doré, 1995; Grogan et al., 1999). The crustal structure around Hopen is dominated by a series of NE-SW trending lineaments, oblique to the regional N-S trend of structures in Spitsbergen (Doré, 1995; Grogan et al., 1999).

The island features regionally and gently northwards dipping strata, dissected by a series of NW-SE trending normal faults dipping to both the SW and NE. The stratum of the island also display gentle synclinal and monoclonal structures, with limbs dipping to both the NE and SW (Smith et al., 1975; Mørk et al., 2013; Klausen and Mørk, 2014).

Exposures of the island represent three formations (Fig. 2) of the Late-Triassic in Svalbard (Mørk et al., 1999). These include; the uppermost of the De Geerdalen Formation, with its heterolithic nature of alternating sandstone and siltstone deposited in a paralic deltaic setting (Klausen and Mørk, 2014). The entirety of the overlying Flatsalen Formation, with the Slottet Bed at its base can be observed at Lyngefjellet in the NE of the island. Lyngefjellet is capped by a c. 35 m thick cliff forming succession of the Svenskøya Formation of Norian and possibly Rhaetian age (Mørk et al., 2013; Vigran et al., 2014) and is the only locality at Hopen where this formation is present (Mørk et al., 1999; 2013).

The De Geerdalen Formation on Hopen is dated as Late-Triassic, Carnian to Norian in age, based on the presence of ammonites, palynology and magneto-stratigraphy (Pčelina, 1972; Korčinskaja, 1980; Tozer and Parker, 1968; Launis et al., 2014; Lord et al., 2014; Vigran et al., 2014). The uppermost part of the De Geerdalen Formation on Hopen is interpreted as showing an increasing marine influence, exhibiting lower net-to-gross succession, dominated by hummocky cross-stratification. This upper part of the De Geerdalen Formation has been defined as the Hopen Member (Mørk et al., 2013; Lord et al., 2014), a time equivalent unit to the Isfjorden Member of central Spitsbergen.

Recent advances in the understanding of the development of the De Geerdalen Formation throughout the Triassic (see Worsley, 2008; Klausen and Mørk, 2014; Gjørstad-Clark et al., 2010; Lundschienn et al., 2014, Lord et al., 2014; Rod et al., 2014) show that the Triassic strata of Hopen represent some of the youngest and most regressive onshore exposures, of a large-scale deltaic system, that gradually filled the Barents shelf during the Triassic (Worsley, 2008; Gjørstad-Clark et al., 2010; Lundschienn et al., 2014). The palaeogeographic map in Figure 2 illustrates a reconstruction of this deltaic environment during the Late-Triassic.

This enclosed shelf, in the northern coastline of the Pangean supercontinent stretched out to the boreal Panthalassa Sea and was gradually filled with sediments, derived from the Uralian mountain chain (Puchkov, 2009; Pózer Bue and Andresen, 2013; Lundschienn et al., 2014). The Ural Mountains were uplifted as a series of tectonic and orogenic events throughout the Late Devonian, Late Carboniferous and Permian (Puchkov, 2009), as the Siberian Plate collided with the smaller landmasses of Kazakhstan and Pangea itself.

The outcrops that represent the most distal parts of this deltaic system are observed on central Spitsbergen within the De Geerdalen Formation, whereas the corresponding paralic and proximal part of this delta within the Triassic succession can be found on the islands of Barentsøya, Edgeøya and Hopen. The axis of Hopen lies relatively perpendicular to the interpreted NW direction of deltaic progradation (Klausen and Mørk, 2014; Lundschienn et al., 2014).

The youngest Triassic exposures found in Svalbard are present on Spitsbergen and Hopen and are not exposed on...
Triassic channel bodies on Hopen, Svalbard

Sedimentary Rocks

- **Kapp Toscana Group**
  - Wilhelmeya Subgroup
    - Svenskøya Formation: medium-grained, porous, light-coloured sandstone
  - Flatsalen Formation: dark grey, silty shale with silt- and sandstone beds; base: carbonate-cemented sandy siltstone (Slottet Bed)

- **Storfjorden Subgroup**
  - De Geerdalen Formation
    - Hopen Member: marine sandstone, siltstone, dark shale, mudstone
    - De Geerdalen Formation (lower part): shallow marine to terrigenous sandstone, siltstone, shale

Map projection: UTM, zone 35X
Vertical reference basis: Mean sea level
Contour interval: 50 m
Channel Types and Architecture

Rivers and channels are a major pathways of sediment routing through a terrestrial environment and their nature can be considered complex (Collinson, 1996). Here we provide a simple overview of channel types seen in the rock record and the ways in which they can be interpreted in outcrop.

Ancient channels are generally classified with regards to their internal architectures (Collinson, 1996; Gibling, 2006; Miall, 1988, 1996, 2013). As no vertical sequence is diagnostic of any specific channel type, their architecture and geometry become major facets in determining the channel facies (Miall, 1985).

The description of channel sand body geometries is based primarily on the visual characteristics observed from photo mosaics and measured in the 3D model. Channel sand bodies can be seen to range in size and shape considerably and thus an overview of the terminology used for describing both sandstone channel bodies is presented in Figure 3. Individual sandstone channel bodies can be described as forming several distinctive geometrical shapes, being symmetrical, asymmetrical and lenticular. These become complex within channel systems involving multiple channels, where they can become multilateral, stacked or are seen to form laterally extensive sheets.

Channel forms and architecture can range from simple individual sandstone channels to multilateral channels or stacked channel systems. Individual channels can represent small systems with little or no avulsion. Multilateral / laterally accreting channels generally represent the lateral migration of a channel due to erosion on the outside of a bend and deposition on the inside. This often results in the presence of heterolithic channel bodies with notable accretion surfaces (Collinson, 1996). Stacked channel systems represent the repeated activation of a watercourse over time showing evidence of a primary sediment pathway where numerous rivers repeatedly erode into earlier underlying channels.
Channels can be isolated within the stratigraphy or be amalgamated into systems representing a major watercourse, sediment routing pathway. These amalgamated systems can themselves be isolated within floodplain deposits or form widespread lateral sheet sands composed of multiple channel systems that spread over a wide area.

Methodology

PhotoModeler™ 3D Geological Model

A 3D geological model of the island has been produced utilising PhotoModeler™ software from EOS Systems (Solvi, 2013). The model applies a large database of high resolution digital photographs to make a 3D visualisation of the island, overlying a digital elevation model (provided by the Norwegian Polar Institute). This model can be manipulated and used to interpret the islands geological characteristics.

The method of constructing the model uses a series of photographs taken with a high resolution camera, using 85 mm or 300 mm lenses. In total 4900 photographs of the island have been used. Visual interpretation of these images was used to document the occurrence and distribution of channel bodies throughout the De Geerdalen Formation.

These photographs are then used in panoramic combinations within the PhotoModeler™ program, where known points are selected to reference their locations to a digital elevation model. The addition of aerial photographs of the island, provided by the Norwegian Polar Institute, allowed for a greater level of detail and accurate geometrical measurements of the geology to be made. Formation thicknesses have been calibrated based on stratigraphical log data recorded in the field and height reference points measured by GPS, to ensure feature are accurately represented in the model.

The criteria for the identification of channel bodies, observed within the geological model, rely on the identification of features evidently formed by an erosive process. Vertically incising and laterally constrained features that are seen within the model are interpreted as channel bodies, with the addition of evidence from their internal architectures.

Field Studies

Conventional field studies form the bulk of the geological understanding of Hopen. Sections are provided by the Hopen Geology Project and have been drawn by small team operating throughout the island over relatively short periods of time; herein we integrate these sections.

Those channels that have been logged and their sedimentary structures analysed to determine their facies association are displayed in Figure 4. Field studies are used to assist the interpretation of channels that have not been directly observed in the field. Understanding of channels seen within the geological model is based on observed channel architecture and geometry, whilst the nature of the depositional environment is inferred by extrapolating the stratigraphical level of the channel laterally towards logged sections.
Depositional Environments

Delta top & Plain: Root beds, minor coals, palaeosol, fluvial trunk and distributary channels, crevasse splay deposits.

Delta front/ Shoreface: Tidal and wave dominated deposition, tidal flats, tidal and estuarine channels, minor root structures, abundant bioturbation.

Shallow marine/ Prodelta: Offshore muds, tempestites, hummocky cross stratified sands, bioturbation and marine fossils.

Channel Type

Trunk River: Major fluvial channel, multilateral, multi story, large cliff forming sandstone bodies. Lithologically homogeneous, deep erosive scour.

Fluvial Distributary Channel: Asymmetric geometry, often with channel wing, generally heterolithic with clear lateral accretion surfaces, mud plugs/ abandonment features common.

Estuarine Channel: Large relatively homogeneous sandstone channel with tidal bundles, forms as an amalgamation of channels and large scale dunes.

Tidally Influenced Channel: Large heterolithic channel, featuring deep erosional base, tidal bundles, escape structures, mud drapes or forsets.

Figure 4. Overview of stratigraphical logs from Hopen, locations are marked on the map and stratigraphy is flattened at the base of the Hopen Member. Logged channels are highlighted and a simplified interpretation of depositional environment is given. Each channel zone is denoted.
Based on the depositional environments and the position of all channels identified is shown in the cross section. Logs are provided by the Hopen Geology Project with map, cross section and facies after Mørk et al. (2013).
Channels and the Stratigraphy

Throughout the stratigraphy channel sandstone bodies can be arranged into a relatively discrete stratigraphy (Solvi, 2013; Klausen and Mørk, 2014), herein we provide greater evidence for this trend and discuss the type of channels found at the varying stratigraphical intervals. When flattening the stratigraphy of the island in relation to the Slottet Bed and also the recently defined Hopen Member, to avoid disruption by faulting (Mørk et al., 2013; Lord et al., 2014); the stratigraphical relationships and the lateral extent of depositional environments can be seen (Fig. 4).

25 channel bodies have been identified on the island of which 12 have also been directly observed in the field. Those that have not been directly observed in the field have been identified within the 3D model and their nature is determined based on their visual characteristics. Here, we explain the basis for classifying the different channels and where they are located in the stratigraphy. Table 1 presents a complete overview of channel characteristics, geometries and architectures. These are ordered into three defined stratigraphical intervals and channels are ordered in relation to their stratigraphic position below the Hopen Member. These stratigraphic intervals are defined as the lower, middle and upper channel zones as shown in the correlation on Figure 4.

In most instances channel features are seen to scour into underlying, soft, highly heterolithic sediments and feature a lateral pinch out. Based on the observations presented in Table 1, three primary channel types are interpreted. Fluvial channels are observed and assist the definition of overall depositional environments for various stratigraphic intervals. Fluvial, tidally influenced fluvial and estuarine channels are also observed and defined based upon their internal channel heterogeneity and sedimentological characteristics. Fluvial channels are the most abundant and are seen to vary in facies type, with trunk rivers, distributary channels and individual channels often displaying abandonment features.

Strata of the De Geerdalen Formation, initially deposited within a shallow marine environment or prodelta environment (See legend in Fig. 4), are comprised of highly heterolithic beds formed in several marine facies types. These include: Sediments deposited in a low energy environment, consisting of fine grained mud and silt, with fine laminae containing distal storm beds host to minor hummocky cross-stratification. In addition bioturbated thin sandstones and shales often seen in conjunction with abundant wave ripple structures are common within this facies. This depositional environment also incorporates the uppermost unit of the De Geerdalen Formation, the Hopen Member, which represents a widespread flooding surface visible throughout the island (Mørk et al., 2013; Lord et al., 2014).

Some sections of Hopen's stratigraphy is interpreted to represent tidally dominated sedimentation within a delta front environment and here sediments are seen to be richer in sand, featuring abundances of bioturbation and hummocky cross-stratified sands (Fig. 4). Heterolithic packages of shale interspersed with minor cross stratified sand beds are present suggesting a greater influence of wave and tidal re-working of sediments. Minor root structures are present within this facies association and are interpreted as a tidal marsh environment.

The delta top setting present within the De Geerdalen Formation is evident based on the presence of notable root beds, minor coal beds and an abundance of plant fragments (Launis et al., 2014). Dominant facies within this environment are crevasse splay deposits, floodplain deposits of non-marine mud and shale, and minor root beds alongside palaeosol horizons.

The Upper Channel Zone

Fluvial Channels in the Upper Zone

At the SW cliff section of Lyngefjellet (Fig. 5A) some 4 m from the base of the Hopen Member a channel body with a thickness of 8 m and a lateral extent of 240 m is observed in the 3D geological model. The sandstone comprising this feature is laterally extensive for 90 m, whilst the pinch outs appear to consist of finer grained sediments. This channels architecture reveals that the NE pinch out is represented by a channel wing, whilst lateral accretion surfaces are present. This channel is interpreted as being a fluvial distributary channel.

On NE Lyngefjellet a channel body has been observed in the field and is shown in log K: Lyngefjellet NE (Fig. 4) and Figure 5B. This laterally extensive channel sandstone is 11 m in thickness and of unknown width, featuring trough cross stratified medium to coarse grained sand, upwards fining to current rippled fine sand. The log does not suggest any evidence for a stacked channel complex or, this having a multilateral architecture. However, the sandstone is capped by a succession of fines that coarsen upwards and include root horizons, probably representing abandonment features. This channel is interpreted as being a major fluvial channel, most probably a distributary although a trunk channel cannot be ruled out.

18 m below the base of the Hopen Member, on the mountain of Johan Hjortfjellet lays a 28-32 m thick sandstone body, measuring approximately 950 m in width (Fig. 5C). Its exact lateral extent is undetermined due to its northern pinch out (when observed from the eastern side of the island) being very discrete. This channel has been logged in its entirety, log G: Russevika, S which shows the fine to medium grained sandstone channel eroding into soft underlying shales. Its internal architecture is dominated by large scale trough-cross
<table>
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<td>Lyngsfjellet SW</td>
<td>5A</td>
<td>4 m</td>
<td>240 m / 8 m</td>
<td>Asymmetrical channel scour with channel wing, features lateral accretion surfaces terminating at the base of the channel. Visual characteristics suggest relatively homogeneous composition.</td>
<td>Fluvial Distributary Channel</td>
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<td>Lyngsfjellet NE</td>
<td>5B</td>
<td>10 m</td>
<td>Undetermined / 11 m</td>
<td>Trough cross-stratified medium/ coarse grained sandstone finely up wards to medium grained current rippled sandstone.</td>
<td>Fluvial Distributary Channel of potential Trunk River</td>
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<tr>
<td>Johan Hjortsfjellet</td>
<td>5C</td>
<td>18 m</td>
<td>c. 600 m / 32 m</td>
<td>Single storey channel, with an erosive base and lithological homogeneity, featuring large scale trough cross stratification.</td>
<td>Trunk River (after Klausen &amp; Mørk 2014)</td>
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<td>Binnedalen</td>
<td>5D</td>
<td>24 m</td>
<td>Undetermined / 7-15 m</td>
<td>Prominent trough and cross trough bedding, mud clasts line the base of troughs. Gentle upw ards forming observed into current rippled sandstone with rootlets.</td>
<td>Fluvial Distributary Channel</td>
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<td>Braastadskaret NW</td>
<td>5E</td>
<td>25 m</td>
<td>100 m / 7 m</td>
<td>Amalgamated, multi lateral channel body with laterally accreting beds, channel wing and potential mud plug.</td>
<td>Fluvial Distributary Channel</td>
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<tr>
<td>Blåfjell</td>
<td>5F</td>
<td>c. 28 m</td>
<td>325-475 m / 13-19 m</td>
<td>Heterolithic composition with near symmetrical geometry. Laterally accreting beds present. No channel wing or evidence for mud plug. Features sand lenses.</td>
<td>Fluvial Distributary Channel</td>
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<tr>
<td>Lyngsfjellet W (Upper)</td>
<td>5G</td>
<td>29 m</td>
<td>210 m / 11 m</td>
<td>Single storey, medium grained channel sandstone. Featuring an erosive base, extensive cross stratification with the uppermost fining to massive fine sand. Notable lateral accretion surfaces present with potential mud plug.</td>
<td>Fluvial Distributary Channel</td>
</tr>
<tr>
<td>Iversenfjellet (Upper)</td>
<td>-</td>
<td>29 m</td>
<td>Undetermined / 12 m</td>
<td>Trough and planar cross stratified sandstone with plant fragments. Fining upwards to small upwards coarsening deposits, representing lateral accretion beds.</td>
<td>Fluvial Distributary Channel</td>
</tr>
<tr>
<td>Nordstefjellet (Upper)</td>
<td>5H</td>
<td>30 m</td>
<td>Undetermined / 10-15 m</td>
<td>Appears at similar stratigraphical level to the channel body in Binnedalen.</td>
<td>Fluvial Distributary Channel</td>
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<tr>
<td>Nordstefjellet SW</td>
<td>-</td>
<td>42 m</td>
<td>200 m / 15 m</td>
<td>Symmetrical body. No notable internal structures, geometry is highly lenticular with a concave base and top. Bending of overlying beds suggests a component of differential compaction.</td>
<td>Major Fluvial Channel (Possible Trunk River)</td>
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<tr>
<td>Lyngsfjellet W (Lower)</td>
<td>5I</td>
<td>30 m</td>
<td>145 m / 6 m</td>
<td>Heterolithic composition with accretion surfaces and mud plug, asymmetric geometry and isolated in the stratigraphy.</td>
<td>Fluvial Distributary Channel</td>
</tr>
<tr>
<td>Kvasstoppen W</td>
<td>5J</td>
<td>50 m</td>
<td>Undetermined / 30 m</td>
<td>Scouring sandstone body, truncated by fault however shows evidence for finit lateral accretion surfaces suggesting multilateral channel architecture with relative lithological homogeneity.</td>
<td>Fluvial Distributary Channel</td>
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<tr>
<td>Nordstefjellet (Lower)</td>
<td>5K</td>
<td>60 m</td>
<td>1000 m / 36 m</td>
<td>Multilateral channel sandstone, laterally accreting surfaces, with an erosive base and lithological homogeneity. Minor trough cross stratification is observed, but is not prominent.</td>
<td>Trunk River (after Klausen &amp; Mørk 2014)</td>
</tr>
<tr>
<td>Blåfjell W</td>
<td>5L</td>
<td>Undetermined</td>
<td>Undetermined</td>
<td>Asymmetrical geometry with notable channel wing. Laterally accreting beds terminating at the base of channel scou r, heterolithic composition with a mud plug.</td>
<td>Fluvial Distributary Channel</td>
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<td><strong>Middle Channel Zone</strong></td>
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<tr>
<td>Kollerfjellet W (Upper)</td>
<td>5M</td>
<td>130 m</td>
<td>815 m / 25 m</td>
<td>Prominent cliff forming sandstone, deep scour and lenticular geometry, possible upwards fining trend with lateral accretion surfaces evident.</td>
<td>Fluvial Channel (with potential marine influence)</td>
</tr>
<tr>
<td>Djupskaret</td>
<td>-</td>
<td>135 m</td>
<td>150 m / 5 m</td>
<td>Lateral accretion surfaces are prevalent consisting clearly of lighter coloured sediments within finer grained (darker) material. Indication for possible mud plug.</td>
<td>Fluvial Channel (with potential marine influence)</td>
</tr>
<tr>
<td>Blåfjell E (Upper)</td>
<td>5N</td>
<td>c. 140 m</td>
<td>415 m / 30 m</td>
<td>Amalgamated channel bodies, tidal bundles.</td>
<td>Estuarine Channel</td>
</tr>
<tr>
<td>Blåfjell E (Lower)</td>
<td>5N</td>
<td>145 m</td>
<td>100 m / 7 m</td>
<td>Erosional base, mud drapes, wave ripples and large scale trough-cross stratification.</td>
<td>Tidally Influenced Fluvial channel</td>
</tr>
<tr>
<td><strong>Lower Channel Zone</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Iversenfjellet (Lower)</td>
<td>-</td>
<td>178 m</td>
<td>Undetermined / 15 m</td>
<td>Thick trough and planar cross bedded medium grained sandstone, fining up wards.</td>
<td>Fluvial Distributary Channel</td>
</tr>
<tr>
<td>Kollerfjellet W (Lower)</td>
<td>5O</td>
<td>179 m</td>
<td>915 m / 20 m</td>
<td>Highly vegetated, fractured and weathered exposure. Potential multilateral-channel system with lateral accretion surfaces evident.</td>
<td>Trunk River</td>
</tr>
<tr>
<td>Vesterodden</td>
<td>5P</td>
<td>183 m</td>
<td>Undetermined / 15 m</td>
<td>Notable cliff forming sandstone, no apparent internal architecture, however a potential mud-plug is observed.</td>
<td>Trunk River</td>
</tr>
<tr>
<td>Werenskioldsfjellet W</td>
<td>5Q</td>
<td>190 m</td>
<td>210 m / 22 m</td>
<td>Erosional scour, no obvious internal structures due to extensive fracturing and weathering of this exposure.</td>
<td>Fluvial Distributary Channel</td>
</tr>
<tr>
<td>Hopen Meteo NE</td>
<td>5R</td>
<td>200 m</td>
<td>232 m / 15 m</td>
<td>Asymmetrical geometry. Deep scour and mud plug, potentially stacked channel with some minor lateral accretion surfaces present.</td>
<td>Fluvial Distributary Channel</td>
</tr>
<tr>
<td>Russevika</td>
<td>5S</td>
<td>200 m</td>
<td>Undetermined / 13 m</td>
<td>Symmetrical channel geometry. Trough and cross stratified bedding within channel sandstone suggesting multilateral architecture. Deposited atop terrestrial sediments with coal and root beds.</td>
<td>Potential Trunk River Channel</td>
</tr>
<tr>
<td>Russevika Reef</td>
<td>5T</td>
<td>230 m</td>
<td>c. 150 m / unknown</td>
<td>Cross stratified medium grained sandstone with large tree fossils. Cutting into heterolithic sediments.</td>
<td>Potential Trunk River Channel</td>
</tr>
</tbody>
</table>
Figure 5 A-T. Images of channel bodies observed on Hopen. Photos relate to those indicated in Table 1 and channel positions are marked on the map in Figure 1. See text for detailed explanation of channels.
stratification. Due to this channels exposure being at a higher position in the stratigraphy, foresets of these troughs have formed a weathering surface and de-lamination is prominent. This inherently adds difficulty in the observation of larger structures due to the highly irregular expression of this sandstone and thus no lateral accretion surfaces are observed, nor evidence for this channel being component to a stacked complex. This channel body represents a large trunk river channel, following the interpretation of Klausen and Mørk (2014). This is based on the large channel geometry, its lateral extent and despite no visual evidence for lateral accretion surfaces, the log shows that the body is comprised of multiple packages trough cross and planar cross bedded sandstones, suggesting a component of lateral migration.

The sandstone channel body seen within the valley of Binnedalen in the northern end of Hopen is laterally discontinuous; 7 m in thickness and featuring a clear erosional scour (Fig. 5D). The width is undetermined as scree inhibits lateral tracing of this channel body. The sandstone lies 24 m below the base of the Hopen Member within heterolithic, laminated shale and thin sandstones. Beds below the base of this body consist of siltstones, with minor root beds and loading structures. The internal architecture of the sandstone shows pronounced large scale trough cross bedding with an abundance of rip up mud clasts and organic material observed at the base of the troughs. Internal bed packages show a tendency for gentle fining upwards and the uppermost parts of these are dominated by uni-directional current ripples. The channel is topped by a minor upwards fining package of sand to silt, featuring coalified root structures and desiccation cracks. These characteristics suggest a delta top environment in a fluvial dominated system. The channel lack marine or tidal influence and the internal architecture of the sandstone, suggest that this channel body represents a fluvial distributary channel.

On the western cliff section, on the NW flank of Braastadskaret (Braastadskaret NW, Fig. 5E), a channel scour is seen to erode into the underlying strata some 25 m below the base of the Hopen Member. Measurements indicate that this feature is 7 m thick and 100 m wide. The internal architecture of this channel is seen to display a series of laterally accreting, dipping bedding planes that terminate at the base of the scour. This channel may represent a laterally accreting body similar to several others observed on the island. In addition, interpretation from the model suggests the channels features a mud plug suggesting that the dipping beds may represent a migrating point bar within the bend of a fluvial distributary channel, which has then been abandoned.

On Blåfjell a channel scour estimated at approximately 13-19 m thick and 325 – 475 m in width is observed at approximately 28 m below the base of the Hopen Member (Blåfjell, S Fig. 5F). The internal architecture of this channel scour is dominated by a series of gently dipping sandstone beds intermittently dispersed with finer grained material, suggesting that this channel is multilateral in nature. Furthermore, observations made from the model show evidence for sand lenses within the scour and there is also potential for this channel being part of a stacked channel complex, with a younger channel scouring into an older channel body at the same stratigraphical interval. This is interpreted as representing a fluvial distributary channel, showing evidence of abandonment with potential reactivation of the watercourse at a later time.

The uppermost channel on the western coastline of Lyngsfjellet (Lyngsfjellet W, Upper) is situated approximately 29 m below the base of the Hopen Member and its dimensions are 11 m in thickness and 210 m in lateral extent (Fig. 5G). The channel is present in the log taken at Lyngsfjellet (L: Lyngsfjellet, S), on the eastern side of Hopen. This channel features a scouring base into soft underlying sediments and its internal architecture is also well defined in the 3D geological model. A series of laterally dipping beds of medium grained sandstone can be seen. The presence of fine grained material suggests that this channel has undergone abandonment at some stage and subsequent filling by fine grained flood deposits. The sandier accretion packages were deposited by the migration of a point bar. This is interpreted as a fluvial distributary channel.

In the upper sections of Iversenfjellet in southern Hopen features a sandstone channel body of 12 m thickness and an undetermined width, lying 29 m below the Hopen Member. The channel is homogeneous, composed of medium grained sandstone featuring trough and planar cross bedding. The uppermost of this body is defined by minor upwards coarsening packages. This channel is interpreted as representing a fluvial distributary channel. At Nordstefjellet, 30 m below the base of the Hopen Member a channel sandstone body is observed, (Nordstefjellet Upper, Fig. 5H). This channel is not logged but does appear at a similar interval to that in Binnedalen and appears isolated within the surrounding strata. It is laterally extensive with no noticeable internal architecture. The thickness is determined to be some 10-15 m whilst the lateral extent is unknown. Given the relative homogeneity of this sandstone body, with no evidence for lateral accretion surfaces or obvious fines formed during abandonment, this channel is interpreted as being a fluvial distributary channel.

On the SW flank of Nordstefjellet a laterally discontinuous, lenticular shaped sandstone channel body is observed to be down cutting some 8 m into underlying sediments. Stratigraphically, it occurs 42 m below the base of the Hopen Member at a similar interval to the fluvial channel observed in the coastal cliff section at NE Nordstefjellet. The sandstone has a thickness of 15 m and a width of 200 m. This deep scour and symmetrical geometry suggest that this channel represents a major
watercourse, with no evidence for lateral migration being seen. The channel is interpreted as representing a major fluvial channel, possibly a trunk river.

The lowermost channel on the western coastline of Lyngefjellet (Lyngefjellet W, Lower) occurs some 50 m below the base of the Hopen Member and its geometry forms a laterally discontinuous scour, of 6 m in thickness and 145 m in lateral extent (Fig. 5I). The channel displays two prominent characteristics with regards to its internal architecture. First and foremost, a series of notable, sandy accretion surfaces are observed dipping laterally within the channel scour. Alongside, a series of fine grained sediments are observed. These are interpreted as the accreting planes of point bar deposits within a meandering river system, with fine grained sediments representing the ultimate abandonment of this channel and subsequent filling by sediments over time, suggesting this river is a fluvial distributary channel branching from a major watercourse.

On the western side of the mountain of Kvasstoppen (Kvasstoppen W) on southern Hopen, a 30 m thick sandstone body has been observed (Fig. 5I). Its lateral extent is undetermined due to fault displacement. Its position in the stratigraphy is 50 m below the Hopen Member. Despite Kvasstoppen not being capped by the Hopen Member, the position has been determined by laterally tracing prominent beds across the fault to Iversenfjellet. This places the body within delta plain sediments seen in the upper parts of the De Geerdalen Formation, beneath the Hopen Member. Although not logged, subtle bed packages are observed. Given its stratigraphical position, thickness and homogeneity, this sandstone might represent a fluvial, distributary channel deposit.

At Nørdstefjellet in the northern end of the island is a 36 m high and 1000 m wide sandstone body evident in the lower cliff section, shown in log N: Nørdstefjellet 2, (Fig. 5K). This single storey, multilateral channel body shows a clear lateral pinch out to fine grained sediments and a scour of some 17-20 m. It is present on both sides of the island as a notable cliff and is subject to minor oblique fault displacement. Within this channel body, the sandstone is relatively homogeneous with trough cross bedding surfaces being visible. The base is sharp, with an irregular contact into the underlying shale, which comprise minor, laterally discontinuous coals and coalified root structures. This channels stratigraphical position is determined to be approximately 60 m below the base of the Hopen Member. Given the multilateral nature, geometry and sheer size of this channel it is interpreted as representing a trunk river.

A channel scour is observed on the southern side of Bláfjell, named as Bláfjell, W (Fig. 5L). Within this scour, lateral accretion surfaces are observed in the 3D geological model, with a discontinuous layer of darker and presumably more mud rich deposits being evident. The position in the stratigraphy and extrapolation of the level to nearby logs, suggest this channel lies within delta top sediments and therefore it may represent a minor, formerly meandering fluvial distributary channel, with a mud plug formed as a result of channel abandonment.

The Middle Channel Zone

Fluvial, Tidal and Estuarine Channels in the Middle Zone

The upper cliff section on the western side of Kollerfjellet (Kollerfjellet W Upper, Fig. 5M) is seen to enclose a laterally discontinuous cliff forming sandstone body. Its position in the stratigraphy is measured as being 179 m below the base of the Hopen Member. This channel is determined to be 20 m thick and with an estimated width of 915 m (which cannot be accurately determined due to faulting). The channel was interpreted as being a fluvial channel, however given its stratigraphical position, the potential remains for this to represent a tidally dominated or estuarine channel. Within the narrow and steep sided gully of Djupskaret, a 5 m thick and 150 m wide channel occurs at a stratigraphical level some 135 m below the base of the Hopen Member. A section slightly north of this is logged at Dijupsalen (Log E: Dijupsalen), where a minor component of this channel body has been observed at the same stratigraphical level. The logged strata display a clear palaeosol horizon with intermittent current ripple laminated sandstones and root structures. Within the De Geerdalen Formation at various locations throughout Svalbard, most noticeably on the eastern island Edgeøya, palaeosols are common and they are characterised by bleached zones (Miall, 2006). On Hopen, however, they are observed to primarily be thin oxidised beds often seen in conjunction with coal shale, minor coal beds and coalified roots. Palaeosols can also be defined as a common flood plain facies (Miall, 2006; Kraus and Aslan, 1993), which suggests that this channel is deposited within a delta plain environment. Analysis of the internal architecture shows evidence for lateral accretion surfaces, indicating the lateral migration of a point bar. The heterolithic composition shows evidence for a mud plug. The relatively small lateral extent and minor thickness of this body, alongside the associated facies, indicate that this channel is representative of a relatively minor fluvial distributary channel. Given the position in the stratigraphy which is dominated by marine influenced facies it is likely this channel was initially flowing in a very near shore environment, where major channel paths have branched into smaller systems.

Along the coastline at Bláfjell two channels are observed to form a stacked channel system, where one is seen to scour into one below as shown in Figure 5N. The uppermost channel forms a vertical cliff of 30 m
height, with an overall width of 415 m. This prominent sandstone body incising into the channel beneath it and its approximate stratigraphical position is c. 175 m below the base of the Hopen Member. The internal architecture of this channel body displays a series of prominent erosional scours along individual bed boundaries, which are observed to be of thicknesses between 3-5 m. They are interpreted as representing the amalgamation of small channels, with a minor lateral extent of some 10-15 m. This channel system has been logged (Blåfjell, E) and the upper part of this section reveals the presence of mud drapes along wave ripple crests, loading structures in the form of flame casts and Klausen and Mørk (2014) report the presence of tidal bundles within the lower packages of the channel body. This package is defined by Klausen and Mørk (2014) to be the deposits of an estuarine system where dune migration within a confined channel system represents scour and fill.

The lowermost channel of this stacked system and also this channel zone occurs some 180 m below the base of the Hopen Member and is seen to scour into underlying sediments. This channel body is 7 m thick and is documented in the stratigraphical log I: Blåfjell, E and in Figure 5N. The width is measured at some 100 m despite this channel being incised by an overlying channel body. The internal channel architectures, observed in the 3D geological model, shows that the channel contains a series of beds, where multiple erosional scours form their basal geometry. This can thus be considered as a stacked channel system, composed of minor stacked and amalgamated channels. Further information is provided from the sedimentological log Blåfjell, E where the lowest exposures of this channel have been logged along with the overlying channel body. The log shows a gentle upwards fining trend of fine to medium grained sandstone with an erosional base. Internal structures show the presence of large scale trough-cross stratification and mud-drapes. Mud drapes are common features in tidally influenced environments (Bhattacharya, 2006). Based on the presence of mud drapes, suggesting a bi-directional flow, this lower channel body is interpreted as being deposited within a tidally influenced environment and is defined as a tidal channel.

The Lower Channel Zone

Fluvial Channels in the Lower Zone

The basal sections of the mountain of Iversenfjellet in southern Hopen are seen to contain a sandstone channel body of 15 m thickness. The extent of this channel is undetermined due to extensive cover in the lower slopes of the mountain in this area. The channel consists of medium grained trough and planar cross bedded sandstone, seen to fine upwards into siltstone. This upwards fining trend suggests a slow abandonment of this channel. No evidence for a multilateral architecture is observed and no erosional surfaces are seen within the channel itself. This channel is within a zone dominated by delta top sediments and is interpreted as representing a fluvial distributary channel.

The cliff section on the western side of Kollerfjellet is seen to enclose a laterally discontinuous cliff forming sandstone body (Table 1, Fig. 5O). Its position in the stratigraphy is measured as being 179 m below the base of the Hopen Member. This channel is determined to be 20 m thick and with an estimated width of 915 m. The cliff section of the channel itself is seen to be highly vegetated and weathered, thus no internal characteristics can be observed. This channel appears to have a homogeneous composition, its geometry and scale suggests it represents a very large channel system and is thus interpreted as representing a trunk river.

At the SE tip of Hopen, a prominent cliff forming sandstone is present in the section at Vesterodden, approximately 183 m below the base of the Hopen Member (Table 1, Fig. 5P). This channel has been subject to faulting thus its lateral extent is undetermined; its thickness is measured to be 15 m. No sedimentological logs cover this channel; however neighbouring strata show that this interval is dominated by fine grained sediments with current ripple lamination. The stratigraphical interval here also contains an upwards fining sandstone bed with an erosional base, interpreted in this case to be a crevasse splay. The channel body is interpreted to be a fluvial trunk river, within a delta top setting.

The western flank of Werenskioldfjellet, to the SW of the Hopen meteorological station contains a 22 m thick and 210 m wide channel sandstone body, clearly eroding into the underlying sediments (Fig. 5Q). The channel body is present in the stratigraphy approximately 190 m below the base of the Hopen Member and correlates well to the stratigraphical level of the log taken at Iversenfjellet SE (Fig. 4). Strata in this interval consist of fine grained sediments containing wave and current ripple laminations, along with minor bioturbation. No direct environment indicators are evident; however the presence of symmetrical wave ripples and the occurrence of bioturbation suggest that this channel has been deposited in an environment with close proximity to wave or potentially tidal influence, such as a lower delta plain environment. This channel is thus interpreted as representing fluvial distributary channel at a point in the delta system where rivers have branched or anastomosed into smaller channels.

To the NE of the Hopen meteorological station a channel scour is present in the stratigraphy, approximately 200 m below the base of the Hopen Member (Fig. 5R). Its dimensions are measured to be 15 m in thickness and 232 m in overall width, however, a potential pinch out laterally to the north cannot be determined due to the presence of a deeply incised gully. The internal
architecture as observed in the geological model shows the presence of an 8 m thick package of dark, fine grained sediments forming what is interpreted to be a mud plug. This channel was presented in Nystuen et al. (2008) although with no additional interpretation. No other prominent internal structures are noted. It is interpreted that this channel represents an abandoned fluvial distributary channel.

Sandstone channel bodies are also evident on the beach section at Russevika in central east Hopen, where a 13 m thick channel is observed to scour into soft underlying shales. Field observations show that this underlying stratum contains wave rippled siltstone with mud drapes, minor coals, root beds and small stream scours (see Figs. 5S and 6A-C). The channel consists entirely of sandstone, with large scale trough and cross-trough bedding present. Due to cover the full lateral extent is undetermined. The stratigraphical position of this channel body is 200 m below the base of the Hopen Member. The channel facies is representative of a fluvial channel with no evidence for any tidal influence being seen within the channel body itself; however wave ripples and bioturbation is seen in the underlying beds in addition to a minor coal bed and coalified root structures. The channel is interpreted to be a fluvial distributary channel based on the primarily heterogenic composition of the sand and lack of evidence for external environmental influences being present.

A further sandstone that is classified as fluvial in origin is observed to protrude from the island as a shallow, wave cut platform beneath the channel at Russevika (Fig. 5T), termed 'Russevika Reef' in Table 1. The exact geometries are unknown, yet it is laterally discontinuous in the order of ca. 75-100 m, and lithologically homogenic (when observed at low tide). This sandstone is considered to have similarity with those channels seen at Nordstefjellet and Johan Hjortfjellet. It is suggested on this basis that this sandstone is almost certainly representative of a fluvial channel, possibly representing a trunk river. Furthermore, field observations show that this channel is seen to be transporting large trees (Fig. 6D), a feature also seen in the trunk river channel at Johan Hjortfjellet.

Discussion

The nature of channel sandstone bodies on the island of Hopen can be interpreted as being indicative of three different depositional environments. Fluvial trunk river channels and fluvial distributary channels are seen to be present within delta top dominated sediments, whilst tidal and estuarine channels are seen within sediments dominated by a delta front environment. The geometry of these bodies and their architectures also vary in this regard. Fluvial trunk rivers are seen to be homogeneous in composition and form either lenticular or near symmetrical sandstone bodies, that typically feature a greater width to thickness ratio (Gibling, 2006). Fluvial distributary channels are in comparison characterised by their asymmetric geometry. At some locations, such as those seen at Lyngefjellet SW, Braastadskaret NW or Blåfjell S (Figs. 5A, E, L) the potential for the presence of a channel wing is evident. This is observed by the noticeable thinning of the channel's form laterally away from the scour, however this has only been observed in photomosaics. Both types of fluvial channels are seen to be isolated within the stratigraphy and do not form stacked systems or lateral sheets (Fig. 3). Channels of both types however, show evidence for lateral accretion surfaces, with these being most evident in the heterolithic sediments seen in fluvial distributary channels.

Fluvial channels can be seen to represent both meandering rivers systems and also anastomosed systems, based on the presence of lateral accretion surfaces seen in distributary channels. Fluvial trunk channels are suggested to represent a moderate sinuosity, multi-channel system flowing through an area characterised by extensive vegetation with a large proportion of overbank deposits. A number of channels also display abandonment features, characterised by their overall heterolithic composition, internal architecture and evidence for abandonment based on the presence of mud plugs. This is most evident in the channels at Lyngefjellet SW, Braastadskaret NW and Blåfjell W (Figs. 5A, E, L). These channel features are suggested to have formed on or near the apex of a bend in a meandering river system. Meanders are eroded through leaving an oxbow lake or meander scar that is later in-filled with fine grained sediments, through lake like deposition (Collinson, 1996).

The lowermost exposures present on the island of Hopen are dominated by terrestrial floodplain sediments, in which 7 channels incising into heterolithic sediments have been identified. These channels are shown within the lower channel zone in Table 1, which corresponds to interval 1a of Klausen and Mørk (2014) and is determined to occur approximately 180-200 m below the Hopen Member. These channels are located at Hopen Meteo NE, Kollerfjellet W (Lower), Iversenfjellet (Lower), Vesterodden, Werenskioldfjellet W, Russevika and protruding out to sea at Russevika Reef (Fig. 4). Only the channels at Hopen Meteo NE and the two at Russevika have been observed in the field, the remainder are identified in the 3D geological model.

This lower zone is of unknown thickness, as the De Geerdalen Formation continues in the subsurface. The presence of the fluvial Russevika Reef channel coupled with the Iversenfjellet SE and Hopen Radio N logs in Figure 4 suggest that the interval remains predominantly within a delta-top to delta front environment continuing in the immediate subsurface. A minor marine incursion of unknown lateral extent is interpreted within this zone (as shown in Figure 4), however, channels in this lower zone are dominantly distributary channels.
The strata dominating the middle section of the stratigraphy, between c. 70 and 180 m below the Hopen Member, is interpreted as being dominated by facies that display a marine influence. This ca. 100 m thick interval consists primarily of shallow marine and delta front facies associations. Here abundant bioturbation, wave ripples and laterally discontinuous sandstone beds featuring hummocky cross-stratification are prevalent. This is a visually discrete interval and corresponds closely to interval 1b of Klausen and Mørk (2014). It is considered laterally extensive, spanning the entirety of the island; however, fault displacement and scree cover make facies correlation difficult.
The middle zone is also interspersed with minor occurrences of delta front and delta top facies as show in Figure 4. Here channels are interpreted to be influenced to a greater extent by marine processes, given the individual channel architecture, geometries and sediment characteristics. Two primarily marine channels are observed at Bláfjell, where a lower tidally dominated channel is present, which is seen to be subsequently eroded into by an estuarine channel system. The two remaining channels seen in the middle zone are deemed to be fluvial distributary channels. They feature internal characteristics inherent of a fluvial system and in the case of the channel at Djupskaret are in close relation to delta top sediments. Given their stratigraphical position, however, an aspect of marine influence cannot be ruled out, as this interval is dominated by marine processes, suggesting fluvial channels are a result of delta switch.

The uppermost strata of the De Geerdalen Formation on Hopen, below the Hopen Member, are interpreted as being dominated by delta top and delta plain sediments, with minor marine influenced intervals being present where delta front facies are observed. This is defined as the upper channel zone (Table 1) which corresponds to intervals 2b and 2c of Klausen and Mørk (2014). Within this zone a total of 14 fluvial channels are observed. Of these 14 channels, 6 have been logged and their depositional facies has been determined through direct observation whilst the remaining channels are interpreted with evidence from photographs and the 3D geological model.

The De Geerdalen Formation on Svalbard was reported as a shallow marine to fluvial succession by Buchan et al. (1965) and Mørk et al. (1982). Deltaic conditions were reported from Barentsøya and western Edgeøya (Knarud, 1980; Lock et al., 1978; Mørk et al., 1982) and fluvial to delta top with coal beds further east on Edgeøya (Lock et al., 1978). Sedimentological data from Hopen was not presented, but the general depositional conditions as reported on the other main Svalbard islands were assumed to continue also to Hopen. In the Barents Sea, the correlative Snadd Formation was also reported as shallow marine to deltaic, however it is more fluvial in nature, especially in its upper part and this is noted by many authors (e.g. Høy and Lundschiien, 2011; Klausen and Mørk, 2014; Riis et al., 2008; Glørstad-Clark et al., 2010).

The abundant presence of channels, within the De Geerdalen Formation on Hopen was first reported by Mørk et al. (2013) and these channels was compared with channels detected by seismic methods in the southern Barents Sea in the Snadd Formation by Klausen and Mørk (2014). Observations supported by shallow drilling data in the northern Barents Sea (Lundschiien et al., 2014) show that this area was covered by extensive paralic deposits from mainland Norway through to Hopen. Authors interpreting seismic data demonstrated that during the Carnian four seismic sequences, up to 400 m thick, were progressing across the Barents Sea and passed Hopen in the uppermost sequence (e.g. Lundschiien et al., 2014). The Hopen exposures thus display the nature of these prograding sequences with its arrangement of different channel belts.

The exposed Hopen succession as a whole is younger than the section at Edgeøya (Riis et al., 2008; Lord et al., 2014; Lundschiien et al., 2014) and together they give a view of the total Late Triassic succession on the eastern Svalbard Islands. Hopen provides excellent exposures along a near perpendicular plane to the major palaeoflow direction of rivers during the Carnian. Klausen and Mørk (2014) show a clear trend of channels seen in seismic migrating to the W and NW. The perpendicular aspect of the island to this palaeoflow and the steep sections allow for excellent studies to be made. On Edgeøya, outcrops are generally oblique to the orientation of channels and thus their abundance may be under reported as their presence is not evident as with channels seen on Hopen.

On Spitsbergen; the Triassic succession is mostly complete (Buchan et al., 1965; Mørk et al., 1982, 1999), although the uppermost part (Wilhelmøya Subgroup) is quite condensed, especially in the central and western areas. Detailed facies studies by Rod et al. (2014) demonstrate that the paralic nature of the De Geerdalen Formations extends from Edgeøya into central Spitsbergen. Delta front sediment is, however, more abundant in these areas than distinct channels as seen on Hopen.

In comparison to the wider extent of the De Geerdalen Formation in Svalbard, the facies seen at Hopen is comparable to that on Edgeøya, despite being younger in age. Rod et al. (2014) document a paralic environment in the upper parts of the De Geerdalen Formation seen in western Edgeøya. A significantly greater extent of delta front and shore face facies is observed in central Spitsbergen with an inherently greater abundance of inter-distributary facies. In addition, a greater tidal influence is seen within distributary channels in Spitsbergen. Rod et al. (2014) report mud drapes and herringbone structures in distributary channels found in Spitsbergen, while distributary channels on Edgeøya lack diagnostic features that suggest any tidal influence (Rod et al., 2014) has been overprinted by a stronger fluvial signal.

The Triassic of western Spitsbergen cannot be correlated directly with the units of eastern Svalbard due to a different development of these sediments. This shows a clear regressive development of a paralic environment into the latter part of the Triassic, both on Spitsbergen, Edgeøya and Hopen. The depositional environment seen on Hopen represents the most regressive stage of this development seen in Svalbard, but similar to observations in cores from the Northern Barents Sea (Lundschiien et
al., 2014), and seismic data in the southern Barents Sea (Klausen and Mørk, 2014).

The offshore development of the Late Triassic is also well documented by Klausen and Mørk (2014), who present the De Geerdalen Formation at Hopen as an analogue to the Triassic Snadd Formation in the subsurface. The clear evidence for the development of meandering river systems in the Carnian (Klausen and Mørk, 2014) provides good evidence for a regressive deltaic system at this time. Hopen features sandstone channel bodies, of similar scale to those observed in the Barents Sea Snadd Formation and thus provides a good analogue to the Late-Triassic in the Barents Sea. Palaeoflow indicators also suggest a primarily westwards direction, with a provenance source to the east (Mørk, 1999; Rod et al., 2014) consistent with the trend of deltaic progradation seen in seismic (Høy and Lundschien, 2011; Riis et al., 2008; Glørstad-Clark et al., 2010).

The creation of the Hopen Member (Mørk et al., 2013; Lord et al., 2014) and its evident correlation to the Isfjorden Member in central Spitsbergen, displays one of the regional sequence stratigraphic intervals within the De Geerdalen Formation. The gentle onset of a transgression, shown by the development of marine influenced strata overlying the paralic sediment, further highlights the fact that the sediments in the De Geerdalen Formation at Hopen are the youngest and most regressive stage of this Carnian deltaic system.

Conclusions

25 sandstone channel bodies are observed on the island of Hopen. Stratigraphical positioning of channels show they form discrete intervals, dominated by a particular depositional style. The channels are dispersed throughout the stratigraphy and are numerous in the upper part of the De Geerdalen Formation, below the Hopen Member. Channels observed lower in the succession are less frequent and estuarine and tidal influence is observed for some of these channels.

Channels are isolated within the stratigraphy, forming individual bodies or multilateral stacked systems. Internal architecture and heterogeneities of channels vary considerably; from massive or highly cross-stratified, laterally accreting sandstone bodies deposited within a terrestrial fluvial environment, to more heterolithic stacked channel systems indicative of a tidally influenced system.

The upper channel zone occurs at 0-60 m below the base of the Hopen Member, the middle channel zone occurs 130-145 m, whilst the lower channel zone occurs 180-200 m. These zones are interpreted as representing a fluctuating sea level, inherent within a paralic environment (Klausen and Mørk 2014; Riis et al., 2008; Glørstad-Clark et al., 2010; Lundschien et al., 2014; Rod et al., 2014). The middle and upper zones together represent an overall shallowing upwards sequence, overlain by the Hopen Member.

The presence of trunk river and distributary channels on Hopen indicates a fluvially influenced setting, for the De Geerdalen Formation in this region. This is in contrast to central Spitsbergen where a stronger tidal signal is observed (Rod et al., 2014) and Edgeøya where diagnostic tidal features are sparse. In eastern Svalbard a paralic depositional environment is evident in the upper part of the succession (Lundschien et al., 2014; Rod et al., 2014). This allows for a composite of the stratigraphy of these locations to give a strong indication of the overall nature of the Triassic succession in the northern Barents Sea.

The depositional environment for the De Geerdalen Formation on Hopen is a fluvially dominated and tidally influenced delta plain, given the highly heterolithic nature of sediments and rapid fluctuations between terrestrial and marginal marine facies. The De Geerdalen Formation is present throughout Svalbard, becoming increasingly distal towards the NW. This gradual development is controlled by the W and NW direction of delta progradation as defined by Riis et al. (2008), Høy and Lundschien (2011), Glørstad-Clark et al. (2010) and Lundschien et al. (2014).

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