Triassic lithostratigraphy of the Wandel Sea Basin, North Greenland

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The Wandel Sea Basin in eastern North Greenland forms the northern continuation of the offshore Danmarkshavn Basin and the conjugate margin to the western Barents Shelf south of Spitsbergen. The Triassic succession of eastern North Greenland, up to 700 m thick, spans the Induan (Dienerian) – Norian. The Triassic sediments rest unconformably on Upper Carboniferous and Upper Permian sediments, and are unconformably overlain by Upper Jurassic – Lower Cretaceous deposits. Based on recent fieldwork in the Wandel Sea Basin, five new and revised Triassic formations are described and included in the Trolle Land Group (revised). The Lower Triassic (Induan) Parish Bjerg Formation (revised) consists of marine sandstones, fluvial conglomerates and sandstones, and muddy flood-plain deposits. It is conformably overlain by Lower Triassic (Dienerian – lower Spathian) offshore mudstones with minor sand-dominated intervals of the Ugleungernes Dal Formation (new). The upper Spathian to Ladinian Dunken Formation (revised) is represented mainly by marine sandstones. A marked erosional unconformity characterises the base of the overlying Upper Triassic (Carnian – Norian) Storekløft Formation (new) composed of marginal marine to marine, massive sandstones and conglomerates as well as cross-bedded and biomottled marine sandstones and minor mudstone units. The Isrand Formation (mainly Middle Triassic) consists of laminated mudstones with minor thin sandstone units that were deposited in slope and basin floor settings in the eastern deeper part of the Wandel Sea Basin in Kronprins Christian Land. The Triassic succession of the Wandel Sea Basin represents a well-constrained shallow shelf to deep shelf / basin floor transect and thus forms an excellent outcrop analogue to the time-equivalent intervals in the western Barents Sea basins and the Danmarkshavn Basin offshore North-East Greenland.

Keywords: Triassic, Arctic, Greenland, sedimentology, lithostratigraphy, palaeogeography, Peary Land, Kronprins Christian Land.

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The Triassic of the greater Barents Sea area as represented by the Kara Sea, Barents Sea, Timan Pechora, Franz Josef Land, Svalbard and eastern North Greenland areas, is considered to have been deposited in a relatively shallow shelf setting (Mørk *et al.* 1989). Numerous studies have dealt with the depositional evolution and petroleum geological potential, especially based on exposures on Svalbard (e.g. Mørk *et al.* 1989; Lundschien *et al.* 2014; Vigran *et al.* 2014). In contrast, the Wandel Sea Basin in the eastern part of North Greenland, where Triassic sediments are exposed in Herluf Trolle Land in the eastern part of Peary Land, Kronprins Christian Land and Amdrup Land (Fig. 1), has been neglected in regional Triassic palaeogeographic reconstructions, most likely due to the very limited amount of published data (e.g. Glørsted-Clark *et al.* 2010, Klausen *et al.* 2015).

The first report of Triassic sediments in North Greenland came from the Danish Peary Land Expedition 1948–49 (Troelsen 1950). The collected ammonoids were described by Kummel (1953), and the remaining macrofossils including bivalves, brachiopods, fish

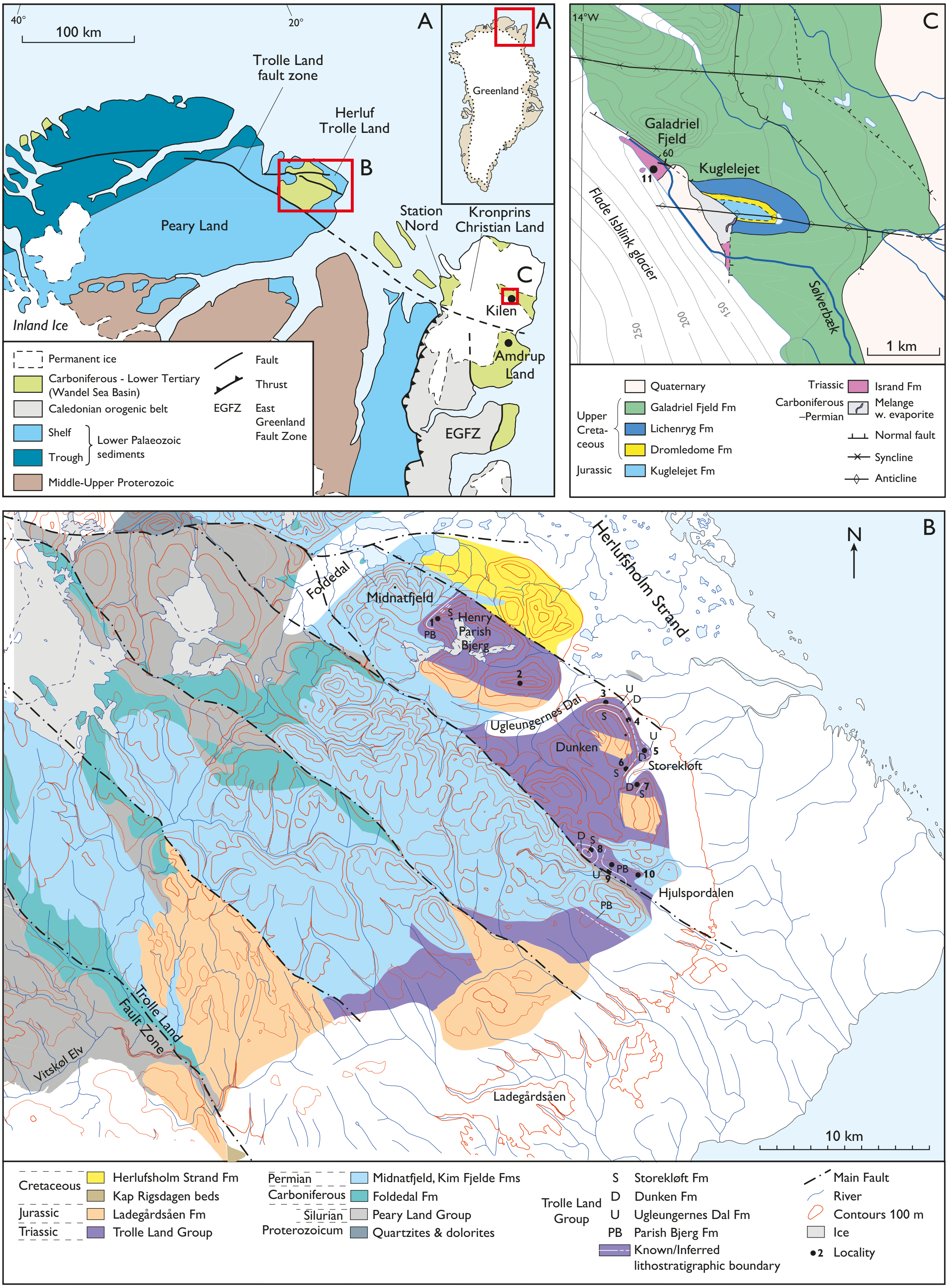


Fig. 1. A: Geological map of eastern North Greenland (Peary Land to Amdrup Land). **B**: Detailed geological map of Herluf Trolle Land (eastern Peary Land) with localities 1–10 indicated. Modified from Zinck-Jørgensen (1994). **C**: Geological map of the Galadriel Fjeld area in Kilen (Kronprins Christian Land) with locality 11 indicated. From Alsen *et al.* (2017).

remains and vertebrates were briefly listed in Peel *et al.* (1974). Until recently, Triassic sediments were not considered to occur outside Peary Land (Fig. 1). A discovery of ammonoids and halobiid bivalves in a shale succession in Kronprins Christians Land and a revision of ammonoid findings from Amdrup Land now extend the Triassic distribution to include these eastern areas (Alsen *et al.* 2017).

The Triassic Parish Bjerg and Dunken Formations were provisionally described by Håkansson (1979) and later formalised by Stemmerik & Håkansson (1989) (Fig. 2). The biostratigraphy of the Triassic strata was based on limited palynological and macrofossil data. Palynological data from the Parish Bjerg Formation indicated a Triassic age for parts of the formation (Håkansson 1979). Ammonoids from two stratigraphic levels in the Dunken Formation were documented and referred to the Smithian and Lower Anisian, respectively (Kummel 1953; Håkansson *et al.* 1991; Mølgaard *et al.* 1994). The major part of the Triassic succession remained undated and the boundary between the Parish Bjerg and Dunken Formations was not known (Stemmerik & Håkansson 1989). At Kilen in the northern part of Kronprins Christian Land, a new Triassic mudstone-dominated succession was discovered in 2013 and assigned to the Isrand Formation (Fig. 1; Alsen *et al.* 2017).

This study presents a revised and new lithostratigraphic subdivision of the Triassic in the Wandel Sea Basin in eastern North Greenland, framed in a regional context of the greater Barents Sea area. Lithostratigraphic data were collected during field campaigns in North Greenland in 2012–2013 and 2016. Key localities were sedimentologically logged and systematically sampled for macrofossils and palynomorphs in order to provide biostratigraphic constraints and information on the depositional environment. The succession is now known to range from the Lower Triassic (Induan) to the Upper Triassic (Norian) (Figs 2–4), based on biostratigraphic correlation to the Boreal Triassic ammonoid zonation of Dagys & Weitschat (1993), the Arctic Canadian ammonoid zonation of Tozer (1994) and the palynological composite assemblage zones of Svalbard and Barents Sea of Vigran *et al.* (2014).

Wandel Sea Basin

The Upper Palaeozoic – Lower Cenozoic Wandel Sea Basin forms a structurally complex basin configuration combining a NW–SE oriented structural regime between Peary Land in eastern North Greenland and Spitsbergen in Svalbard, and with a transition and junction to the N–S trending rift regime in Kronprins Christian Land and Amdrup Land that is related to the Caledonian trend between Greenland and Norway (Fig.1; Håkansson & Stemmerik 1989). NW–SE trending structural lineaments controlling basin configuration and formation of grabens and half-grabens are linked to the Trolle Land Fault Zone in eastern North Greenland (Håkansson & Stemmerik 1989). N–S trending structural lineaments are associated with the northward continuation of the onshore basins in North-East Greenland and the offshore Danmarkshavn Basin (Hamann *et al.* 2005; Fyhn & Hopper, in press). The latter trend continues northwards into the western Barents Sea area (Glørstad-Clark *et al.* 2010).

In a depositional context, the Triassic of the Wandel Sea Basin forms the south-western part of a series of inherited Late Palaeozoic connected intracratonic basins in the Greater Barents Sea area (Stemmerik & Worsley 2005; Glørstad-Clark *et al.* 2010; Henriksen *et al.* 2011). Sediments were sourced from uplifted Caledonian domains on the conjugate Greenland and Norwegian margins and from the Uralide Orogen farther to the east (e.g. Riis *et al.* 2008; Klausen *et al.* 2017; Eide *et al.* 2018).

In Peary Land, the Triassic sediments rest unconformably on Upper Permian carbonates and siliciclastics of the Midnatfjeld Formation (Figs 3, 5; Håkansson 1979) and are erosionally overlain by Upper Jurassic – Lower Cretaceous siliciclastics of the Ladegårdsåen Formation. The succession is exposed in fault-bounded blocks trending NW–SE and dipping slightly towards the east, forming an inverted structural complex as a result of a post-Mesozoic, N–S oriented compressional component (Zink-Jørgensen 1994; Pedersen & Håkansson 1999; von Gosen & Piepjohn 2003; Svennevig *et al.* 2016).

Stemmerik & Håkansson 1989			This study			
Group	**Formation**	**Chronostratigraphy**	**Group**	**Formation**		**Chronostratigraphy**
Trolle Land (incl. Upper Permian Midnatfjeld Fm)	Dunken	Scythian–Anisian	Trolle Land	Storekløft	Isrand	Carnian-Norian
				Dunken		Upper Olenekian – Ladinian
	Parish Bjerg	Triassic		Ugleungernes Dal		Olenekian
				Parish Bjerg		Induan

Fig. 2. Previous and present Triassic lithostratigraphy in the Wandel Sea Basin.

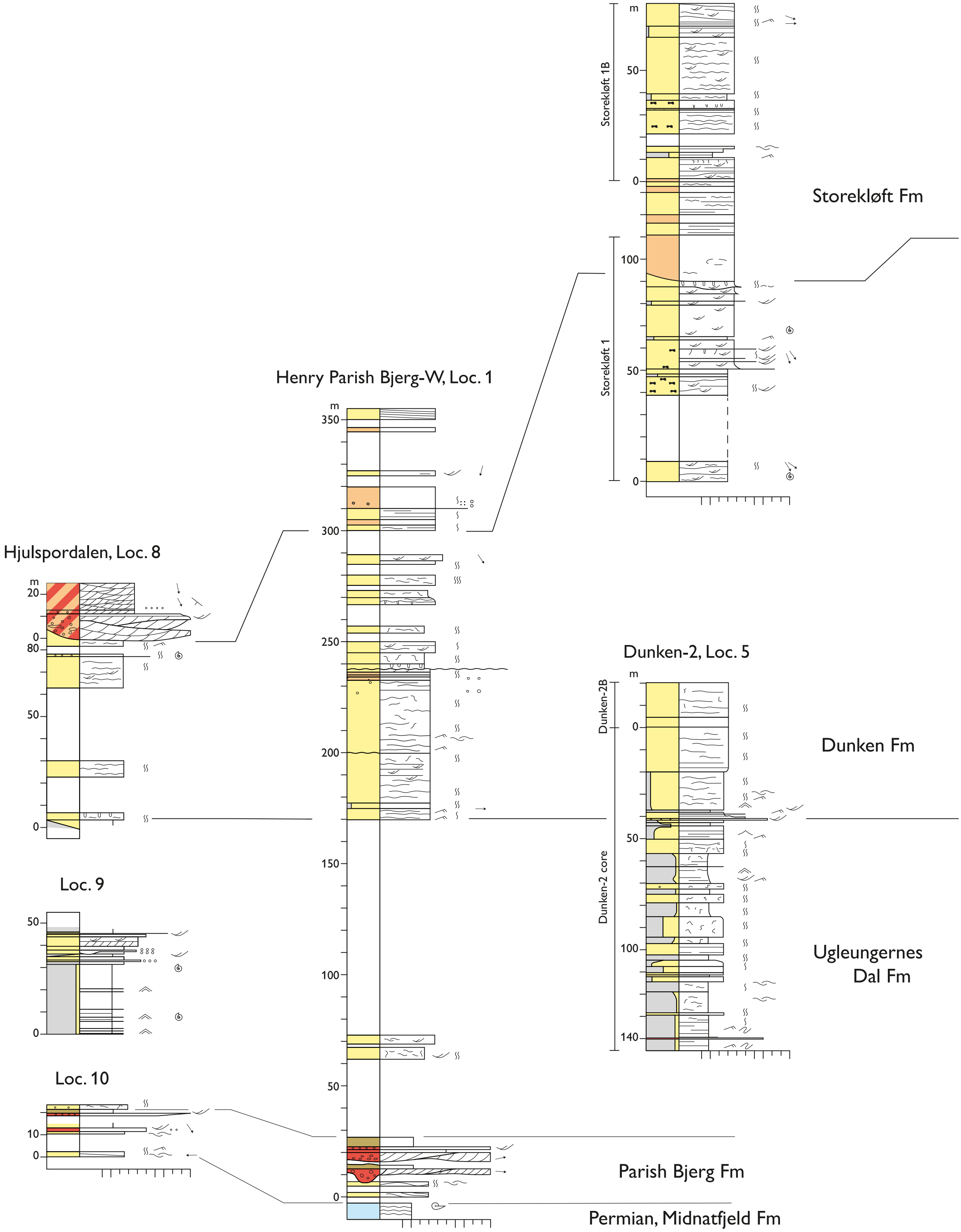
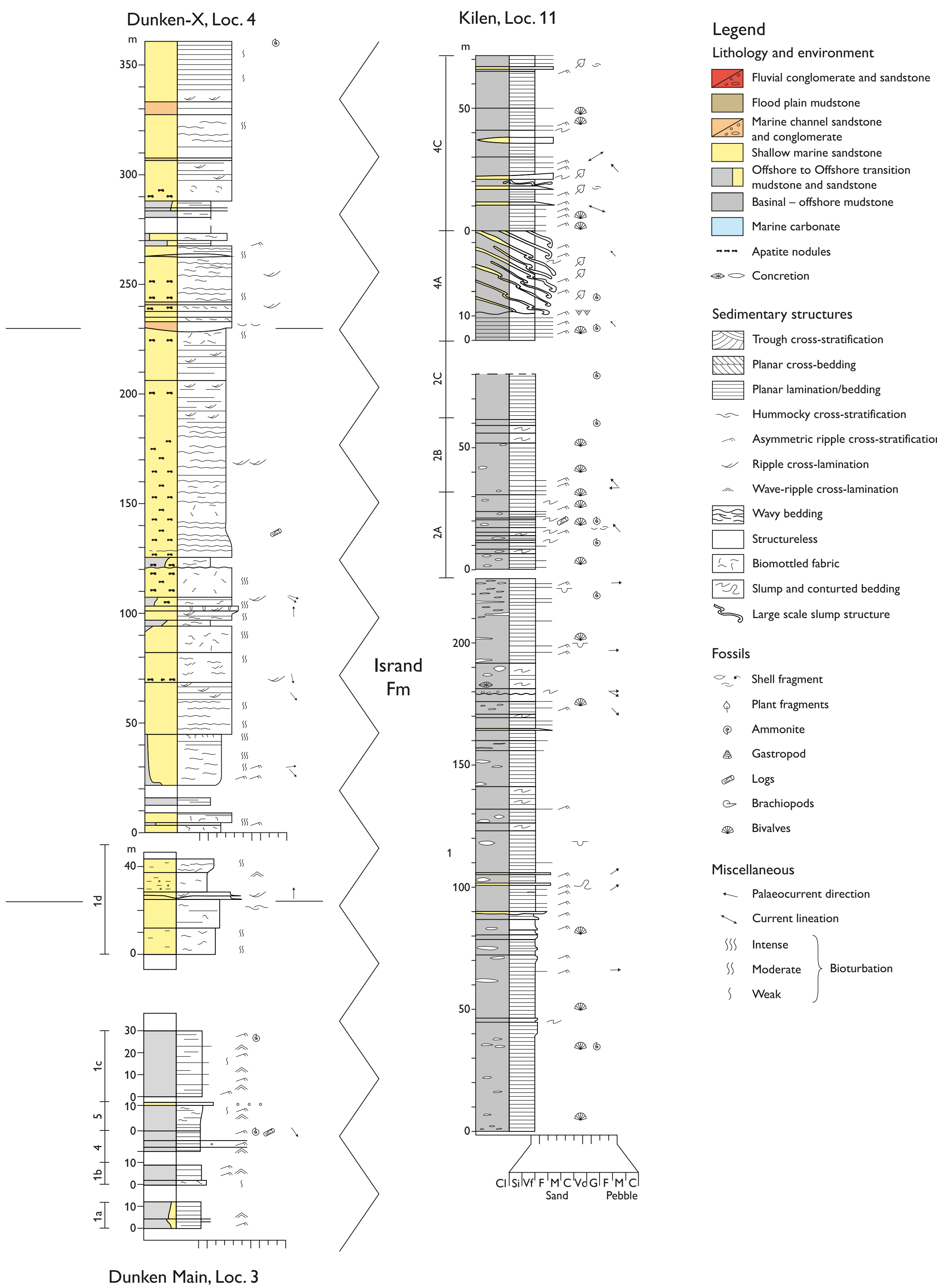
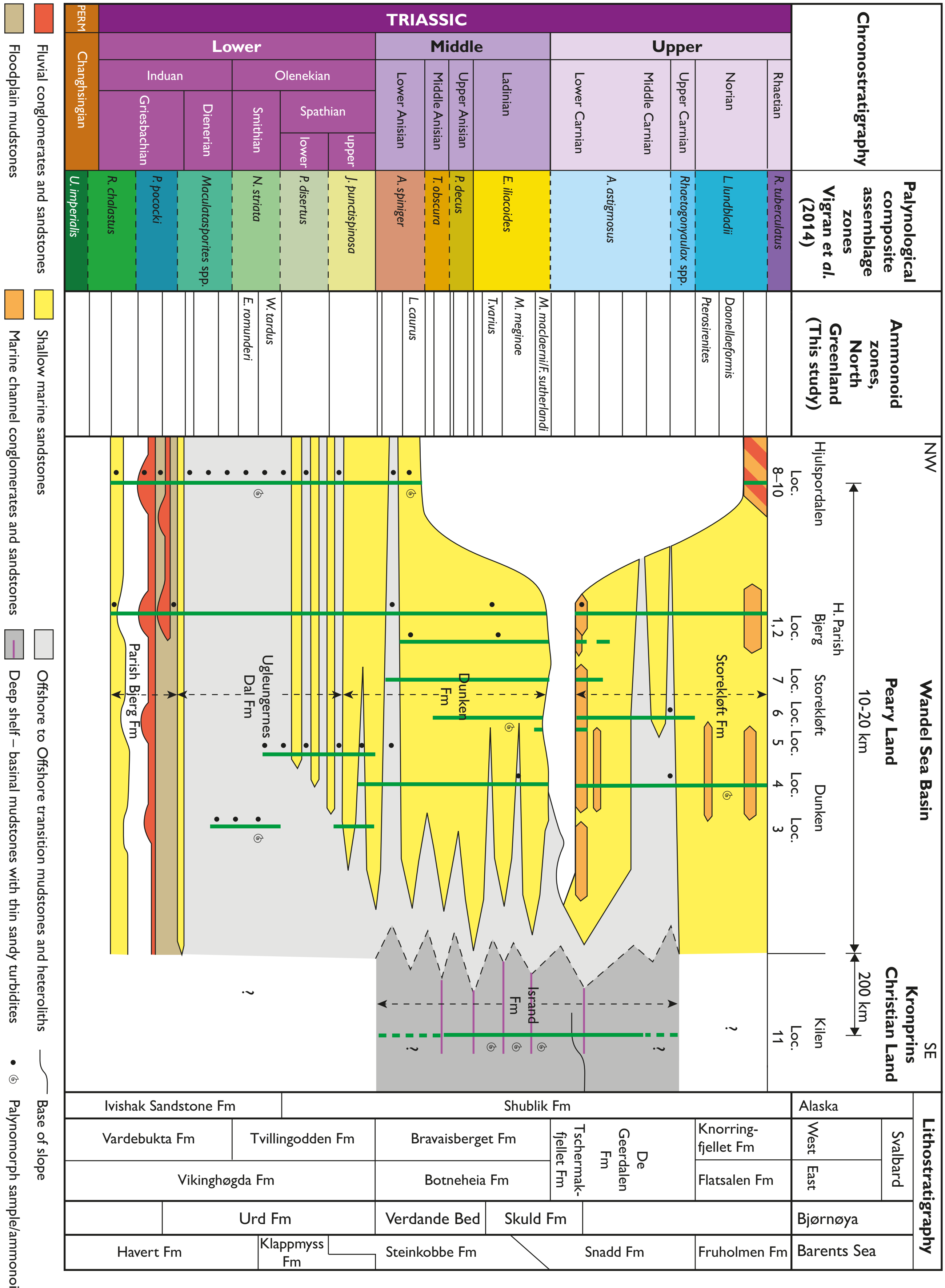


Fig. 3. Correlation panel with lithostratigraphic type sections and reference sections for the Triassic sediments in the Wandel Sea Basin.


Dunken-X, Loc. 4
Kilen, Loc. 11
Dunken Main, Loc. 3
Isrand Fm
m
4C
4A
2C
2B
2A
1d
1c
5
4
1b
1a
1
Cl Si Vf F M C Vc G F M C
Sand
Pebble
Legend
Lithology and environment
Fluvial conglomerate and sandstone
Flood plain mudstone
Marine channel sandstone and conglomerate
Shallow marine sandstone
Offshore to Offshore transition mudstone and sandstone
Basinal – offshore mudstone
Marine carbonate
Apatite nodules
Concretion
Sedimentary structures
Trough cross-stratification
Planar cross-bedding
Planar lamination/bedding
Hummocky cross-stratification
Asymmetric ripple cross-stratification
Ripple cross-lamination
Wave-ripple cross-lamination
Wavy bedding
Structureless
Biomottled fabric
Slump and conturted bedding
Large scale slump structure
Fossils
Shell fragment
Plant fragments
Ammonite
Gastropod
Logs
Brachiopods
Bivalves
Miscellaneous
Palaeocurrent direction
Current lineation
Intense
Moderate
Weak
Bioturbation


Chronostratigraphy
TRIASSIC
PERM
Lower
Middle
Upper
Changhsingian
Induan
Olenekian
Griesbachian
Dienerian
Smithian
Spathian
lower
upper
Lower Anisian
Middle Anisian
Upper Anisian
Ladinian
Lower Carnian
Middle Carnian
Upper Carnian
Norian
Rhaetian
Palynological composite assemblage zones Vigran et al. (2014)
U. imperialis
R. chalastus
P. pococki
Maculatasporites spp.
N. striata
P. disertus
J. punctispinosa
A. spiniger
T. obscura
P. decus
E. iliacoides
A. astigmosus
Rhaetogonyaulax spp.
L. lundbladii
R. tuberculatus
Ammonoid zones, North Greenland (This study)
E. romunderi
W. tardus
L. caurus
T. varius
M. meginae
M. maclaerni/F. sutherlandi
Pterosirenites
Daonellaeformis
NW
SE
Wandel Sea Basin
Peary Land
Kronprins Christian Land
10-20 km
200 km
Hjulspordalen
H. Parish Bjerg
Storekløft
Dunken
Kilen
Loc. 8–10
Loc. 1,2
Loc. 7
Loc. 6
Loc. 5
Loc. 4
Loc. 3
Loc. 11
Storekløft Fm
Dunken Fm
Ugleungernes Dal Fm
Parish Bjerg Fm
Isrand Fm
?
Lithostratigraphy
Alaska
Ivishak Sandstone Fm
Shublik Fm
Svalbard
West
East
Vardebukta Fm
Tvillingodden Fm
Bravaisberget Fm
Tschermak-fjellet Fm
De Geerdalen Fm
Knorring-fjellet Fm
Vikinghøgda Fm
Botneheia Fm
Flatsalen Fm
Bjørnøya
Urd Fm
Verdande Bed
Skuld Fm
Barents Sea
Havert Fm
Klappmyss Fm
Steinkobbe Fm
Snadd Fm
Fruholmen Fm
Fluvial conglomerates and sandstones
Floodplain mudstones
Shallow marine sandstones
Marine channel conglomerates and sandstones
Offshore to Offshore transition mudstones and heteroliths
Deep shelf – basinal mudstones with thin sandy turbidites
Base of slope
Palynomorph sample/ammonoid

In Amdrup Land, newly reassigned Triassic deposits (previously inferred to be Jurassic) occur as small outcrops overlying Upper Carboniferous carbonates of the Foldedal Formation (Alsen *et al.* 2017). In the northern part of Kronprins Christian Land, a deeper-water mudstone succession assigned to the Isrand Formation (Alsen *et al.* 2017) is exposed in an oblique fold structure. The lower boundary of the succession is probably situated beneath the adjacent Flade Isblink glacier, and the top of the formation is fault-bounded against Cretaceous mudstone (Fig. 1).

Lithostratigraphy

The here presented lithostratigraphy is revised from Stemmerik & Håkansson (1989) (Fig. 2). The Triassic succession is assigned to the Trolle Land Group (sensu Stemmerik *et al.* 1996) and divided into the Parish Bjerg (revised), Ugleungernes Dal (new), Dunken (revised) and Storekløft (new) formations in Peary Land and the Isrand Formation in Kronprins Christian Land. The upper part of the Parish Bjerg Formation (sensu Stemmerik & Håkansson 1989) is now included in the Ugleungernes Dal, Dunken and Storekløft Formations, and the Dunken Formation (sensu Stemmerik & Håkansson 1989) is now subdivided to be included in the Ugleungernes Dal, Dunken and Storekløft Formations based on new lithological and stratigraphical data. Overall, the Triassic succession is widely distributed but poorly exposed in eastern Peary Land, and the subdivision presented here is based on improved understanding of the distribution of genetically related sedimentary units in the area, combined with a greatly improved biostratigraphy.

Trolle Land Group

Revised group

History. The group is named after Herluf Trolle Land, which defines the eastern part of Peary Land (Fig. 1). The unit was provisionally erected by Håkansson (1979) and formally described by Stemmerik & Håkansson (1989) to include the Upper Permian – Triassic, mainly siliciclastic succession in the Wandel Sea Basin. The Permian Midnatfjeld Formation was later suggested reassigned to the Mallemuk Mountain Group due to its genetic and conformable relationship with the underlying Kim Fjelde Formation (Stemmerik *et al.* 1996). This reassignment is followed here; hence, the Trolle Land Group now solely represents the Triassic succession of the Wandel Sea Basin (Fig. 2).

Type area. Herluf Trolle Land in the eastern part of Peary Land.

Thickness. More than 350 m thick at Henry Parish Bjerg (upper boundary not known); more than 550 m thick and possibly up to 700 m thick in Dunken mountain area (lower part not exposed); > 400 m thick in Kronprins Christian Land (lower part not exposed and upper part not known). A thickness of about 1 km of the Triassic succession was estimated by Håkansson *et al.* (1991) and Stemmerik *et al.* (2000), but was based on combined thicknesses of measured sections with inadequate biostratigraphic control, which would have demonstrated partial repetition of strata across major faults.

Lithology. Mainly reddish-brown conglomerates and mudstones of the Parish Bjerg Formation, dark grey to black mudstones of the Ugleungernes Dal Formation, shallow marine sandstones of the Dunken Formation, and interbedded massive sandstones, bioturbated and cross-bedded sandstones of the Storekløft Formation. Black and very dark grey shales dominate the Isrand Formation.

Fossils. The fauna comprises few to common ammonoids and bivalves. Minor to rare occurrences of brachiopods, crinoids, fish and vertebrate remains are recorded. Trace fossils are common to abundant in the marine units. Floral occurrences include silicified wood and plant remains as wells as spores, pollen and dinoflagellate cysts from several levels.

Depositional environment. Shallow marine and fluvial in the lower part and marine offshore to shallow marine in the middle and upper parts in Peary Land, marine basin floor and lower slope in Kronprins Christian Land.

◀ **Fig. 4.** Stratigraphic scheme of the Triassic in the Wandel Sea Basin, showing the inferred transition from shallow shelf in Peary Land to deep shelf in Kronprins Christian Land. Green vertical lines mark the stratigraphic range of measured sections. Lithostratigraphic correlation is shown to adjacent Arctic areas, Svalbard and Barents Sea (Vigran *et al.* 2014; Rossi *et al.* 2019) and Alaska (Parrish *et al.* 2001).

Boundaries. The lower boundary has a slight angular unconformity where marine sandstones of the Parish Bjerg Formation overlie fossiliferous and dark grey calcareous shales of the Upper Permian Midnatfjeld Formation (Stemmerik *et al.* 1996). The upper boundary is generally poorly exposed. Where present, it is represented by an erosional unconformity overlain by Upper Jurassic – Cretaceous siliciclastics of the Ladegårdsåen Formation.

Distribution. The group was originally confined to Herluf Trolle Land in eastern Peary Land, but new discoveries in the southern part of Kilen in Kronprins Christian Land, and re-dating of outcrops in Amdrup Land in the eastern part of North Greenland (previously assigned to the Jurassic, Stemmerik *et al.* 1998, 2000) have extended the distribution (Alsen *et al.* 2017; Fig. 1).

Chronostratigraphy. Induan–Norian, based on ammonoids and palynomorphs.

Subdivisions. The group comprises the Parish Bjerg, Ugleungernes Dal, Dunken, Storekløft and Isrand Formations as defined in this paper.

Key references. Håkansson (1979); Håkansson & Stemmerik (1984, 1989); Stemmerik & Håkansson (1989); Håkansson *et al.* (1991); Stemmerik *et al.* (1996, 2000); Alsen *et al.* (2017).

Parish Bjerg Formation

Revised formation

History. The formation was provisionally erected by Håkansson (1979) and formally described by Stemmerik & Håkansson (1989). It was named after the mountain Henry Parish Bjerg in Herluf Trolle Land (Fig.1), where it originally included a succession about 350 m thick and comprised markedly different lithological units. The succession was assigned to the Lower Triassic based on a very limited biostratigraphic dataset (Håkansson 1979). The formation is here revised to represent the lowermost, mainly reddish interval of conglomerates, sandstones and mudstones with well-defined lower and upper boundaries. This interval is easily recognised in the field in moderate to well-exposed areas. The overlying succession at Henry Parish Bjerg is now included in the Ugleungernes Dal, Dunken and Storekløft Formations based on new biostratigraphical data and lithological characteristics. A fault-bounded sliver of sandstones and minor mudstones in the southern part of Henry Parish Bjerg was previously assigned to the Parish Bjerg Formation; it is now included in the Cretaceous Ladegårdsåen Formation based on new biostratigraphic data.

Type area and section. The western part of Henry Parish Bjerg (Loc. 1) in Herluf Trolle Land (Figs 1, 3, 5); the base of the section is located at 82°44.4053′N, 021°58.9517′W, elevation 495 m.

Reference section. The section Hjulspordalen in the southern part of Herluf Trolle Land (Figs 1, 3, Loc. 10).

Thickness. The formation is at least 25 m thick at the type locality and about 20 m thick at Hjulspordalen.

Lithology. The basal part of the formation consists of greyish yellow, fine-grained sandstones with hummocky cross-bedding and planar bedding. Trace fossils of *Gyrocorte*, *Helminthopsis*, *Nereites* and *Planolites* are common in the fine-grained sandstones. The sandstones are erosionally overlain by two couplets of characteristic reddish-brown conglomerates, and pebbly sandstones with trough cross-bedding succeeded by reddish-brown mudstones (Figs 3, 5B). The clast assemblage of the conglomerates comprises mainly extraformational sedimentary clasts of greenish sandstones, quartzite and chert.

Fossils. Some bedding surfaces contain abundant fossil wood fragments, and plant remains are present in the muddy sediments overlying the conglomerates. Palynological assemblages are poorly preserved, only *Verrucosisporites* spp., *Densoisporites* sp., *Lunatisporites* sp., *Alisporites* sp. and a possible specimen of *Uvaesporites* sp. could be positively identified.

*Depositional environments. S*hallow marine in the lower part and succeeded by coarse-grained fluvial and muddy flood-plain deposits.

Boundaries. The base is a slightly angular erosional surface in calcareous shales of the Upper Permian Midnatfjeld Formation (Stemmerik & Håkansson 1989), which is overlain by shallow marine sandstones of the Parish Bjerg Formation. A prominent internal erosional boundary occurs at the base of the fluvial conglomerates. The upper boundary represents a flooding surface where the red flood plain mudstones are conformably overlain by shallow marine biomottled muddy sandstones of the Ugleungernes Dal Formation in Hjulspordalen.

Distribution. Henry Parish Bjerg, Hjulspordalen and presumably Ladegårdsåen area. It is probably scattered and poorly exposed in the shallow plain north-east of the Dunken mountain in Herluf Trolle Land.

Chronostratigraphy. Lower Triassic, based on sparse and poorly constrained spore-pollen assemblages. Presumably restricted to the Induan based on diagnostic palynomorphs in overlying sedimentary units in the Hjulspordalen area.

Key references. Håkansson (1979); Stemmerik & Håkansson (1989); Håkansson *et al.* (1991).

Ugleungernes Dal Formation

New formation

History. The formation is a fairly easily recognisable, mappable unit of mudstone-dominated strata that corresponds to the lower muddy interval of the Dunken Formation sensu *Håkansson (1979)* and Stemmerik &

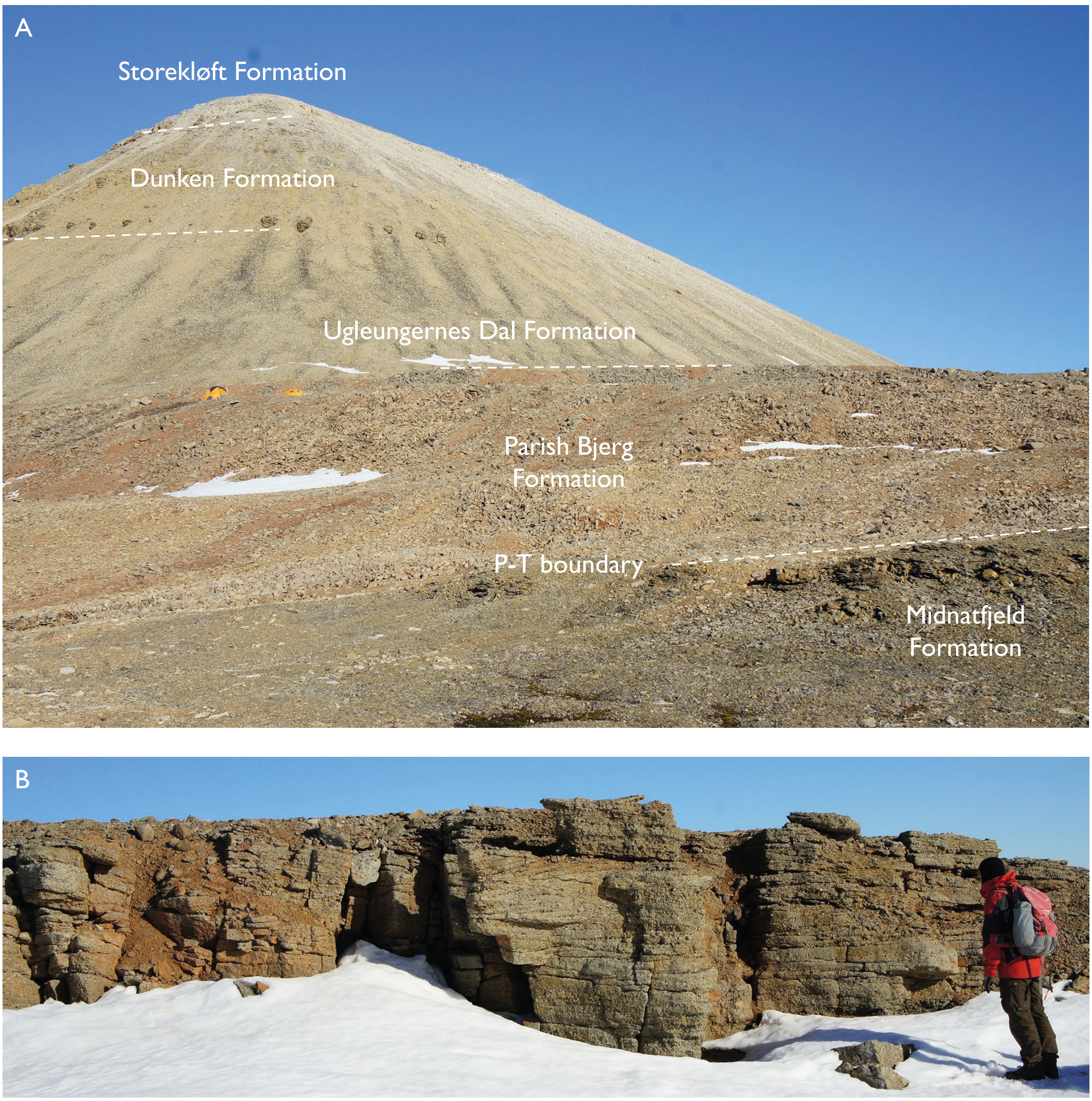


Fig. 5. A: Triassic succession 350 m thick in the western part of Henry Parish Bjerg (Loc. 1), and type locality of the Parish Bjerg Formation, unconformably overlying Permian carbonates of the Midnatfjeld Formation **B**: Fluvial conglomerates with trough cross bedding, Parish Bjerg Formation at the type locality.

Håkansson (1989). It is also represented by a similar lithological unit in Hjulspordalen previously assigned to the Parish Bjerg Formation in Stemmerik & *Håkansson* (1989). New biostratigraphical data show that these mudstone units are age-equivalent and hence they are combined in a new formation with a

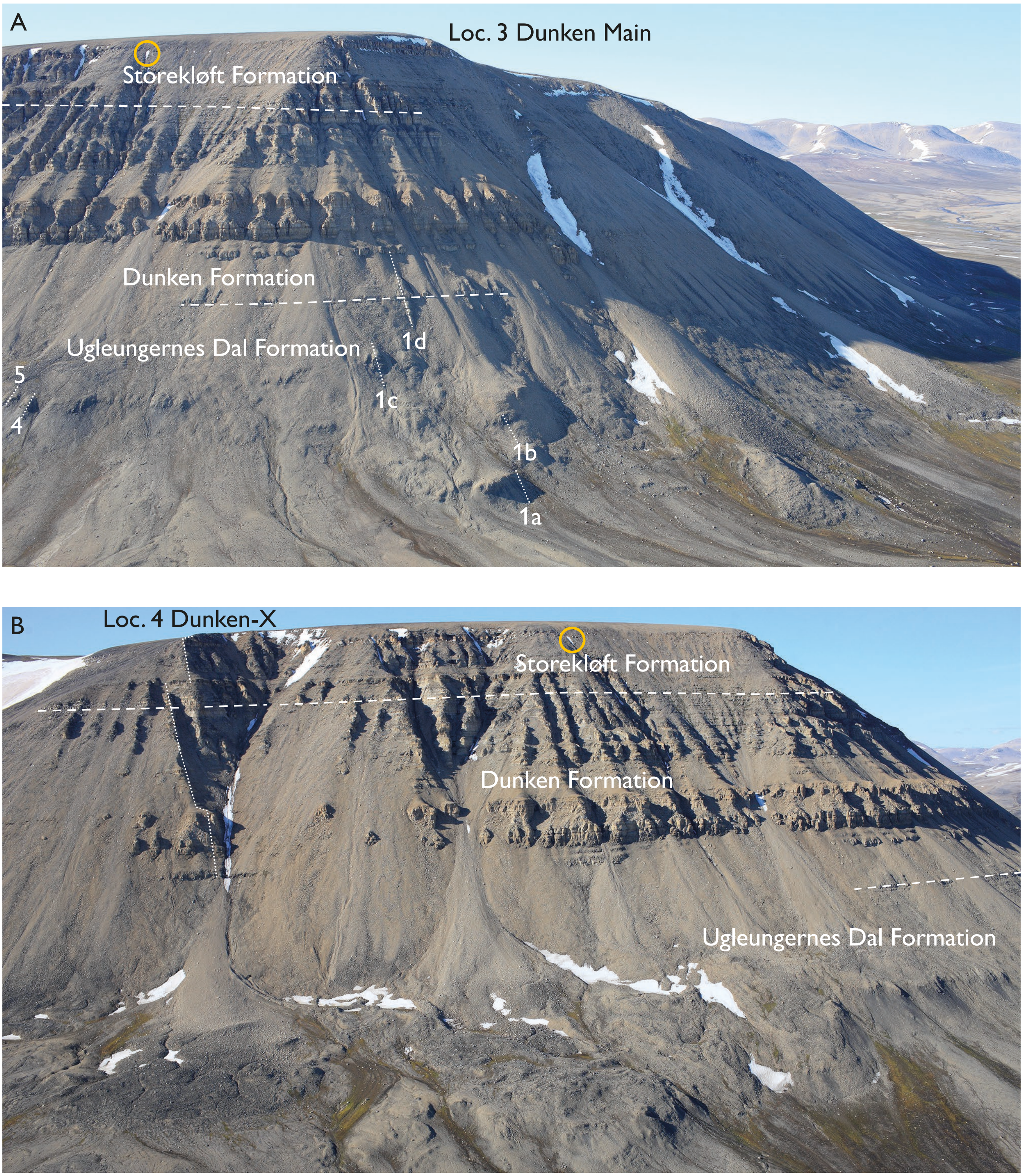


Fig. 6. Triassic succession about 600 m thick in Dunken mountain; the lower boundary of the Triassic in not exposed. The yellow circles mark the same snow patch on both figures (Photos by Kristian Svennevig). Dotted lines mark the the location of logs in Fig. 3. **A**: Northern part of Dunken representing the type locality of Ugleungernes Dal Formation (Loc. 3). **B**: Eastern part of Dunken representing the type locality and section of the Dunken Formation (Loc. 4).

well-defined stratigraphic range. It is named after the valley north of the Dunken mountain, where the lower and middle part of the unit is well exposed (Figs 1, 6). The name 'Ugleungernes Dal' in Danish translates into 'valley of the juvenile owls'.

Type area. The north-eastern part of Dunken with the Dunken Main sections 1a–d, 4, 5 (Loc. 3; Figs 1, 3). The base of the section is located at 82°41.8909'N, 021°10.4232'W, elevation 123 m.

Reference sections. Hjulspordalen (Loc. 9), Dunken-2 borehole (Loc. 5).

Thickness. More than 125 m is recorded in the north-eastern part of Dunken, more than 100 m in the Dunken-2 drill core (lower boundary not reached in the hole), and about 65 m at Hjulspordalen.

Lithology. The lower part is characterised by laminated to weakly laminated dark grey to black mudstones with common thin beds of ripple and planar laminated fine sand. The middle part is dominated by dark grey biomottled sandy mudstones and muddy sandstones, fine heterolithic mudstone-sandstone intervals (Fig. 7A), and a few thin conglomeratic beds. The top of the formation is characterised by biomottled grey to light-grey muddy sandstones. Slump structures are common in several intervals. Trace fossils include *Thalassinoides*, ?*Scolicia*, *Rhizocorallium*, *Planolites* and *Chondrites*. Diverse and well-preserved palynofloral assemblages are recorded in the muddy sediments in the southern localities. The formation is slightly calcareous with a carbonate content of 2–6%.

Fossils. Ammonoids and bivalves are recorded in the upper part of the formation. Ammonoids occur at few levels and are mainly represented by *Arctoceras blomstrandi*, but a single specimen of a possible *Radioceras* is also recorded. The Smithian part is dominated by spores of mainly *Densoisporites*, *Pechorosporites*, *Kraeuselisporites* and *Punctatisporites fungosus*, while the Spathian is dominated by bisaccate pollen of *Lunatisporites noviaulensis* and *Protohaploxypinus samoilovichii* along with common spores of *Rewanispora foveolata*.

Depositional environment. Mainly offshore to lower shoreface environments in an overall shallowing-upward succession with several minor transgressive-regressive intervals.

Boundaries. The base is exposed at Hjulspordalen and corresponds to a flooding surface where bioturbated muddy sand conformably overlies muddy flood-plain deposits of the Parish Bjerg Formation (Fig. 3). The upper boundary is an erosional surface in muddy bioturbated sand overlain by a thin conglomeratic or pebbly sandstone bed and bioturbated sandstones of the Dunken Formation.

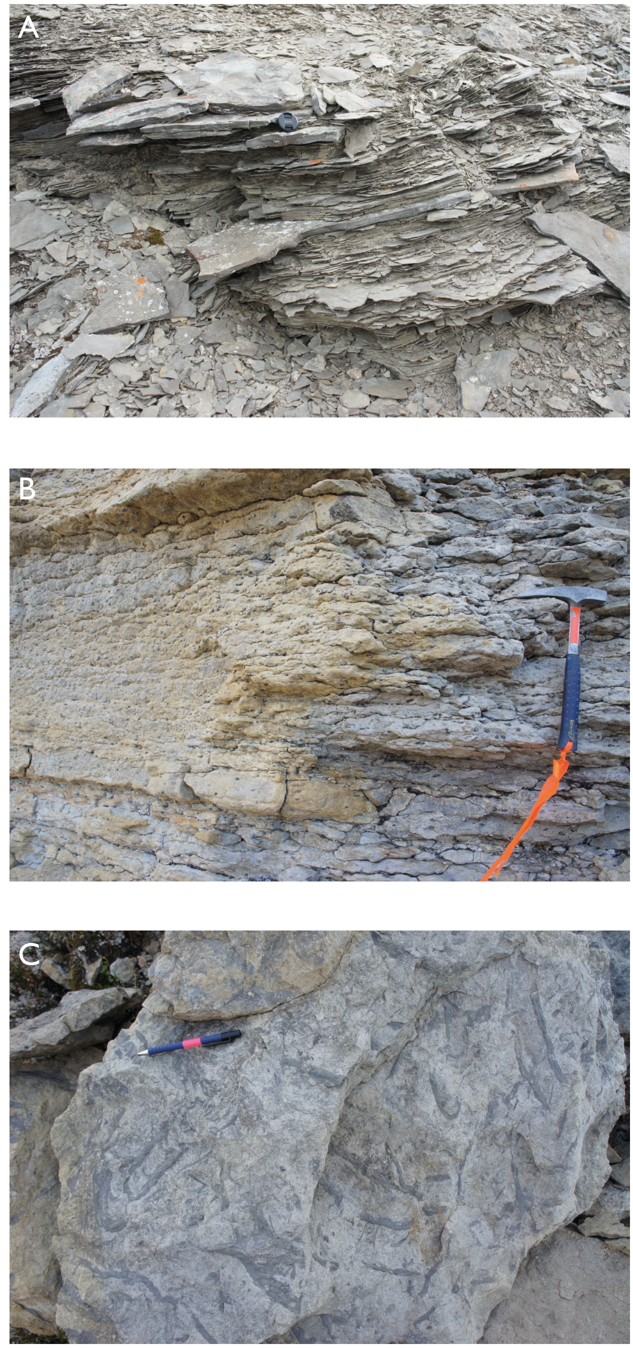


Fig. 7. A: Sandy mudstones and ripple laminated sandstones in the upper part of the Ugleungernes Dal Formation at Dunken. Camera lens cap for scale, 5 cm. **B**: Biomottled shallow marine sandstones with abundant apatite nodules, Dunken Formation in Storekløft (Loc. 6). Length of hammer 32 cm. **C**: Bedding-parallel surface of a shallow marine sandstone with abundant *Rhizocorallium* trace fossils, Dunken Formation in Storekløft (Loc. 6). Length of pencil 14 cm.

Fig. 8. Upper shoreface planar-bedded and cross-bedded sandstones of the Dunken Formation, Loc. 6. The hammer is located at level 53 m in the Storekløft-1 section in Fig. 3. Height of exposed section is about 8 m.

Distribution. The formation is well exposed in Dunken mountain and at Hjulspordalen; it is probably present although poorly exposed at Henry Parish Bjerg, south of Storekløft and in the Ladegårdsåen area (Fig. 1). Similar, age-equivalent deposits occur in Amdrup Land (Alsen *et al.* 2017), extending the distribution of the formation to this area (Fig. 1).

Chronostratigraphy. Upper Induan (Dienerian) – Olenekian (Smithian–Spathian) based on palynology and ammonoids (Lindström *et al.* 2019). The palynological assemblages are correlated with the four consecutive zones: the *Maculatasporites*, the *Naumovaspora striata*, the *Pechorosporites disertus,* and the *Jerseyaspora punctispinosa* Composite Assemblage Zones of Vigran *et al.* (2014). The recorded ammonoids are characteristic of the Smithian *Euflemingites romunderi* and *Wasatchites tardus* Zones in Canada (Tozer 1994) and occur together with palynological assemblages of the *Naumovaspora striata* Composite Assemblage Zone (Fig. 4).

Key references. Kummel (1953); Håkansson (1979); Stemmerik & Håkansson (1989); Håkansson *et al.* (1991); Stemmerik *et al.* (2000); Alsen *et al.* (2017).

Dunken Formation

Revised formation

History. The formation was provisionally erected by Håkansson (1979) and formally described by Stemmerik & Håkansson (1989) to represent the Triassic succession at the Dunken mountain. New lithological and biostratigraphic data and a better understanding of the regional context form the basis of a revision of the formation. The formation is now restricted to the sandstone-dominated interval in the middle part of the Triassic succession at Dunken (Stemmerik & Håkansson 1989) and the lower part of the Storekløft section in Mølgaard *et al.* (1994). The formation is thus lithostratigraphically separated from the underlying mudstone-dominated succession of the new Ugleungernes Dal Formation, and from the overlying Upper Triassic sandstones and conglomerates of the new Storekløft Formation (see below, Fig. 8). Despite the present revision to a restricted and well-defined stratigraphic interval, the formation is more widely distributed in the region than previously anticipated. It now includes the middle part of the Triassic succession on Henry Parish Bjerg and Hjulspordalen that earlier was mapped as part of the Parish Bjerg Formation by Stemmerik & Håkansson (1989). The formation represents a shallow marine equivalent to the Isrand Formation at Kilen (Alsen *et al.* 2017).

Type area and section. The Dunken mountain area (Loc. 4, Fig. 1) with several sections measured in the north-eastern slopes (Figs 3, 6A,B). Section 1d (Loc. 3, Fig. 1) shows the base and lower part of the formation, and section Dunken-X (Loc. 4) represents the main part of the formation including the upper boundary. The base of the section is located at 82°41.3289’N, 021°08.2579’W, elevation 200 m. The Dunken-2 drill core (Loc. 5) additionally records the lower boundary.

Reference sections. The formation is well exposed in Storekløft (Loc. 6). Part of the formation and especially the lower and upper boundary intervals are exposed at Hjulspordalen in the southern part of Herluf Trolle Land (Loc. 8).

Thickness. The formation is about 230 m in type area, 80 m thick in Hjulspordalen, and possibly >130 m thick at Henry Parish Bjerg, where the formation is poorly exposed.

Lithology. The formation is dominated by biomottled light grey to yellowish grey fine-grained sandstones, slightly muddy sandstones and planar and trough cross-bedded, medium-grained sandstones (Figs 7B, 7C, 8). Minor interbedded units of very dark grey mudstones, sandy mudstones and heterolithic sandstone-mudstones occur. Subordinate thin beds of pebbly sandstones and conglomerates are present at certain levels. Apatite nodules are common throughout the formation (Fig. 7B). Highly diverse trace fossil assemblages are recognised including *Rhizocorallium*, *Diplocraterion*, *Skolithos*, *Planolites* and *Chondrites*. The trace fossil assemblages are commonly superimposed on an intensely biomottled fabric (Fig. 7C).

Fossils. Ammonoids occur at several levels and include typical Anisian taxa: *Lenotropites caurus, Lenotropites tardus, Groenlandites* cf. *nielseni* and *Pearylandites* aff. *troelseni*, as well as Ladinian forms such as *Indigirites* sp., *Indigirites* cf. *stolleyi, Zestoceras* sp. and *Nathorstites* sp. Bivalves are rare. Plant remains, spores and pollen and marine acritarchs of various degrees of preservation are predominantly recorded in the muddy sediments. The spore-pollen floras are mostly dominated by bisaccate pollen, including taeniate and non-taeniate forms. Age diagnostic taxa for the late Spathian include the first occurrences of *Cyclotriletes oligogranifer, Jerseyiaspora punctispinosa, Illinites chitonoides* and *Striatoabieites balmei,* and the last occurrences of *Rewanispora foveolata* and *Pechorosporites disertus.* Taxa typical for the Anisian include the first occurrence of *Eresinia spinellata* and the first common occurrence of *Anapiculatisporites spiniger*, as well as the last occurrences of *Densoisporites nejburgii* and *J.*

punctispinosa in the lower and upper Anisian, respectively. The first occurrences of *Echinitosporites iliacoides, Schizaeoisporites worsleyi,* and *Staurosaccites quadrifidus* occur in the lowermost Ladinian strata.

Depositional environment. Mainly shallow marine lower to upper shoreface with minor offshore intervals representing several transgressive–regressive cycles.

Boundaries. The base is marked by a pebble lag and medium- to coarse-grained sandstones that erosionally overlie bioturbated muddy sandstone of the Ugleungernes Dal Formation. The upper boundary is a major erosional boundary in fine- to medium-grained biomottled sandstones or trough cross-bedded, medium-grained sandstones overlain by prominent massive sandstones with an occasionally conglomeratic basal part of the Storekløft Formation.

Distribution. The formation was previously restricted to the Dunken mountain – Storekløft area (Håkansson 1979). The new data presented herein shows that the revised formation is much more widely distributed in the region, e.g. at Henry Parish Bjerg and Hjulspordalen (Fig. 1), and possibly also in the Ladegårdsåen area in eastern Peary Land.

Chronostratigraphy. Upper Olenekian (Spathian) – Ladinian based on ammonoids and palynomorphs. The palynological assemblages in the lower part of the formation are correlated with the upper Spathian – lower Anisian *Jerseyaspora punctispinosa* and *Anapiculatisporites spiniger* Composite Assemblage Zones, while the upper part of the formation belongs to the Ladinian *Echinitosporites iliacoides* Composite Assemblage Zone of Vigran *et al.* (2014) (Fig. 4). The recorded ammonoids are characteristic of the lower Anisian *Lenotropites caurus* Zone, and the upper Ladinian *Meginoceras maginae* and *Mclearnoceras maclearni – Frankites sutherlandi* Zones in Canada (Tozer 1994).

Key references. Kummel (1953); Håkansson (1979); Stemmerik & Håkansson (1989); Håkansson *et al.* (1991); Mølgaard *et al.* (1994).

Storekløft Formation

New formation

History. The unit encompasses the upper sandstone-dominated part of the Dunken main section previously included in the Dunken Formation of Stemmerik & Håkansson (1989) and the upper part of the Storekløft section in Mølgaard *et al.* (1994). The base of the new formation is identified as a prominent unconformity with increasing hiatal magnitude towards the basin margin, e.g. from the Dunken area to Hjulspordalen (Figs 4, 9). The lower part comprises a characteristic and easily mappable interval of channelised massive sandstones with varying thicknesses (Fig. 3). The deposits of this unit are for the first time dated to encompass the Upper Triassic, which together with the diagnostic deposits in the basal part justify the separation of a new formation.

Type area and section. The formation is well exposed in both sides of the Storekløft valley (Storekløft is Danish for 'large gorge'), which accordingly serves as the type area (Figs 1, 9). The type section is Storekløft (Loc. 6), with the base located at 82°39.4684'N, 021°09.0173'W, elevation 195 m. The lower and middle part of the formation is well-exposed in the type area, and the upper part is mainly present at Dunken.

Reference sections. The Dunken-X section (Loc. 4) in Dunken mountain and the western part of Henry Parish Bjerg (Loc. 1, Fig. 3). Hjulspordalen in the southern part of Herluf Trolle Land (Loc. 8) represents a proximal and very coarse-grained example of the formation.

Thickness. Minimum 130 m at Storekløft and Dunken, and about 50 m at Henry Parish Bjerg. At Hjulspordalen the formation is represented by 25 m.

Lithology. In the Dunken area, the lower part consists of massive sandstones, occasionally with a conglomeratic base comprising intraformational mudclasts and extraformational Palaeozoic rock types. The massive sandstones comprise amalgamated lenticular bodies commonly separated by thin bioturbated sandy mudstones (Figs 3, 9). It is overlain by interbedded massive sandstones and biomottled sandstones with an interval of mudstone and heterolithic mudstone and sandstones in the middle part. Phosphatic nodules occur occasionally in the lower and middle part of the formation in the Dunken area. At Hjulspordalen the formation is represented by a prominent conglomerate unit up to about 12 m thick, with large intraclasts of sandstones and mudstones and extraformational clasts of quartzite and chert (Fig. 10). The conglomerate is overlain by a few metres of pebbly sandstones and in turn well-sorted medium-grained sandstones with cross-bedding. At Henry Parish Bjerg the formation comprises massive, planar-bedded and trough cross-bedded sandstones with a few conglomeratic beds. Trace fossils of *Rhizocorallium, Diplocraterion, Skolithos* and *Planolites* are common in the biomottled intervals. *Lockeia* occurs occasionally in abundance on

Fig. 9. Type locality of Storekløft Formation at Storekløft (Loc. 6). **A**: Massive sandstones at the base of the Storekløft Formation (dashed line) at Storekløft. Person for scale to the left. **B**: Erosional conglomerate at the lower boundary of the Storekløft Formation (dashed line). Note dispersed black mudstone clasts in the conglomerate. Length of hammer 32 cm.

Fig. 10. Conglomerates of the Storekløft Formation in Hjulspordalen (Loc. 8).

sandstone bedding surfaces especially in the upper part of the formation.

Fossils. A few ammonoids that are relatively poorly preserved and tentatively assigned to cf. *Brouwerites maclearni* occur at Dunken mountain. Palynological assemblages from primarily mudstones and heteroliths are of variable preservation, but are generally diverse and dominated by acritarchs and bisaccate pollen. Palynological events used for recognition of the Carnian include: the first occurrences of *Enzonalasporites* spp., *Patinasporites densus* and *Vallasporites ignacii* in the lowermost Carnian, with the last occurrences of *Echinitosporites iliacoides* and *Triadispora verrucatus* in the lower and middle Carnian, respectively. Upper Carnian to Norian strata contain the first occurrences of poorly preserved dinoflagellate cysts assigned to *Shublikodinium* spp. and *Suessia swabiana.* The top of the Carnian is marked by the last occurrences of *Illinites chitonoides, Podosporites amicus, Protodiploxypinus gracilis* and *Staurosaccites quadrifidus.*

Depositional environment. The conglomerates in the basal part of the formation at Hjulspordalen represent proximal fluvial to marine marginal deposits in an incised valley. In the Storekløft area, the prominent channelised and erosional massive sandstones with thin interbedded bioturbated sandy mudstones were deposited from episodic gravity flows in a marine environment. The biomottled sandstones and cross-bedded sandstones represent marine lower to upper shoreface environments. The muddy interval probably represents an offshore transition environment. Several transgressive–regressive cycles are recorded in the formation.

Boundaries. In Storekløft the base is a prominent erosional surface incised into biomottled sandstones of the Dunken Formation and overlain by massive sandstones with or without a conglomeratic basal part (Fig. 9). In Hjulspordalen the base is a steep and undercutting erosional surface associated with a considerable hiatus (Fig. 4) and overlain by conglomerates (Figs 3, 10). The upper boundary is generally poorly exposed but probably represents a major erosional unconformity overlain by mudstones and sandstones of the Upper Jurassic – Cretaceous Ladegårdsåen Formation.

Distribution. Storekløft, Dunken mountain, south of Storekløft, Henry Parish Bjerg, Hjulspordalen, possibly Ladegårdsåen area in eastern Peary Land.

Chronostratigraphy. Carnian–Norian, based mainly on palynomorphs and on a few ammonoids. The palynomorph assemblages are correlated with the Carnian *Aulisporites astigmosus* and *Rhaetogonyaulax* spp. Composite Assemblage Zones of Vigran *et al.* (2014) (Fig. 4). The assemblages assigned to the *Rhaetogonyaulax* spp. Composite Assemblage Zone may also correlate with the *Protodiploxypinus* Assemblage from Hopen island, Svalbard (Paterson & Mangerud 2015).

Key references. Troelsen (1950); Kummel (1953); Håkansson (1979); Stemmerik & Håkansson (1989); Håkansson *et al.* (1991); Mølgaard *et al.* (1994).

Isrand Formation

History. The Isrand Formation was described and named by Alsen *et al*. (2017). It comprises an outcrop of a Triassic mudstone succession that was discovered during GEUS's Expedition to North Greenland 2012–2013 along both sides of the Sølverbæk river, which drains melt water from the Flade Isblink glacier in the western central part of Kilen in Kronprins Christian Land (Fig. 1). The unit had previously been mapped as part of the Upper Jurassic Kuglelejet Formation (Pedersen 1989). The retreat of the ice sheet has increased the exposure during the last decades as seen from comparison of aerial orthophotos and recent oblique photogrammetry (Svennevig *et al*. 2016). Macrofossils include bivalves and ammonoids collected from an interval in the middle part of the formation and indicate a Middle Triassic age (Alsen *et al.* 2017). The name 'Isrand' is the Danish word for the glacial margin that delimits the outcrop towards the west.

Type area and section. The western central part of Kilen between the flanks of the Sølverbæk river and the glacier margin constitutes the type area (Loc. 11, Figs 1, 11). The type section is combined from three subsections (Figs 3, 11) with base of the section located at 81°13.2453′N, 013°56.2115′W, elevation 117 m.

Thickness. The combined sections in the type area record a thickness of 400 m. The base of the succession is not exposed as the lower part is presently still covered by the ice sheet of the Flade Isblink glacier (Figs 1C, 11A).

Lithology. The formation consists of black laminated mudstones with prominent bedding-parallel concretionary horizons and lenses (Figs 11–12). Thin planar, wavy and ripple laminated sand beds occur frequently, and slumped sandstone beds and lenses are common in the upper part of the succession. Abundant bivalve shell accumulations occur commonly on bedding surfaces.

Fossils. Abundant halobiid bivalves of *Daonella subarctica* occur throughout the formation. Ammonoids are recorded at several levels and include in the lower part *Aristoptychites euglyphus* and further up in the succession *Nathorstites* cf. *macconnelli*. Wood and plant fragments are present in certain intervals in the upper part of the formation. Due to the thermal maturity of the organic material, the palynological samples were either barren or contained very few unidentifiable fragments of bisaccate pollen grains and unidentifiable spores. Only a single specimen of the long-ranging spore taxon *Gordonispora fossulata*, which first appears in the early Spathian *Pechorosporites disertus* Composite Assemblage Zone of Vigran *et al.* (2014), has been identified in the samples from the Isrand Formation.

Depositional environment. Lower slope and basin floor in oxygen deficient environments.

Boundaries. The lower boundary is not exposed. The upper boundary is constituted by a fault against Lower Cretaceous mudstones of the Galadriel Fjeld Formation (Hovikoski *et al.* 2018).

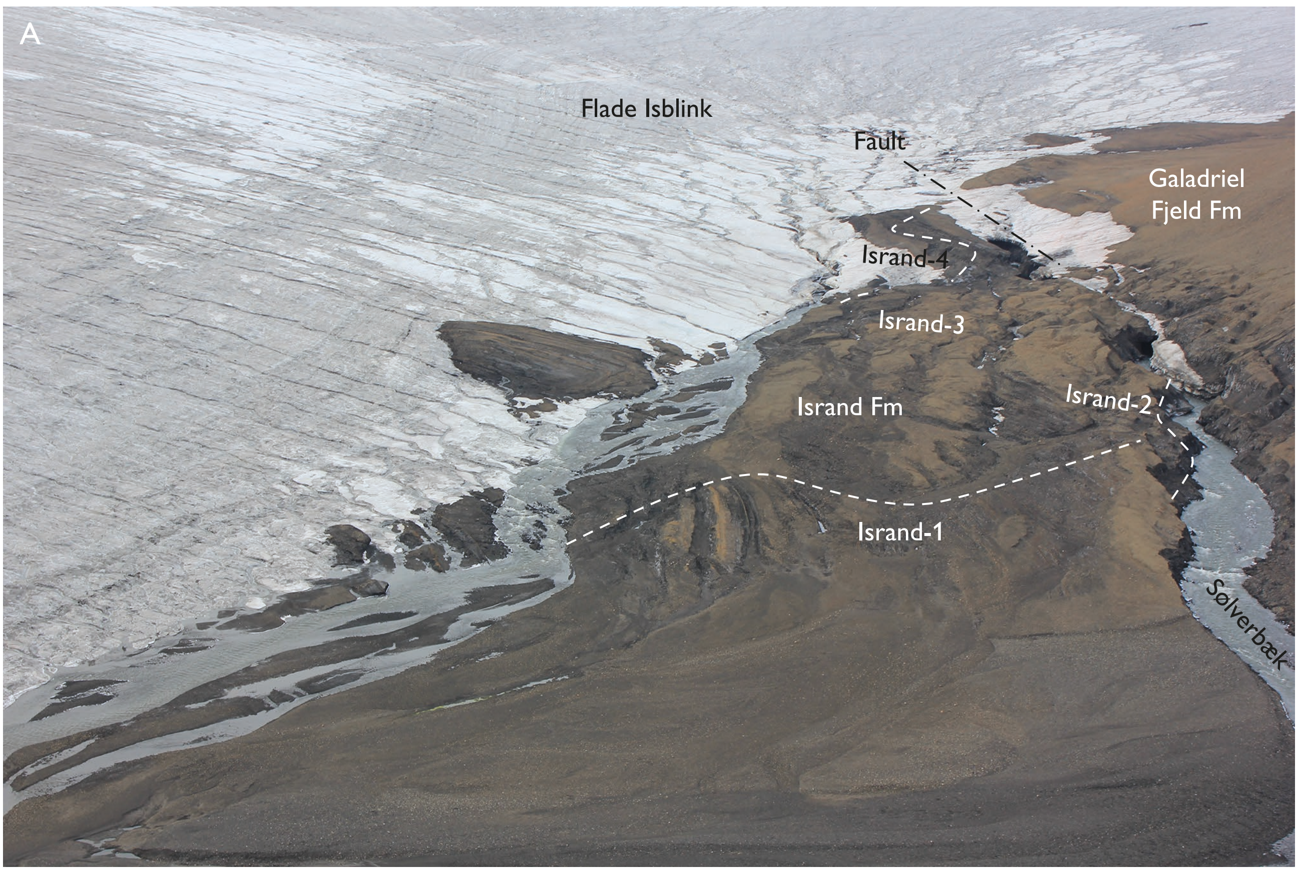


Fig. 11. A: Overview of the Triassic succession at Kilen (Loc. 11) showing the positions of measured type sections 1–4 in the Isrand Formation, view towards the north-west. **B**: Lower part of the Isrand Formation showing dark grey mudstones and shales and bedding-parallel light brown concretionary horizons (Section Isrand-1), view towards the south-east.

Distribution. The western central part of Kilen in Kronprins Christian Land. The formation represents marine basinal facies, which are time-equivalent to the more basin marginal and shallow marine deposits of mainly the Dunken Formation and possibly also the Storekløft Formation in Peary Land.

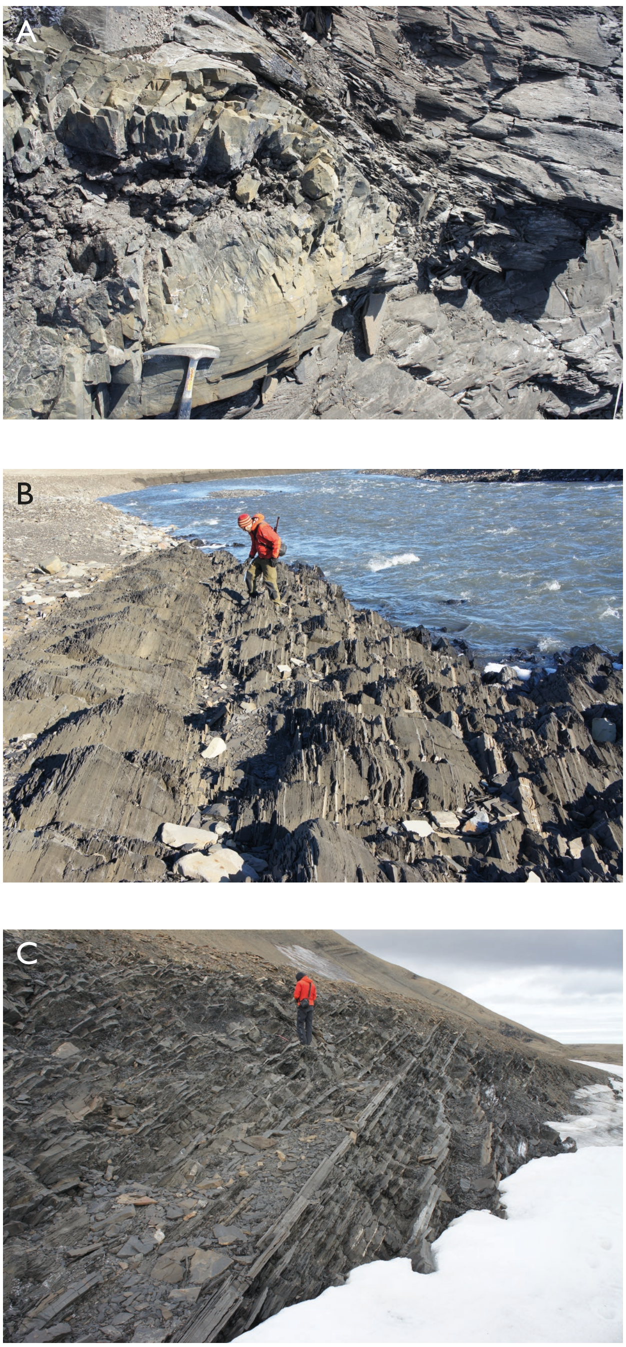


Fig. 12. A: Large septarian concretion in the lower part of the IsraND Formation, section Israand-1, log 63 m. **B**: Very dark grey to black mudstones with thin, bedding-parallel ellipsoidal concretions in the middle part of the Israand Formation. **C**: Laminated shales and thin turbidite sandstones in the upper part of the Israand Formation, section Israand-4.

Chronostratigraphy. The recorded ammonoid zones include the Ladinian *Tsvetkovites varius* Zone, *Meginoceras meginae* Zone, *Mclearnoceras maclaerni* Zone and *Frankites sutherlandi* Zone. The middle levels with halobiid bivalves belong to the Ladinian *Daonella subarctica* bivalve zone. The lowermost 30 m and uppermost 100 m of the formation remains presently undated, and most likely the formation reaches downwards into the Anisian and upwards into the Carnian. Stratigraphy from palynomorphs remains unsolved due to poor preservation and a high maturity level in the mudstones.

Key references. Svennevig *et al.* (2016); Alsen *et al.* (2017).

Discussion and Arctic correlation

The stratigraphy and depositional evolution of the Triassic in North Greenland has hitherto been essentially unknown. It was tentatively and provisionally described as two coarsening-upward lithostratigraphic units with a few biostratigraphic data suggesting a lower to middle Triassic age (Håkansson *et al.* 1991). This study presents a coherent Triassic lithostratigraphy of the Wandel Sea Basin in a robust biostratigraphic framework that represents a near-complete Triassic succession from the Induan to the Norian (Fig. 4). The lithostratigraphic framework represents a geological transect with an overall basin marginal setting in Peary Land to a deeper water basinal setting in Kronprins Christian Land (Figs 4, 13).

The base of the Triassic succession is only exposed in Peary Land, where it forms an erosional unconformity against Upper Permian marine carbonates and mudstones of the Midnatfjeld Formation. The basal Triassic deposits belong to the Induan Parish Bjerg Formation, which is up to 25 m thick. It consists of a thin veneer of shallow marine storm-influenced sandstones that is erosionally overlain by fluvial conglomerates and muddy flood-plain deposits. Time-equivalent deposits are not presently exposed in Kronprins Christian Land. The Parish Bjerg Formation is probably time equivalent to the shallow marine deposits in the lower parts of the Vardebukta Formation on Svalbard (Vigran *et al.* 2014), and the depositional facies belts were probably parallel aligned in the palaeogeographic context (Fig. 13A). The Parish Bjerg Formation is also considered time equivalent to the deltaic Tana fan of the Havert Formation in the south-western Barents Sea (Eide et al. 2018).

The base of the overlying Ugleungernes Dal Formation represents a Dienerian transgressive surface. The deposits consist of a thin unit of shallow marine

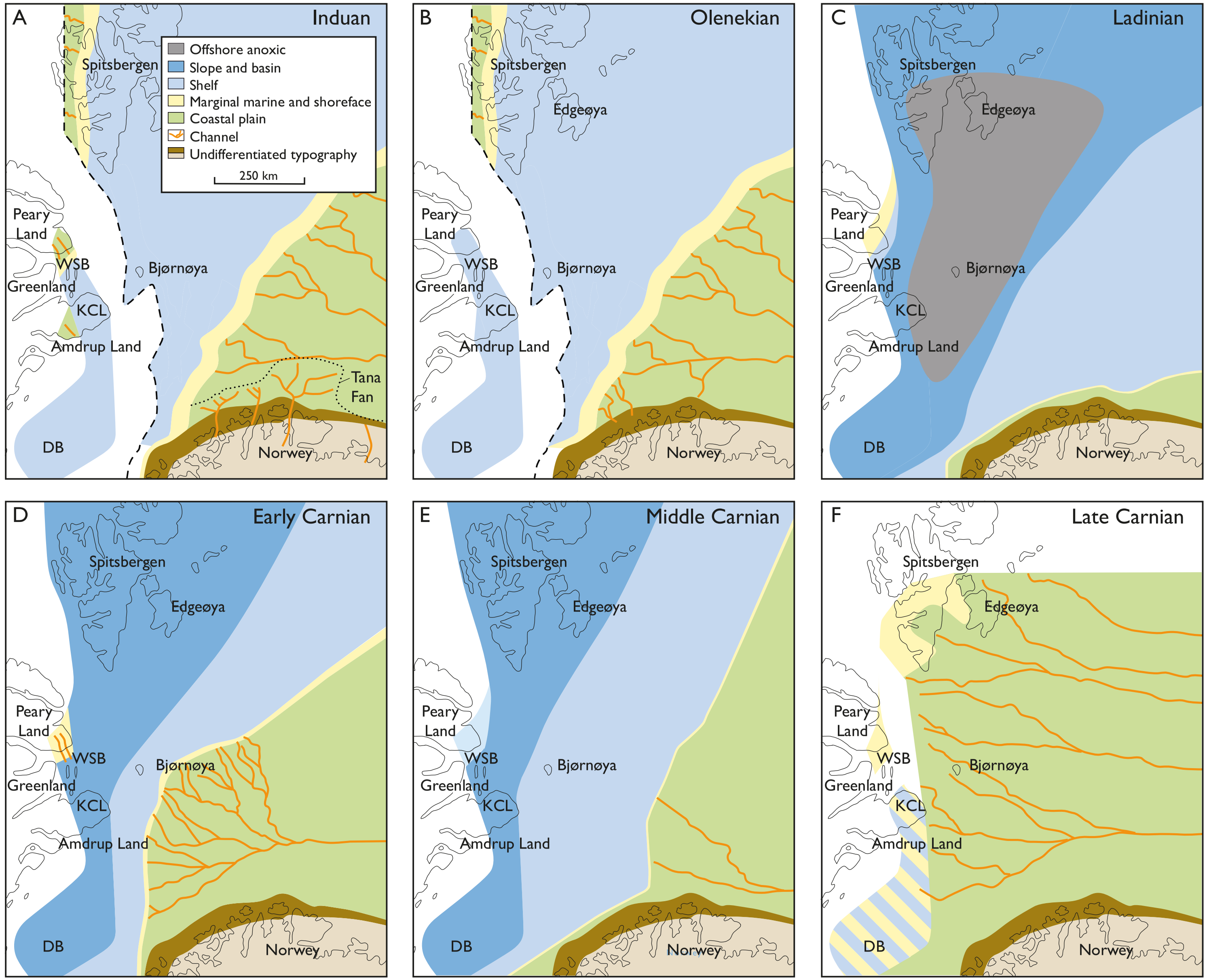


Fig. 13. Regional palaeogeographic maps of the western Barents Sea and Wandel Sea Basin. The Barents Sea area is based on Eide *et al.* (2018) in A, Glørstad-Clark *et al.* (2010) in A–B, and on Klausen *et al.* (2015) in C–F. Dashed lines in A and B show the western limit of the study area in Glørstad-Clark *et al.* (2010), as represented by the Late Mesozoic – Cenozoic tectonic deformation boundary. DB: Danmarkshavn Basin. KCL: Kronprins Christian Land. WSB: Wandel Sea Basin.

sandstones followed by an offshore mudstone-dominated interval about 150 m thick and encompass the Dienerian – Spathian. A thin, prograding shallow marine unit in Peary Land marks a regressive coarse-grained interlude in the lower Spathian. The recently discovered marine Triassic deposits in Amdrup Land belong to this interval, which extends the deposition of the marine deposits to these areas (Fig 13B; Alsen *et al.* 2017). The Ugleungernes Dal Formation correlates with the Urd Formation on Bjørnøya where a similar depositional trend is recorded (Mørk *et al.* 1990), and with the upper part of the Vardebukta and Vikinghøgda Formations on Svalbard (Fig. 4; Vigran *et al.* 2014).

The Spathian – Ladinian Dunken Formation in Peary Land represents shallow marine sandy shelf deposition that experienced several flooding episodes as represented by condensed organic biomottled mudstone deposits in the lower Anisian and two such intervals in the Ladinian (Figs 3, 4). The formation correlates with the lower to middle part of the Isrand Formation at Kronprins Christian Land, which is dominated by offshore organic-rich mudstones with alternating minor amounts of distal, thin, low-density gravity-flow sandstones. The latter show depositional characters similar to the time-equivalent Botneheia Formation at Svalbard (Krajewski 2008, 2013; Vigran *et al.* 2014) and the Steinkobbe Formation in the Barents Sea (Mørk & Elvebakk 1999).

A marked erosional unconformity occurs at the base of the Carnian in Peary Land, with associated marine channel deposits of massive sandstones and conglomerates up to about 50 m thick, which belong to the lower part of the Storekløft Formation. The possible equivalent interval in the deeper part of the basin in Kronprins Christian Land is represented by a slumped base of slope succession, 35 m thick, of mudstones and gravity-flow sandstones in the upper part of the Isrand Formation (Figs 3, 4, 13D). The interval is time-equivalent to deltaic mudstones and sandstones with abundant channelised sandy units in the lower part of the De Geerdalen Formation in the eastern part of Svalbard (Edgeøya, Barentsøya and Hopen; Vigran *et al.* 2014; Lord *et al.* 2014), and to channelised sandstones in the Snadd Formation in the Barents Sea (Klausen & Mørk 2014). In Peary Land the channelised marine sandstones are succeeded by mainly shallow marine sandstones of the Storekløft Formation with two intervals of offshore organic-rich mudstones that probably correlate to black and dark grey deep shelf – basin floor mudstones in the uppermost part of the Isrand Formation (Figs 3, 4, 13E), as well as to Carnian maximum flooding intervals described from the Barents Sea by Klausen *et al.* (2015). The Storekløft Formation extends well into the Norian and has a total thickness of up to 130 m. A prominent channelised unit, 25 m thick, comprises marginal marine conglomerates and sandstones of inferred Norian age at Hjulspordalen (Figs 3, 4). It may correlate with shallow marine coarse clastic units of the Svenskøya Formation on Svalbard (Hopen) and Fruholmen Formation in the Barents Sea (Sentralbanken and Nordkapp Basin, Lundschien *et al.* 2014; Lord *et al.* 2014).

Conclusions

The Wandel Sea Basin represents a nearly complete Triassic succession with an estimated combined thickness of 700 m. The basal part of the Induan is fluvial, and the remaining Triassic is marine, representing a sand-dominated basin marginal succession in Peary Land to the west and a marine basinal mudstone succession in Kronprins Christian Land to the east.

The Wandel Sea Basin formed the western continuation of the basins in the western Barents Sea and the northern continuation of the Danmarkshavn Basin offshore North-East Greenland and thus represents a key area for the understanding of the depositional evolution from the western Barents Sea area and into the north-east Atlantic basins in Triassic times. Major depositional sequences in the Wandel Sea Basin correlate genetically well with time-equivalent units especially onshore Svalbard, but also on a regional scale in the greater Barents Sea area.

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References

Alsen, P., McRoberts, C., Svennevig, K., Bojesen-Koefoed, J., Hovikoski, J. & Piasecki, S. 2017: The Isrand Formation: a Middle Triassic Daonella-bearing, black shale unit in Kilen, North Greenland (with a note on the Triassic in Amdrup Land). Newsletters in Stratigraphy 50(1), 31–46.

Dagys, A.S. & Weitschat, W. 1993: Correlation of the Boreal Triassic. Mitteilungen Geologisches-Palaontologisches Institut Universität Hamburg 75, 249–256.

Eide, C.H., Klausen, T.G., Katkov, D., Suslova, A.A. & Helland-Hansen, W. 2018: Linking an Early Triassic delta to antecedent topography: Source-to-sink study of the southwestern Barents Sea margin. Geological Society of America Bulletin 130, 263–283.

Fyhn, M.B.W. & Hopper, J.D. in press: North-East Greenland Rifted Continental Margin Tectono-Sedimentary Element. In: Drachev, S. *et al.* (eds) Arctic Sedimentary Basins. Geological Society, London, Memoirs.

Glørsted-Clark, E., Faleide, J.I., Lundschien, B.A. & Nystuen, J.P. 2010: Triassic sequence stratigraphy and palaeogeography of the western Barents Sea area. Marine and Petroleum Geology 27, 1448–1475.

Håkansson, E. 1979: Carboniferous to Tertiary development of the Wandel Sea Basin, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse 88, 73–83.

Håkansson, E. & Stemmerik, L. 1984: Wandel Sea Basin – The North Greenland equivalent to Svalbard and the Barents Shelf. In: Spencer, A.M. *et al*. (eds), Petroleum geology of the north European margin, 97–107. London: Graham & Trotman. Norwegian Petroleum Society.

Håkansson, E. & Stemmerik, L. 1989: Wandel Sea Basin – A new synthesis of the late Paleozoic to Tertiary accumulation in North Greenland. Geology 17, 683–686.

Håkansson, E., Heinberg, C. & Stemmerik, L. 1991: Mesozoic and Cenozoic history of the Wandel Sea Basin area, North Greenland. Bulletin Grønlands Geologiske Undersøgelse 160, 153–164.

Hamann, N.E., Whittaker, R.C. & Stemmerik, L. 2005: Geological development of the Northeast Greenland Shelf. In: Doré, A.G. & Vining, B.A. (eds), Petroleum Geology: North-West Europe and Global Perspectives. Proceedings of the 6th Petroleum Geology Conference, 887–902. Geological Society, London.

Henriksen, E., Ryseth, A.E., Larssen, G.B., Heide, T., Rønning, K., Sollid, K. & Stoupakova, A.V. 2011: Tectonostratigraphy of the greater Barents Sea: Implications for petroleum systems. Geological Society, London, Memoirs 35, 163–195.

Hovikoski, J., Pedersen, G.K., Alsen, P., Lauridsen, B.W., Svennevig, K., Nøhr-Hansen, H., Sheldon, E., Dybkjær, K., Bojesen-Koefoed, J., Piasecki, S., Bjerager, M. & Ineson, J. 2018: The Jurassic–Cretaceous lithostratigraphy of Kilen, Kronprins Christian Land, eastern North Greenland. Bulletin of the Geological Society of Denmark 66, 61–112.

Klausen, T.G. & Mørk, A. 2014: The Upper Triassic paralic deposits of the De Geerdalen Formation on Hopen: outcrop analog to the subsurface Snadd Formation in the Barents Sea. AAPG Bulletin 98 (10), 1911–1941.

Klausen, T.G., Ryseth, A.E., Helland-Hansen, W., Gawthorpe, R. & Laursen, I. 2015: Regional development and sequence stratigraphy of the Middle to Late Triassic Snadd Formation, Norwegian Barents Sea. Marine and Petroleum Geology 62, 102–122.

Klausen, T.G., Müller, R., Slama, J. & Helland-Hansen, W. 2017: Evidence for Late Triassic provenance areas and Early Jurassic sediment supply turnover in the Barents Sea Basin of northern Pangea. Lithosphere 9(1), 14–28.

Krajewski, K.P. 2008: The Botneheia Formation (Middle Triassic) in Edgeøya and Barentsøya, Svalbard: lithostratigraphy, facies, phosphogenesis, paleoenvironment. Polish Polar Research 29(4), 319–364.

Krajewski, K.P. 2013: Organic matter–apatite–pyrite relationships in the Botneheia Formation (Middle Triassic) of eastern Svalbard: Relevance to the formation of petroleum source rocks in the NW Barents Sea shelf. Marine and Petroleum Geology 45, 69–105.

Kummel, B. 1953. Middle Triassic ammonites from Peary Land. Meddelelser om Grønland 127(1), 21 pp.

Lindström, S., Bjerager, M., Alsen, P., Sanei, H. & Bojesen-Koefoed, J. 2019: The Smithian–Spathian boundary in North Greenland: implications for extreme global climate changes. Geological Magazine. https://doi.org/10.1017/S0016756819000669

Lord, G.S., Solvi, K.H., Ask, M., Mørk, A., Hounslow, M.W. & Paterson, N.W. 2014: The Hopen Member: a new Member of the Triassic De Geerdalen Formation, Svalbard. Norwegian Petroleum Directorate Bulletin 11, 81–96.

Lundschien, B.A., Høy, T. & Mørk, A. 2014: Triassic Hydrocarbon potential in the Northern Barents Sea; integrating Svalbard and stratigraphic core data. Norwegian Petroleum Directorate Bulletin 11, 3–20.

Mølgaard, S., Heinberg, C., Håkansson, E. & Piasecki, S. 1994: Triassic stratigraphy and depositional environment of eastern Peary Land. Scientific report #10, Wandel Sea Basin: Basin Analysis. EFP-91 Project No. 0012, Completion report to the ministry of Energy. University of Copenhagen, 5 pp, 8 Figures.

Mørk, A. & Elvebakk, G. 1999: Lithological description of subcropping Lower and Middle Triassic rocks from the Svalis Dome, Barents Sea. Polar Research 18, 83–104.

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

Mørk, A., Vigran, J.O. & Hochuli 1990: Geology and palynology of the Triassic succession of Bjørnøya. Polar Research 8, 141–163.

Parrish, J.T., Droser, M.L. & Bottjer, D.J. 2001: A Triassic upwelling zone: The Shublik Formation, Arctic Alaska, USA.

Journal of Sedimentary Research 71 (2), 272–285.

Paterson, N.W. & Mangerud, G. 2015: Late Triassic (Carnian–Rhaetian) palynology of Hopen, Svalbard. Review of Palaeobotany and Palynology 220, 98–119.

Pedersen, S.A.S. 1989: Geological map of Kilen, Kronprins Christian Land, North Greenland, 1:100 000. Unpublished geological map in the archives of the Geological Survey of Denmark and Greenland (GEUS), Copenhagen.

Pedersen, S.A.S. & Håkansson, E. 1999: Kronprins Christian Land orogeny deformational styles of the end Cretaceous transpressional mobile belt in eastern North Greenland. Polarforschung 69, 117–130.

Peel, J.S, Daves, P.R. & Troelsen J.C. 1974: Notes on some Lower Palaeozoic to Tertiary faunas from eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse 65, 18–23.

Riis, F., Lundschien, B.A., Høy, T. Mørk, A. & Mørk, M.B. 2008: Evolution of the Triassic shelf in the northern Barents Sea region. Polar Research 27, 318–338.

Rossi, V.M., Paterson, N.W., Helland-Hansen, W., Klausen, T.G. & Eide, C.H. 2019: Mud-rich delta-scale compound clinoforms in the Triassic shelf of northern Pangea (Havert Formation, south-western Barents Sea) Sedimentology, 34 pp, doi: 10.1111/sed.12598

Stemmerik, L. & Håkansson, E. 1989: Stratigraphy and depositional history of Upper Palaeozoic and Triassic sediments in the Wandel Sea Basin, central and eastern north Greenland. Rapport Grønlands Geologiske Undersøgelse 143, 21–43.

Stemmerik, L. & Worsley, D. 2005: 30 years on – Arctic Upper Palaeozoic stratigraphy, depositional evolution and hydrocarbon prospectivity. Norwegian Journal of Geology 85, 151–168.

Stemmerik, L., Håkansson, E., Madsen, L., Nilsson, I., Piasecki, S., Pinard, S. & Rasmussen, J.A. 1996: Stratigraphy and depositional evolution of the Upper Palaeozoic sedimentary succession in eastern Peary Land, North Greenland. Bulletin Grønlands Geologiske Undersøgelse 171, 45–71.

Stemmerik, L., Dalhoff, F., Larsen, B.D., Lyck, J., Mathiesen, A. & Nilsson, I. 1998: Wandel Sea Basin, eastern North Greenland. Geology of Greenland Survey Bulletin 180, 55–62.

Stemmerik, L., Larsen, B.D. & Dalhoff, F. 2000: Tectono-stratigraphic history of northern Amdrup Land, eastern North Greenland: implications for the northernmost East Greenland shelf. Geology of Greenland Survey Bulletin 187, 7–19.

Svennevig, K, Guarnieri, P. & Stemmerik L. 2016: Tectonic inversion in the Wandel Sea Basin: A new structural model of Kilen (eastern North Greenland). Tectonics 35(12), 2896–2917.

Tozer, E.T. 1994: Canadian Triassic ammonoid faunas. Geological Survey of Canada Bulletin 467, 663 pp.

Troelsen, J.C. 1950: Geology. In: Winther P.C., Troelsen, J.C., Holmen, K., Johansen P., Fristrup, B. & Knuth, E.: A preliminary account of the Danish Peary Land Expedition, 1948–9. Arctic 3, 6–8.

Vigran, J.O., Mangerud, G., Mørk, A., Worsley, D.& Hochuli, P.A. 2014: Palynology and geology of the Triassic succession of Svalbard and the Barents Sea. Geological Survey of Norway Special Publication 14, 1–247.

von Gosen, W. & Piepjohn, K. 2003: Eurekan transpressive deformation in the Wandel Hav Mobile Belt (northeast Greenland). Tectonics 22(4), 28 pp. doi:10.1029/2001TC901040

Zinck-Jørgensen, K. 1994: The Trolle Land fault system, Kim Fjelde, eastern Peary Land. In: Håkansson, E. (ed.), Wandel Sea Basin: basin analysis. Technical & scientific reports 18, 17 pp. Unpublished report, University of Copenhagen, Denmark.