Are there Upper Cretaceous sedimentary rocks preserved on Sørkapp Land, Svalbard?

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Paleogene formations on eastern Sørkapp Land contain common, reworked, Middle and Late Cretaceous terrestrial and marine microfloras. This observation questions the Late Cretaceous age reported for the Firkanten Formation in the Øyrlandet Graben on western Sørkapp Land, as the pollen and spores reported from this graben may not be in situ. The present palynostratigraphic data from the eastern Sørkapp Land suggest that the Firkanten and Basilika formations were deposited in a relatively short time-period during the Early to Mid Thanetian. The youngest Cretaceous deposits documented from the Carolinefjellet Formation in eastern Sørkapp Land are of Late Albian age.

Keywords: Paleogene, Cretaceous, stratigraphy, dinoflagellates, Sørkapp, Svalbard, Arctic

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Introduction

The ages and chronology of the Cenozoic formations on Svalbard have been a ticklish problem for decades (see reviews in Manum & Throndsen, 1986 and Čepok & Krutzsch, 2001). Some of the initial studies based on land plants and molluscs suffered from the low stratigraphic resolution of this material. Likewise, the very abundant terrestrial palynomorph assemblages found in these deltaic to shallow-marine sequences of the Cenozoic succession generally only contain long-ranging species of limited value for high-resolution biostratigraphy (Manum, 1962; Čepok & Krutzsch, 2001). More precise age determinations have been obtained from foraminifera, nannofossils and dinoflagellate cysts (Manum, 1960; Feyling-Hansen & Ulleberg, 1984; Head, 1984; Manum & Throndsen, 1986; Matthiessen, 1986; Smelror, 1996; Čepok, 2001; Harding et al., 2011) and from geochemical data (Dypvik et al., 2011; Harding et al., 2011), but these

fossils and geochemical records are confined to intervals of strong marine influence.

The present study was carried out on behalf of the Norwegian Petroleum Directorate (NPD) with the objective to investigate the potential for more precise biostratigraphic dating of Paleogene rocks from outcrop sections on eastern Sørkapp Land (Fig. 1). The main goal was to constrain the ages of the youngest Cretaceous and the Paleogene lithostratigraphic units mapped in the area. In addition to the in situ microfloras, which document a late Early to early Late Paleocene age for the Firkanten and Basilika formations on eastern Sørkapp Land, the examined samples also contain common reworked Aptian–Albian and Late Cretaceous pollen, spores and dinoflagellate cysts. This observation apparently questions the Late Cretaceous age reported for the Firkanten Formation in the Øyrlandet Graben on western Sørkapp Land by Krutzsch (2001).

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Figure 1. Outcrop of Tertiary formations on Sørkapp Land, Svalbard (based on the maps of Dallmann (1991) and Winsnes et al. (1993).

The Cretaceous–Tertiary boundary strata on Svalbard

On Svalbard, the boundary between the Cretaceous and the Tertiary sedimentary successions is marked by a major hiatus corresponding to the Late Cretaceous and earliest Tertiary time interval. The hiatus is well

documented in the Central Spitsbergen Basin and on Sørkapp Land (Fig. 2). Further, a similar hiatus is well documented from exploration wells and seismic correlations over large areas on the western Barents Shelf.

The youngest confirmed Cretaceous rocks on Svalbard are Aptian–Albian shale, siltstone and sandstone of the Carolinefjellet Formation (Fig. 2; Parker, 1967;

Figure 2. Cretaceous and Paleogene chronostratigraphy and lithostratigraphy of Svalbard, with a list of selected *in situ* and dinoflagellate cysts recovered from Paleogene formations on Sørkapp Land.

Figure 3. Outline stratigraphy and depositional conditions of the lower and middle parts of the Paleogene succession along a southwest–northeast transect crossing the Central Basin of Spitsbergen (based on Nagy, 2005).

Nagy, 1970; Dallmann, 1999). The formation is divided into four members. The youngest member is the Schönrockfjellet Member, dated as Albian by ammonites (Nagy, 1970). The member represents marine, moderately deep shelf environments, and it is locally preserved in Heer Land on Spitsbergen (Dallmann, 1999).

Overlying the Early Cretaceous deposits on Spitsbergen is the Paleocene–?Oligocene Van Mijenfjorden Group (Figs. 2, 3; Dallmann, 1999). The oldest sedimentary rocks of this group constitute the Paleocene Firkanten Formation, a unit of conglomerates, sandstone, shale and coal deposited in alluvial/deltaic to shallow-marine environments. The lowermost part of the Firkanten Formation comprises the Grønfjorden Bed, a basal conglomerate overlying the Carolinefjellet Formation with a low-angle unconformity (Dallmann, 1999).

The Firkanten Formation thickens and deepens from north–northeast towards south and west (Helland-Hansen, 1990; Dallmann et al., 1993). Towards the south in the Central Tertiary Basin, the lowermost Firkanten Formation is represented by sandstone, shale and coals of the Todalen Member (Dallmann, 1999). The lower, coal-bearing Todalen Member of the formation represents a stacked series of deltaic lobes, while the upper part assigned to the Endalen Member shows a transgression repeated shoaling-upward barrier shoreline deposits building repeatedly from the northeast (Helland-Hansen, 1990). Overlying the basal Grønfjorden Bed and the Todalen Member are the Endalen Member and the Kolthoffberget Member. The latter member represents repeated shoaling-upward settings in a prodelta or shallow shelf, whereas the Endalen represents a deltaic

or barrier shoreline deposit building repeatedly from the northeast (Helland-Hansen, 1990; Dallmann, 1999).

The Basilika Formation comprises shale, siltstone and mudstone deposited in a shelf setting. The lower boundary of the formation is well defined by the incoming of thick shales over the sandstones of the underlying Firkanten Formation (Dallmann, 1999). The formation is dated as Late Paleocene based on palynology (Manum & Thronsdén, 1986) and foraminifera (Nagy et al., 2000; Nagy, 2005).

Material and methods

A total of 53 samples from different locations on eastern Sørkapp Land were analysed for their palynological content. The samples were taken from locations at Daudbjørnpynten, Skolthuken, Mirefjellet, Randberget, Dumskolten and east of Tvillingtoppen (Fig. 1). More information on the locations of the examined sections and the outcrop of the Tertiary formation on eastern Sørkapp Land can be found on the geological map of Sørkapp in 1:100,000 scale (Winsnes et al., 1993). All samples were prepared following standard palynological procedures at the NPD laboratory. The examined palynological slides are stored at the IKU Petroleum Research core-store in Trondheim. With few exceptions the analysed samples yielded determinable palynomorphs. The preservation of the material and the productivity of the samples, however, were generally modest to rather poor.

Age of the Firkanten and Basilika formations

The samples from the Firkanten and Basilika formations on Sørkapp Land contain dinoflagellate cyst assemblages of late Early to early Late Paleocene age (Figs. 4–12). Most samples contain common to abundant *Palaeoperidinium pyrophorum*, and common *Areoligera*/*Glaphyrocysta* spp., together with *Cerodinium speciosum*, *Cerodinium striatum* and *Hystriochosphaeridium tubiferum*. One sample from Randberget (19.0 m) contains common *Operculodinium severinii* (Fig. 7). Rare specimens of *Alisocysta* spp. were found at the Dumskolten II section (340.0 m; Fig. 9), while *Deflandrea denticulate* and *Thalassiphora inflata* were found in the Dumskolten III section (Fig. 10, at 619.0 m and 631.0 m, respectively).

The consistent occurrences of *Cerodinium speciosum* and *Cerodinium striatum* appear to provide good evidence of a late Early to early Late Paleocene age for the deposits. According to Powell (1992), *C. striatum* ranges from the late Early to early Late Paleocene in the North Sea area (i.e., in beds time-equivalent to the NP4 to NP7 calcareous nannoplankton zones).

Nøhr-Hansen & Sheldon (2000) reported *C. striatum* from Danian deposits in the Nuussuaq Basin in West Greenland, while Nøhr-Hansen (2012) reported the youngest occurrence of *Cerodinium striatum* and the Acme of *Areoligera* spp. in the Late Selandian Klitterhorn Member (upper Sediment Bjerger Formation) in the Kangerlussuaq Basin, southern East Greenland. Nagy et al. (2004) recovered *C. striatum* in Selandian to Ypresian deposits (i.e., strata correlated to the BSP2–BSP4 Foraminiferal zones) of the Torsk Formation in the southwestern Barents Sea.

According to the stratigraphic range published by Powell (1992), the presence of *C. speciosum* indicates an early Late Paleocene age (Selandian–Early Thanetian) corresponding to the NP5–NP7 zones for the Basilika and Firkanten formations on eastern Sørkapp Land.

An age no younger than Early Thanetian (NP7) is also supported by the consistent occurrence of *Palaeoperidinium pyrophorum*. Mudge & Bujak (2001) found that the youngest occurrences of common and abundant *Palaeoperidinium pyrophorum* correspond to the lower NP6 zone in the Faeroe–Shetland Basin. However, more sporadic occurrences of this species are reported from younger Early Paleogene strata (NP9–

Figure 4. Range chart of dinoflagellate cysts recovered from the Daudbjørnpynten section, Sørkapp Land. Abbreviations: Alb. – Albanian; Lt. Pal. – Late Paleocene; Car. – Carlinefjellet Formation; Firkant. – Firkanten Formation.

Alb.	Lt. Pal.	Age		
1.00	29.80	49.10		
		Depth m		
		Dinoflagellates		
		×	Cyclopsiella spp	
		×	Exochosphaeridium sp.	
		×	cf. Microdinium sp.	
×	×	×	×	Spiniferites ramosus
		×		Cerodinium speciosum
		×		Diconodinium spp.
		×		Florentinia ferox
		×		Palaeocystodinium golzowense
		×		Wallodinium sp.
		×		aff. Raphidodinium sp.
		×	×	?Aeoligera/Glaphorocysta spp.
		×	×	Fromea fragilis
		×	×	Hysterochosphaeridium tubiferum
		×	×	Laciniadinium spp
		×	×	Palaeoperidinium pyrophorum
		×	×	Thalassiphora cf. delicata
×		×	×	Cleistosphaeridium spp.
×			×	Odontochitina operculata
×			×	Oligosphaeridium pulcherrimum
×	×	×	×	Oligosphaeridium complex
×		×		Cordosphaeridium inodes
		×		Lejeuncysta hyalina
		×		Lithodinia sp.
		×		Subtilisphaera sp.
		×		? Hapsocysta sp.
		×		Pterodinium cingulatum
×	×			cf. Palaeoperidinium pyrophorum
	×			cf. Leberidocysta sp.
	×			Leptodinium sp.
	×			Canninga spp
	×			Cribroperidinium cf. orthoceras
	×			Exochosphaeridium bifidum
	×			Gonyalulacysta sp.
	×			Hapsocysta? benteae
	×			Litosphaeridium siphonophorum
	×			Palaeoglenodinium cretaceum
	×			Vesperopsis sp.
×	×			Cribroperidinium sp.
×	×			Ellipsoidictyum imperfectum
×	×			Vesperopsis mayi
×	×			Hystrichosphaeridium sp.
×	×			Canningia sp. A
×				Circulodinium distinctum
×				Circulodinium spp.
×				Exochosphaeridium phragmites
×				Fromea cf. expolita
×				Kleithriasphaeridium sp.
×				Palaeoperidinium cretaceum
×				Spinidinium spp.
Car.	Firkant.			Lithostratigraphic unit

Lt. Paleocene				Age
277.00	297.00	327.00	367.00	397.00
				Depth m
				Dinoflagellates
				× <i>cf. Florentinia</i> sp.
				× <i>Cerodinium</i> sp.
				× <i>Cyclopsiella</i> spp.
				× <i>Cerodinium</i> spp.
				× <i>Palaeohystrichophora infusorioides</i>
				× <i>Trithyrodinium</i> sp.
				× <i>Xenascus ceratioides</i>
	×	×	×	× <i>Oligosphaeridium</i> complex
	×	×	×	× <i>cf. Areligera/Glaphyrocysta</i> spp.
×	×	×	×	× <i>Cerodinium speciosum</i>
×	×	×	×	× <i>Cleistosphaeridium</i> spp.
×	×	×	×	× <i>Fromea laevigata</i>
×	×	×	×	× <i>Palaeoperidinium pyrophorum</i>
×	×	×	×	× <i>Spiniferites ramosus</i>
×	×	×	×	× <i>Subtilisphaera</i> spp.
			×	× <i>cf. Cyclopsiella</i> sp.
			×	× <i>cf. Leptodinium</i> sp.
			×	× <i>Cerodinium wardenense</i>
			×	× <i>Hystrichosphaeridium tubiferum</i>
		×	×	× <i>Impagidinium</i> sp.
×	×	×	×	× <i>Cerodinium striatum</i>
×	×	×	×	× <i>Spinidinium</i> spp.
	×	×		× <i>Lejeunacysta hyalina</i>
		×		× <i>Operculodinium sverinii</i>
		×		× <i>Diconodinium</i> sp.
	×			× <i>Fromea fragilis</i>
	×			× <i>Aspiniferites cf. pseudofurcatus</i>
	×			× <i>cf. Cordosphaeridium</i> sp.
×	×			× <i>Isabelidinium</i> sp.
×				× <i>Odontochitina operculata</i>
Firkanten Fm				Lithostratigraphic unit

Figure 5. Range chart of dinoflagellate cysts recovered from the Skolthuken section, Sørkapp Land.

Late Paleocene								Age
12.20	25.00	26.00	42.00	63.50	94.50	159.00	176.00	190.50
								Depth m
								Dinoflagellates
							×	× <i>Cerodinium</i> sp. A
								× <i>Florentina feroks</i>
			×				×	× <i>Ceratiopsis</i> sp. 1 Malm et al., 1984
			×	×		×	×	× <i>Odontochitina operculata</i>
	×							× <i>Impagidinium</i> spp.
	×	×	×	×	×		×	× <i>Cerodinium</i> spp.
	×	×	×	×			×	× <i>Spinidinium</i> spp.
×	×		×	×	×	×	×	× <i>Cerodinium speciosum</i>
×	×				×	×	×	× <i>Lejeunacysta hyalina</i>
×	×	×	×	×	×	×	×	× <i>Oligosphaeridium</i> complex
×	×	×	×	×	×	×	×	× <i>Palaeoperidinium pyrophorum</i>
×	×	×	×	×	×	×	×	× <i>Spiniferites ramosus</i>
							×	× <i>Cleistosphaeridium</i> sp.
×	×	×	×			×	×	× <i>Subtilisphaera</i> spp.
						×		× <i>Pterodinium cingulatum</i>
				×	×			× <i>Laciniadinium</i> spp.
	×	×	×	×	×			× <i>Chlamydothorella nyei</i>
					×			× <i>Muderongia tetracantha</i>
	×	×	×	×	×			× <i>Cleistosphaeridium</i> ssp.
×	×	×	×	×	×			× <i>Cerodinium striatum</i>
				×				× <i>?Hapsocysta</i> sp.
			×					× <i>Exochosphaeridium</i> sp.
			×					× <i>Fromea fragilis</i>
			×					× <i>Palaeohystrichophora infusorioides</i>
			×	×				× <i>Impletosphaeridium</i> spp.
		×	×					× <i>Isabelidinium acuminatum</i>
	×		×					× <i>Exochosphaeridium bifidum</i>
	×	×						× <i>Chatangiella</i> spp.
×	×	×	×					× <i>?Aeroligera/Glaphyrocysta</i> spp.
×	×	×						× <i>Hystrichosphaeridium tubiferum</i>
	×							× <i>Cometodinium</i> sp.
	×							× <i>Evansia evittii</i>
	×							× <i>Exochosphaeridium phragmites</i>
	×							× <i>Fromea laevigata</i>
	×							× <i>Gonyaukacysta helicoidea</i>
	×							× <i>Subtilisphaera perlucida</i>
	×							× <i>Systematophora</i> sp.
	×							× <i>Thalassiphora pelagica</i>
	×							× <i>Trithyrodinium</i> sp.
	×	×						× <i>Cordosphaeridium inodes</i>
	×							× <i>Achilleodinium cf. bififormes</i>
	×							× <i>Spiniferites cornutus</i>
×	×							× <i>Circulodinium distinctum</i>
×								× <i>Oligosphaeridium pulcherrimum</i>
×								× <i>Operculodinium severinii</i>
Firkanten Fm								B.
								Lithostratigraphic unit

Figure 6. Range chart of dinoflagellate cysts recovered from the Mirefjellet section, Sørkapp Land. Abbreviation: B. – Basiliika Formation.

Figure 7. Range chart of dinoflagellate cysts recovered from the Randberget section, Sørkapp Land. Abbreviations: Lt. Pal. – Late Paleocene; Firk. – Firkanten Formation.

Figure 8. Range chart of dinoflagellate cysts recovered from the Dumskolten I section, Sørkapp Land. Abbreviations: Lt. Paleo.- Late Paleocene; Firk. Fm. – Firkanten Formation.

NP10) in Northeast Greenland (Nøhr-Hansen et al., 2011).

Nøhr-Hansen (2012) defined a *Palaeoperidinium pyrophorum* Palynozone in the Kangerlussuaq Basin in southern East Greenland. The lower boundary of the zone is recognised by the oldest Acme of *Palaeoperidinium pyrophorum*, while the upper boundary is defined by the youngest occurrence of this species. The age of this palynozone is interpreted to be Mid to Late Selandian, based on correlation with the *P. pyrophorum* Zone DP4 of Mudge & Bujak (1996) in the U.K. central North Sea.

The records of *Deflandrea denticulata* and *Thalassiphora inflata* in the Dumskolten III section (Fig. 10) support an Early to Mid Thanetian age. According to the stratigraphic range published in Powell (1992), *D. denticulata* does not occur in strata younger than the Mid Thanetian (NP7), while *T. inflata* is normally restricted to the Early to Mid Thanetian (NP5–NP6). The ranges

published by Powell (1992) are based on North Sea data, and should not be expected to be completely concurrent with the high latitude ranges. However, the age evidence seems consistent enough to conclude that the Firkanten and Basilika formations on Sørkapp Land are of Early to Mid Thanetian age.

Age of the uppermost Carolinefjellet Formation

Samples from the uppermost Carolinefjellet Formation were collected at Daudbjørnpynten (2 samples, Fig. 4) and at the section east of Tvillingtoppen (2 samples, Fig. 11).

At Daudbjørnpynten, the lowest sample from the Carolinefjellet Formation (1.0 m) yielded a moderately diverse dinoflagellate assemblage, characterised by

Lt. Paleocene				Age
24000	31000	34000	37000	Depth m Dinoflagellates
			x	<i>Spinidinium balmei</i>
			x	<i>Oligosphaeridium anthophorum</i>
		x	x	<i>Cyclonephelium membraniphorum</i>
	x	x	x	<i>Hystriochodinium pulchrum</i>
	x	x	x	<i>Spinidinium</i> spp.
	x	x	x	<i>Hystrosphaeridium tubiferum</i>
	x			<i>Implestosphaeridium whitei</i>
	x	x	x	<i>Palaeocystodinium golzowense</i>
	x	x	x	<i>Spiniferites</i> cf. <i>pseudofurcatus</i>
x	x	x	x	? <i>Aeroligera</i> / <i>Glaphyrocysta</i> spp.
x	x	x	x	<i>Chlamydothella nyei</i>
x	x	x	x	<i>Circulodinium distinctum</i>
x	x	x	x	<i>Cleistosphaeridium armatum</i>
x	x	x	x	<i>Cleistosphaeridium</i> spp.
x	x	x		<i>Exochosphaeridium phragmites</i>
x	x	x	x	<i>Laciniadinium</i> spp.
x	x	x	x	<i>Odontochitina operculata</i>
x	x	x	x	<i>Oligosphaeridium complex</i>
x	x	x	x	<i>Palaeohystrichophora infusorioides</i>
x	x	x	x	<i>Palaeoperidinium pyrophorum</i>
x	x	x	x	<i>Spiniferites ramsus</i>
x				<i>Surculosphaeridium?</i> <i>longifurcatum</i>
			x	<i>Cibropidinium edwardsii</i>
			x	<i>Elytrocysta drugii</i>
	x	x	x	<i>Ceratiopsis</i> sp. 1 Malm et al. 1984
x	x	x		? <i>Florentinia</i> sp.
x	x	x	x	<i>Isabelidinium acuminatum</i>
x	x	x	x	<i>Trichodinium castanea</i>
		x		? <i>Alisocysta</i> sp.
		x		<i>Cycladophysis monmouthensis</i>
		x		<i>Hystriochodinium vogtil</i>
		x		<i>Hystrosphaeropsis</i> sp.
		x		<i>Kleithrisphaeridium</i> sp.
		x		<i>Odontochitina costata</i>
		x		<i>Rattenesita borussica</i>
	x	x		<i>Cerodinium speciosum</i>
	x	x		<i>Phelodinium magnificum</i>
x	x	x		<i>inopterygium</i> sp.
x	x	x		<i>Exochosphaeridium bifidum</i>
x		x		<i>Palaeogelenodinium cretaceum</i>
	x			? <i>Aptedinium</i> sp.
	x			? <i>Disphaera</i> sp.
	x			<i>Trithyrodinium</i> sp.
	x			<i>Exhosphaeridium</i> sp.
	x			<i>Fromea laevigata</i>
	x			<i>Implestosphaeridium</i> sp.
	x			<i>Isabelidinium bakeri</i>
	x			<i>Pterodinium</i> sp.
	x			<i>Spongodinium delitiense</i>
	x	x		<i>Impagidinium</i> spp.
	x	x		<i>Palaeoperidinium cretaceum</i>
x	x	x		<i>Pterodinium cingulatum</i>
x	x	x		<i>Subtilisphaera</i> spp.
	x			<i>Florentinia mantellii</i>
	x			<i>Trithyrodinium fragile</i>
x	x			<i>Chatangiella spectabilis</i>
x	x			<i>Cyclopsella</i> spp.
x				? <i>Hapsocysta</i> sp.
x				<i>Cerodinium striatum</i>
x				<i>Cibropidinium</i> sp.
x				<i>Oligosphaeridium pulcherrimum</i>
x				<i>Trithyrodinium suspectum</i>
x				<i>Xenascus ceratioides</i>
Firkanten Fm				Lithostratigraphic unit

Figure 9. Range chart of dinoflagellate cysts recovered from the Dumskolten II section, Sørkapp Land.

Late Paleocene						Age
61900	62200	62600	63100	63600	64200	Depth m Dinoflagellates
						<i>Cibropidinium septimentus</i>
						<i>Dinopterygium</i> sp.
						<i>Surculosphaeridium?</i> <i>Longifurcatum</i>
				x	x	<i>Cordosphaeridium inodes</i>
				x	x	<i>Cyclonephelium membraniphorum</i>
				x	x	<i>Pterodinium cingulatum</i>
		x	x	x	x	<i>Chlamydothella nyei</i>
		x				<i>Hystrosphaeridium tubiferum</i>
		x	x			<i>Isabelidinium acuminatum</i>
		x				<i>Isabelidinium bakeri</i>
		x				<i>Lejeuncysta hyalina</i>
		x	x	x	x	<i>Odontochitina operculata</i>
		x				<i>Palaeocystodinium golzowense</i>
		x	x			<i>Palaeohystrichophora infusorioides</i>
	x	x	x	x	x	<i>Spiniferites</i> cf. <i>pseudofurcatus</i>
	x		x	x	x	? <i>Aeroligera</i> / <i>Glaphyrocysta</i> spp.
	x		x	x	x	<i>Circulodinium distinctum</i>
	x	x	x			<i>Florentinia ferox</i>
x	x	x	x	x	x	<i>Cerodinium speciosum</i>
x	x	x	x	x	x	<i>Cerodinium striatum</i>
x	x	x	x	x	x	<i>Cleistosphaeridium</i> spp.
x	x	x				<i>Fromea laevigata</i>
x		x	x	x	x	<i>Oligosphaeridium complex</i>
x	x	x	x	x	x	<i>Palaeoperidinium pyrophorum</i>
x			x	x	x	<i>Spinidinium</i> spp.
x	x	x	x	x	x	<i>Spiniferites ramosus</i>
x	x	x	x	x	x	<i>Subtilisphaera</i> spp.
				x		<i>Alterbia</i> cf. <i>circula</i>
				x		<i>Implestosphaeridium</i> sp.
				x		<i>Membranosphaera</i> sp.B
				x	x	<i>Operculodinium severinii</i>
				x	x	<i>Palaeotetradinium minusculum</i>
				x	x	<i>Trichodinium castanea</i>
	x	x	x	x	x	<i>Ceratiopsis</i> sp. 1 Malm et al., 1984
x		x	x	x		<i>Cyclopsella</i> spp.
			x			<i>Cleistosphaeridium armatum</i>
			x			<i>Hystriochodinium pulchrum</i>
			x			<i>Hylstrichostrogylon membraniphorum</i>
			x			<i>Oligosphaeridium pulcherrimum</i>
			x			<i>Phelodinium magnificum</i>
			x			<i>Spiniferites</i> sp.I
		x	x			<i>Cibropidinium</i> spp.
		x	x			<i>Operculodinium</i> spp.
	x		x			<i>Palaeohystrichophora infusorioides</i>
			x			? <i>Implestosphaeridium</i> sp.
			x			<i>Thalassiphora inflata</i>
			x			aff. <i>Operculodinium severinii</i>
		x				<i>Operculodinium</i> sp.A
x	x					<i>Impagidinium</i> spp.
x						<i>Chatangiella spectabilis</i>
x						<i>Deflandera denticulata</i>
x						<i>Palaeoperidinium cretaceum</i>
Firkanten Fm						Lithostratigraphic unit

Figure 10. Range chart of dinoflagellate cysts recovered from the Dumskolten III section, Sørkapp Land.

Figure 11. Range chart of dinoflagellate cysts recovered from the east of Tvillingtoppen section, Sørkapp Land. Abbreviations: L P. - Late Paleocene; Carol. - Carolinefjellet Formation; Firk. - Firkanten Formation.

dominant *Oligosphaeridium complex* and common *Cleistosphaeridium* spp. and *Spiniferites ramosus* (Fig. 4). The presence of *Ellipsoidictyum imperfectum* suggests a general Late Aptian to early Late Albian age. The upper sample (29.0 m) also contained common *O. complex*, together with *E. imperfectum*. The sample further contained *Hapsocysta? bentae* which, according to Nøhr-Hansen (1993), is a good marker for the Albian in East Greenland. Another species, *Vesperopsis mayi*, found in the assemblage is a typical Aptian to middle Late Albian species. The record of *Litosphaeridium siphonophorum* further restricts the age of the sample to the Late Albian, as this species has previously not been reported from pre-Late Albian strata (Nøhr-Hansen, 1993).

The lower sample (40.0 m) from the east of Tvillingtoppen section contained a low diversity dinoflagellate cyst assemblage, with the most prominent species being *Oligosphaeridium complex* (Fig. 11). The occurrence of *Vesperopsis mayei* in the sample is evidence for a general Apian to middle Late Albian age. The upper

Figure 12. Range chart of dinoflagellate cysts recovered from the Dumskolten East section, Sørkapp Land.

sample proved less productive and contained no age-diagnostic species, with the exception of *Operculodinium operculata* which is consistent with a Mid Cretaceous age.

In conclusion, the combined dinoflagellate cyst assemblages recovered from the uppermost Carolinefjellet Formation in eastern Sørkapp Land point to a Late Albian age for the youngest Cretaceous strata in the area.

Reworked palynomorph assemblages in the Tertiary formations

Reworked Cretaceous dinoflagellates and terrestrial playnomprphs are common to abundant in samples through all the investigated outcrop sections.

The samples from the Firkanten Formation (5 samples from the Kolthoffberget Member and 2 samples from the

Endalen Member) and the two samples from the Basilika Formation at the Mirefjellet section all contain reworked Cretaceous dinoflagellate cysts (Fig. 6). Most of these are long-ranging species, but the presence of *Subtilisphaera perlucida* and *Gonyaulacysta helicoidea* at 26.0 m, and *Trithyrodinium* sp. and *Isabelidinium acuminatum* at 26.0 m and 63.5 m, respectively, shows that both Lower and Upper Cretaceous sediments have been reworked into the Kalthoffberget Member. A single specimen of *Evansia evittii* further documents reworking from Middle Jurassic strata. Further upwards, the presence of *Muderongia tectracantha* at 95.5 m is evidence for reworking from the Lower Cretaceous into the Endalen Member. *Aquilapollentites* found at 159.0 m may have been redeposited from Upper Cretaceous sediments, but this pollen may also occur in situ in the Paleocene.

In the Dumskolten I section the recovery of *Chatangiella madura* at 7.4 m is evidence of recycling from Upper Cretaceous sediments (Fig. 7). The record of taeniated pollen at 174.0 m points to reworking from Permo-Triassic strata. In the Dumskolten II section (Fig. 9), characteristic reworked Late Cretaceous species include *Spinidinium balmei* (400.0 m), *Elytrocysta druggii* (370.0 m), *Isabelidinium acuminatum* (240.0 m, 310.0 m, 340.0 m, 370.0 m), *Isabelidinium bakeri* (310.0 m), *Spondinium delitiense* (310.0 m), *Trithyrodinium fragile* (270.0 m), *Trithyrodinium suspectum* (240.0 m), *Palaeoglenodinium cretaceous* (240.0, 340.0 m), and *Xenascus ceratoides*. The Late Cretaceous-Paleocene *Aquilapollentites* was recovered at 270.0 m and 370.0 m. The reworked Cretaceous palynomorphs found in the Dumskolten III section have also been sourced from both Lower and Upper Cretaceous strata. The Late Cretaceous species include *Isabelidinium acuminatum* (631.0 m, 636.0 m, 643.0 m), *Isabelidinium bakeri* (631.0 m, 643.0 m), *Phelodinium magnificum* (636.0 m) and *Chatangiella spectabilis* (619.0 m).

No age-diagnostic reworked Cretaceous palynomorphs have been found in the Firkanten Member at the Dumskolten east section (Fig. 12) and the east of Tvillingtoppen section (Fig. 11). Only Early Cretaceous reworked dinoflagellate cysts and terrestrial palynomorphs have been found in the 3 examined samples from the Todalen Member at the Daudbjørnpynten section. In the Skolthuken section (Fig. 4), however, both Early and Late Cretaceous reworked dinoflagellate cysts are found. Recycling from Upper Cretaceous sediments is shown by the presence of *Isabelidinium* sp. at 277.0 m, and by *Trithyrodinium* sp. and *Xenascus ceratoides* at 397.0 m.

Discussion

The present palynostratigraphic data from the eastern Sørkapp Land suggest that the Firkanten and Basilika formations were deposited in a relatively short time-period during the Early to Mid Thanetian. Further, calcareous nannofossils reported from the Firkanten Formation at Scott-Ruudfjellet in the northern part of Sørkapp Land by Čepék (2001) point to a Late Paleocene age.

Except for the report by Krutzsch (2001), no Upper Cretaceous sedimentary rocks have been documented from Svalbard, and consequently the report of an Upper Cretaceous microflora from Øyrlandet Graben on Sørkapp Land (Krutzsch, 2001) is intriguing. The Triprojectacites (*Aquilapollites*) microflora was found in one sample from undeformed, sandy sediments assigned to the Firkanten Formation by Dallmann et al. (1993).

Upper Cretaceous strata occur in NE Greenland (Balkwill et al., 1983; Håkansson et al., 1991) and they are also present in the Maud Basin and Tromsø Basin on the western Barents Shelf. While the Upper Cretaceous of NE Greenland contains terrestrial deposits (i.e., the Herlufsholm Strand Formation) and marine deposits (i.e., the Nakkehoved Formation), the Upper Cretaceous of the Hammerfest, Maud and Tromsø basins comprises marine claystones and siltstones deposited in an open marine environment (Faleide et al., 1993; Radmacher et al., 2013, 2014).

The present recovery of abundant Upper Cretaceous palynomorphs in eastern Sørkapp Land questions the assumption that the Upper Cretaceous microflora found in one single sample in the Øyrlandet Graben documents a Late Cretaceous age for this sample. On the other hand, the fact that no marine palynomorphs were reported in the sample from the Øyrlandet Graben may also suggest that this sample represents an isolated body of Upper Cretaceous terrestrial deposits. Thus, the question as to whether there are any Upper Cretaceous deposits preserved on Sørkapp Land still remain unsolved.

It must also be mentioned that Late Cretaceous dinoflagellate cysts, pollen and spores are commonly found reworked in the Paleogene and younger Cenozoic deposits in the western Barents Shelf basins (i.e., documented in a number of unpublished biostratigraphy well reports). Abundant reworked Late Cretaceous palynomorphs have also previously been reported in the Upper Pliocene-Pleistocene deposits recovered at ODP Sites 910 and 911 on the Yermak Plateau (Willard, 1996) and at Site 986 west of southern Svalbard (Smelror, 1999). As discussed by Willard (1996) and Smelror (1999), these documented findings are sourced from the Late Cretaceous *Aquilapollenites* (Triprojectacites)

floral province. The subsequent records from Sørkapp Land (Krutzsch, 2001, and the present paper) support the assumption that the Western Barents Shelf (including Svalbard) was a part of this province in Late Cretaceous time.

Conclusions

The Paleogene formations on eastern Sørkapp Land contain common, reworked, Middle and Late Cretaceous terrestrial and marine microfloras (Figs. 4–12). The present palynostratigraphic data from eastern Sørkapp Land suggest that the Firkanten and Basilika formations were deposited in a relatively short time-period during the Early to Mid Thanetian. The youngest Cretaceous deposits documented from the Carlinefjellet Formation in eastern Sørkapp Land are of Late Albian age.

The observations of common, reworked, Upper Cretaceous palynomorphs in the Firkanten Formation question the Late Cretaceous age reported for the Firkanten Formation in the Øyrlandet Graben in western Sørkapp Land, as the pollen and spores reported from this graben may not be in situ. On the other hand, the fact that no marine palynomorphs were found in the sample from the Øyrlandet Graben may also suggest that this sample may represent an isolated body of Upper Cretaceous terrestrial deposits. Thus, the question as to whether there are Upper Cretaceous deposits preserved on Sørkapp Land still remains unsolved.

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