

# Triassic of the Central Graben

Palynological evaluation of wells  
7/11-8, 8/11-1 and 9/4-5

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## Introduction and Biostratigraphic summary

This biostratigraphic study was carried out by the Geological Survey of Denmark and Greenland (GEUS) during the fall of 2009 as a consultancy project on behalf of Statoil in Norway, with the aim to improve the biostratigraphic correlation between wells located within the Central Graben in the northern North Sea. The study comprise the three wells 7/11-8, 8/11-1, and 9/4-5 (Fig. 1).

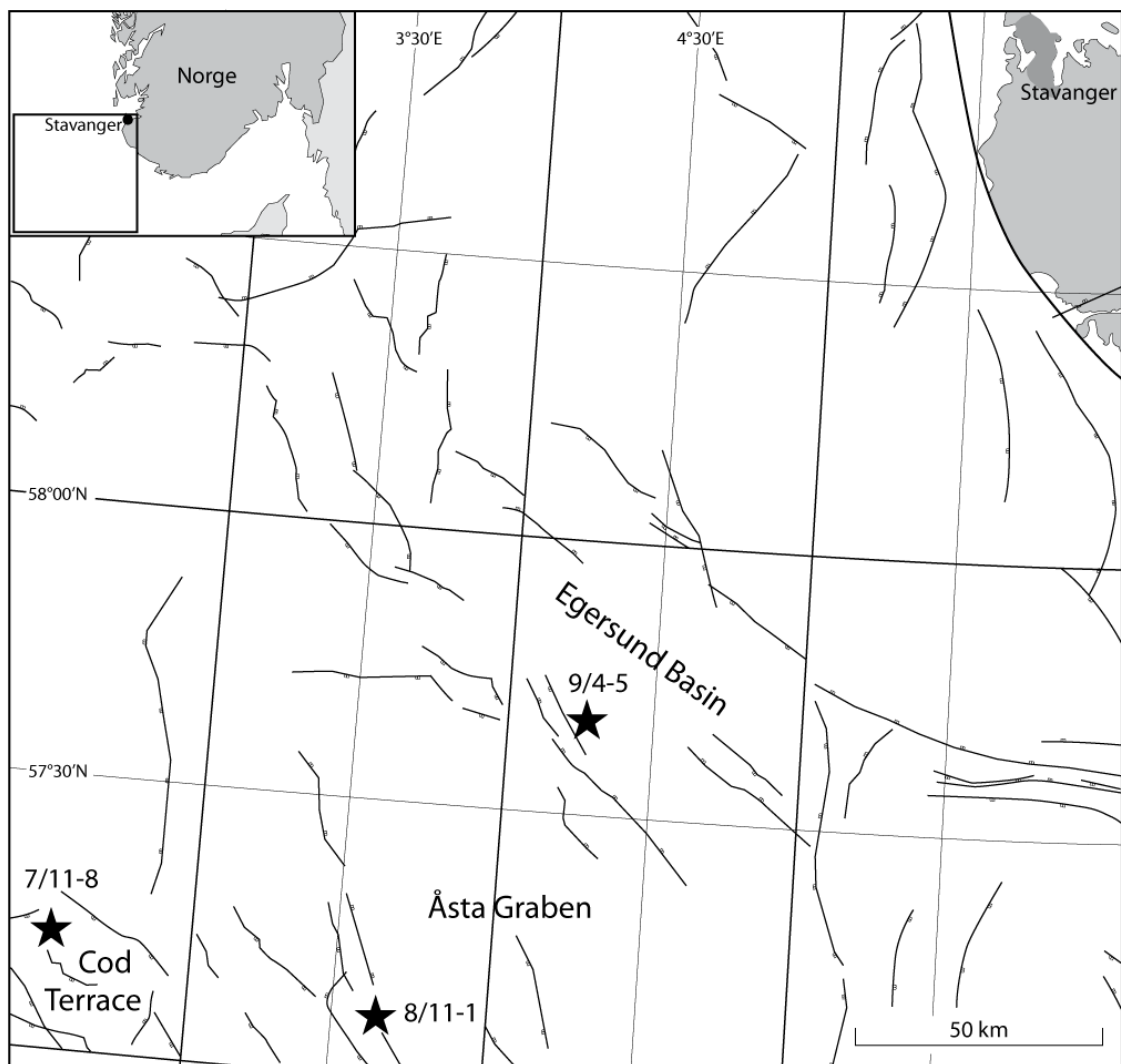


Fig. 1. Map showing the location of the herein investigated wells and structural elements mentioned in the text.

The main objective was to identify palynological markers of Ladinian-Early Carnian age that have previously been reported from the Skagerrak and Oddesund Formations in the Nor-

wegian–Danish Basin (Bertelsen, 1975; Lindström *et al.* 2009). The results are summarized in Table 1 below.

Well	Studied interval	Formation (top)	Number of samples	Presence of Triassic palynomorph markers	Caving
7/11-8	4422–4580m	Smith Bank Fm (top 3725m)	22	No <i>in situ</i> palynomorphs encountered	Ample caving of Paleocene or younger angiosperm floras, and less abundant Early Cretaceous dinocysts, spores and pollen
8/11-1	2990–3182m <3182m	Skagerrak Fm (top 2871m) Smith Bank Fm (top 3182m)	11	Possible top Carnian marker (3072m) Top Early Carnian marker (3100m) Top Ladinian marker (3182m)	Ample caving of Middle Jurassic to Cretaceous spores, pollen and dinocysts
9/4-5	3773–4349m	Skagerrak Fm (top 2836m)	17	Carnian marker (3773m) Top Early Carnian marker (4084m)	Minor to moderate caving of primarily Middle Jurassic to Cretaceous dinocysts, pollen and spores

Table 1. Summary of results.

## 1.1 Geochronologic framework

The geochronological framework used in this study generally follows the recommendations of the International Commission of Stratigraphy (ICS). The chronostratigraphic scheme is shown in Fig. 2.

## 1.2 Palynostratigraphic analysis

A total number of 50 samples from three wells, all located within the Central Graben (Fig. 1) have been analysed palynostratigraphically. The samples were processed, using standard

palynological maceration techniques, at the Geological Survey of Denmark and Greenland (Poulsen *et al.*, 1990). The palynological analysis included qualitative studies, taxonomic identification and palynostratigraphic evaluation. Stratigraphical datings of the samples were based on taxa identification, key-taxa occurrences, and quantitative assessments of taxa abundances. The biostratigraphic data are presented as a range chart for each well (Enclosures 1–3).

### 1.3 Palynostratigraphic framework

The biostratigraphic results of this study are compared and correlated with established palynostratigraphic schemes for the Triassic to Early Cretaceous of western Europe. The terrestrial palynostratigraphy is primarily based on the works of Heunisch (1986), Dybkjær (1991), Batten & Koppelhus (1996), Abbink (1998), Herngreen *et al.* (2000) and Schulz & Heunisch (2005). The dinoflagellate cyst stratigraphy used herein is based on Davey (1979), Heilmann-Clausen (1987), Riding & Thomas (1992), Herngreen *et al.* (2000), and Poulsen & Riding (2003).

All the assemblages investigated in this study are from ditch cuttings samples, thus, the last occurrence (LO) of a taxon in a section (unless reworked) is considered a more reliable datum than its first occurrence (FO) due to caving. For explanation of abbreviations used herein, please consult the "abbreviations" section at the last page. The LO of a taxon within a succession does not always correspond to its known last appearance datum (LAD), e.g. due to lack of samples, or there may be a hiatus within the succession, or the taxon may be extremely rare or absent due to palaeoenvironmental factors. In this report any considerations, discussions, or discrepancies regarding the age of a sample or an interval are discussed under each interval and well. Important Triassic biostratigraphic events are shown in Fig 2.

Chrono-stratigraphy		Spore-pollen events	Dinocyst events	
TRIASSIC	Upper	Rhaetian	<ul style="list-style-type: none"> <li>← Ricciisporites tuberculatus (common)</li> <li>← Rhaetipollis germanicus,</li> <li>← Granuloperculatipollis rudis</li> <li>← Enzonasporites vigens,</li> <li>← Vallasporites ignacii</li> </ul>	<ul style="list-style-type: none"> <li>← Rhaetogonyaulax rhaetica</li> <li>← Lunnomidinium scaniense</li> </ul>
		Norian	<ul style="list-style-type: none"> <li>← Perinopollenites elatoides</li> <li>← Granuloperculatipollis rudis FCO</li> </ul>	<ul style="list-style-type: none"> <li>← Dapcodinium priscum</li> </ul>
		Carnian	<ul style="list-style-type: none"> <li>← Camerosporites secatus,</li> <li>← Duplicisporites granulatus</li> <li>← Triadispora verrucata</li> <li>← Ricciisporites tuberculatus</li> <li>← Protohaploxylinus rieberi</li> <li>← Staurosaccites quadrifidus</li> <li>← Corollina meyeriana</li> <li>← Angustisulcites klausii</li> </ul>	<ul style="list-style-type: none"> <li>← Rhaetogonyaulax rhaetica</li> </ul>
		Ladinian	<ul style="list-style-type: none"> <li>← Illinites chitonoides</li> <li>← Podosporites amicus</li> <li>← Enzonasporites vigens</li> </ul>	
		Anisian	<ul style="list-style-type: none"> <li>← Illinites chitonoides</li> </ul>	
	Middle		<ul style="list-style-type: none"> <li>← Duplicisporites granulatus</li> <li>← Camerosporites secatus</li> <li>← Ovalipollis ovalis,</li> <li>← Staurosaccites quadrifidus</li> <li>← Podosporites amicus</li> </ul>	

Fig. 2. Chronostratigraphy of the relevant timeslice with selected important palynological events (mainly after de Graciansky et al. 1998, Schulz & Heunisch, 2005).

## 2. Palynological evaluation

### 2.1 7/11-8

The well 7/11-8 is located on the Cod Terrace of the North Sea, north of the Mime Field (Fig. 1). Drilled in 1983 to TD at 4750m, almost one km into Triassic sediments of the Smith Bank Fm (top 3725m). Gumbo problems and problems with seal assembly were experiences during drilling (NDP fact sheet).

In this well Triassic strata of the Smith Bank Fm are directly underlying lower Cretaceous shales of the Rødby Fm (top 3676m). Chalk of the Shetland Group (top 3039m), and sediments of the Rogaland (top 2899m), Hordaland (top 1404m), and Nordland (top 102m) groups comprise the remaining part of the succession (NPD fact sheet).

A previous palynological study carried out on this well, covering the interval 4350-4597m reports rare *in situ* bisaccate pollen and spores of high thermal maturity, including *Acanthotriletes* spp., *Baculatisporites* spp., *Cyathidites* spp., *Dictyophyllidites mortonii*, *Lycopodiacidites rugulatus*, *Retitriletes austroclavatidites*, *Punctatisporites minor* and unidentified bisaccate pollen, but no palynostratigraphical markers (Geostrat report 2008).

#### 2.1.1 Results

For the present study twenty-two samples were selected from 7/11-8 covering the interval from 4422m to 4580m (Enclosure 1). *None of the investigated samples contain palynomorphs typical of Triassic strata.* All the samples contain palynomorphs caved from higher stratigraphical levels. In general these represent two groups of different ages:

1. A primarily terrestrial palynoflora of Paleocene or younger age, which is generally dominated by angiosperm pollen (including *Alnus*, *Corylus*, *Carya*, and a large variety of other angiosperms), gymnosperms e.g. bisaccates and *Taxodium*, and fern spores (*Laevigatosporites*, *Deltoidospora/Cyathaceae*, *Osmundacidites*).

This angiosperm assemblage is always of low thermal maturity (yellow to dark yellow in colour), and occasionally it contains herein unidentified dinoflagellate cysts of similar thermal alteration. It seems possible that the angiosperm floras from the lower and upper parts of the investigated interval were caved from slightly different stratigraphical

levels, as those from the lower part appear more diverse than those from the top. At 4460m there is abundance of zygnamatacean freshwater algae (mainly *Ovoidites*).

2. A primarily marine palynoflora of probably Early Cretaceous age generally consisting of dinoflagellate cysts, mainly *Oligosphaeridium* spp., *Hystriosphæridium* sp., *Chlamydomphorella* spp., with rare *Batioladinium longicornutum* and *Rotosphaeropsis thula*. Occasionally dark coloured spores and pollen were encountered, some of which indicate a Late Jurassic to Cretaceous age (*Cicatricosisporites* spp. and *Rugubivesiculites reductus*), but most of which have rather long stratigraphic ranges including Early Cretaceous strata. These Cretaceous palynomorphs are of high thermal maturity (brown to blackish brown, usually dark brown).

Thus, in the present study no *in situ* Triassic palynomorphs were encountered. This is probably due to a combination of the low palynological preservation potential in red and multicoloured strata deposited in arid to semiarid environments, and the large depth of the samples and hence very high thermal maturity (black to totally broken down) of any *in situ* organic material.

## 2.2 8/11-1

The well 8/11-1 was drilled in 1975 by Phillips Petroleum Company Norway on the crest of an elongated faulted anticline in the Åsta Graben (Fig. 1). The well penetrated Quaternary–Tertiary rocks (down to 2143m), Cretaceous and Jurassic strata (down to 2835m), and TD at 3810m in Triassic red beds. The dark shales in the Jurassic interval were considered to be of Portlandian–Late Kimmeridgian age, and the top of the Triassic assumed to be in the interval between 2855m and 2900m (NPD website). The Early Cretaceous–Triassic succession was divided into the Åsgard Formation (top 2658m), Flekkefjord Formation (top 2807m), Sandnes Formation (top 2835m), Skagerrak Formation (top 2871m) and Smith Bank Formation (top 3182m) (NDP fact sheet).

A previous palynological study carried out on this well, covering the interval 2972–3182m report rare *in situ* bisaccate pollen and spores of high thermal maturity, including *Baculatisporites* spp., *Brachysaccus* spp., *Cyathidites* spp., *Podocarpidites* spp. and unidentified bisaccate pollen, but no palynostratigraphical markers (Geostrat report 2008).



## 2.2.1 Results

Eleven samples covering the interval 2990–3182m, encompassing the top Smith Bank Formation and a major part of the Skagerrak Formation, were selected for the present study (Enclosure 2). All the samples contain abundant caved palynomorphs; spores, pollen, dinocysts, acritarchs and algae of Middle Jurassic to Cretaceous age. The common occurrence of caved specimens of the presumed brackish or near shore dinocyst *Jansonia manifesta* within the Triassic interval is particularly interesting, as its known range is restricted to the Bathonian (Riding and Thomas, 1992), thus indicating the presence of previously unknown Middle Jurassic deposits in this well.

However, very rare occurrences of typical Triassic taxa are herein regarded to be *in situ* and indicate the following stratigraphic breakdown for the interval:

Interval	Age	Palynological marker
2990–3072m	Late Triassic undefined	
3072–3182m	Carnian	Presence of <i>Rhaetogonyaulax rhaetica</i> FAD around Carnian/Norian boundary) at 3072m LO <i>Staurosaccites quadrifidus</i> (LAD top Early Carnian) at 3099.6m
3182m	Ladinian	LO <i>Illinites chitonoides</i> (LAD top Ladinian) at 3182m

The presence of *Illinites chitonoides* at 3182m indicate a top Ladinian age, while the last occurrence (LO) of *Staurosaccites quadrifidus* at 3099.6m suggest a top Early Carnian age. A specimen of *Rhaetogonyaulax rhaetica* was identified at 3072m. As *R. rhaetica* has its known FAD around the Carnian/Norian boundary this possibly indicates a latest Carnian age. Other typical Triassic taxa encountered within this study include *Protodiploxypinus* spp, *Triadispora* spp. and *Enzonasporites* spp. all typical Middle to Late Triassic pollen taxa.

## 2.3 9/4-5

The well 9/4-5 is located in the Egersund Basin, SW of the Yme Field in the North Sea. It was drilled in 2006 with the main target being a faulted four way anticlinal structure with presumed Late Permian Rotliegendes sandstones. The well penetrated Neogene, Paleo-

gene, Cretaceous–Middle Jurassic rocks down to 2836m where Triassic rocks of the Skagerrak Fm were encountered, and at 4638m the well reached top Smith Bank Fm, and further into Permian strata from 5224m down to TD at 5838m.

A previous palynological study carried out on this well, covering the interval 3858–4148m report rare *in situ* bisaccate pollen and spores of high thermal maturity, including, *Baculatisporites* spp., *Brachysaccus* spp. *Cyathidites* spp., *Alisporites robustus*, *Aratrisporites palletae*, *Dictyophyllidites mortonii*, and unidentified bisaccate pollen. The presence of *A. palletae* was taken as an indicator of a ?Ladinian–?early Norian age at 4084–4093m (Geostrat report 2008).

### 2.3.1 Results

Seventeen samples covering the interval 3773–4349m of the Skagerrak Formation were selected for this study (Enclosure 3). Caved palynomorphs, primarily from Upper Jurassic to Lower Cretaceous strata, are common in some of the samples, but caving is only sparse to moderate. A number of Triassic spore-pollen taxa were recovered in the samples. These *in situ* palynomorphs are darkbrown to black in colour reflecting the high thermal alteration of the organic matter due to the large burial depth. Based on the presence of a few key taxa the following stratigraphic breakdown is suggested for the interval:

Interval	Ages	Palynological markers
3773–4084m	Late Carnian	LO <i>Duplicisporites granulatus</i> (LAD top Carnian)
4084–4322m	Top Early Carnian	LO <i>Protohaploxypinus rieberi</i> (LAD top Early Late Carnian) at 4084m LO <i>Staurosaccites quadrifidus</i> (LAD top Early Carnian) at 4084m

The presumed *in situ* spores and pollen assemblages recovered from this well differ from those described by Lindström *et al.* (2009) in that they lack *Ovalipollis ovalis*. Instead taeniate bisaccate pollen such as members of *Lunatisporites* and *Protohaploxypinus*, especially the important *P. rieberi* are the most striking forms. The latter taxon has its LAD at top early Late Carnian. The presence of *Staurosaccites quadrifidus* at the same level (Fig. 2), however, indicates a top Early Carnian age for at least the uppermost part of the interval.

### 3. Conclusions

A palynostratigraphic study of fifty samples from selected Triassic intervals in three wells from the Central Graben shows the presence of Triassic palynomorphs in two of the investigated wells, 8/11-1 and 9/4-5 (Enclosure 4). A previous reported presence of Triassic palynomorphs in the third well, 7/11-8, could however not be confirmed. Thermally altered, brown to darkbrown spores, pollen and dinoflagellate cysts recovered from this well appear all to be caved from Lower Cretaceous strata.

In well 8/11-1 Triassic palynomorphs are very rare, brown in colour. The presence of *Illinites chitonoides* at 3182m and *Staurosaccites quadrifidus* at 3100m indicate a top Ladinian and top Early Carnian age, respectively. Other Triassic palynomorphs identified are e.g. *Enzonalasporites* spp., and *Protodiploxypinus* spp.

In well 9/4-5 Triassic palynomorphs could be identified within the investigated interval (3773–4349m), even though they were of very high thermal maturity, darkbrown to black in colour. Most of the palynomorphs present in these assemblages are poorly preserved beyond recognition, but some are still identifiable. The presence of *Staurosaccites quadrifidus* (LAD top Early Carnian) and *Protohaploxypinus rieberi* (LAD early Late Carnian) at 4084m suggest an age not younger than top Early Carnian at that level. The co-occurrence of *Triadispora* sp. Cf. *T. crassa*, *Enzonalasporites* spp., and *Duplicisporites granulatus* somewhat higher within the investigated interval may suggest a Late Carnian age for that interval.

During the Middle to early Late Triassic the Central Graben was situated around 30–35°N and the arid to semi-arid conditions that had developed during the Early Triassic continued. While Middle to lower Upper Triassic successions of the Arctic, Alpine and Tethys regions show evidence of fairly rich and diverse vegetation, the pre-Rhaetian Triassic red beds of the North Sea area contain only sparse palynomorphs. This does not necessarily mean that there were no plants growing in the area at the time of deposition. Most arid areas today host some vegetation adapted to such hostile climate, but conditions for palynomorph preservation in such areas are generally poor due to oxidation of the sediments. However, the present study indicates that during a restricted interval in the latest Middle Triassic the area hosted a relatively diverse vegetation and the climatic conditions in the area were better suited for palynomorph preservation (Lindström *et al.* 2009).

The Ladinian to Carnian palynofloras recovered in this study contain several elements typical of warm and dry conditions. The taeniate bisaccates, e.g. *Lunatisporites* and *Protohap-*

*Ioxypinus*, are generally regarded to have been produced by pteridosperms, and adapted to warm and dry conditions. The bisaccate pollen of *Triadispora*, *Protodiploxypinus*, *Illinites* and *Staurosaccites*, as well as the monosaccate pollen *Enzonalsporites*, and pollen of the Circumpolles group, i.e. *Duplicisporites*, are all believed to be derived from conifers. The Circumpolles group is only recorded in some of the investigated assemblages. They are regarded to be related to the cheirolepids, a group of conifers often associated with warm and dry conditions. In similar aged palynofloras from central and south Europe, pollen of the Circumpolles group tend to be much more abundant.

Thus, despite the high to very high thermal maturity of the organic material, Ladinian to Early Carnian palynofloras could be identified in the uppermost Smith Bank Formation and the Skagerrak Formation of the Central Graben (Enclosure 4). The palynofloras indicate a generally warm and dry climate, but with conditions that at times favoured palynomorph preservation. The palynofloras can be partly correlated with the Ladinian palynofloras reported from the Norwegian–Danish Basin by Lindström et al. (2009).

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## **Abbreviations**

The following abbreviations are used in the report when referring to the stratigraphic occurrence of a taxon within the investigated wells.

LO= Last occurrence, i.e. highest stratigraphic occurrence of a taxon in the investigated wells

FO= First occurrence, i.e. lowest stratigraphic occurrence of a taxon in the investigated wells

The following abbreviations are used in in this report in order to describe the known stratigraphic occurrences of palynomorph taxa in the literature.

LAD= Last appearance datum, known last occurrence of a taxon

LCAD= Last common appearance datum, known last common appearance of a taxon

FAD= First appearance datum, known first occurrence of a taxon

FCAD= First common appearance datum, known first common appearance of a taxon