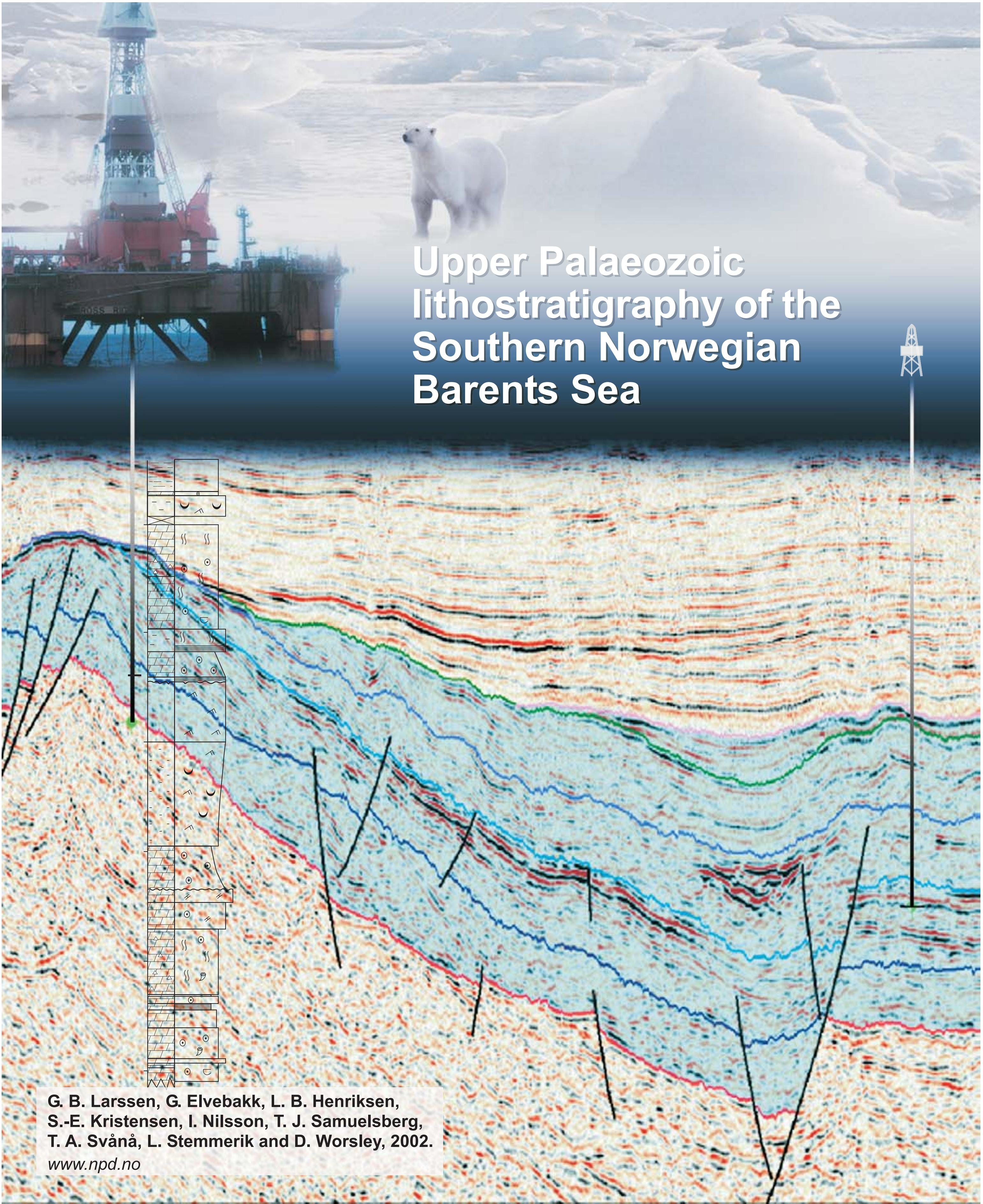

# Upper Palaeozoic lithostratigraphy of the Southern Norwegian Barents Sea

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S.-E. Kristensen, I. Nilsson, T. J. Samuelsberg,
T. A. Svånå, L. Stemmerik and D. Worsley, 2002.

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***Frontpage***

The frontpage collage illustrates the Upper Palaeozoic succession on the Loppa High from its crest eastwards towards the Bjarmeland Platform, showing fault control on sedimentation and reefoid features in both the Gipsdalen and Bjarmeland groups. A sedimentological log from well 7120/2-1 on the crest of the Loppa High illustrates parts of the Falk Formation.

# UPPER PALAEOZOIC LITHOSTRATIGRAPHY OF THE SOUTHERN NORWEGIAN BARENTS SEA

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## *Abstract*

The Norwegian sector of the southern Barents Sea has been the target for hydrocarbon exploration for over 20 years and to date almost 60 exploration wells have been drilled in this still under-explored province. Only a quarter of these wells have penetrated the Upper Palaeozoic succession, often only because of a TD criterion set by the authorities – although some wells have targeted varied play types within the Upper Palaeozoic. Accumulated knowledge from this exploration programme has gradually led to the present-day situation, where exploration of these Upper Palaeozoic plays may well represent the next major development in the area.

In contrast to the overlying Mesozoic and Cenozoic successions, no formal lithostratigraphical framework has yet been established for these Upper Palaeozoic strata, which although similar in gross terms to the onland exposures of the Svalbard archipelago also display significant differences, clearly contrasting the generally stable platform aspect of the Svalbard exposures and the more labile platforms and significant basinal developments offshore.

This work was therefore commissioned by the Norwegian Petroleum Directorate in recognition of the need for a formal lithostratigraphical framework for a succession that may well prove to be of great commercial interest in coming years. Reviews of all seismic and well data from the area have led to our recognition and acceptance of the long-established usage of the Billefjorden, Gipsdalen and Tempelfjorden groups from onshore Svalbard, but we define 8 new formations and assign them to these groups to reflect the offshore development of the Upper Palaeozoic succession. In addition, we define 3 formations that together represent the Bjarmeland Group – a mid-Permian carbonate development only poorly represented – and as yet poorly defined - in highly condensed sequences onshore Svalbard.

## *Preface*

Upper Palaeozoic rocks underlie most of the extensive Barents Shelf, and a long awaited formal lithostratigraphical scheme is now been proposed for the region, with the participation of geologists with long experience of this succession in the area.

The Norwegian Petroleum Directorate (NPD), through the senior author of this contribution, initiated the study and a committee was appointed in 1994 in order to pool the collective experience of the Norwegian oil companies active in the region. The work has been sponsored and supported by the Norwegian Project on Exploration Cooperation, led by NPD. Preparation of the publication has taken several years, with delays resulting from restructuring of exploration activity in the area and resulting reassignment and changes in company affiliation of many key contributors; the original group of authors has been changed and extended in the course of the work. The committee's recommendations were integrated with the revision of the post-Caledonian lithostratigraphy of Svalbard led by Winfried K. Dallmann (Dallmann et al. 1999). Geir B. Larssen has coordinated the work during the entire study.

The manuscript has been review by the Norwegian Committee on Stratigraphy (Johan Petter Nystuen, Winfried K. Dallmann and Atle Mørk), and the Norwegian names have been approved by Norsk språkråd (Marit Hovdenak).

A provisional version of this new lithostratigraphical framework was first presented at the Norwegian Geological Society's (NGF) 16th Congress in Stavanger in January 1999, and a somewhat condensed version, with a smaller number of figures, will be formally printed in a recognised journal. This present version, with extensive plates and diagrams, represents the first formal electronic publication on the World Wide Web that has been approved by the Norwegian Committee on Stratigraphy, and this WWW version is to be regarded as a fully refereed and editorially approved publication. The correct way to refer to this publication is indicated below.

Trondheim November 2002

Atle Mørk

Chairman, Norwegian Committee on Stratigraphy

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**We sincerely hope that this contribution will provide a framework for future exploration in the Norwegian Barents Sea.**

# INTRODUCTION

## *Background*

The Barents Sea covers a vast shelf area that extends from Novaya Zemlya in the east to the continental slope of the Norwegian-Greenland Sea in the west, and from Svalbard and Franz Josef Land in the north to the coasts of Norway and Russia in the south. The dividing line between Russia and Norway has not yet been resolved; Norwegian authorities suggest a midline division between the various Norwegian and Russian land areas and islands while the Russians favour a sector-based division generally extending from the mainland Russian/Norwegian border towards the North Pole (Fig. 1). The Barents Sea between the Norwegian coast and Svalbard comprises a continuous shelf area, mainly covered by thick Upper Palaeozoic to Tertiary sequences. Caledonian and earlier basement is only exposed along the Norwegian coast, on the island of Bjørnøya on the Stappen High and on and around the islands of Spitsbergen and Nordaustlandet on the northern Barents Shelf (Worsley *et al.* 1986; Harland 1997). At present most of the southern part of the Norwegian sector is open for commercial exploration; this comprises an area of about 240 000 km$^2$, delimited to the north by the 74°30′ N latitude, to the south by 69°30′ N, with the baseline marking the limit of the Norwegian north coast; to the west, 16° eastern longitude marks the limit from 72° N to 74°30′ N. Because of availability of data this present study concentrates on the southern sector of the Norwegian Barents Sea, in itself almost double the size of the Norwegian North Sea. However, we will also make comparisons to time-equivalent sequences in the northern Barents Shelf, onland Svalbard, the Russian sector and northern Greenland and arctic Canada.

Geological exploration of the Norwegian Barents Shelf started with seismic surveys in the 1970s, resulting in the first differentiation of the province into a series of major subprovinces with a complex structural and sedimentological development (Rønnevik *et al.* 1982; Rønnevik & Jacobsen 1984; Faleide *et al*. 1984). Hydrocarbon exploration drilling started in 1980 and this ongoing exploration activity has resulted in a series of papers integrating regional well information with the steadily expanding seismic grid and pointing out the regional similarities of the geological development of Svalbard and both the Norwegian and Russian sectors of the Barents Shelf (e.g. Johansen *et al.* 1993; Nøttvedt *et al*. 1993). A total of 59 exploration wells have been drilled in the Norwegian Barents Sea, with more than half of these located in a relatively small area either in, or in close proximity to the Hammerfest Basin (Figs. 1 & 2). The remaining wells are spread across the shelf and have tested a variety of plays - 14 wells have drilled in-situ Upper Palaeozoic strata (Table 1), but only 6 of these had the Upper Palaeozoic succession as a primary or additional target. In most cases the coring programme was limited, an important exception being 7128/6-1 on the Finnmark Platform, which cored almost half of the 900 m thick Upper Palaeozoic section there (Ehrenberg *et al.* 1998a). In addition, the oil industry has financed IKU Petroleum Research[1] to drill over 50 shallow stratigraphic boreholes (normally penetrating up to 200 metres into bedrock and giving a total of 3700 m of core) during the latter half of the 1980s. Eleven of these reached the Upper Palaeozoic succession (Table 1, see also Bugge *et al.* 1995). In addition to the well and core data, almost 400 000 kilometres of 2D seismic and 10 000 $km^2$ of 3D seismic have been acquired in the southern Norwegian Barents Sea; these data, integrated with relevant wells and shallow cores, have permitted increasingly more sophisticated analyses and syntheses of the late Palaeozoic development of the area (Nilsen *et al.* 1993; Cecchi 1993; Gudlaugssen *et al.* 1994; Ehrenberg *et al.* 1998a,b, 2000, 2001, 2002; Elvebakk *et al.* 2002).

Two wells drilled in 1984/5 as a result of the 5th Concession Round were aimed at the Upper Palaeozoic succession of the Finnmark Platform margins, although this round's main thrust was to explore the Mesozoic potential of the Hammerfest Basin. More emphasis was placed on the Upper Palaeozoic succession in the 9th Concession Round and this resulted in 3 wells on the southern margins of the Loppa High, drilled in 1985 and 1986. One of these (7120/2-1) had a significant oil column, although there has been much discussion as to whether unsuccessful testing suggested this was biodegraded "dead" oil (Knutsen *et al.* 2000) or that the carbonate reservoir was apparently tight and testing inadequate. Other wells drilled as a result of the drilling campaigns of the 5th to 12th concession rounds encountered or had TD in the Upper Palaeozoic, giving partial information on the upper parts of this succession. From the 11th Round in 1987 onwards the exploration area was extended to the entire southern sector of the Barents Sea, and especially in the 13th and 14th concession rounds in 1991 and 1993, play models with the Upper Palaeozoic succession as reservoir target were among the most important to be tested. A small gas and oil discovery was made in Upper Permian rocks in well 7128/4-1 drilled on the Finnmark Platform in 1993 and 7128/6-1 in the same area had oil shows in Upper Carboniferous carbonates. These finds, together with promising reservoir properties in older wells on the Finnmark Platform and the Loppa High, led the authorities to increase their expectations to the amount of undiscovered resources in the succession (NPD 1996). The Finnmark Platform and the Loppa High were therefore key exploration areas for the Upper Palaeozoic in the "Barents Sea Project", a cooperative effort between the authorities and the oil industry, which resulted in 1997 in the awards of several large "seismic option areas", where it was hoped that further work by the licensees would result in the future allocation of licences to drill exploration wells. No wells have yet been drilled in this ongoing exploration campaign, but well 7228/7-1 (13th Round) drilled in the Nordkapp

[1] Now SINTEF Petroleum Research

Basin in 2000 encountered hydrocarbons in Triassic sandstones, apparently confirming the side-sealing capacity of Upper Palaeozoic salt diapirs in the Nordkapp Basin (see also below).

## *Procedure*

In the present work, use of the formal group names of the correlative Upper Palaeozoic succession of Svalbard has been extended to the southern Barents Sea because of the overall regional continuity and lithological similarities to the onshore succession. In addition, one new group has been introduced to include a thick succession of Permian cool-water carbonates in the offshore areas that are represented by the apparently condensed development of the Hambergfjellet Formation on Bjørnøya. All the offshore formations are new and are formally defined; well logs illustrate the type and reference sections and, where possible, sedimentological logs and photos of cored intervals are also presented. In accordance with the recommendations of the Norwegian Stratigraphic Committee (Nystuen 1986), wells with adequately cored intervals have been given precedence as type sections if these cored intervals are otherwise typical for the particular formation when compared to uncored reference sections with only electrical logs.

Because of the limited number of wells penetrating the Upper Palaeozoic succession, the new lithostratigraphic units are defined in relatively general terms in this paper and our proposals are open to further refinement when more wells are drilled. This is particularly the case for the basinal evaporite-dominated succession of the Gipsdalen Group. Unpublished descriptions of cores through the Upper Palaeozoic succession of Hopen drilled by Fina in the late 1960s and early 1970s and recent work in the northern sector of the Norwegian Barents Sea (Grogan *et al.* 1999) suggest that the same group divisions will also be applicable in those northern areas, but neither formational assignations nor definitions of new formational units are yet feasible there.

## *Presentation of data*

Exploration well logs are presented with depths cited as metres relative to KB. Data from IKU shallow cores are referred to with depths below mean sea level (in contrast to Bugge *et al.* 1995, where depths refer to sea-bottom). The well logs display interpreted lithology together with gamma ray, density, neutron and sonic logs (lithological symbols are defined in Fig. 3). Text descriptions of unit boundaries are presented stratigraphically, *i.e.* with upward variation in log response across a boundary. For each group, a correlation scheme is presented giving a broad lithological overview of the formations and pictures of typical lithologies are shown throughout. Core descriptions of type sections are also presented.

## *Chronostratigraphic framework*

Ages referred to in the text are generally at stage level, and more precise ranges are only presented when this is possible. Age designations for the different units are based on unpublished consultant and in-house reports and on data published by Nilsson (1993), Mangerud (1994), Bugge *et al.* (1995), Stemmerik *et al.* (1995, 1998) and Ehrenberg *et al.* (1998a, 2000, 2001). The published material is given preference. Age designations are based mainly on palynomorphs in the Lower Carboniferous and Upper Permian part of the succession and on fusulinids in the Upper Carboniferous and Lower Permian. Nomenclature in general corresponds to the time scale of Gradstein & Ogg (1996), including a twofold division of the Permian (Fig. 4).

## *Geological setting*

The present Barents Sea, including the Svalbard archipelago, is a pericontinental shelf area bounded by two passive margins: in the west by the Norwegian-Greenland Sea and in the north by the Eurasian Basin. Towards the east, the shelf is delimited by the extension of the Ural mountain chain through Novaja Zemlya and in the south by the Baltic Shield. The principal structural elements of the Norwegian sector of the southern Barents Sea were defined by Gabrielsen *et al.* (1990) and augmented by Gudlaugsson *et al.* (1994). Since those publications, the Norwegian Petroleum Directorate has extended its mapping in the region, particularly in the Northern Barents Sea, and new names have been introduced to establish a complete description of the structural elements in the region (NPD 1996; Grogan *et al.* 1999). The region exhibits a more or less continuous sedimentary succession from the Carboniferous to Quaternary; many structural elements reflect Jurassic and later tectonism: not least a Tertiary phase of differential uplift had a profound effect on the final sculpting of the province (Nyland *et al.* 1992).

The most important Upper Palaeozoic tectonic provinces are described below: we should note that the region had a totally different setting in the Upper Palaeozoic, when it formed part of a vast continental shelf extending from the developing Uralides westwards through northern Greenland and the Arctic Canada Sverdrup Basin to Alaska (Worsley *et al.* 1986; Beauchamp *et al.* 1989; Doré 1991; Stemmerik & Worsley, 1989, 1995). The northern limits of that late Palaeozoic shelf are still a matter of debate – some authors have presented reconstructions invoking the existence of land areas to the north – slivers of northern Alaska and northeastern Siberia (Harland *et al*. 1984; Embry 1989, 1993) - to explain the provenance of siliciclastic sediments from that direction. This vast province was characterised by a series of intrashelf basins, some – e.g. the Nordkapp and especially the Sverdrup Basin - of huge dimensions. The Upper Palaeozoic in this entire region displays 4 major sequences (Fig. 4), the boundaries between which reflect significant changes in climate, sea-level and tectonic regime; not least climate was an important controlling factor on sedimentational regimes – the region apparently passed from the humid tropical zone in the early Carboniferous through the northern arid zone in the mid-Carboniferous to early Permian, before entering more temperate conditions in the mid-Permian (Steel & Worsley 1984; Worsley *et al.* 1986; Stemmerik & Worsley 1989; Beauchamp 1993; Stemmerik 1997, 2000).

### *Hammerfest Basin*

The Hammerfest Basin is bounded by the Finnmark Platform in the south and by the Loppa High and the Bjarmeland Platform in the north (Fig. 1). The basin is fault-controlled, extending E-W and was probably established in the Late Carboniferous (Gabrielsen *et al.* 1990), although main subsidence occurred in the Triassic and the early Cretaceous. Basinal development largely culminated in the mid-Cretaceous, but highly condensed upper Cretaceous and thin lower Tertiary shales are also preserved, in the basin, in spite of extensive late Tertiary uplift. There is no evidence of extensive late Palaeozoic evaporite deposition or of diapirism in the basin, in contrast to the Tromsø Basin to the west and the Nordkapp Basin to the east. The basin's internal structure is characterised by a central dome located along the basin axis and by a complex pattern of dominantly westerly and west-northwesterly trending faults; all of these features predominantly reflect late Jurassic tectonism. A total of 29 exploration wells have been drilled in the Hammerfest Basin but only 2 have penetrated the Upper Palaeozoic succession (7120/9-2 in the basin itself had TD about 117 m below the top Permian, while 7120/12-2 on the southern margins penetrated a 1000 m thick upper Permian sequence resting on lower Permian dolomites and then red beds and basement).

### *Finnmark Platform*

The Finnmark Platform is bounded by the Norwegian mainland to the south, by the southernmost extension of the Ringvassøy-Loppa Fault Complex to the west, and by the Hammerfest and Nordkapp basins to the north (Fig. 1). The eastern part of the Finnmark Platform in the Norwegian sector is characterised by an underlying rift topography with fault blocks containing siliciclastic sediments of Early Carboniferous age; these were onlapped in the mid-Carboniferous and the overlying sequence is carbonate-dominated, with minor evaporites in certain intervals (Figs. 5a & b). This development continues eastwards, paralleling the Kola Peninsula and on to the Timan-Pechora Basin, which shows a generally similar development (Johansen *et al.* 1993). During the course of the Permian the entire more stable western platform area (west of approx. 25°) was transgressed, resultant sequences being characterised by siliciclastic and carbonate deposits. Late Jurassic movements along pre-existing faults later modified the platform, and late Tertiary differential uplift resulted in the present, gentle northward tilt of the platform. Five exploration wells have been drilled on the Finnmark Platform, all reaching the Upper Palaeozoic (7120/12-4 on the western platform and 7229/11-1, 7128/4-1, 7128/6-1 and 7228/9-1 in the east). In addition, 8 shallow cores have penetrated various parts of the Upper Palaeozoic succession, providing important stratigraphic and sedimentological information (Bugge *et al.* 1995; Stemmerik *et al.* 1995).

### *Loppa High*

The Loppa High is a marked structural feature, sharply separated by the E-W trending Asterias Fault Complex from the Hammerfest Basin to the south and by the Ringvassøy – Loppa and the Bjørnøyrenna fault complexes from the Tromsø and Bjørnøya basins to the west (Gabrielsen *et al.* 1990) (Fig. 1). Eastwards it grades gently downwards into the Bjarmeland Platform. The area has undergone a complex geological history characterised by several phases of uplift/subsidence and subsequent tilting and erosion. The Loppa High exhibits a Mid-Carboniferous rift topography that was filled and draped successively by Upper Palaeozoic siliciclastic deposits, evaporites and carbonates (Figs 5c & d). Tectonic tilting during the Late Permian and Early Triassic was followed by gradual onlap during the early and mid-Triassic before rapid subsidence and the deposition of an unusually thick Upper Triassic succession, which now subcrops the Quaternary. Three exploration wells have been drilled on the Loppa High, all penetrating the Upper Palaeozoic succession (7120/1-1, 7120/2-1 and 7121/1-1).

### *Bjarmeland Platform*

The Bjarmeland Platform includes the extensive platform areas east of the Loppa High and north of the Nordkapp Basin (Figs. 1, 5Bb). Towards the south and west, the platform is divided into minor highs and sub-basins, thick evaporites and diapirism characterising one of these (the Svalis Dome, site of extensive shallow coring by IKU). The platform was established in the Permian, but subsequent uplift and erosion tilted the Palaeozoic and Mesozoic sequences towards the south so that unconsolidated Quaternary sediments overlie successively older rocks towards the north. Five exploration wells have been drilled on the Bjarmeland Platform, two of them in the transitional area between the platform and the Nordkapp and Hammerfest basins - both of these wells reached the Upper Palaeozoic (7226/11-1 and 7124/3-1), the former demonstrating mid-Carboniferous onlap of basement.

### *Nordkapp Basin*

The Nordkapp Basin is a fault-controlled basin located along the northeast-southwest trending Palaeozoic rift that extends eastwards from the Hammerfest Basin (Gabrielsen *et al.* 1990). The basin is bounded by the Bjarmeland Platform to the north and the Finnmark Platform to the south (Fig. 1) and is divided into a southwestern and a northeastern segment. During the late Palaeozoic this was a site of extensive halite deposition and the basin is characterised by pronounced salt diapirism. The movement of Palaeozoic salt began in the Early Triassic, and the diapirs have undergone several phases of development. The basin is apparently dominated by a thick, Mesozoic, mainly Triassic, succession, but poor seismic resolution makes determination of Palaeozoic thicknesses uncertain – although in contrast to the Hammerfest Basin, they were surely significant. One exploration well (7228/9-1S) drilled on the margin of the Nordkapp Basin penetrated the Upper Palaeozoic succession; it bottomed in mobilised halite of the Gipsdalen Group. A second well (7228/7-1) drilled recently in the basin itself penetrated Triassic sandstones abutting a late Palaeozoic diapir; this well also encountered an apparently allochthonous block of Permian carbonates, apparently moved out of place as a result of the diapirism.

### *Ringvassøy-Loppa and Bjørnøyrenna fault complexes*

The boundary between the older platform areas and highs in the east and the deep, younger basins along the western margin of the Barents Sea is defined by a series of fault complexes in the area south of 74º30' N. The heavily faulted and tilted zone along the western margins of the Finnmark Platform passes northwards into the NNE-trending Ringvassøy-Loppa Fault Complex, which separates the Hammerfest Basin from the deep Tromsø Basin and the Loppa High, before forming the southwestern margins of the Loppa High (Gabrielsen *et al.* 1990) (Fig. 1). Towards the north, this abuts the NNE trending Bjørnøyrenna Fault Complex, which defines the junction between the northern Loppa High and the Bjørnøya Basin. The main faults within this province are of Palaeozoic and older origin and were reactivated several times during the Mesozoic and Tertiary. Several exploration wells have been drilled in the area; one of them, 7119/7-1 in the downfaulted Tromsø Basin, was terminated in a diapir mobilising salt of probable late Palaeozoic age.

### *The Bjørnøya Basin*

The Bjørnøya Basin trends NE-SW between the Loppa and Stappen highs. It is separated by the Leirdjupet Fault Complex into a deeper western and shallower eastern part (the Fingerdjupet Subbasin). Although predominantly a Mesozoic feature, with an extremely thick Cretaceous section, rifting may have started already in the late Palaeozoic to form a precursor to the major Mesozoic subsidence event. Three exploration wells have been drilled in the in the Fingerdjupet Subbasin, one of them, 7321/8-1 penetrated 86 m of Upper Permian rocks.

### *The Barents Sea western margin*

The Barents Sea margin consists of deep basins of late Mesozoic and Tertiary age, including the Harstad Basin, the Tromsø Basin, the Sørvestsnaget Basin and the Vestbakken volcanic province (Fig. 1). The Mesozoic Senja Ridge and the Veslemøy High define the southeastern margins of the Sørvestsnaget Basin. Seismic observations suggest the presence of salt or mud diapirs in the Sørvestsnaget Basin, in the former case possibly suggesting a Late Palaeozoic age for the basin. None of the exploration wells drilled so far on the Barents Sea margin have reached the Upper Palaeozoic.

## *Stappen High/Bjørnøya*

The Stappen High trends N-S from 73º30′ N to at least 75º30′ N at 18 to 19º E (Gabrielsen *et al*. 1990). Bjørnøya forms its highest point lying at the boundary between the Barents Sea marginal basins and the Palaeozoic and Mesozoic platform areas in the east. The Stappen High, like the Loppa High, underwent a complex late Palaeozoic development involving several phases of uplift, faulting and tilting, all of which have resulted in a condensed and highly variable Upper Palaeozoic and Triassic sedimentary succession (Worsley *et al*. 2001). Thermal indicators suggest rapid subsidence (Sættem *et al*. 1994) through the rest of the Mesozoic before the area again became a positive element at some stage in the Tertiary.

## LITHOSTRATIGRAPHY

Our proposed lithostratigraphic nomenclature for the Upper Palaeozoic succession in the southern Norwegian Barents Sea is based on studies of 13 exploration wells and 12 IKU shallow cores, combined with relatively good seismic coverage (Figs. 2 & 5). Recently, important stratigraphic and sedimentological information based on data from the wells have been presented in a series of papers (Bugge *et al.* 1995; Ehrenberg *et al.* 1998a, 1998b, 2000, 2001; Stemmerik *et al.* 1995, 1999; Blendinger *et al.* 1997; Groves & Wahlman 1997), and a formal lithostratigraphic framework for the offshore areas is needed to avoid nomenclatorial confusion in future publications. So far, different authors have often assigned units and sequences to chronostratigraphic epochs with or without the additional use of varying numerical or alphanumerical schemes (see e.g. Bruce & Toomey 1993; Bugge *et al.* 1995; Cecchi 1993; Ehrenberg *et al*. 1998a; Nilsen *et al.* 1993).

The offshore succession comprises 4 major depositional units, *viz*. the Billefjorden Group, the Gipsdalen Group, the Bjarmeland Group and the Tempelfjorden Group. Only three groups were originally defined by Cutbill & Challinor (1965) in the time-equivalent onshore successions of Spitsbergen and Bjørnøya, but Dallmann *et al.* (1999) recognised the presence of Bjarmeland Group representatives on Bjørnøya – *viz*. the Hambergfjellet Formation. The Billefjorden, Gipsdalen and Tempelfjorden groups represent significantly different major lithostratigraphical units that are easy to recognise both onshore and offshore as their boundaries reflect major shifts in depositional conditions caused by changes in palaeoclimate, basin configuration, drainage patterns, relative sea level and tectonic setting. We believe that the Bjarmeland Group is represented by a major hiatus in most onshore areas of Svalbard – apart, as noted above – from Bjørnøya (Fig. 6).

Seismic images from the Loppa High and the Bjarmeland Platform and from the Finnmark Platform into the Nordkapp Basin illustrate the distinctive regional character of these groups in the southern Norwegian Barents Sea (Fig. 5). The seismic image from the Loppa High (Fig. 5a) shows a regional event truncating the Gipsdalen Group and we believe that this event is the reason why sediments equivalent to the Bjarmeland Group are missing or very thinly developed in the onshore area. The seismic images also give examples of large-scale carbonate buildups in the Gipsdalen and the Bjarmeland groups on the Bjarmeland Platform (Fig. 5b). The buildups are all located along older structural highs or show a preference to stack on top of each other. The seismic image from the Finnmark Platform into the Nordkapp Basin (Fig. 5c) illustrates how salt pillows within the Gipsdalen Group have been formed along the margin of the basinal area. Further south on the Finnmark Platform the seismic image (Fig.5d) shows an example of carbonate buildups overlain by spiculites in the Tempelfjorden Group - these appear as seismic anomalies. The seismic images also illustrate the thickness variations in the Billefjorden Group which are strongly controled by Middle-Upper Carboniferous tectonics.

## Billefjorden Group (Billefjordgruppa)

***Name:***

Cutbill & Challinor (1965) introduced the term "Billefjorden Group" for a suite of non-marine sediments now recognised to be of late Devonian to early Carboniferous age. The type area is in the environs of Billefjorden in central Spitsbergen. The Billefjorden Group is a well-established lithostratigraphic unit and its overall facies development and depositional evolution is well known (e.g. Gjelberg 1981; Steel & Worsley 1984). Lower Carboniferous units in the southern Norwegian Barents Sea are herein also assigned to the group. The offshore development of the group resembles that described from onshore with one major exception: the upper part of the group includes some shallow marine deposits in the southeastern Finnmark Platform. As yet enigmatic red-bed sequences on the Loppa High are also tentatively assigned to the group, but need further investigation (see below).

***Offshore reference areas:***

The Barents Sea subsurface reference area is located on the eastern Finnmark Platform (Figs. 1, 2 & 7), where the Billefjorden Group has been penetrated in its entirety in wells 7128/4-1 from 2503 to 2058 m (Fig. 8) and 7128/6-1 from 2533.5 m to 2150 m (Fig. 9). Southwards, towards the Norwegian mainland, the Upper Palaeozoic succession subcrops against the Pliocene/Pleistocene unconformity and the IKU shallow cores 7127/10-U-02, 7127/10-U-03 and 7029/03-U-01 penetrated different intervals of the group (Bugge *et al.* 1995). Present seismic coverage and quality provides reasonable control on the seismic-scale lateral development of the group on the Finnmark Platform.

***Thickness:***

Thicknesses of 445 m and 384 m in wells 7128/4-1 and 7128/6-1 respectively should be compared to cumulative thicknesses of up to 2500 m in the type area of Billefjorden and of 590 m on Bjørnøya (Dallmann *et al*. 1999; Worsley *et al*. 2001). As elsewhere, the group's sediments were deposited in the early phase of a period with active rifting, and both wells are located over the crests of structural highs in the southern part of the Finnmark Platform; seismic data indicate that the group is more than 600 m thick in the adjacent half-grabens. Well 7120/2-1 on the Loppa High penetrated an 847 m thick succession of sediments tentatively assigned herein to the Billefjorden Group; the succession was encountered from 2624 m to 3471 m, before the well was terminated in a possible dolerite (Fig. 10, see also discussion in next section).

***Lithology:***

On the Finnmark Platform, medium- to coarse-grained, occasionally conglomeratic, sandstones and minor siltstones and coals dominate the basal part of the succession represented by the Soldogg Formation. These are overlain by a succession of stacked metre-scale fining-upward cycles of sandstone, siltstone, claystone and coal assigned to the Tettegras Formation. The upper part of the group, represented by the Blærerot Formation, is characterised by a basal unit of fossiliferous limestones, overlain by marine shales and fine- to medium-grained, fluvial and shallow marine sandstones.

Sediments tentatively assigned to the group are very differently developed on the Loppa High where well 7120/2-1 penetrated 847 m of varicoloured arkosic breccias, conglomerates, ignimbrites and other types of volcanoclastic deposits (Fig. 10). The basal 115 m are dominated by brownish siltstone and mudstone. The red nature of these sediments, together with their high content of volcanoclastics, makes them anomalous representatives of the Billefjorden Group in this area, although palynomorphs indicate an early Carboniferous age (Viséan PU to VF Miospore zones from 3467 to 2682 m and early Serpukhovian TK Zone from 2645 to 2630 m) (Lindström, in press). The only other arctic areas where lower Carboniferous red beds have been found are in the northern part of eastern Greenland (Stemmerik *et al*. 1993), but even there the change to red beds appears to have occurred in the late Tournaisian – i.e. older than the earliest datings on the Loppa High. The Loppa sequence's overall lithology and tectonic setting seems rather to suggest closer affinities to the lowermost clastics of the overlying mid-Carboniferous Gipsdalen Group. More work is clearly needed on this problem, especially in view of this representing the only occurrence of volcanoclastics in the Upper Palaeozoic of the Barents Shelf; we note that dolerite dykes of probable mid- to late Carboniferous age have been reported by Lippard & Prestvik (1997) on Magerøy in Finnmark and mid-Carboniferous volcanics have also been identified on the adjacent Kola peninsula in northern Russia (Ulmishek 1982). In view of these uncertainties, this sequence has not yet been defined as a formational unit, and its assignment to the Billefjorden Group is still tentative.

***Lateral extent and variation:***

The group is generally difficult to map outside the Finnmark Platform and little is known about its regional distribution and variation, although the overall impression is that the Billefjorden Group represents thick siliciclastic-dominated wedges that fill developing Carboniferous half-grabens in the southwestern Barents Sea. On the Finnmark Platform itself seismic mapping of the group suggests pronounced lateral variations in thickness due to infill of local half grabens resulting from Viséan–Serpukhovian rifting. Most of the thickening and probably most of the lateral facies changes are in the uppermost part of the group. The rift event appears to be less pronounced east of approximately 29°30' on the Finnmark Platform where the base of the group is poorly defined seismically. A possibly pre-Viséan sedimentary succession is present locally in this eastern part of the platform. The group's representatives also seem to infill local half-grabens on the Loppa High and the Norsel High (central Bjarmeland Platform), and deeply buried half-graben systems appear to be also present further to the east on the Bjarmeland Platform. Thick wedge-shaped units corresponding to the Billefjorden Group are observed on seismic lines along the margins of the Nordkapp Basin, suggesting that the basin already formed a major depocentre at that time.

Sediments assigned to the Billefjorden Group are generally separated from the underlying strata by an angular unconformity, as seen in wells 7128/6-1, 7128/4-1 and core 7029/03-U-01. In 7128/6-1, the group rests on Precambrian metasandstones (Røe & Roberts, 1992) at 2533.5 mRKB, with a 45 m thick transitional zone of conglomeratic sandstones interpreted as weathered and reworked basement rocks. These sediments are included in the Billefjorden Group (see definition of Soldogg Formation). Upwards, they pass into more mature sandstones with rare siltstone and coal beds defined by a sharp upward decrease in bulk density and sonic velocity at 2488.5 m.

***Age:***

The Billefjorden Group has been assigned to the Famennian to Viséan in the onshore areas of Bjørnøya and Spitsbergen (Dallmann *et al*. 1999; Worsley *et al*. 2001). The offshore development has been dated to the Viséan to early Serpukhovian. On the Finnmark Platform, palynomorphs suggest that the basal part of the group is of middle to late Viséan age (Bugge *et al.* 1995), i.e. significantly younger than the Famennian to Tournaisian age recorded for the basal sediments onshore. The upper part of the group is apparently of late Viséan to early Serpukhovian age (Bugge *et al.* 1995; Simon-Robertson 1992 and Geochem Group 1994). As noted above - the succession on the Loppa High has been dated to the Viséan to early Serpukhovian (Lindström, in press).

***Depositional environments:***

The Billefjorden Group is characterised by an overall transition from continental fluvially dominated deposits of the Soldogg and Tettegras formations into transitional continental to marginal marine deposits of the Blærerot Formation on the eastern Finnmark Platform. The presence of coal indicates deposition in overall humid climatic conditions - in contrast to the overlying Gipsdalen Group that is characterised by sediments deposited in more arid climates.

Shallow core data from 7029/03-U-01 suggest that the lower parts of the Soldogg Formation represent basement wash and braided river deposits. These pass upwards into delta/coastal plain sandstones, siltstones, claystones and coals of the Tettegras Formation, and are overlain by marine and transitional continental to marginal marine deposits of the

Blærerot Formation in well 7128/6-1. The transitional nature of this upper part is demonstrated by rare coal beds in the lowermost part of the formation at well 7128/6-1. The Blærerot Formation appears to be missing in 7128/4-1 either as the result of local uplift and erosion or because the marine transgression never reached the high on which the well was drilled. This depositional area was separated by a major fault southwest of well 7128/4-1 from the provenance areas of basement rocks and metasediments towards the Finnmark coast (Gabrielsen *et al.* 1990). Shallow cores 7127/10-U-02 and 7127/10-U-03 were taken in a proximal position, 2-3 km away from this main fault and record a thick development of Viséan syn-rift fluvial deposits (Bugge *et al.* 1995).

The succession on the Loppa High apparently represents deposition in alluvial fans and proximal braided river systems in a rapidly subsiding sub-basin. Local volcanic activity is suggested on the basis of the large amount of volcanoclastic material in well 7120/2-1.

The depositional environments recorded from the Finnmark Platform generally resemble those recognised in the onshore areas of Spitsbergen and Bjørnøya. The most important difference is the evidence of marine flooding of the eastern Finnmark Platform, perhaps suggesting more prevalent marine conditions in the contemporaneous Nordkapp Basin, with transgression from the east. The lithofacies and depositional environments of the Billefjorden Group on Spitsbergen and Bjørnøya are summarised by Gjelberg (1981), Steel & Worsley (1984) and Harland (1997), all emphasising the considerable facies variations related to local variations in tectonic regime. The reservoir potential of the group's sandstones has been noted by several authors (Grønlie *et al*. 1980, Steel & Worsley 1984, Worsley *et al*. 2001).

***Formations assigned to the group:***

The Billefjorden Group is represented by three formations on the Finnmark Platform and these are formally defined and described herein. Formational names are selected from land plants found in northern Norway that utilise nourishment from insects that stick to their leaves. The succession in well 7120/2-1 on the Loppa High is not yet given any formal formational status.

### *Soldogg Formation (Soldoggformasjonen)*

***Name:***

From the Norwegian name for the plant Sundew (*Drósera* spp.).

***Definition:***

The type section is defined as the interval from 2503.0 m to 2350.5 m in well 7128/4-1 on the Finnmark Platform (Fig. 8; Table 1), approximating to the base of the "Viséan sandstone unit" of Ehrenberg *et al*. (1998a). One core, 27.47 m long, was taken from the upper part of the formation (Fig. 11) in this well. The transition from the underlying basement metasediments into the basal beds of the Soldogg Formation is defined by lower GR readings.

***Reference sections:***

Reference sections are defined as the interval from 2533.5 m to 2358 m in well 7128/6-1 and from 515.5 m to 501.8 m in IKU shallow core 7029/03-U-01 (Figs 9 & 12; Table 1). Both reference sections are located on the Finnmark Platform. It appears that Ehrenberg *et al*. (1998a, fig.4) placed the base of their "Viséan sandstone unit" in 7128/6-1 at the transition from basement wash conglomeratic sandstones to cleaner interbedded sandstones, siltstones and interbedded fines at 2488.5 m. In 7128/6-1 and 7029/03-U-1, the transition from basement to the basal Soldogg Formation conglomerates is represented by a marked erosional unconformity.

***Thickness:***

The formation is 152.5 m thick in the type well, 175.5 m in well 7128/6-1 and approximately the lowermost 13 m are represented by shallow core 7029/03-U-01 (Fig. 12).

***Lithology:***

Sandstones and conglomeratic sandstones with thin beds and laminae of carbonaceous siltstones, shales and coal dominate the formation. The cored interval in well 7128/4-1 (core 4) consists of cross-bedded and laminated sandstones and siltstones with three coal beds, each less than 1 m thick (Figs. 8 & 13). Coal beds occur most abundantly in the upper part of the formation in this well, but are not as abundant as in the overlying Tettegras Formation. Petrographic examination of sidewall cores and cuttings from well 7128/6-1 shows a dominance of medium- to coarse-grained quartzose sandstones similar to those observed in well 7128/4-1.

Shallow core 7029/03-U-01 is dominated by fining-upward units of conglomerates and laminated and trough cross-bedded sandstones (Figs. 14 & 15). Siltstones are rare in this core.

***Lateral extent and variation:***

The Soldogg Formation is only known from the type- and reference wells in the eastern Finnmark Platform. Seismic mapping around the well locations indicates a thickness range of 100-200 m, reflecting deposition prior to or in the early stages of main rifting (c.f. Steel & Worsley 1984; Ehrenberg *et al.* 1998a). The Soldogg Formation becomes difficult to identify seismically eastward and westward on the Finnmark Platform and northward toward the margins of the Nordkapp Basin. It thins, possibly due to erosional truncation south and southeast of the type well. In 7029/03-U-01 it is capped by an almost 1 m thick calcrete horizon, implying prolonged subaerial exposure and non-deposition in this area during deposition of the Tettegras Formation.

***Age:***

Based on palynological data, the basal Soldogg Formation is no older than the middle Viséan TC Miospore Zone in well 7128/4-1 (Geochem Group 1994). The rest of the formation in this well is assigned to the NM Miospore Zone in terms of the NW European Miospore zonation of Clayton *et al.* (1977). Simon-Robertson (1992) assigned the interval assigned herein to the Soldogg Formation in well 7128/6-1 to the upper part of the TC and the NM Miospore zones and a similar age range is given for the formation in 7029/03-U-01 (Bugge *et al.* 1995).

***Depositional environments:***

The sandstones encountered in well 7029/03-U-01 are interpreted as braided river deposits (Bugge *et al.* 1995). The sediments in core 4 from well 7128/4-1 are interpreted as representing various environments within a floodplain-dominated environment, including bar units, channel floor and crevasse splay deposits. They formed four general fining-upward rhythms of which two are characterised by the formation of coal beds at the top. According to log data, the cored sections are very similar to the uncored intervals and Ehrenberg *et al.* (1998a) suggested that the entire interval was deposited in an alluvial fan to braided river system, fining up into floodplain-dominated environments.

***Correlation:***

As described above, a general correlation to the Billefjorden Group on Spitsbergen can be made, although no more detailed correlation at the formation level is appropriate.

### *Tettegras Formation (Tettegrasformasjonen)*

***Name:***

From the Norwegian name for the plant Butterwort (*Pinguícula vulgáris*).

***Definition:***

The type section is defined as the interval from 2358 m to 2202 m in well 7128/6-1 (Fig. 9; Table 1) and corresponds to the "Viséan coaly/shaly unit" of Ehrenberg *et al.* (1998a) in this well. One core, 27.4 m long, exists from the upper part of the formation (Fig. 16). The transition from the Soldogg Formation into the basal beds of the Tettegras Formation is defined by higher GR readings and overall a more rapidly changing GR curve, reflecting the transition from sandstones with rare siltstone and coal beds into rhythmically deposited sandstones, siltstones, claystones and coal.

***Reference sections:***

Reference sections are defined as the intervals from 2350.5 m to 2058 m in well 7128/4-1 (in contrast to Ehrenberg *et al*. 1998a who appear to also include our overlying Blærerot Fm in their "Viséan coaly/shaly unit" in this well), from 479.2 m to 348 m in IKU core 7127/10-U-02 and 417.0 m to 338.9 m in 7127/10-U-03 (for locations see Table 1). The IKU cores penetrated neither top nor bottom of the Tettegras Formation, but seismic correlation suggests that the two cored intervals are separated by an approximately 175 m thick uncored succession (see Bugge *et al.* 1995, Fig. 7).

***Thickness:***

The formation is 156 m thick in the type well and 292.5 m in well 7128/4-1, thickening to 650-700 m in a half-graben where the two IKU wells (7027/10-U-02 and –03) drilled about 210 m of the unit. This thickness is atypical, and reflects onset of active rifting and deposition of thick sequences in active half-grabens, with thinning and even erosion of adjacent highs. This is most marked close to the major fault that separated the area of deposition from southern provenance areas near or on the Baltic Shield.

***Lithology:***

The formation is dominated by alternating beds of fine-grained sandstone, siltstone, claystone and coal. The sediments are generally stacked to form less than 5 m thick fining upward units of supposed delta-plain or coastal flood-plain origin, separated by thicker units of fluvial sandstone and siltstone. Well logs suggest that the cored intervals are representative of the entire unit in this area.

***Lateral extent and variation:***

The Tettegras Formation is only known from the type and reference wells on the eastern Finnmark Platform. Seismic mapping indicates thickness variations from zero over the crest of structural highs to more than 650 m in the half-graben areas, reflecting infill of half-graben topography related to the initial phase of mid-Carboniferous rifting. The formation becomes difficult to identify seismically both toward the east and the west on the Finnmark Platform, and northwards toward the margins of the Nordkapp Basin. It thins toward the south and southeast, and is missing at core site 7029/03-U-01 in the southeastern part of the platform, probably as a result of erosional truncation.

***Age:***

In the type well (7128/6-1) the interval below 2251 m is assigned to the Viséan TC-NM Miospore zones of Clayton *et al.* (1977) whereas the upper part is dated as belonging to the VF Miospore Zone (Simon-Robertson 1992). Similar ages are reported from well 7128/4-1 (Geochem Group, 1994), whereas the formation is dated as belonging entirely to the TC-NM Miospore zones in the IKU cores 7027/10-U-02 and –03 (Bugge *et al.* 1995).

***Depositional environments:***

The rhythmic occurrence of coal-topped fining-upward cycles is taken as evidence for deposition on a vast flood plain or a delta plain (Bugge *et al.* 1995; Ehrenberg *et al.* 1998a). High amplitude seismic reflectors typical for this coal-bearing unit are observed on seismic data throughout the eastern Finnmark Platform. Although it has not yet been possible to map the detailed transition from fluvial to marine deposits or the position of the possible delta front suggested by Bugge *et al.* (1995, Fig. 8), Ehrenberg *et al.* (1998a) note that about 25 km north of the wells studied, seismic data show a strong northward progradational pattern, suggesting transition into a prograding coastline.

***Correlation:***

A general assignation to the Billefjorden Group of Spitsbergen can be made, although no correlation at the formation level seems appropriate.

## *Blærerot Formation (Blærerotformasjonen)*

***Name:***

From the Norwegian name for Bladderwort (*Utriculária vulgáris*).

***Definition:***

The basal stratotype is defined at 501.8 m in IKU core 7029/03-U-01 on the Finnmark Platform (Figs. 12 & 17; Table 1). Increased sonic velocities, imaging the contrast between the underlying porous sandstones and overlying tight carbonates, define the transition from the Tettegras Formation into the basal beds of the Blærerot Formation.

Bedrock is overlain by glacial drift at 436 m in the core so that the formation's upper part and total thickness is unknown in the type section (Fig. 12). Bugge *et al* (1995) noted that the upper 15 m of the core, dated by them to the Serpukhovian, appear to show facies characteristic for both the Billefjorden and Gipsdalen groups, "reflecting a probable gradual transition between the two groups" in this area.

***Reference section:***

A reference section is defined in the interval from 2202 m to 2150 m in well 7128/6-1 (Fig. 9; Table 1). No cores were cut in this well, but logs show the same pattern as in the type section.

***Thickness:***

The preserved thickness is 65.8 m in the type well and the total thickness 52 m in the reference well.

***Lithology:***

The lowermost five metres of the Blærerot Formation consist of intensely bioturbated grey to yellowish brown limestone and sandy dolomites in core 7029/03-U-01. Bugge *et al.* (1995) described these as partially dolomitised mudstones and wackestones containing gastropods, brachiopods, bivalves, trilobites, foraminifers and crinoids. Large, laminated irregular nodules, interpreted as oncoids, are present in the lower part. The carbonates are overlain by a 23 m thick coarsening-upward succession of dark grey silty shale with a total organic carbon (TOC) content of 3-4% in the lower part. The shale becomes more bioturbated and less organic-rich upwards. It contains much of the same marine fossils as in the underlying carbonate unit, but in addition abundant terrestrial plant remains are present. There is sharp transition towards the overlying 22 m thick sandstone dominated unit, which consists of two coarsening-upwards cycles with basal dark grey siltstones. The sandstones are fine- to medium-grained and contain low-angle trough cross lamination and wave ripples (Fig. 17). Yellowish-brown silty shales with some coal abruptly overlie the apparently shallow marine succession of the lower Blærerot Formation and these are interpreted as coastal plain deposits (Fig. 18). Log correlation suggests that the same overall lithologies are present in the reference well 7128/6-1. Cuttings from the basal carbonate bed in this well include a fauna very similar to that described from the type section.

***Lateral extent and variation:***

The formation is only known from 7029/03-U-01 and 7128/6-1. It is thinnest in 7128/6-1, which is located over the crest of a rotated fault block. The formation is missing from 7128/4-1 on the crest of an adjacent uplifted block. Available biostratigraphic data suggest that the Blærerot Formation interfingers laterally with the Tettegras Formation towards the south (see Bugge *et al.* 1995).

***Age:***

Palynomorphs in the type section indicate a late Viséan – early Serpukhovian age in the type section (Bugge *et al.* 1995). A similar age range is indicated for the formation in well 7128/6-1 (Simon-Robertson 1992).

***Depositional environments:***

The carbonate beds at the base of the formation record the first marine flooding of the Finnmark Platform. Initial deposition of shallow marine platform carbonates was followed by deposition of shale in lower shoreface environments. The sandstones in the top of the type section are of upper shoreface to possibly fluvial origin (Bugge *et al.* 1995). The entire formation represents deltaic or shoreface progradation as the depositional response to a rapid marine transgression and its development resembles that of the classical Yoredale cycles of the UK (see e.g. Elliott 1975).

***Correlation:***

Marine sediments are not known from the Billefjorden Group onshore Spitsbergen and Bjørnøya. Age-equivalent, non-marine sediments are widespread in the region and lacustrine organic-rich shales have been reported from the Sverdrup Basin (Goodarzi *et al.* 1987; Davies & Nassichuk 1988). However, this unit probably represents the farthest extent of a marine transgression, presumably from the Timan-Pechora Basin to the east (c.f. Alsgaard 1993; Johansen *et al.* 1993) and correlative marine sequences should be expected to be present at depth in the Nordkapp Basin.

## *Gipsdalen Group (Gipsdalsgruppa)*

***Name:***

Cutbill and Challinor (1965) introduced the term Gipsdalen Group for a suite of rocks of mid-Carboniferous to early Permian age. The group is widely exposed on Svalbard, with its type area in central Spitsbergen. The group's overall geological development is well known onshore, both on Spitsbergen itself (e.g. Steel & Worsley 1984; Dallmann *et al.* 1999) and on Bjørnøya on the Stappen High (Worsley *et al.* 2001). The Gipsdalen Group is here extended to cover the offshore mid-Carboniferous to early Permian succession in the southern Norwegian Barents Sea and is there dominated by red-coloured siliciclastics and warm-water, often dolomitised carbonates – also with the significant presence of evaporites and the halite diapirs in the Nordkapp Basin. Wells 7121/1-1, 7124/3-1 and 7226/11-1 from the margins of the Loppa High and the Bjarmeland Platform record deposition in deeper marine settings than seen onshore. The formational scheme proposed herein is relatively broad and reflects three, easily recognised, highly diachronous stages of development starting with red-bed sedimentation in isolated fault-controlled basins, followed by mixed siliciclastic-carbonate deposition and terminated by carbonate-dominated sedimentation on the platforms and carbonates and evaporites in the basins.

***Offshore reference areas:***

In the Norwegian Barents Sea, 11 wells and 4 shallow cores have penetrated strata assigned to Gipsdalen Group. The subsurface reference area is located on the eastern Finnmark Platform where this succession has been penetrated by 7229/11-1 and 7228/9-1S on the northern margin and 7128/6-1 and 7128/4-1 in a more central position on the platform (Fig.19). Further toward the south, IKU drilled three cores (7029/03-U-02, 7030/03-U-01 and 7129/10-U-02) close to the Finnmark coast where the group's sediments subcrop against the Pliocene/Pleistocene unconformity (Bugge *et al.* 1995). Additional information on the group's development comes from well 7120/12-4 on the western Finnmark Platform.

The Loppa High also forms an important reference area with good seismic coverage, including a 3D survey, and three wells, *viz.* 7120/1-1, 7120/2-1 and 7121/1-1, that penetrate the succession in the southern Loppa High area (Figs. 19, 20). Further to the east, the group was encountered in wells 7124/3-1 and 7226/11-1 on the southern margins of the Bjarmeland Platform. A shallow core and several minicores have also been drilled on the Svalis Dome on the Bjarmeland Platform (Nilsson *et al.* 1996).

***Thickness:***

The Finnmark and Bjarmeland platforms and the Loppa High formed low-angle ramps dipping toward the Nordkapp and eastern Hammerfest basins during deposition of the Gipsdalen Group. The thickest drilled succession is from the southern flanks of the Loppa High, where the group is more than 1000 m thick in well 7121/1-1 and seismic data suggest that a further 500 m is present below TD. This is comparable to the up to 1800 m thick successions recorded locally in marked half-graben structures such as Inner Hornsund and Billefjorden on Spitsbergen. In contrast the group's sediments are totally absent on the crest of the Loppa High – as on southern Bjørnøya on the Stappen High – while well 7120/2-1 in a near-crestal position shows a 680 m thick development, similar to the 595 m thick development on northern Bjørnøya.

The group thins from approximately 315 m in well 7128/6-1 to 250 m in 7128/4-1 on the Finnmark Platform; IKU cores suggest comparable thicknesses (Bugge *et al.* 1995). Further to the west, well 7120/12-4 penetrated the upper 85 m of the group. Wells 7228/9-1S and 7229/11-1 on the northern Finnmark Platform penetrated only the upper (Moscovian-Sakmarian) part of the group: this interval is 211 m and 333 m thick respectively in these wells - significantly thicker than the corresponding interval in 7128/4-1 and 7628/6-1 further to the south. The group thickens even more towards the northwest and seismic data from the Nordkapp Basin indicate thicknesses of several hundred metres. On the Bjarmeland Platform, the group is more than 800 m thick in well 7226/11-1, where Bashkirian carbonates rest directly on basement. A total thickness of 1000 m is suggested by the 465 m penetrated in 7124/3-1 combined with seismic data from the underlying section. The group is 670 m thick in well 7120/1-1 where it rests on garnet mica schists/gneisses of Caledonian age.

***Lithology:***

The group is composed of metre-thick to rarely tens of metre-thick rhythmic units generally showing shallowing upward trends continental red bed sandstones, siltstones and conglomerates dominate the basal part of the succession. These are overlain by mixed carbonates and siliciclastics where the siliciclastics are grey-coloured marine sandstones, conglomerates and shales and the carbonates include a variety of shallow marine facies. The upper part of the group is dominated by rhythmically bedded limestones and dolomites with occasional small phylloid algal – *Palaeoaplysina* buildups, and minor evaporites on the platform areas. The biota is of chlorozoan composition and dominated by algae and foraminifers (c.f. Lees & Buller 1972). Seismic data suggest that the shelf carbonates pass into several hundred metre thick successions of stacked buildups in the deeper ramp areas (Elvebakk *et al.* 2002). These buildups have not been drilled and their internal composition and exact stratigraphic position is therefore unknown. However, similar relationships are described from age equivalent rocks in the Sverdrup Basin where the largest buildups occur on the basin slope (Beauchamp 1993). Evaporites dominate in the basinal areas; anhydrite occurs interbedded with carbonates near platform margins whereas halite dominates in more distal settings.

***Lateral extent and variation:***

The group's sediments are found throughout the Norwegian Barents Sea. Thickest developments are seen in the Nordkapp Basin and other basinal areas where the succession is dominated by evaporites. The thickest carbonate-dominated successions are found on the distal parts of the platforms, such as the eastern flanks of the Loppa High and the northern margins of the Finnmark Platform. The group thins towards structural highs and mainland Norway: it shows a clearly onlapping development, so that the lower non-marine parts were deposited in isolated half-grabens, while platforms and highs only became part of the depositional basin later, when relative second order sea-level rise led to marine flooding of the entire circum-Arctic region (c.f. onland Spitsbergen, Steel & Worsley 1984). The group's occurrence resting directly on basement in 7226/11-1 (see above) confirms this general pattern. The considerable variations in lithology, both laterally and vertically, reflect the ongoing sea level rise and resultant varying timing of drowning of different siliciclastic provenance areas. A larger proportion of shallow marine siliciclastics are expected updip on the platforms, while carbonate buildups are best developed on basinal margins. The Loppa and Stappen highs experienced several phases of tectonism during deposition of the group, in contrast to the vast bulk of offshore platforms and basins, and onshore exposures on Bjørnøya show interesting analogues for the development expected on the Loppa High (Worsley *et al.* 2001).

The boundary between the Gipsdalen Group and the underlying Billefjorden Group is only known with certainty from wells 7128/4-1 and 7128/6-1 on the Finnmark Platform and from 7120/2-1 on the Loppa High. On the Finnmark Platform, the sharp contact between Lower Carboniferous grey fluvial siliciclastics with coals below and red bed facies with caliche above marks a boundary represented by a major regional unconformity in the circum-Arctic and is associated with a significant change in palaeoclimate from warm and humid to warm and arid to semi-arid (Steel & Worsley 1984; Stemmerik & Worsley 1989; Stemmerik 2000).

***Age:***

The basal non-marine red-bed succession contains palynomorphs indicating a general Serpukhovian to Bashkirian age. Fusulinids suggest a late Bashkirian to Sakmarian age for the marine part of the group (Stemmerik *et al.* 1998; Ehrenberg *et al.* 1998a). In onshore areas of Svalbard, the group's sediments have been dated to the late Serpukhovian to early Artinskian (Dallmann *et al.* 1999) (Fig.6).

***Depositional environments:***

The basal non-marine red-bed succession of the Ugle Formation was deposited during active rifting in the ?late Serpukhovian to Bashkirian and cores from 7120/2-1 represent alluvial fan and braided river deposits. The overlying Falk Formation marks the transition into shallow marine deposition at a time when there still was siliciclastic supply from emergent highs. The Ørn Formation uppermost in the group was deposited in a variety of shallow to deeper marine carbonate environments during sea level highstands. The presence of extensive subaqueous anhydrite and halite deposits in the basins and sabkha evaporites on the platforms clearly suggests deposition took place in warm semi-arid to arid climates (Steel & Worsley 1984; Stemmerik 2000). The platform succession is characterised by stacked rhythmic shelf deposits often terminated by subaerial exposure surfaces, reflecting deposition during a time period characterised by high frequency and high amplitude fluctuations in sea level (e.g. Stemmerik & Worsley 1989; Pickard *et al.* 1996; Stemmerik *et al.* 1998; Ehrenberg *et al.* 1998a; Samuelsberg & Pickard 1999; Worsley *et al*. 2001).

The depositional environments recorded from the platform areas generally resemble those recognised onshore Spitsbergen and Bjørnøya. The deeper marine, outer ramp and basinal deposits have no counterparts onshore.

***Formations assigned to the group:***

Three formations are formally described below and these are named after birds of prey common to northern Norway. The still poorly known outer platform and basinal succession is provisionally included in the uppermost Ørn Formation.

## *Ugle Formation (Ugleformasjonen)*

***Name:***

From the Norwegian name for an owl (several species are found in northern Norway - among them the Hawk Owl *Surnia ulula*).

***Definition:***

The formation is defined by the interval from 2624 m to 2221 m (log depth) in well 7120/2-1 on the Loppa High (Fig. 20; Table 1). The base is characterised by an abrupt log break below a 54 m thick siltstone-dominated unit and overlies a conglomeratic unit with coal fragments. The boundary is marked by uniformly higher gamma log readings and a decrease in density and interval transit time. The upper part of the formation is cored and the top corresponds to 2225.7 m in the core (Fig. 21).

***Reference sections:***

Reference sections are provided by the intervals from TD at 2202 m to 2118 m in well 7120/12-4 on the western Finnmark Platform's northern margins towards the Hammerfest Basin and from TD at 509 m to 498.6 m in core 7029/03-U-02 on the southeastern Finnmark Platform (Figs 22, 23; Table 1). The base of the formation was not penetrated in these wells but seismic data suggest that in the area around 7029/03-U-02 this probably correlates to a regional angular unconformity approximately 50 m below TD (Bugge *et al.* 1995).

***Thickness:***

The formation is 403 m thick in the type well 7120/2-1, at least 84 m thick in 7120/12-4 and, according to Bugge *et al.* (1995), approximately 60 m thick in the area around 7029/03-U-02. The formation was not developed in wells 7226/11-1, 7128/6-1, 7128/4-1 and 7120/1-1, while wells 7124/3-1, 7121/1-1, 7228/9-1S and 7229/11-1 reached TD higher in the Gipsdalen Group.

***Lithology:***

The formation is characterised by reddish-brown to brown conglomerates, coarse-grained sandstones and minor siltstones. In well 7120/2-1, the formation is dominated by approximately 10 metre thick fining-upward units of reddish brown coloured conglomerate to siltstone with light grey calcite nodules at the top (Fig. 20). The pebbles are dominated by variously coloured volcanoclastic material with red- and grey coloured feldspar crystals. The core from 7029/03-U-02 consists of alternating fining-upward coarse pebbly sandstones and reddish brown and greyish green mottled siltstones (Fig. 23). Sediments are more fine-grained in well 7120/12-4 and there mainly consist of reddish brown to brown mottled sandy siltstones with frequent light grey to greyish green calcareous nodules (Fig. 22).

***Lateral extent and variation:***

The Ugle Formation was deposited in isolated half-grabens which developed during mid-Carboniferous rifting. These features appear to be widespread across the platform areas of the Norwegian Barents Sea (c.f. Worsley *et al.* 2001: fig. 11B) and correlative units to this formation may well be thickly developed in deeper basinal areas. The formation is only locally developed on the Finnmark Platform and was not deposited in well 7126/11-1 on the southern margin of the Bjarmeland Platform.

***Age:***

Dating of the formation is difficult because of its lack of fossils. However, a diverse palynomorph assemblage of late Serpukhovian to early Bashkirian age (SO-KV Zone) has been reported recently in well 7120/2-1 in the interval around 2420 m (Lindström, in press). The youngest age of the formation is suggested by the basal part of the overlying Falk Formation, dated as late Bashkirian in well 7120/2-1 (Stemmerik *et al.* 1998).

***Depositional environments:***

An overall arid to semi-arid terrestrial environment of deposition is indicated by the dominance of red-coloured sediments, widespread caliche soils and the absence of marine fossils. Conglomerates were probably deposited in the proximal parts of alluvial fans building out from active faults. In 7120/2-1, massflow deposits rich in volcanoclastic pebbles dominate the conglomerates, indicating volcanic activity on or near the Loppa High during mid-Carboniferous times. These coarse facies interfinger down-stream with more fine-grained flood-plain sandstones and overbank fines; fluvial channel-fill deposits are rare.

***Correlation:***

Alluvial red-bed sediments were deposited in numerous half-grabens throughout the Arctic during the mid-Carboniferous and are assigned to a vast number of lithostratigraphic units spanning over differing segments of mid-Carboniferous time, but all reflecting ongoing syndepositional rifting. The Ugle Formation correlates to red-beds of the Landnørdingsvika Formation on Bjørnøya (Fig. 6, see also Gjelberg 1981; Gjelberg & Steel 1981, 1983; Worsley *et al.* 2001), perhaps to the lowermost Hyrnefjellet Formation in the Inner Hornsund Trough of southern Spitsbergen, the Petrellskaret Formation in Bellsund, the Brøggertinden Formation on Brøggerhalvøya and the Hultberget and Ebbadalen formations in the Billefjorden Trough. Holliday & Cutbill (1972) and Johannessen & Steel (1992) have described the development of the Billefjorden Trough in detail (see also Dallmann *et al.* 1999 for full references).

## *Falk Formation (Falkeformasjonen)*

***Name:***

From the Norwegian name for a falcon (4 species, all belonging to the genus *Falco,* are found in northern Norway).

***Definition:***

The type section is defined in the interval from 2221 m to 2024 m (log depth) in well 7120/2-1 on the Loppa High (Fig. 20; Table 1). The base corresponds to 2225,7 m in core depth (Fig. 24). The formational base reflects an abrupt change from non-marine, reddish brown conglomerates of the Ugle Formation to dark grey, marine shales and marks the first marine transgression in the area; this gives a log response characterised by a change toward overall lower readings on the gamma ray log as a result of the transition into carbonates (Fig. 20). The formation otherwise shows a noisy log pattern, reflecting the intercalation of siliciclastics and carbonates.

***Reference sections:***

Reference sections are found from 2150 m to 2050 m in well 7128/6-1 (Fig. 25), 2058 m to 1952 m in 7128/4-1 (Fig. 26), 498.6 m to 363.5 m in core 7029/03-U-02 (Fig. 27) and from TD at 481.7 m to 458 m in 7030/03-U-01 (Fig. 28), all located on the Finnmark Platform. In 7029/03-U-02 the base also represents an abrupt change in both colour and overall lithofacies from non-marine, red and green mottled silty shales to marine, greenish-grey, bioturbated silty shales. In wells 7128/4-1 and 7228/6-1 the formation corresponds to units L1 and L2 of Ehrenberg *et al.* (1998a).

***Thickness:***

The formation is thickest in the type well (201.7 m); it is 135 m thick in 7029/03-U-02 on the southern Finnmark Platform and thins northwards to 100 m in well 7128/6-1 and 58 m in 7128/4-1 (Fig. 19). The formation is missing in 7226/11-1 where carbonates of the overlying Ørn Formation rest directly on basement, while wells 7124/3-1, 7121/1-1, 7228/9-1 and 7229/11-1 reached TD higher in the Gipsdalen Group.

***Lithology:***

The formation consists of a mixture of shallow marine sandstones, marine siltstones and shallow marine carbonates. In 7120/2-1, the lower 51 m consists of stacked, less than 5 m thick rhythms of coarse-grained pebbly sandstone with minor shale and dolomite (Fig. 24). Trough cross-bedding and horizontal lamination is common. This lower development is overlain by a 125 m thick unit of rhythmically interbedded shales, fossiliferous dolomitic mudstones to packstones (locally with anhydrite or chert nodules), and fine- to medium-grained sandstones with a few pebbly sandstone beds. Crinoids, brachiopods, fusulinids, small foraminifers and corals are the most abundant fossils, together with occasional phylloid algae and palaeoaplysinid plates.

In the lower part of core 7029/03-U-02 and in 7030/03-U-01, the Falk Formation consists of 1 to 5 m thick fining upward units of light grey, medium- to coarse-grained, pebbly, trough cross-bedded to planar-laminated sandstones grading upwards into laminated greenish silty shales. Each unit has a sharp and erosive lower boundary. Marine fossils are limited to very rare brachiopods. The upper part of the formation in 7128/6-1 and 7029/03-U-02 consists of cycles of fine- to very fine-grained sandstone, green silty shale and carbonate wackestones to boundstones (Figs 25, 27, 29).

***Lateral extent and variation:***

The base of the formation represents a major transgression of the platform areas as seen in 7120/2-1 from the Loppa High and in the Finnmark Platform wells 7128/4-1, 7128/6-1 and 7029/03-U-02, where marine siliciclastics overlie continental deposits or basement. The top of the Falk Formation is likely to be highly diachronous as it reflects the differing times when local siliciclastic source areas were drowned and the mixed siliciclastic-carbonate depositional system was replaced by carbonates. The formation is accordingly expected to be thickest in proximal platform areas and around tectonically active highs; thinnest developments are expected distally on the platforms, and either highly condensed or missing in the basins; these prognoses are supported by the gross wedge-shaped geometry of the formation seen on the Finnmark Platform. The formation is missing in areas that have been sheltered from siliciclastic supply, like the local high on the southern Bjarmeland Platform where well 7226/11-1 was drilled: in this location carbonates of the overlying Ørn Formation rest directly on basement.

***Age:***

Stemmerik *et al.* (1995, 1998) suggested a late Bashkirian to early-middle Gzelian age based on fusulinid data. The formation is of late Bashkirian to Moscovian age in 7120/2-1, where the lower part of the overlying Ørn Formation is dated as being of late Moscovian age (Stemmerik *et al.* 1998). The top of the formation in 7030/03-U-01 apparently coincides with the Kasimovian-Gzelian boundary whereas an even younger age is indicated in 7029/03-U-02 where the uppermost part of the formation extends into the early to middle Gzelian (Stemmerik *et al.* 1995; Bugge *et al.* 1995). In 7128/6-1, the formation is of late Moscovian to early Gzelian age (Ehrenberg *et al.* 1998a).

***Depositional environments:***

The Falk Formation is characterised by sediments deposited as a response to high frequency and high amplitude fluctuations in sea level (see e.g. Stemmerik *et al.* 1998; Stemmerik & Worsley 2000). Deposition also took place during an overall rise in relative sea level in shallow shelf environments ranging from offshore silt-dominated to shoreface sand-dominated lithofacies during deposition of the lower part of the formation. Sediments in the upper part of the formation suggest that the relative sea level rise had by then flooded most platform areas so that lithofacies there are characterised by more fine-grained siliciclastic input, deposited in offshore to lower shoreface environments, and by subtidal carbonates. The presence of caliche indicates periods of subaerial exposure of the carbonates, and during sea level lowstands the platform areas apparently formed vast lowlands.

***Correlation:***

Mixed siliciclastics and shallow marine carbonates are common in the lower part of the Gipsdalen Group in the onshore areas of Svalbard. The formation correlates to the Kapp Kåre and Kapp Hanna formations on Bjørnøya (Worsley *et al*. 2001; Stemmerik & Worsley 2000), perhaps to the uppermost red-bed Hyrnefjellet Formation and lower Treskelodden Formation in Hornsund, the Tårnkanten/Schleteligfjellet and lower Wordiekamen formations of western Spitsbergen, and the Minkinfjellet, Malte Brunfjellet, Hårbardbreen and lowermost Wordiekammen formations of central to eastern Spitsbergen and Nordaustlandet (Dallmann *et al.* 1999: Fig. 6). In contrast to the offshore and most onshore areas, both Bjørnøya and Hornsund were characterised by significant syndepositional tectonism at the time.

***Possible members:***

No formal members are proposed herein, but the work of Ehrenberg *et al.* (1998a) and seismic mapping on the Finnmark Platform indicates that the formation in this area may comprise two distinctive units ("L-1" and "L-2") separated by a hiatus spanning the lower Kasimovian in well 7128/6-1. This corresponds to a period of tectonic activity on Bjørnøya (Worsley *et al*. 2001). On a seismic scale, however, these two informal units appear to be conformable on the Finnmark Platform.

## *Ørn Formation (Ørneformasjonen)*

***Name:***

From the Norwegian name for an eagle (3 species, including the Sea Eagle *Haliaetus albicilla*, are found in the northern Norway).

***Definition:***

The type section is defined as the interval from 2050 m to 1834.5 m in well 7128/6-1 on the Finnmark Platform (Fig. 30; Table 1). The upper boundary corresponds to 1836.2 m in core depth (Fig. 31). The base of the formation is defined at a change towards overall lower readings on the gamma ray log and a less noisy gamma ray pattern, reflecting the dominance of carbonates (Fig. 30). The formation corresponds to units L-3 to L-7 of Ehrenberg *et al.* (1998a) in this type well.

***Reference sections:***

Reference sections are provided by the intervals:

2024.0 m to 1945.0 m in 7120/2-1 (Fig. 20) and from TD at 5000 m to 3990 m in 7121/1-1 (Fig. 32), both on the Loppa High; in 7120/2-1 the base is marked by a pronounced drop on the gamma ray curve and the preserved part of the formation is characterised by uniformly low gamma ray values.

5137 m to 4334.5 m in 7226/11-1 on the Bjarmeland Platform (Fig. 33; Table 1);

1952 m to 1820 m in 7128/4-1 (Fig. 26), 426.7 m to 334.7 m in 7030/03-U-01 (Fig. 34); 383.8 m to 319.6 m in 7029/03-U-02 (Fig. 35); and 455.9 m to 399.6 m in 7129/10-U-02, all located on the Finnmark Platform (Table 1).

***Thickness:***

The Ørn Formation is 215 m thick in 7128/6-1 and 132 m thick in the adjacent 7128/4-1 well; a composite thickness of 150 to 200 m is also recorded in the IKU cores further south on the Finnmark Platform. The formation thickens northwards to about 246 m in well 7228/9-1S and to 358 m in 7229/11-1 near the platform's northern margins. It is about 800 m thick in well 7226/11-1 and probably about 1000 m thick in and under 7124/3-1 on the southern margins of the Bjarmeland Platform. Further to the west, on the southern margins of the Loppa High, the formation is over 1000 m thick in well 7121/1-1, while it thins and is progressively eroded updip so that only 79 m are preserved in well 7120/2-1 near the crest of the high.

***Lithology:***

The formation is dominated by shallow marine carbonates on the platform areas and interbedded carbonates and evaporites in the more distal ramp to basinal settings. The carbonates contain a warm-water biota dominated by small foraminifers, fusulinids and calcareous algae and with abundant fragments of *Palaeoaplysina* (Figs. 36, 37). Crinoids, bryozoans, brachiopods and corals are also present. Siliciclastics are rare in the Ørn Formation and the vast bulk of its rhythmic development is characterised by pure carbonates, or more distally, carbonates and evaporites - in contrast to the mixed siliciclastics and carbonates of the underlying Falk Formation. A temporary return to mixed carbonates and shales near the top of the formation is characterised by a gamma ray peak on the logs.

In well 7128/6-1, the lower part of the formation consists of rhythms of dolomitic mudstone and bryozoan wackestone with minor thin shales (Figs. 30, 31, 36, 37). This is followed by a succession of *Palaeoaplysina*-dominated buildups interbedded with fusulinid-dominated wackestone, overlain by an interval dominated by dolomitic mudstone with abundant anhydrite nodules. The upper part of the formation in this well consists of a thick unit dominated by foraminifer- and algal-rich packstones and grainstones overlain by cyclic deposited shales and crinoid-dominated silty wackestones that gradually pass up into foraminifer-dominated packstones and grainstones. The same spectrum of shallow marine carbonate facies is seen in cores from 7120/2-1, 7128/4-1, 7029/03-U-02, 7030/03-U-01, 7129/10-U-01 and 7129/10-U-02, suggesting a fairly uniform development on the platforms. In addition more than 5 m thick beds of massive to laminated anhydrite occur in 7029/03-U-02 and 7030/03-U-01 and native sulphur is locally present between 20 m and 35 m in 7029/03-U-02.

In well 7226/11-1 the lower part of the Ørn Formation consists of light grey to medium dark brownish grey dolomitic mudstones to packstones. These are interbedded with light grey to white massive anhydrite that increases in abundance upward to 4392,5m. Above this level rhythms of dark greyish-green calcareous shale and light grey fossiliferous limestone with chert nodules dominate. This unit is equivalent to the upper part of 7128/6-1. Log correlation suggests that the development in well 7226/11-1 resembles that of other distally located wells such as 7121/1-1 and 7124/3-1. Well 7228/9-1 cored thin dolomite and anhydrite beds in halite-dominated sediments.

***Lateral extent and variation:***

Well data and seismic data indicate that the formation is thinly developed and carbonate-dominated on the inner platforms (e.g. 7128/6-1 and 7128/4-1). It becomes significantly thicker and anhydrite-rich more distally on the platforms (e.g. 7226/11-1, 7124/3-1 and 7121/1-1), and in the basins the presence of salt diapirs indicates a dominance of halite. Seismic data indicate stacking of carbonate buildups into larger mounds along the platform margins (e.g. Elvebakk *et al.* 2002).

The base of the Ørn Formation is highly diachronous since it records the final drowning of local siliciclastic provenance areas. As noted previously, the formation's carbonates directly onlap basement in 7226/11-1. The top of the formation is represented by a subaerial exposure surface in the type well 7128/6-1. This is situated a few tens of metres above the top of a high amplitude seismic reflector mapped as ”the Top Asselian seismic marker” throughout the Barents Sea.

***Age:***

Fusulinid data from the type well 7128/6-1 indicate a late Gzelian to early Sakmarian age for the Ørn Formation at this locality (Ehrenberg *et al.* 1998a). In core 7030/03-U-01 the base of the formation correlates to the Kasimovian-Gzelian boundary and in 7029/03-U-02 the lower part of the formation is of middle Gzelian age (Stemmerik *et al.* 1995). The top of the formation is dated as early Sakmarian in core 7129/10-U-02 (Bugge *et al.* 1995). The base is somewhat older in 7120/2-1 where fusulinids indicative of a late Moscovian age occur in the basal part of the formation (Stemmerik *et al.* 1998).

***Depositional environments:***

The Ørn Formation is characterised by sediments deposited as a response to high frequency and high amplitude fluctuations during times of high second order sea level (Stemmerik 1997; Stemmerik *et al.* 1998). Siliciclastic provenance areas were now drowned and deposition on the platforms took place in a variety of shallow marine carbonate environments. Locally extensive sabkhas developed updip and thick units of dolomitic mudstone with anhydrite nodules belonging to the lower part of the Ørn Formation occur on the Finnmark Platform. Large carbonate mounds developed more distally on the platforms as a result of stacking of smaller buildups; the internal composition of these large mounds is still unknown. Interbedded subtidal highstand carbonates and lowstand anhydrite characterise the deepest parts of the platform, whereas halite deposition in the basin centres is suggested to have taken place during major lowstands when platforms were subaerially exposed and the basins were partly or totally separated from the open sea.

A major flooding event near the Asselian-Sakmarian boundary changed depositional conditions on the platforms and the upper part of the formation is characterised by rhythms dominated by outer shelf marls and wackestones that pass up into packstones.

***Correlation:***

The formation correlates generally to the Kapp Dunér Formation on Bjørnøya, although deposition of that unit apparently terminated in the Asselian and was followed by appreciable uplift and tilting through the Sakmarian (Worsley *et al.* 2001). The *Palaeoaplysina* buildups typical of the Kapp Dunér Formation provide excellent analogues for those of the Ørn Formation (Worsley & Edwards 1976; Lønøy 1988; Stemmerik & Larssen 1993; Stemmerik *et al.* 1994), while inter-buildup deposits on Bjørnøya suggest highly variable hypersaline to normal marine conditions (Siedlecka 1972, 1975; Folk & Siedlecka 1974). Tectonic activity continued in Hornsund, as witnessed by spectacular intraformational conglomerates of the upper Treskelodden Formation with large reworked coral clasts (c.f. Fedorowski 1982). In contrast, the remainder of the Svalbard Platform was relatively stable at the time and most of Spitsbergen and the northern Barents Shelf was covered by deposits of the Wordiekammen and Gipsdalen formations (Dallmann *et al.* 1999); Palaeoaplysinid buildups also occur on Spitsbergen, especially along the margins of the still subsiding Billefjorden Trough (Skaug *et al.* 1982).

## *Bjarmeland Group (Bjarmelandsgruppa)*

***Name:***

Bjarmeland was used by the Vikings to describe the area immediately south of the Barents Sea. The area was visited and described by the Norwegian Viking, Ottar, in the 9$^{th}$ century. The name was more recently used to name a structural element on the Barents Shelf: the Bjarmeland Platform (Gabrielsen *et al.* 1990). The group was introduced and briefly reviewed by Dallmann *et al.* (1999) in the knowledge of the ongoing more detailed work presented herein.

***Type area:***

The Bjarmeland Platform in the southern Norwegian Barents Sea is here defined as type area for the group since the offshore successions are best displayed in wells from this area, including the eastern flanks of the Loppa High (Fig. 38). Three wells show typical developments of the group: 7124/3-1 (4271 m to 3900 m), 7226/11-1 (4334 m to 4103 m) and 7121/1-1 (3990 m to 3502 m): the base of the group is defined by the basal stratotype of the biohermal Polarrev Formation in well 7229/11-1 on the northern Finnmark Platform

***Reference areas:***

Well 7228/9-1S (4361 m to 4065 m) (Fig. 38) located on the Finnmark Platform's northern margins towards the Nordkapp Basin illustrates the group's development in a deeper water basinal setting. The Finnmark Platform itself is an important reference area since the group has been drilled in a variety of settings from the outer platform areas to the north (7229/11-1, 4282 m to 3970 m, Fig. 38) across the central platform (7128/4-1, 1820 m to 1704 m) and 7128/6-1, 1835 m to 1745 m) to the southern updip areas represented by core 7128/12-U-01, 569.2 m to 557.5 m). The succession assigned to the group in 718/4-1 and 7128/6-1 corresponds to lithological unit L-8 of Ehrenberg *et al*. (1998a).

Hambergfjellet on the southern mountain massif of Bjørnøya is designated as an onshore reference area. Hambergfjellet is the type area of the Hambergfjellet Formation, the only onshore unit to be assigned to the Bjarmeland Group at the present time.

***Thickness:***

The group attains a maximum thickness of 488 m in well 7121/1-1 at the eastern flank of the Loppa High. It is thinner, 233-371 m, in wells 7226/11-1 and 7124/3-1 on the Bjarmeland Platform (Fig. 38). On the Finnmark Platform the group thins from 312 m in well 7229/11-1 to 116-89 m in wells 7128/4-1 and 7128/6-1 central on the platform and less than 50 m in the IKU cores further updip. The Hambergfjellet Formation on the southern cliffs of Bjørnøya shows a similar thickness of up to 60 m, but this unit wedges out and disappears northwards on the island.

***Lithology:***

The group is dominated by white to light grey bioclastic limestones containing a typical cool-water fauna of crinoids, bryozoans, brachiopods and siliceous sponges. Silty, dark grey to black, locally bituminous limestones characterise the deeper-water succession. Minor cherts occur, especially in the uppermost part. Siliciclastics are rare, except on the Polheim Subplatform where the group is unusually developed and dominated by fine-grained siliciclastics and marls (well 7120/1-1). The Hambergfjellet Formation on Bjørnøya consists of basal sandstones which onlap all older units from basement to Gipsdalen Group, passing up into sandy bioclastic limestones with a fauna dominated by crinoids, bryozoans and brachiopods (Worsley *et al.* 2001).

***Lateral extent and variation:***

The group is most thickly developed at the eastern flanks of the Loppa High and eastward across the Bjarmeland Platform. The thickest development is in outer platform settings north and south of the Nordkapp Basin where thick bryozoan-dominated buildups occur as isolated mounds or merge to form elongated complexes (Gerard & Buhrig 1990; Nilsen *et al.* 1993). Intermound and basinal areas are dominated by more fine-grained and thinly bedded limestones, which in well 7120/1-1 are interbedded with siliciclastic shales. The platform areas of the eastern Finnmark Platform are characterised by relatively uniform successions of bedded crinoid- and bryozoan-dominated packstones and grainstones.

The group is seen to onlap palaeohighs and the margins of the depositional basin such as the eastern flank and crestal areas of the Loppa High and the southern parts of the Finnmark Platform. It is missing in wells 7120/12-2 and 7120/12-4 from the southern Hammerfest Basin – western Finnmark Platform and onshore it is only known from the Hambergfjellet Formation on Bjørnøya, - although future work may well demonstrate that the uppermost Gipsfjorden Formation and the Vøringen Member (Kapp Starostin

Formation) of the Tempelfjorden Group both age- and facies-wise represent lateral equivalents of parts of the group on Spitsbergen.

***Age:***

Fusulinids suggest a mid-Sakmarian to late Artinskian age in 7128/6-1 (Ehrenberg *et al.* 2000). The base of the group is thought to be highly diachronous, oldest in the more distal settings and youngest on the platforms (Fig. 4). The Hambergfjellet Formation on Bjørnøya is dated as late Artinskian based on fusulinids and conodonts (Nakrem 1991; Nakrem *et al.* 1992). Fusulinids indicate a similar age in cores 7128/12-U-01 and 7129/10-U-01 (Bugge *et al.* 1995; Ehrenberg *et al.* 2000).

***Correlation:***

The lower, Sakmarian to early Artinskian, part of the group may correlate to the uppermost Gipsfjorden Formation of Spitsbergen. The upper, late Artinskian, part - including the Hambergfjellet Formation of Bjørnøya - perhaps should be correlated to the transgressive Vøringen Member of the Kapp Starostin Formation on Spitsbergen (Dallmann *et al.* 1999; Worsley *et al*. 2001).

***Depositional environments:***

The group is characterised by deposition of carbonates dominated by crinoids, bryozoans, brachiopods and siliceous sponges. The fauna is markedly different from the foraminifer-dominated warm-water fauna of the underlying Gipsdalen Group and is believed to reflect deposition in more temperate cool-water environments (Stemmerik 1997). Deposition took place in a variety of cool-water carbonate environments and deposits range from shallow inner shelf bioclastic grainstones to outer shelf bryozoan-dominated buildups and thinly bedded bioclastic wackestones and packstones. Siliciclastic input to the basin was limited - except locally in the west where deeper water shales are interbedded with resedimented carbonates in 7120/1-1; sand input was also significant on Bjørnøya, immediately adjacent to the subaerially exposed parts of the Stappen High. The bryozoan-dominated carbonate buildups formed along the margins of the Nordkapp Basin on the outer part of the platforms. They are often located above older buildups. Distally to the trend of buildups more marly sediments have been recorded in well 7228/9-1S.

***Formations assigned to the group:***

The Bjarmeland Group is represented by three formations in the offshore areas of the southern Norwegian Barents Sea. The formations are formally described herein and named after predators common to Arctic Norway. The Polarrev and Ulv formations show an interfingering of the carbonate buildups of the former and the inter-buildup lithofacies of the latter formation. The Ulv Formation was also developed in the outer platform and basinal areas throughout deposition of the group, while the uppermost Isbjørn Formation in inner shelf areas overlies earlier buildups but does not extend into deeper waters characteristic of the Ulv Formation.

The Hambergfjellet Formation of Bjørnøya, defined by Worsley & Edwards (1976) is included in the group, as it appears to represent a lithologically similar but highly condensed (<60 m thick) development of the Isbjørn Formation.

### *Polarrev Formation (Polarrevformasjonen)*

***Name:***

From the Norwegian name for the Polar Fox (*Alopex lagopus*).

***Definition:***

The type section is defined as the interval from 4282 m to 4046 m in well 7229/11-1 on the northern margin of the Finnmark Platform (Fig. 39; Table 1). Eight cores with a total recovery of approximately 180 m, including the base, exist (Fig. 40). The base of the formation is defined by an abrupt and sharp decrease in gamma ray log response and an accompanying decrease in interval transit time and neutron porosity log response, giving only a slight separation between the neutron and bulk density logs (Fig. 39). The cored base in the type well shows a sharp transition from underlying laminated silty to very fine-grained sandy carbonates to the overlying carbonate buildups typical of the Polarrev Formation (Fig. 40).

***Reference sections:***

Reference sections have been defined in the intervals from 4334 m to 4182 m in well 7226/11-1 (Fig. 41) and 4271 m to 4000 m in 7124/3-1 (Fig. 42), both located on the southern Bjarmeland Platform, and the interval from 3990 m to 3700 m in 7121/1-1 (Fig. 43) on the eastern flanks of the Loppa High. No cores exist from the reference wells.

***Thickness:***

The formation is very locally developed and is absent from most areas as it represents isolated carbonate buildups and carbonate buildup complexes. It attains a maximum thickness of 290 m in well 7121/1-1 on the eastern flank of the Loppa High and thins eastward along the margin of the Bjarmeland Platform, ranging from 271 m in well 7124/3-1 to 152 m in 7226/11-1 (Fig. 38). The formation is 236 m thick in the type well on the northern Finnmark Platform.

***Lithology:***

The formation consists of a variety of facies that characterise carbonate buildups. The bulk of the formation consists of bryozoan- and bryozoan/*Tubiphytes*-dominated wackestones and cementstones with abundant early marine cement (Fig. 44). Wackestones dominate the bioherm encountered in the type well, where a sparse assemblage of fenestrate bryozoans, brachiopods and crinoids formed a loose framework that trapped the carbonate mud. The wackestones also display *Stromatactis*-like cavities, which form a complex interconnected pore system. The cavities are often partly supported by fenestrate bryozoans and brachiopods, and are often filled by geopetal internal sediments with a grainstone or packstone fabric. The geopetal fabrics indicate that deposition occurred on primary slopes of up to $45^{o}$ (Blendinger *et al.* 1997).

The limestone is massive to thickly bedded, white to light grey, locally pinkish grey and light brownish grey in colour. In the lower part of the formation more thin bedded and silty limestones are locally present. The formation has a characteristic (very) low gamma ray response throughout, except for the thin units of silty limestones in the lower part (Fig. 39).

***Lateral extent and variation:***

Seismic data indicate that carbonate buildups belonging to the Polarrev Formation rim the shelf along the Loppa High and around the margins of the Nordkapp Basin (Gerard & Buhrig 1990; Nilsen *et al.* 1993). The buildups also form linear trends across central parts of the Finnmark Platform and across northern areas of the Bjarmeland Platform. Isolated buildup complexes occur in the Norvarg Dome-Mercurius High area and on a structural high on the northeastern Finnmark Platform. The distribution of the laterally extensive buildup complexes seems to be controlled by underlying tectonic elements and they are preferably localised to areas that experienced relatively high rates of subsidence. Therefore the best-developed buildup trends often coincide with pinch-out of salt in the underlying Gipsdalen Group. Isolated buildups have been seen to occur in the proximal parts of the basins where they form isolated patch reefs, apparently located on local palaeotopographic highs. Well data suggest that all drilled buildups have a very uniform composition although the buildups vary significantly in thickness.

The base of the formation may represent a subaerial exposure surface on structural highs, while it is a correlative conformity on the outer part of the platforms and along the margins of the depositional basin.

***Age:***

Fusulinids suggest a mid-Sakmarian age for the basal part of the formation in wells 7229/11-1 and 7121/1-1 and a late Sakmarian age near the top of the formation in the same wells (Davydov 1998, Davydov 2000). Comparisons with overlying units suggest that the formational top is of ?earliest Artinskian age.

***Depositional environments:***

The formation represents deposition in a variety of subenvironments within a bryozoan-dominated bioherm complex. The bulk of the bioherm is composed of repeated graded units of mud-dominated to cement-dominated bryozoan facies believed to represent individual banks. Deposition started in relatively deep water, well below storm wave base. The presence of reworked bioclastic grain-/packstone with fragmented and abraded bioclasts and reworked early marine cement indicates periods of reworking as the bioherm grew upwards into shallower water - possibly near storm wave base. The fine-grained bioclastic limestones in the lower part of the type section (between 4257.5 and 4264.5 m) and other units with higher gamma ray readings were deposited on the distal part of a carbonate ramp below normal wave base.

***Correlation:***

The formation is not known from the onshore areas.

## *Ulv Formation (Ulveformasjonen)*

***Name:***

From the Norwegian name for the Wolf *(Canis lupus).*

***Definition:***

The type section is defined as the interval from 4361 m to 4150 m in well 7228/9-1S on the margin of the Finnmark Platform towards the Nordkapp Basin (Fig. 45; Table 1). One core exists from the lower part, between 4300 m and 4319 m. The base is taken at the first significant and relatively sharp decrease in gamma ray response above the higher gamma ray readings of the underlying Gipsdalen Group (Fig. 39). This is associated with a marked decrease in the neutron porosity log, resulting in a very low separation between the neutron and the bulk density logs. There is also an accompanying decrease in interval transit time.

***Well reference sections:***

Reference sections are found in the intervals from 3220 m to 2997 m in well 7120/1-1 on the Loppa High (Fig. 46; Table 1) and from 4182 m to 4103 m in well 7226/11-1 on the

Bjarmeland Platform (Fig. 41). One core exists from the lower part of the formation in 7120/1-1, between 3185 and 3195,5 m (Fig. 47).

In wells 7121/1-1, 7124/3-1 and 7226/11-1, the lower boundary is marked by an increase in gamma ray values reflecting the transition from cleaner limestones (of the underlying Isbjørn Formation in the first two of these wells and of the Polarrev Formation in the third) up into more silty limestones (Fig. 39).

***Thickness:***

The formation is more than 210 m thick in wells 7120/1-1 and 7228/9-1, thinning to 80 m in 7226/11-1 and to less than 60 m in 7121/1-1 and 7124/3-1. The formation is not developed in wells 7128/4-1, 7128/6-1, 7228/9-1 and 7228/11-1 on the Finnmark Platform.

***Lithology:***

Dark fine-grained bioclastic limestones dominate the formation. The dominant microfacies are bryozoan-crinoidal wackestones and more rarely packstones. Additional faunal elements include siliceous sponges, brachiopods and rare fusulinids. The limestone is thinly bedded and often contains thin silt laminae. Shales and silty limestones are locally abundant and chert nodules occur locally. The formation includes thin, less than 15 m, units of coarser grained bioclastic limestone that lithologically resemble the overlying Isbjørn Formation's dominant lithologies.

***Lateral extent and variation:***

The formation represents deposition in relatively deep water and is not developed on most of the Finnmark Platform. It is believed to be widespread in the distal parts of the platforms, between the Polarrev Formation buildups, and in deeper basinal areas during deposition of the lower part of the Bjarmeland Group. Later in the group's development, the formation appears to have been more widespread, although mainly restricted to outer platform and basinal areas. Landward it interfingers with coarse-grained bioclastic grainstones typical of the Isbjørn Formation.

***Age:***

Fusulinids suggest a mid-Sakmarian to Artinskian age (Davydov 2000).

***Depositional environments:***

Deposition took place in relatively deep shelf environments below storm wave base. More clean limestone intervals reflect either reworking of material from the shallower cool-water carbonate platforms or from adjacent buildups. Siliciclastic input was limited in the eastern part of the region but seems to be more significant along the western margin of the Loppa

High. This suggests syndepositional tectonic instability along the crestal part of the Loppa High.

***Correlation:***

The formation is not known from the onshore areas of Spitsbergen or Bjørnøya, but lateral correlatives may be represented by the interdidal/supratidal dolomites of the Skansdalen, Templet and Sørfonna members uppermost in the Gipsdalen Formation of Spitsbergen and Nordaustlandet.

## *Isbjørn Formation (Isbjørnformasjonen)*

***Name:***

From the Norwegian name for the Polar Bear *(Ursus maritimus)*

***Definition:***

The type section is defined as the interval from 1834.7 m to 1745.4 m in well 7128/6-1 on the Finnmark Platform (Fig. 48), apparently concurring with informal unit L-8 of Ehrenberg *et al.* (1998a). Cores cover the entire section (Fig. 49). In this well the base of the formation is marked by a decrease in gamma ray response, reflecting the transition from silty warm water carbonates to clean cool-water carbonates.

***Reference sections:***

A reference section is defined as the intervals from 3700 m to 3625 m and 3586 m to 3502 m in well 7121/1-1 on the Loppa High, these intervals interfingering with Ulv Formation lithofacies (Fig. 43). A small core, 2,7 m long, exists from the uppermost part of the formation, between 3513.7 m and 3511.0 m. An additional reference section is designated in 7229/11-1 (4046 m to 3970 m), where the Isbjørn Formation rests directly on carbonate buildups of the Polarrev Formation. The uppermost part of the formation has been drilled in the southernmost part of the Finnmark Platform (cores 7128/12-U-01 from 569.2 m to 557.5 m and 7129/10-U-01 from 475.3 m to 464 m) (Bugge *et al.* 1995).

The base is not easy to pick on logs in areas where the formation rests directly on the Polarrev Formation (e.g. 7229/11-1), as the boundary there represents a limestone-limestone contact (Fig. 39). It is recognised by a slight decrease in interval transit time and neutron porosity log values accompanied by an increase in bulk density in wells 7121/1-1 and 7229/11-1. However, over the buildups, the base of the formation is easily picked on seismic data. In 7121/1-1 the transition from the interfingering Ulv Formation up into the

Isbjørn Formation shows a marked decrease in gamma ray response, reflecting the transition from silty wackestones into cleaner packstones and grainstones (Fig. 43).

***Thickness:***

The formation is approximately 75-90 m thick in the central and northern parts of the Finnmark Platform, thinning to 10 m in the IKU cores. It is slightly thinner in 7124/3-1 and absent from the outer shelf environments represented by the Ulv Formation in 7226/11-1 on the Bjarmeland Platform (Fig. 38). The formation is thickest in 7121/1-1 on the southeastern flank of the Loppa High, where its two intercalations have a composite thickness of approximately 160 m (Fig. 43).

***Lithology:***

Bedded, white to light grey bioclastic limestones with a fauna of mainly crinoids and bryozoans dominate the formation. The dominant facies are grainstones and packstones (Fig. 50). The formation has a characteristic low gamma ray response throughout, except for thin intervals of dark grey silty wackestone that represent temporary deeper water deposition related to flooding events. Chert nodules occur sporadically throughout the section. The dark grey silty limestone intervals are lithologically similar to the Ulv Formation but are regarded as part of the Isbjørn Formation if they are of subordinate importance and less than 15-20 m thick. Thicker intervals such as that from 3625 m to 3586 m in well 7121/1-1 are included in the Ulv Formation.

***Lateral extent and variation:***

The formation represents deposition in inner shelf environments. Following a major transgression in the early Artinskian the formation developed over earlier carbonate build-ups and submerged structural highs and platforms. The formation is not known from either outer shelf regimes or from basinal areas.

***Age:***

The base of the formation is apparently diachronous. In the type section in 7128/6-1 fusulinids suggest that the base is of mid-Sakmarian age and the top is late Artinskian (Ehrenberg *et al.* 1998a). In well 7229/11-1 the top of the underlying Polarrev Formation is dated as late Sakmarian, indicating a late Sakmarian or younger age for the formation in this well (Davydov 1998). The formation is apparently of late Artinskian age in IKU cores (Bugge *et al.* 1995).

***Depositional environments:***

The bioclastic crinoid- and bryozoan- dominated grainstones and packstones of the Isbjørn Formation represent deposition in inner shelf environments on cool-water carbonate platforms (Stemmerik 1997). The more silty wackestone facies represent temporary flooding and deposition in slightly deeper environments below storm wave base.

***Correlation:***

The upper part of the Isbjørn Formation correlates age- and facies-wise with the Hambergfjellet Formation on Bjørnøya and with the Vøringen Member of the Kapp Starostin Formation on Spitsbergen.

## *Tempelfjorden Group (Tempelfjordgruppen)*

***Name:***

Cutbill & Challinor (1965) introduced the term Tempelfjorden Group for a suite of spiculites, spiculitic chert, silicified limestones and fine-grained siliciclastics of mid- to late Permian age. The type area is in the innermost part of Isfjorden in central Spitsbergen. The Tempelfjorden Group is a well-established lithostratigraphic unit; its overall facies development and depositional evolution have been described by Steel & Worsley (1984) and Ezaki *et al.* (1994).

***Offshore reference areas:***

The southern Loppa High – Hammerfest Basin, the Bjarmeland Platform and the eastern Finnmark Platform illustrate the quite significant variations in the group's development offshore (Fig. 51). The group is thickly developed along the southern margins of the Loppa High where it has been penetrated by wells 7121/1-1 and 7120/1-1. The upper parts of the group were penetrated by 7120/9-2 (from 4956 m to TD at 5072.6 m, Fig. 52) in the central Hammerfest Basin, while thickest – but sedimentologically atypical - developments are seen in wells 7120/12-2 (4558-3657 m) and 7120/12-4 (2118-1366 m) on the basin's southern margins (Fig. 51).

***Thickness:***

The group thickens from 509 m in well 7121/1-1 and 591 m in well 7120/1-1 on the southern Loppa High, to 752 m in well 7120/12-4 and 901 m in well 7120/12-2 along the southern margins of the Hammerfest Basin (Fig. 51). This is appreciably thicker than the maximum of 460 m observed on land areas of Svalbard. Thinner developments are seen eastwards on the Bjarmeland Platform - 425 m in well 7124/3-1 and 226 m in well 7226/11-1 along the southern margins of the platform. On the eastern Finnmark Platform it forms a distinctive wedge-shaped unit thinning from approximately 180 m in well 7228/9-1 (Fig. 51) on the northern shelf margins to 135 m in wells 7128/4-1 and 7128/6-1 and to less than 30 m further updip in the subcrop areas demonstrated by IKU shallow cores.

The Tempelfjorden Group usually thins over local structural highs - exposures on Bjørnøya on the Stappen High show an extremely condensed (115 m thick) development of the group and highly condensed exposures on the margins of the Sørkapp-Hornsund High are only a few metres thick, thinning to zero over the crest of the structure (Hellem & Worsley 1978). It is not certain whether the group was initially deposited over the crest of the Loppa High, but the succession also thins and is then truncated upflank there, reflecting repeated uplift in the Permian to early Triassic; a roughly similar situation is seen in the inner parts of the Finnmark Platform, although thinning there reflects maximum onlap of the adjacent craton rather than active tectonism.

***Lithology:***

The Tempelfjorden Group is characterised by dark to light grey spiculites, spiculitic cherts, silicified skeletal limestones and fine-grained siliciclastics including marls, calcareous claystones, shales and silt/sandstones in the offshore areas. In the southwestern Hammerfest Basin (7120/12-4 and 7120/12-2) the group contains a significant proportion of coarse siliciclastics. Elsewhere in the Norwegian Barents Sea, spiculites and silicified skeletal carbonates dominate. The carbonates contain a fauna dominated by brachiopods, sponges, bryozoans and crinoids. The condensed development of the Miseryfjellet Formation on the Stappen High contains herringbone cross-bedded sandstones and highly condensed silicified skeletal limestones.

***Lateral extent and variation:***

The group is thickest in the western part of the study area. It forms distinctive wedge-shaped units with maximum thickness in the basins. On the eastern Finnmark Platform, the lower part of the group onlaps the inner Finnmark Platform and subcrops the Quaternary further updip. Lithologies are uniform in the eastern part of the study area and are dominated by chert and chert-rich limestone, while coarse siliciclastic domination in the southern Hammerfest Basin suggests emergent local provenance areas.

Sediments assigned to the Tempelfjorden Group generally overlie the Bjarmeland Group (except in wells 7120/12-2 and 7120/12-4 where they directly overlie the Gipsdalen Group). There is a sharp contact between Artinskian light grey, skeletal limestones below and the overlying dark-grey to black, silicified and spiculitic fine-grained deposits. The boundary represents a major drowning event in the Barents Sea region, and an ongoing change towards cooler climatic conditions (Stemmerik 1997).

***Age:***

The Tempelfjorden Group is dated as late Artinskian to ?Tatarian in the onshore areas (Nakrem 1991; Mangerud 1994). Palynological data from cores 7128/12-U-01 and 7129/10-U-01 indicate a ?Kungurian to Kazanian (-?Tatarian) age for the group updip on the Finnmark Platform (Mangerud 1994; Bugge *et al.* 1995). Palynomorphs from exploration wells indicate a general mid- to late Permian age for the group without permitting a more detailed internal zonation.

***Depositional environments:***

The Tempelfjorden Group represents deposition in cool-water, temperate shelf and basinal environments. The majority of the group was deposited in distal marine, low-energy (below wave base), moderate to deep shelf to basinal environments characterised by a rich siliceous sponge fauna. The group was deposited during an overall transgression accompanied by retrogradation of the coastline. The main accumulations of spiculites appear to be related to transgressive periods when favourable environmental conditions for sponges prevailed over most of the shelf. Cool-water, bryozoan carbonates formed along the margins and formed low-relief platforms during sea level highstand.

Wells in the southernmost Hammerfest Basin are characterised by significant coarse siliciclastic influx from the nearby Baltic Shield.

***Formations assigned to the group:***

Two new formations are assigned to the Tempelfjorden Group herein: their names are selected from fish common to the Barents Sea. The generally underlying Røye Formation is characterised by generally fine-grained highly silicified mudstones and limestones, while the generally overlying Ørret Formation comprises mudstones and some coarser siliciclastics, all of which show much less silicification than the sediments of the Røye Formation. Some wells, especially on the southern margins of the Loppa High or the Hammerfest Basin's southern margins are interpreted to display either only Røye Formation (7121/1-1) or intercalations of both units (7120/1-1, 712012/2 & 4, Fig. 51).

## *Røye Formation (Røyeformasjonen)*

### *Name:*

From the Norwegian name for the Arctic Char (*Salvelinus alpinus*).

### *Definition:*

The type section is defined as the interval from 1745.4 m to 1623.5 m in well 7128/6-1 located on the Finnmark Platform (Fig. 53). The base of the formation is there characterised by a marked increase in the gamma ray log response, and a corresponding decrease in both density and interval transit time based on the density and sonic logs. This represents the transition from tight limestones of the underlying Isbjørn Formation to silicified deposits in the basal part of the Røye Formation (Fig. 54).

### *Reference sections:*

Reference sections are defined:

In Loppa High well 7120/1-1, with formational base at 2997 m on the Ulv Formation; this well shows an interfingering of the Røye and Ørret formations, with typical Røye lithofacies occurring from 2997 m to 2604 m and from 2458 m to 2430 m (Figs. 51, 55),

In Loppa High well 7121/1-1 with formational base on the Isbjørn Formation at 3502 m and direct contact with Triassic shales at 2993 m (Fig. 56),

In 7228/9-1 from 4065 m to 3966 m on the northern margins of the Finnmark Platform (Fig. 57), resting on the Isbjørn Formation.

In well 7120/1-1, the formational base at 2997 m is characterised by a slight increase in both gamma ray and sonic log response (Fig. 55). This well's interfingering of the Røye and Ørret formations shows that the transition from the Ørret back into the Røye Formation at 2458 m displays a marked decrease in both gamma ray response and density, reflecting the transition back from silicified fine-grained siliciclastics to limestone.

### *Thickness:*

The formation is 122 m thick in the type well 7128/6-1 on the central Finnmark Platform. It thins to 19 m in core 7128/12-U-01 further to the south. Along the northern margins of the platform, the formation is 99 m thick in well 7228/9-1S and less than 70 m thick in 7229/11-1. It thickens north of the Nordkapp Basin to 230 m in 7124/3-1 on the Bjarmeland Platform and to its thickest development of 509 m in reference well 7121/1-1 on the southeastern Loppa High; 421 m of Røye Formation occur in the interfingering development found in 7120/1-1 further west on the high. Our tentative interpretations of wells 7120/12-2 and 7120/12-4 on the southern margins of the Hammerfest Basin suggest a very complex interfingering of possible Røye and Ørret formation representatives, the former showing a total of up to about 150 m in several intercalations (Fig. 58); more data are however needed from this area to confirm this interpretation.

***Lithology:***

Silicified sediments dominate the Røye Formation as the result of early silicification processes that were sourced by abundant silica sponge spicules. On the eastern Finnmark Platform, the lower part of the Røye Formation consists of dark grey to black, silicified calcareous claystone with minor pyrite and traces of organic material (e.g. 1745,4 to1728 m in well 7128/6-1; Fig. 54). The lithology of the lower part of the formation changes somewhat toward the Loppa High where it is characterised by interbedded silicified marls, silty carbonate mudstone and calcareous claystone with some thin beds of spiculitic cherts (e.g. 3177 to 2860 m in well 7120/1-1). The relative proportion of these facies varies laterally and spiculitic chert dominates well 7228/9-1 (4064-4014 m) whereas the basal part of the formation in well 7121/1-1 (3502-3367 m) is dominated by silicified silty carbonate mudstone.

The upper part of the formation consists of interbedded spiculite, spiculitic chert, silicified bioclastic, bryozoan-dominated limestone (wackestone to grainstone), silicified carbonate mudstone, silicified marl and calcareous claystone (e.g. 3367 to 2993 m in 7121/1-1, 3800 to 3671 m in 7124/3-1 and 1688 to 1569 m in 7128/4-1). The silicified limestone is best developed on the Loppa High (reference wells 7120/1-1 and 7121/1-1) and on the eastern Finnmark Platform (7128/4-1, 7128/12-U-01 and 7129/10-U-01, Fig. 59). The spiculitic deposits show variable clay and dolomitic lime mud content. These rocks are mainly tight, with no apparent porosity; however, on inner parts of the Finnmark Platform white to light grey porous spiculites are present in wells 7128/4-1, 7128/6-1 and 7128/12-U-01 (Figs 60, 61) – the porosities apparently reflecting secondary solution processes.

***Lateral extent and variation:***

The formation forms a laterally continuous unit at the base of the Tempelfjorden Group from the eastern Finnmark Platform and westward to the Loppa High. In the southern Hammerfest Basin the formation is less clearly developed, but as mentioned above, our interpretation suggests several units, each 30 to 100 m thick, interbedded with sediments herein assigned to the Ørret Formation. The Røye Formation thins toward the east and updip on the Finnmark Platform. Local thinning is also seen above carbonate buildups of the underlying Bjarmeland Group (see e.g. well 7229/11-1, Fig. 51).

***Age:***

Cores from 7128/12-U-01 and 7129/10-U-01 suggest a ?Kungurian to Kazanian – (?Tatarian) age (Mangerud 1994; Bugge *et al.* 1995).

***Depositional environments:***

The lower part of the formation represents distal marine, low-energy deep shelf to basinal conditions established during and after major initial transgression. On the Loppa High and inner parts of the Finnmark Platform bryozoan-dominated, low relief carbonate platforms prevailed. The middle to upper parts of the formation represent distal marine, moderate to deep shelf conditions affected by periodic high-energy storm episodes which reworked the sediments, but with a normal depositional environment characterised by a very rich siliceous sponge fauna. Carbonate ramps were still situated on the Loppa High and inner parts of the Finnmark Platform.

On the Loppa High in well 7121/1-1 the upper part of the formation reflects initial transgression with deposition of deep shelf spiculites succeeded by carbonate platform deposits. Towards the crest of the Loppa High the formation was truncated by late Permian uplift and erosion.

### *Ørret Formation (Ørretformasjonen)*

***Name:***

From the Norwegian name for the Brown Trout (*Salmo trutta*).

***Definition:***

The type section is defined as the interval from 3670 m to 3475 m in 7124/3-1 on the Bjarmeland Platform (Fig. 62, Table 1). The base of the formation is characterised by a sharp increase in gamma ray log response accompanied by increasing neutron and sonic log readings in the type section where the formation overlies silicified limestones of the Røye Formation (Fig. 62).

***Reference sections:***

Reference sections are defined:

In Loppa well 7120/1-1 with base at 2604 m, interfingering with a typical Røye development from 2458 m to 2430 and again overlain by the Røye Formation until the contact with overlying Triassic shales at 2402 m (Figs. 51, 55), from 3966 m to 3884 m in 7228/9-1S on the northern margins of the Finnmark Platform (Fig. 57).

As in the type section, the base of the formation is defined by a sharp increase in gamma ray log response accompanied by increasing neutron and sonic log readings in reference well 7228/9-1S (and in 7229/11-1) on the northern Finnmark Platform, where the formation also overlies silicified sediments of the Røye Formation (Figs. 51, 57).

***Thickness:***

The formation is 195 m thick in the type well and has an aggregate thickness of 173 m in 7120/1-1 on the Loppa High, whereas it is interpreted as not being developed in nearby well 7121/1-1. On the northern Finnmark Platform it is 82 m thick in well 7228/9-1, only 22 m in 7229/11-1 (Fig. 51) and disappears northwards so that wells 7128/4-1 and 7124/6/1 and cores 7128/12-U-01 and 7129/10-U-01 on the central and southern Finnmark Platform show only the Røye Formation directly overlain by Triassic shales. Tentative interpretations on the southern margins of the Hammerfest Basin in wells 7120/12-2 and 7120/12-4 suggest cumulative thicknesses of 656-901 metres.

***Lithology:***

The formation is dominated by siliciclastic sediments and includes sandstones, siltstones and shales. The more fine-grained lithologies dominate. The sandstones (Fig. 62) appear as isolated thin beds, or as up to 35 m thick sandy units, or in intervals with numerous thin sandstone beds separated by shales. The sandstones are particularly common in the upper part of the Ørret Formation in 7120/12-2 (Fig. 58) and 7120/12-4. On the Loppa High and further eastward, organic rich shales become progressively more important. Coal fragments are reported from some levels in association with sandstones. The siliciclastics are, in contrast to those of the Røye Formation, not silicified. Thin limestone beds are rare in the formation.

***Lateral extent and variation:***

The formation is thickest in the deeper basinal and outer ramp areas of the Hammerfest Basin and the Finnmark and Bjarmeland platforms. Updip on the Finnmark Platform and the Loppa High it passes into the shallow marine carbonates of the Røye Formation. The transition from thin and organic-rich shales with rare thin sandstone and limestone beds in the east (7124/3-1, 7226/11-1, 7228/9-1 and 7229/11-1) to thicker, more silty and sandy and less organic-rich lithofacies in wells 7120/12-2 and 7120/12-4 in the southwestern Hammerfest Basin and Finnmark Platform, suggests a southwesterly-located siliciclastic provenance area. In these southwestern wells, where the formation is thought to interfinger with the Røye Formation, the basal transition is always characterised by a sharp increase in gamma ray log response reflecting the transition from silicified carbonates to fine-grained non-silicified siliciclastics (Figs. 58 and 62).

***Age:***

A ?Kungurian to ?Tatarian age is suggested by correlation to lateral equivalents.

***Depositional environments:***

Deposition took place in a variety of siliciclastic-dominated environments ranging from deltaic and lower coastal plain environments in the southwestern Hammerfest Basin to deep shelf environments on the southern Bjarmeland Platform and the northern Finnmark Platform. Dysoxic to anoxic conditions occurred locally in the deeper shelf settings to the east.

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## FIGURE CAPTIONS

Fig. 1. Map of the southern Norwegian Barents Sea showing the main structural elements referred to herein.

Fig. 2. Map of southern Norwegian Barents Sea showing locations of wells and shallow cores penetrating the Upper Palaeozoic succession. Locations of seismic lines shown in Fig.5 are also shown.

Fig. 3. Legend to well log and core descriptions.

Fig. 4. Correlation of Upper Palaeozoic lithostratigraphic units in the offshore areas of the southern Norwegian Barents Sea. For explanation of symbols see Fig. 3.

Fig. 5. Seismic images of the Upper Palaeozoic succession in the southern Norwegian Barents Sea. For location of the sections, see Fig. 2.

5a: Loppa High from its crest eastwards towards the Bjarmeland Platform, showing fault control on sedimentation and reefoid features in both the Gipsdalen and Bjarmeland groups.

5b: Central Bjarmeland Platform, showing an even development of all 4 major units and the reefoid features typical for the Bjarmeland Group.

5c: Northern Finnmark Platform showing half-grabens controlling the Billefjorden Group's development and dramatic thickening of the Gipsdalen Group (with reefoid buildups) towards the platform margins.

5d: Finnmark Platform, showing half-graben formation affecting the development of the Billefjorden Group - note the marked thickening northwards on the platform.

Fig. 6. Correlation of Upper Palaeozoic offshore units defined herein with lithostratigraphic units onshore Svalbard. Note that the Bjarmeland Group is only distinguished on Bjørnøya.

Fig. 7. Correlation of the Billefjorden Group on the Finnmark Platform.

Fig. 8. Well logs of the Billefjorden Group in well 7128/4-1 showing the type section of the Soldogg Formation and the reference section for the Tettegras Formation. For explanation of symbols see Fig. 3.

## TABLE CAPTIONS

# APPENDIX, WELL & SHALLOW CORE LOCATIONS

## *Finnmark Platform*

| | | |
|---|---|---|
| 7128/4-1 (Statoil) | 71° 32' 27.33" N | 28° 04' 54.08"E |
| 7128/6-1 (Conoco) | 71° 31' 04.99" N | 28° 49' 03.41"E |
| 7120/12-4 (Norsk Hydro) | 71° 03' 01.13" N | 20° 42' 32.16"E |
| 7229/11-1 (Shell) | 72° 12' 57.24"N | 29° 38' 29.75" E |
| 7029/03-U-01 (IKU) | 70° 54' 10.13" N | 29° 54' 14.94"E |
| 7029/03-U-02 (IKU) | 70° 56' 07.00" N | 29° 58' 53.60" E |
| 7127/10-U-02 (IKU) | 71º 09’ 39.42" N | 27º 05’ 26.46" E |
| 7127/10-U-03 (IKU) | 71º 10’ 55.04" N | 27º 11’ 02.34" E |
| 7030/03-U-01 (IKU) | 70° 49' 36.20" N | 30° 44' 31.10" E |
| 7128/12-U-01 (IKU) | 71º 14’ 25.61" N | 28º 50’ 28.93" E |
| 7129/10-U-01 (IKU) | 71º 09’ 35.45" N | 29º 16’ 42.77" E |
| 7129/10-U-02 (IKU) | 71° 07' 13.50" N | 29° 13' 23.10" E |

## *Loppa High*

| | | |
|---|---|---|
| 7120/2-1 (Norsk Hydro) | 71° 58' 57.97" N | 20° 28' 35.10" E |
| 7121/1-1 (Esso) | 71° 56' 25.74" N | 21° 04' 36.52" E |
| 7120/1-1 (Shell) | 71° 55' 00.83" N | 20° 18' 07.13" E |
| 7323/07-U-10 (IKU) | 73° 15' 41.33" N | 23° 16' 07.01" E |
| 7323/07-U-11 (IKU) | 73° 15' 41.33" N | 23° 09' 29.57" E |
| 7323/10-U-02 (IKU) | 73° 13' 15.87" N | 23° 18' 42.72" E |

| | | |
|---|---|---|
| 7323/11-U-01 (IKU) | 73° 13' 59.95" N | 23° 27' 00.04" E |

## *Bjarmeland Platform*

| | | |
|---|---|---|
| 7226/11-1 (Statoil) | 72° 14' 18.16" N | 26° 28' 44.78" E |
| 7124/3-1 (Saga Petroleum) | 71° 45' 36" N | 24° 46' 50" E |

## *Nordkapp Basin*

| | | |
|---|---|---|
| 7228/9-1S (Norsk Hydro) | 72° 23' 48.36" N | 28° 43' 08.67" E |
| 7228/7-1A (Statoil) | 72° 15' 28.86" N | 28° 08' 59.38" E |

## *Hammerfest Basin*

| | | |
|---|---|---|
| 7120/12-2 (Norsk Hydro) | 71° 07' 30.3" N | 20° 48' 19" E |
| 7120/9-2 (Norsk Hydro) | 71° 29' 40.81" N | 20° 42' 05.83" E |

## *Tromsøbassenget*

| | | |
|---|---|---|
| 7119/7-1 (Norsk Hydro) | 71° 23' 42.40" N | 19° 15' 18.43" E |

Barents Sea
Main Structural Elements

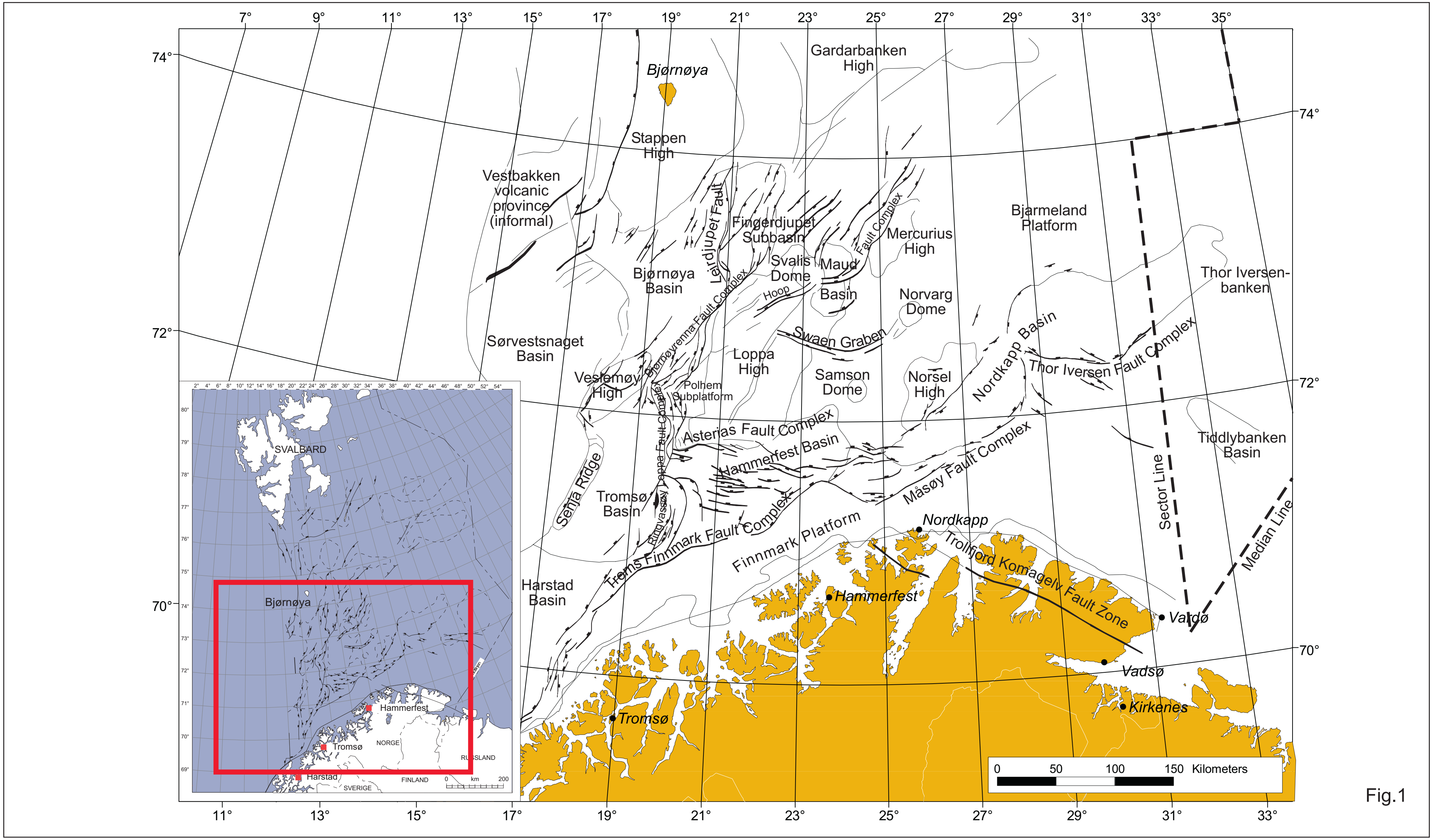



Fig. 1. Map of the southern Norwegian Barents Sea showing the main structural elements referred to herein.

HA/2002_0067_s1/GBL/10.07.02/jse

# Barents Sea

## Wells and seismic lines

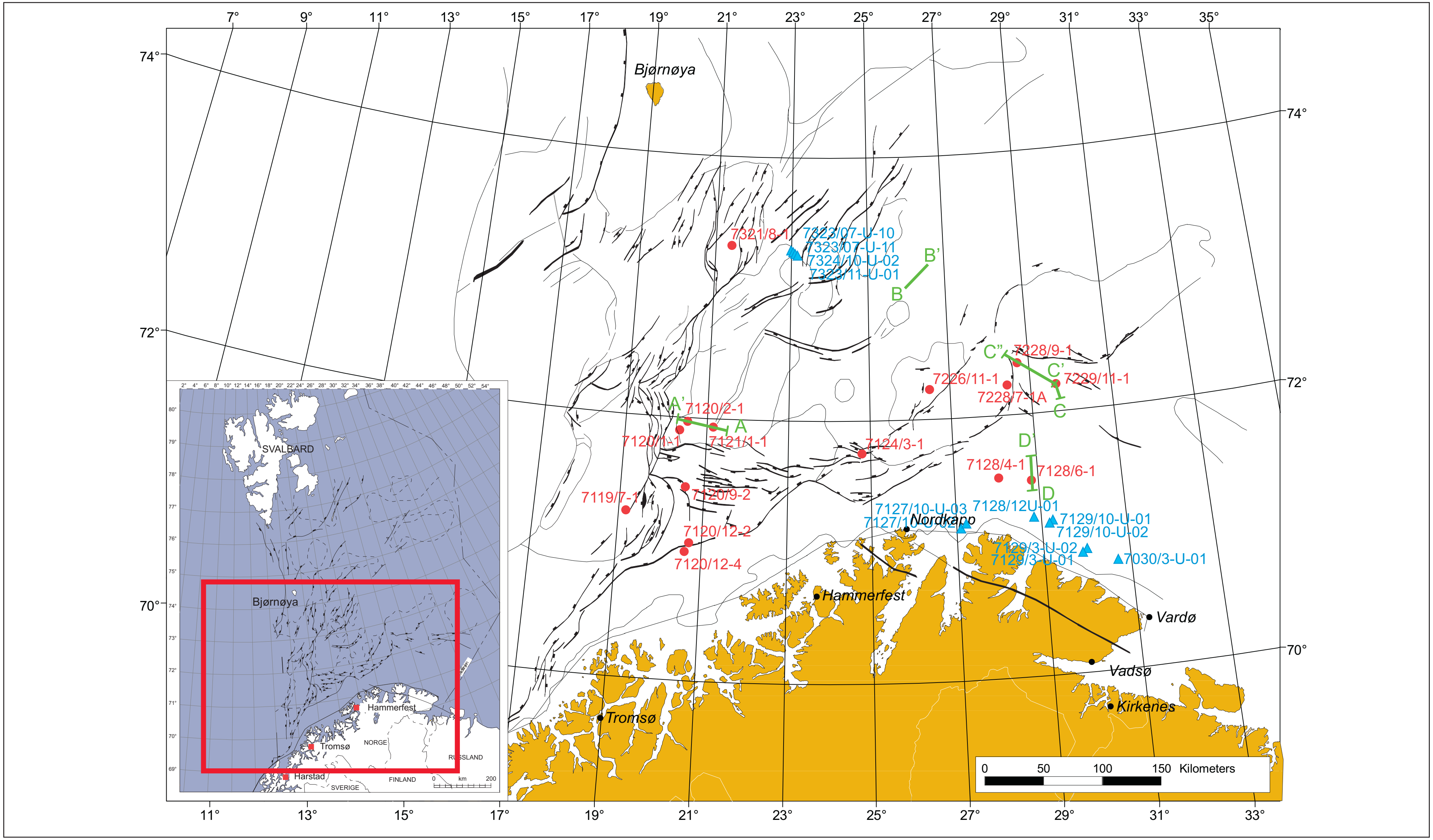
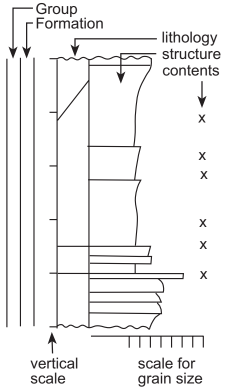



Fig. 2. Map of southern Norwegian Barents Sea showing locations of wells and shallow cores penetrating the Upper Palaeozoic succession. Locations of seismic lines shown in Fig.5 are also shown.

HA/2002_0067_s1/GBL/10.07.02/jse

# LEGEND

## Legend for stratigraphic type sections




1) for clastic rocks:
- cl: clay
- si: silt
- vf: very fine
- f: fine
- m: medium
- c: coarse
- vc: very coarse
- g: gravel
- p: pebbles

(vf–vc: sandstones)

2) for carbonate rocks:
- M: mudstone
- W: wackestone
- P: packstone
- G: grainstone
- B: boundstone

## Siliciclastic rocks

- Conglomerate
- Sandstone
- Siltstone
- Claystone/Shale

## Carbonate rocks

- Limestone
- Dolomite
- Dolomitic limestone/ Calcareous dolomite
- Marl/argillaceous carbonate

## Other layered lithologies

- Coal
- Spiculite
- Evaporite
- Metamorphic rock

## Secondary lithological content

- Glauconite
- P Phosporite
- Pyrite
- Anhydritic/gypsiferous
- Halitic
- Sideritic
- Calcareous/calcite cement
- Dolomitic/dolomite cement
- Cherty
- Argillaceous/shaley
- Silty
- Sandy
- Nodule
- Carbonaceous
- Coaly, coal lenses or fragments
- Mudclasts
- Caliche nodule

## Structure

- Trough cross-bedding
- Tabular/planar cross-bedding
- Herringbone cross-bedding
- Laminated
- Algal laminated
- Cross-bedding, ripple lamination
- Ripple lamination
- Climbing ripple lamination
- Wave ripples
- Lenticular bedding
- Flaser bedding
- Wavy bedding
- Soft sediment deformation
- Enterolithically folded gypsum
- Karst
- Stylolite

## Invertebrate fossils

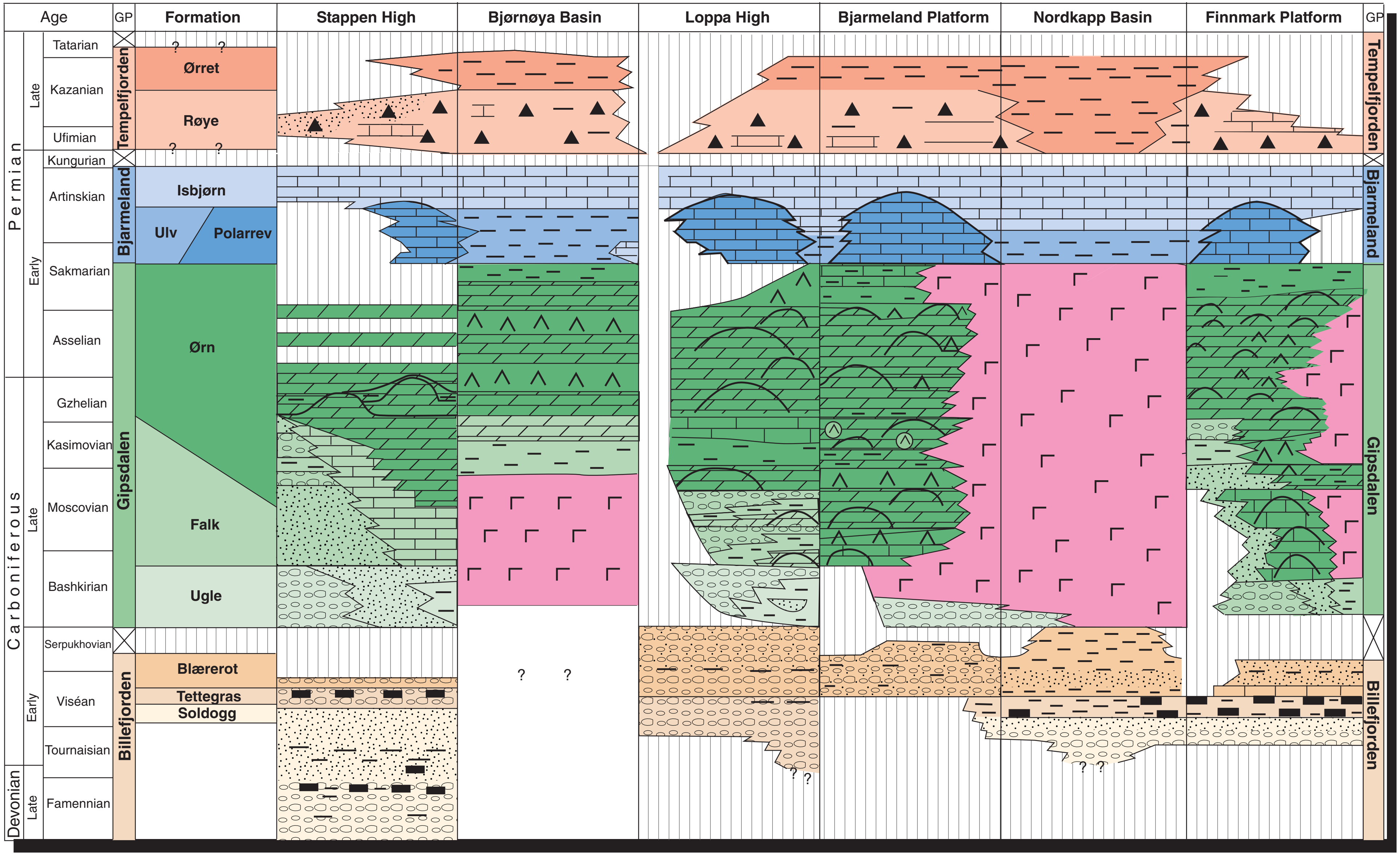
- *Palaeoaplysina*
- Coral
- Colonial coral
- Bivalve
- Gastropod
- Brachiopod
- Bryozoan
- Ostracod
- Trilobite
- Small foraminifer
- Fusulinid
- SP Sponge spicule
- Crinoid
- Ammonoid
- Coquina

## Plant fossils

- Root
- Plant fragment
- Wood fragment
- Algae (unspecified)
- Phylloid algae
- *Tubiphytes*

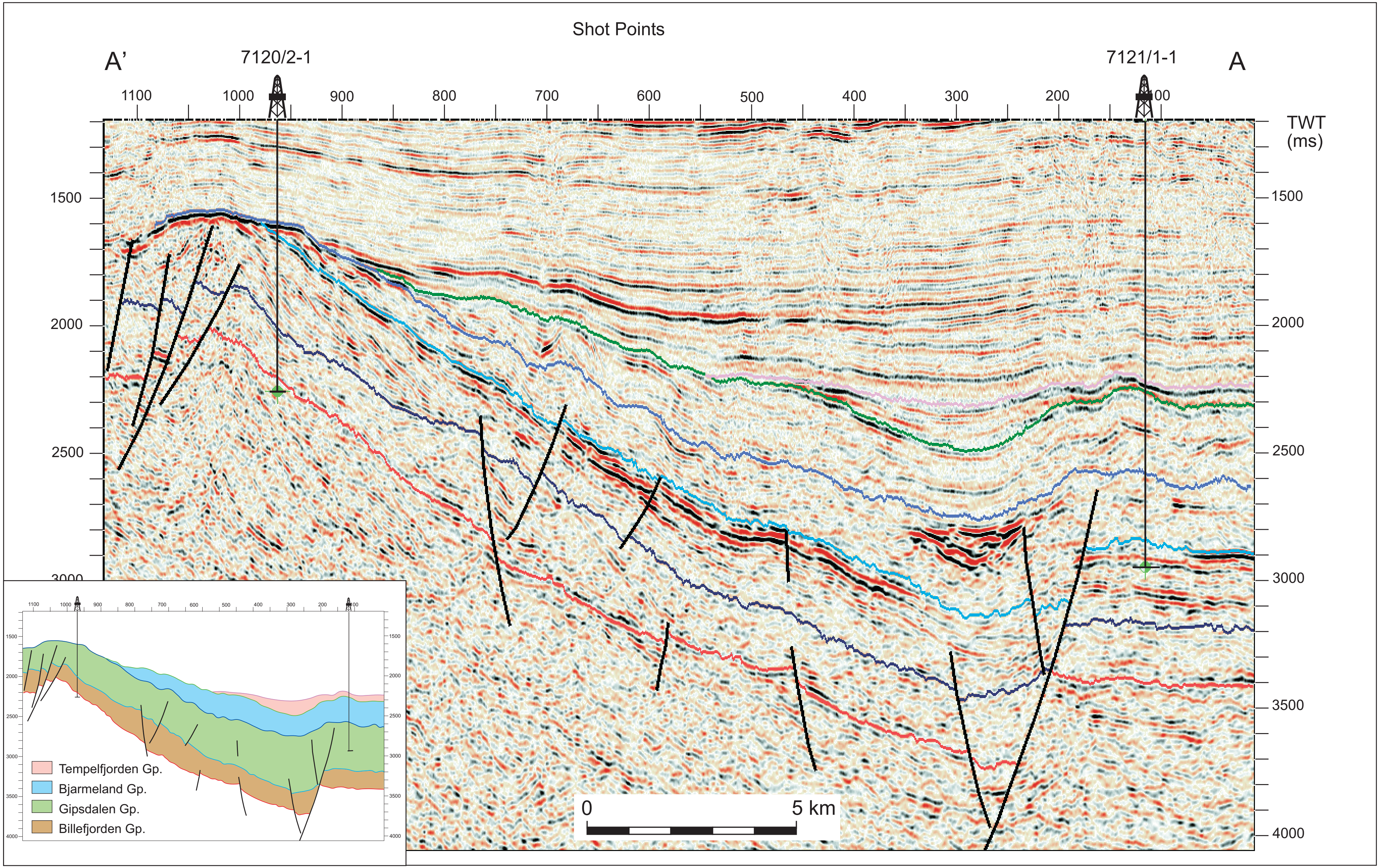
## Trace fossils

- Increasing bioturbation



Age
GP
Formation
Stappen High
Bjørnøya Basin
Loppa High
Bjarmeland Platform
Nordkapp Basin
Finnmark Platform
GP
Permian
Carboniferous
Devonian
Late
Early
Late
Early
Late
Tatarian
Kazanian
Ufimian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Viséan
Tournaisian
Famennian
Tempelfjorden
Bjarmeland
Gipsdalen
Billefjorden
Ørret
Røye
Isbjørn
Ulv
Polarrev
Ørn
Falk
Ugle
Blærerot
Tettegras
Soldogg

# Loppa High
Line SG8737-102

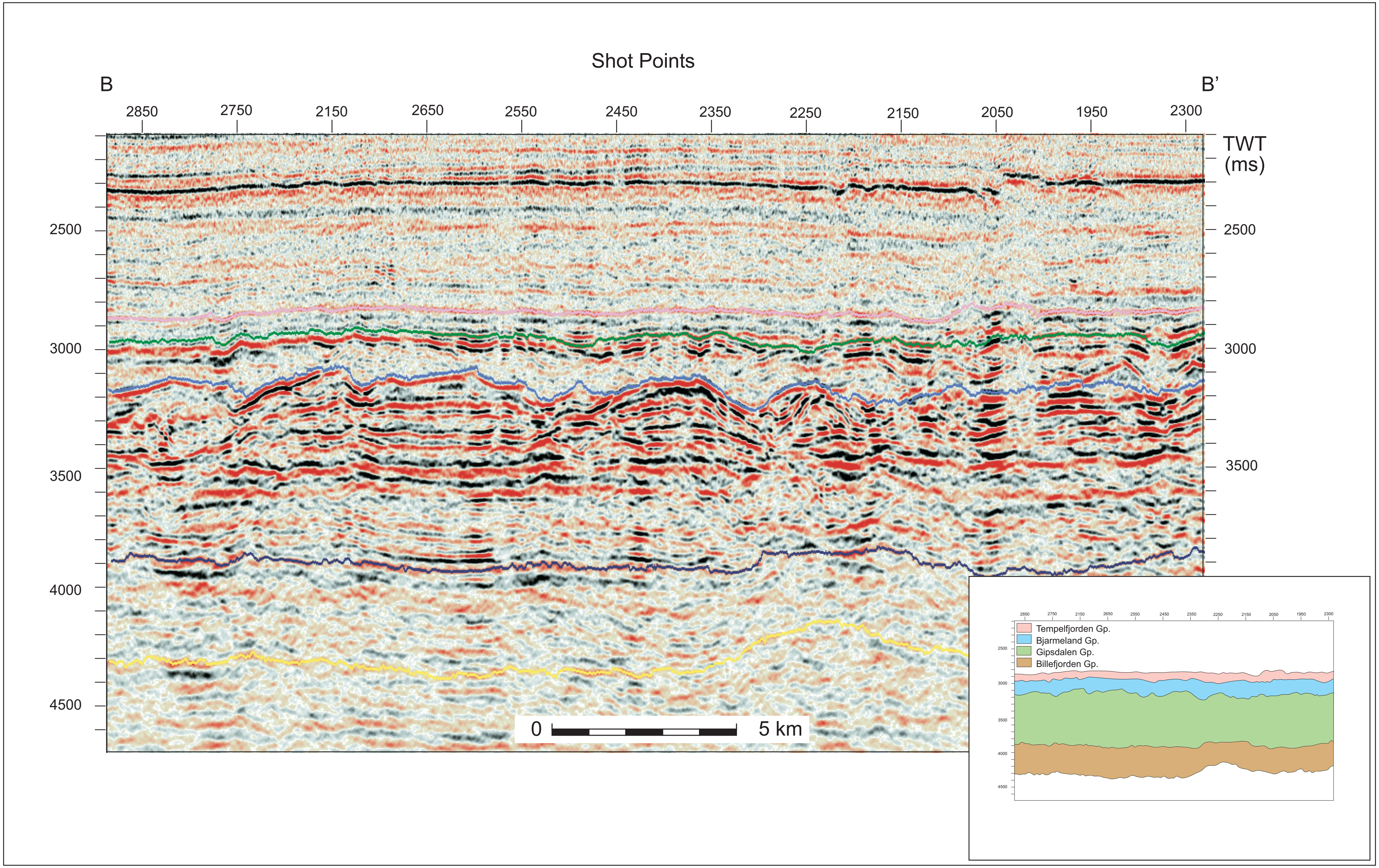



HA/2002_0055_s2/LBH/03.06.02/jse

Fig. 5a

# Bjarmeland Platform

Line SG8837-202A

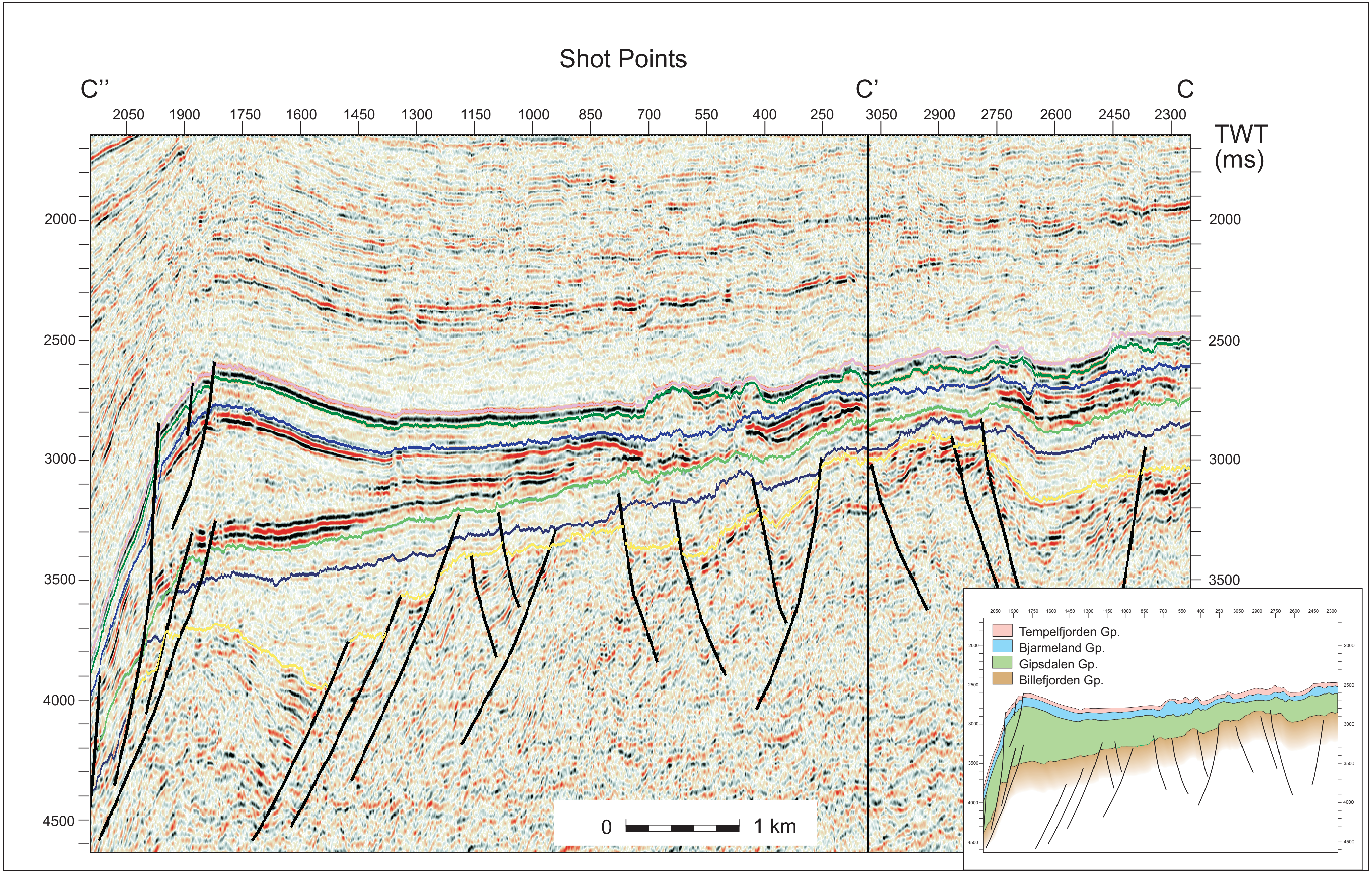



HA/2002_0055_s2/LBH/03.06.02/jse

Fig. 5b

# Nordkapp Basin / Finnmark Platform

Line SG8737-107/106

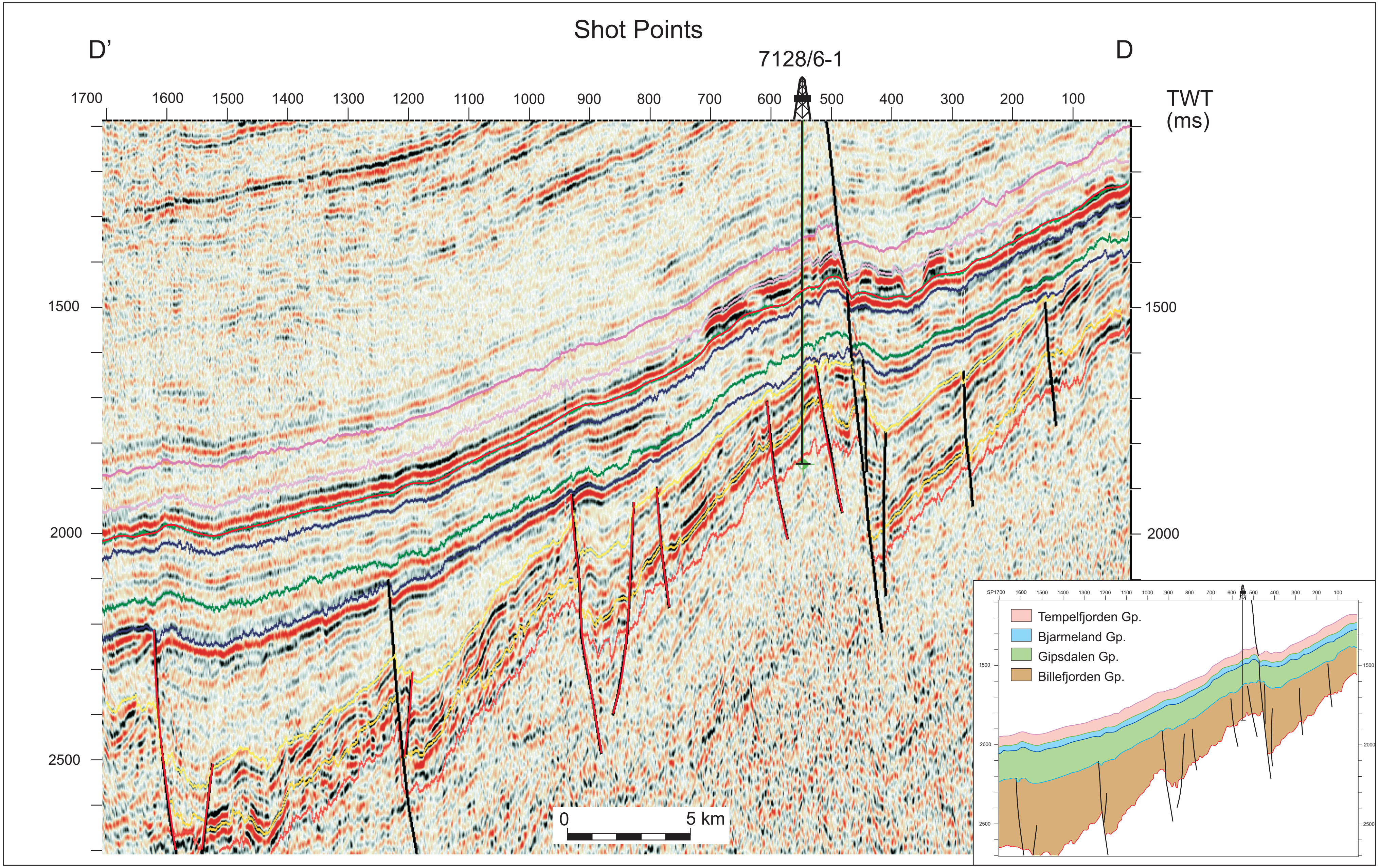



HA/2002_0055_s2/LBH/03.06.02/jse

**Fig. 5c**

# Eastern Finnmark Platform

Line BPGC87-116




HA/2002_0055_s1/LBH/03.06.02/jse

Fig. 5d

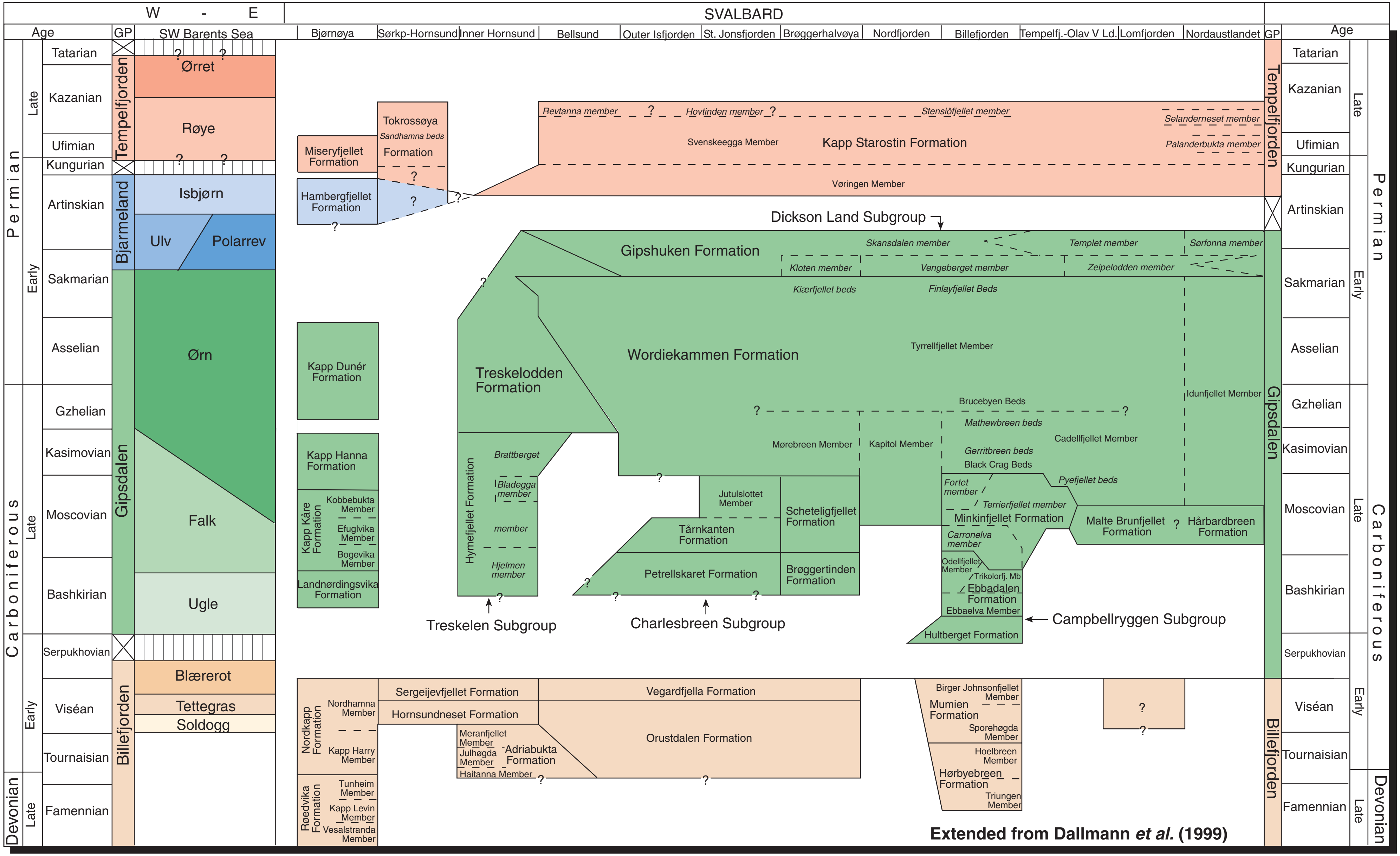
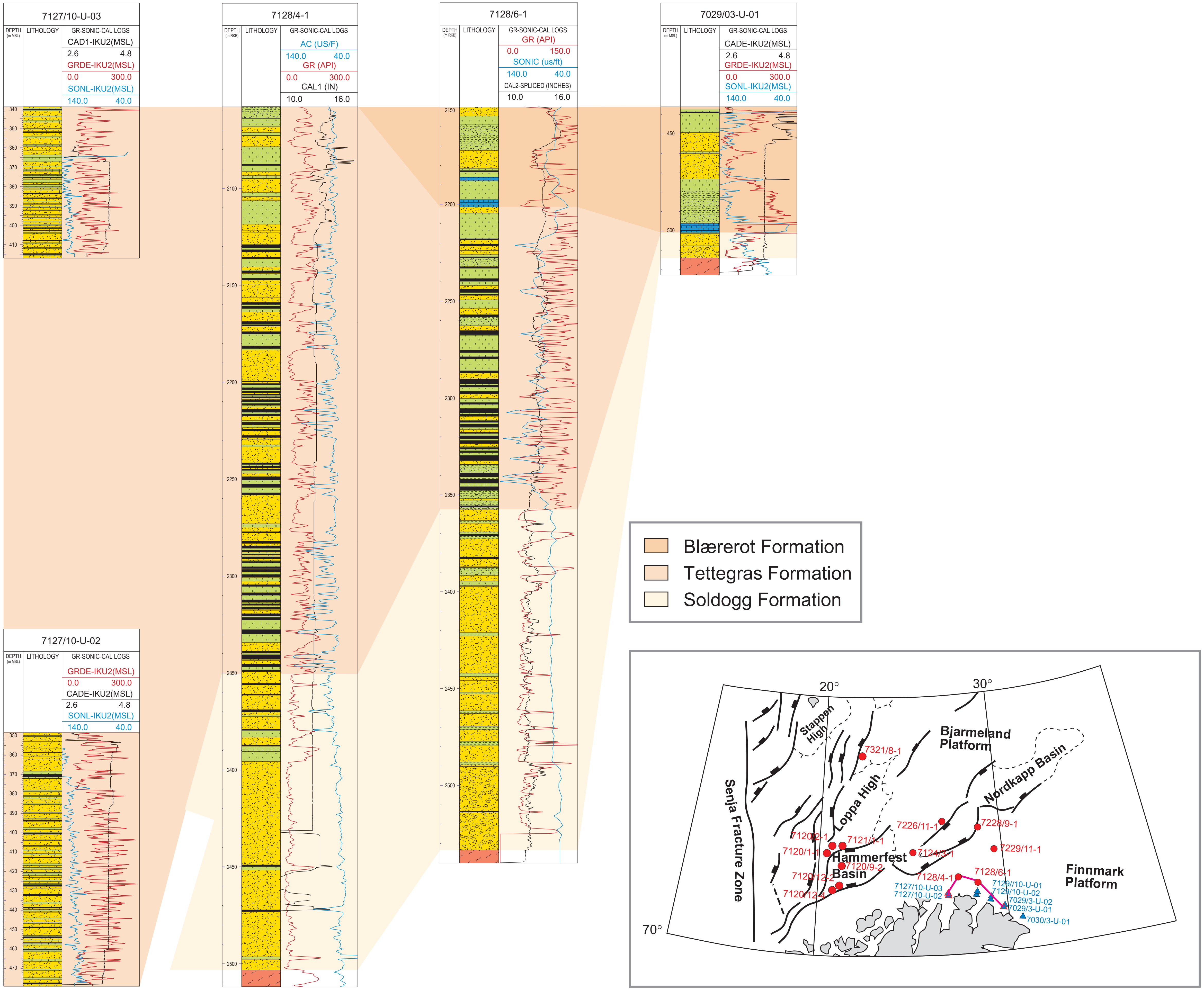
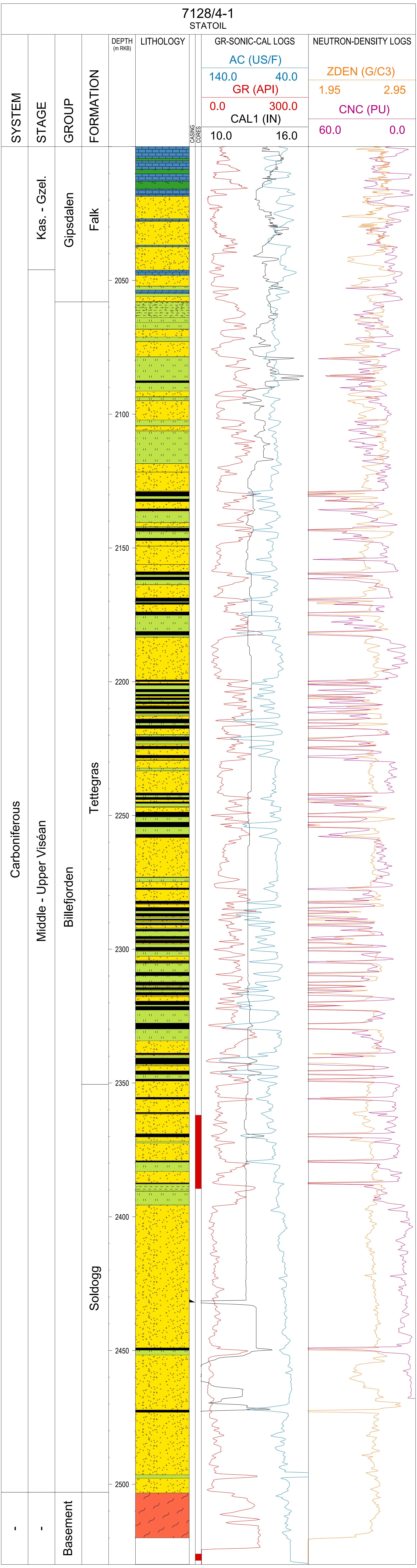

W - E
SVALBARD
Age
GP
SW Barents Sea
Bjørnøya
Sørkp-Hornsund
Inner Hornsund
Bellsund
Outer Isfjorden
St. Jonsfjorden
Brøggerhalvøya
Nordfjorden
Billefjorden
Tempelfj.-Olav V Ld.
Lomfjorden
Nordaustlandet
Permian
Carboniferous
Devonian
Late
Early
Tatarian
Kazanian
Ufimian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Viséan
Tournaisian
Famennian
Tempelfjorden
Bjarmeland
Gipsdalen
Billefjorden
Ørret
Røye
Isbjørn
Ulv
Polarrev
Ørn
Falk
Ugle
Blærerot
Tettegras
Soldogg
Miseryfjellet Formation
Tokrossøya
Sandhamna beds
Formation
Hambergfjellet Formation
Revtanna member
Hovtinden member
Stensiöfjellet member
Selanderneset member
Svenskeegga Member
Kapp Starostin Formation
Palanderbukta member
Vøringen Member
Dickson Land Subgroup
Gipshuken Formation
Skansdalen member
Templet member
Sørfonna member
Kloten member
Vengeberget member
Zeipelodden member
Kiærfjellet beds
Finlayfjellet Beds
Kapp Dunér Formation
Wordiekammen Formation
Tyrrellfjellet Member
Treskelodden Formation
Idunfjellet Member
Brucebyen Beds
Mathewbreen beds
Mørebreen Member
Kapitol Member
Cadellfjellet Member
Gerritbreen beds
Black Crag Beds
Kapp Hanna Formation
Brattberget
Bladegga member
Hymefjellet Formation
member
Hjelmen member
Jutulslottet Member
Scheteligfjellet Formation
Tårnkanten Formation
Petrellskaret Formation
Brøggertinden Formation
Fortet member
Pyefjellet beds
Terrierfjellet member
Minkinfjellet Formation
Malte Brunfjellet Formation
Hårbardbreen Formation
Carronelva member
Odellfjellet Member
Trikolorfj. Mb
Ebbadalen Formation
Ebbaelva Member
Hultberget Formation
Kapp Kåre Formation
Kobbebukta Member
Efuglvika Member
Bogevika Member
Landnørdingsvika Formation
Treskelen Subgroup
Charlesbreen Subgroup
Campbellryggen Subgroup
Sergeijevfjellet Formation
Vegardfjella Formation
Hornsundneset Formation
Orustdalen Formation
Nordkapp Formation
Nordhamna Member
Kapp Harry Member
Meranfjellet Member
Julhøgda Member
Adriabukta Formation
Haitanna Member
Røedvika Formation
Tunheim Member
Kapp Levin Member
Vesalstranda Member
Birger Johnsonfjellet Member
Mumien Formation
Sporehøgda Member
Hoelbreen Member
Hørbyebreen Formation
Triungen Member
?
Extended from Dallmann et al. (1999)

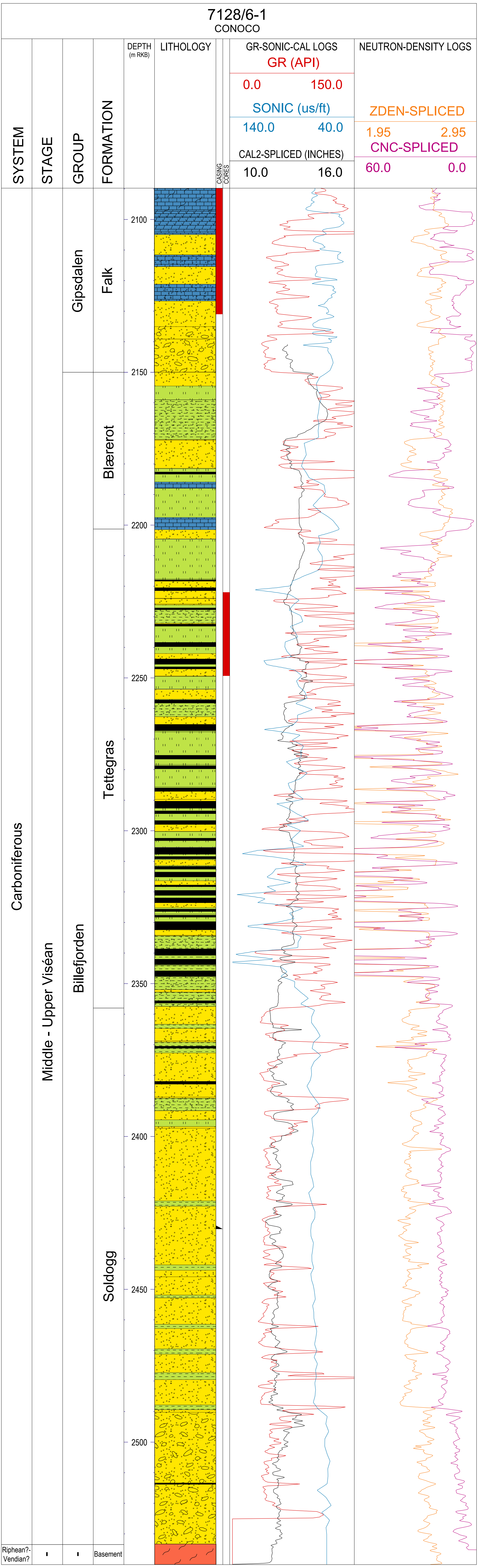
Fig. 6

# Billefjorden Group





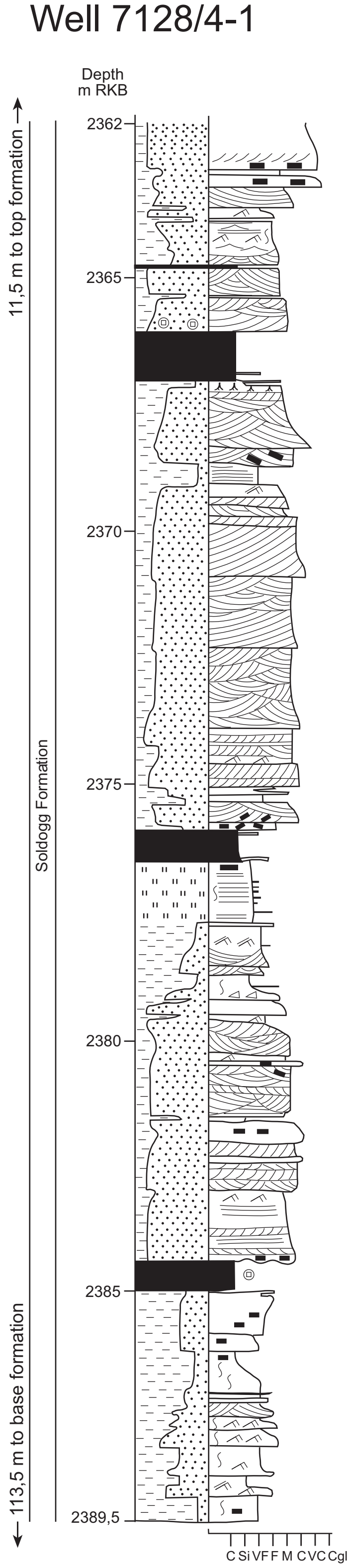
7128/4-1
STATOIL
SYSTEM
STAGE
GROUP
FORMATION
DEPTH
(m RKB)
LITHOLOGY
CASING
CORES
GR-SONIC-CAL LOGS
AC (US/F)
140.0
40.0
GR (API)
0.0
300.0
CAL1 (IN)
10.0
16.0
NEUTRON-DENSITY LOGS
ZDEN (G/C3)
1.95
2.95
CNC (PU)
60.0
0.0
Carboniferous
Kas. - Gzel.
Middle - Upper Viséan
Gipsdalen
Billefjorden
Falk
Tettegras
Soldogg
Basement
-
-
2050
2100
2150
2200
2250
2300
2350
2400
2450
2500



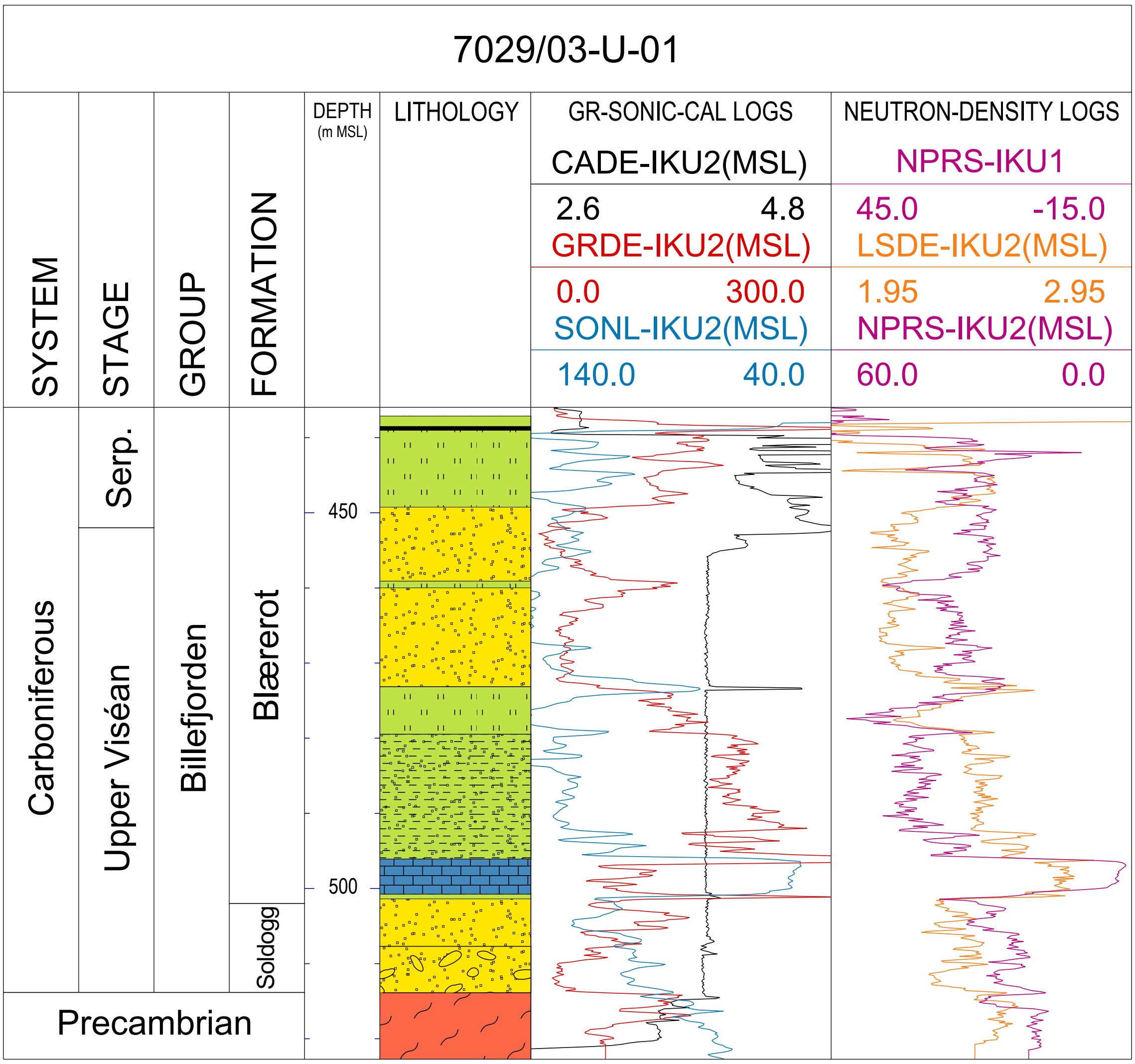
7128/6-1
CONOCO
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CASING
CORES
GR-SONIC-CAL LOGS
GR (API)
0.0
150.0
SONIC (us/ft)
140.0
40.0
CAL2-SPLICED (INCHES)
10.0
16.0
NEUTRON-DENSITY LOGS
ZDEN-SPLICED
1.95
2.95
CNC-SPLICED
60.0
0.0
Carboniferous
Middle - Upper Viséan
Gipsdalen
Billefjorden
Falk
Blærerot
Tettegras
Soldogg
2100
2150
2200
2250
2300
2350
2400
2450
2500
Riphean?-Vendian?
Basement

7120/2-1
NORSK HYDRO
GROUP
FORMATION
DEPTH (m RKB)
GR-SONIC-CAL LOGS
HCAL (in)
6.0 26.0
HDT (m/s)
240.0 40.0
HGR (gAPI)
0.0 150.0
NEUTRON-DENSITY LOGS
HRHO (g/cm3)
1.95 2.95
NPHI (m3/m3)
0.45 -0.15
Gipsdalen
Ugle
Billefjorden
Undifferentiated
2600
2700
2800
2900
3000
3100
3200
3300
3400

Fig. 11



Well 7128/4-1
Depth
m RKB
2362
2365
2370
2375
2380
2385
2389,5
11,5 m to top formation
Soldogg Formation
113,5 m to base formation
C Si VF F M C VC Cgl

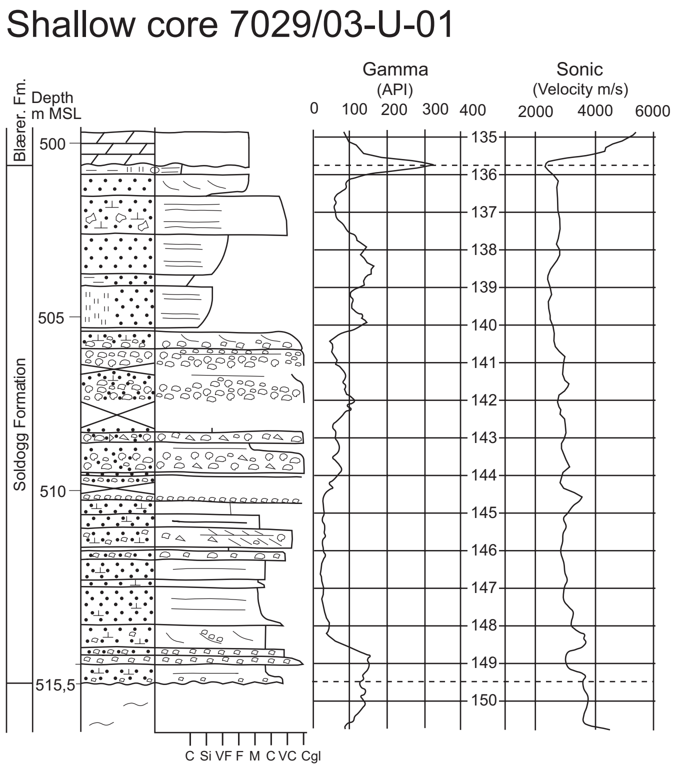


7029/03-U-01
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m MSL)
LITHOLOGY
GR-SONIC-CAL LOGS
CADE-IKU2(MSL)
2.6 4.8
GRDE-IKU2(MSL)
0.0 300.0
SONL-IKU2(MSL)
140.0 40.0
NEUTRON-DENSITY LOGS
NPRS-IKU1
45.0 -15.0
LSDE-IKU2(MSL)
1.95 2.95
NPRS-IKU2(MSL)
60.0 0.0
Carboniferous
Serp.
Upper Viséan
Billefjorden
Blærerot
Soldogg
Precambrian
450
500


STATOIL WELL: 7128/4-1 CORE NO. 4
21 OF 28
TOP 2382.00
BTM 2383.00
22 OF 28
TOP 2383.00
BTM 2384.00
23 OF 28
TOP 2384.00
BTM 2385.00
24 OF 28
TOP 2385.00
BTM 2386.00
KODAK Gray Scale
KODAK Color Control Patches

Fig. 13

Fig. 14


Shallow core 7029/03-U-01
Blærer. Fm.
Depth
m MSL
500
505
510
515,5
Soldogg Formation
C Si VF F M C VC Cgl
Gamma
(API)
0 100 200 300 400
Sonic
(Velocity m/s)
2000 4000 6000
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150

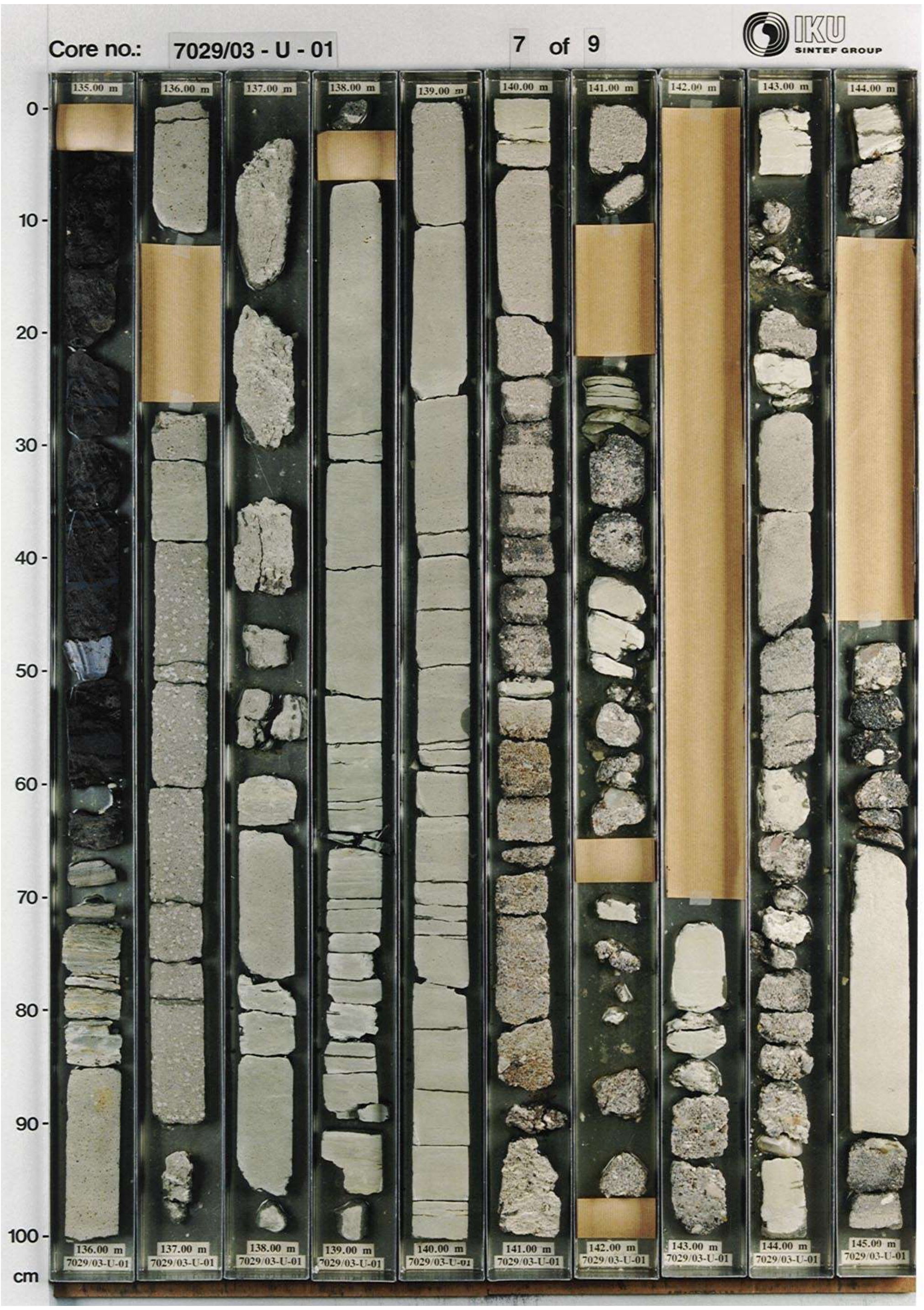

Core no.: 7029/03 - U - 01
7 of 9
IKU SINTEF GROUP
135.00 m
136.00 m
137.00 m
138.00 m
139.00 m
140.00 m
141.00 m
142.00 m
143.00 m
144.00 m
0
10
20
30
40
50
60
70
80
90
100
cm
136.00 m 7029/03-U-01
137.00 m 7029/03-U-01
138.00 m 7029/03-U-01
139.00 m 7029/03-U-01
140.00 m 7029/03-U-01
141.00 m 7029/03-U-01
142.00 m 7029/03-U-01
143.00 m 7029/03-U-01
144.00 m 7029/03-U-01
145.09 m 7029/03-U-01

Fig. 15

Fig. 16

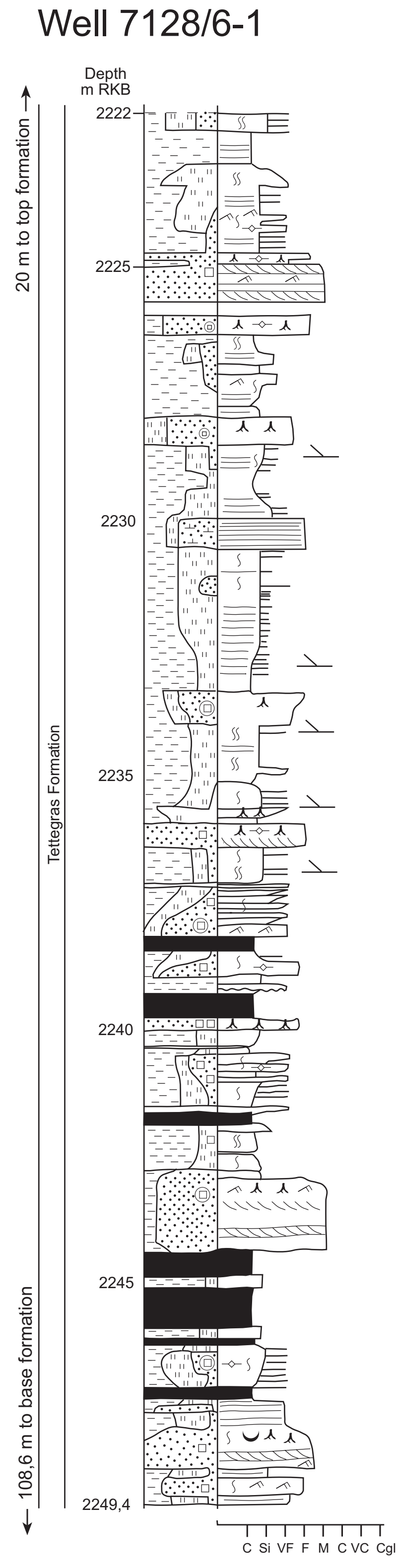
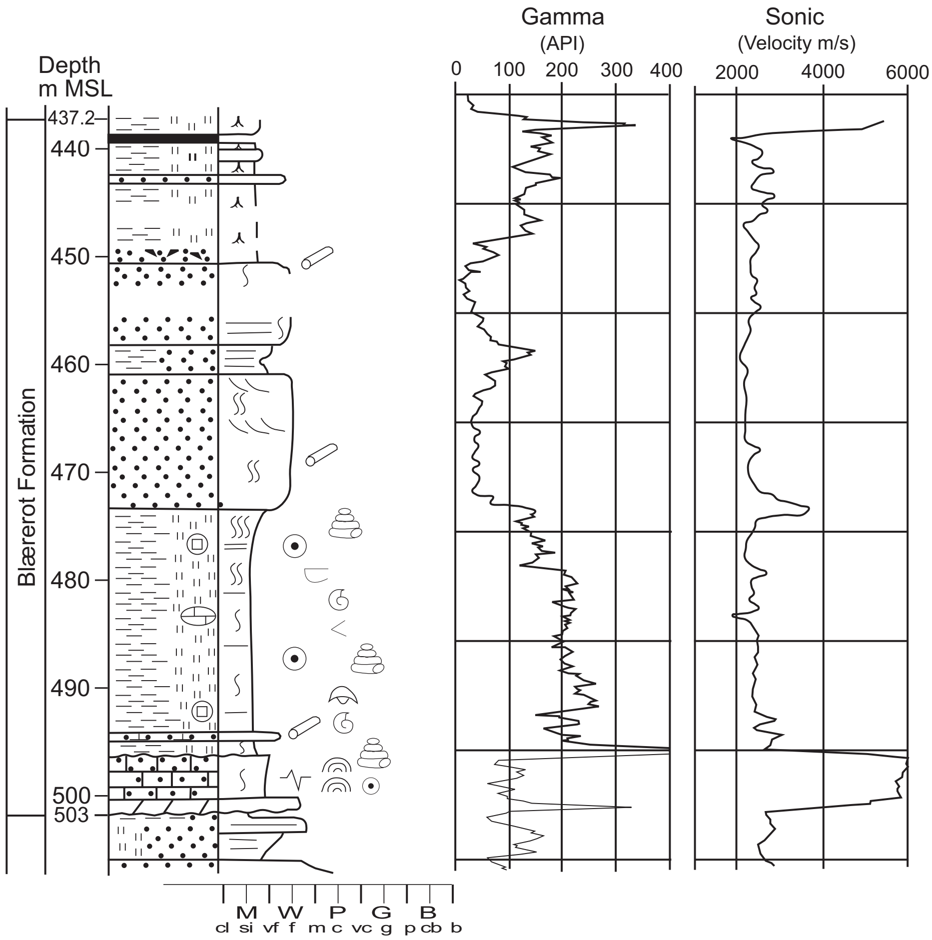
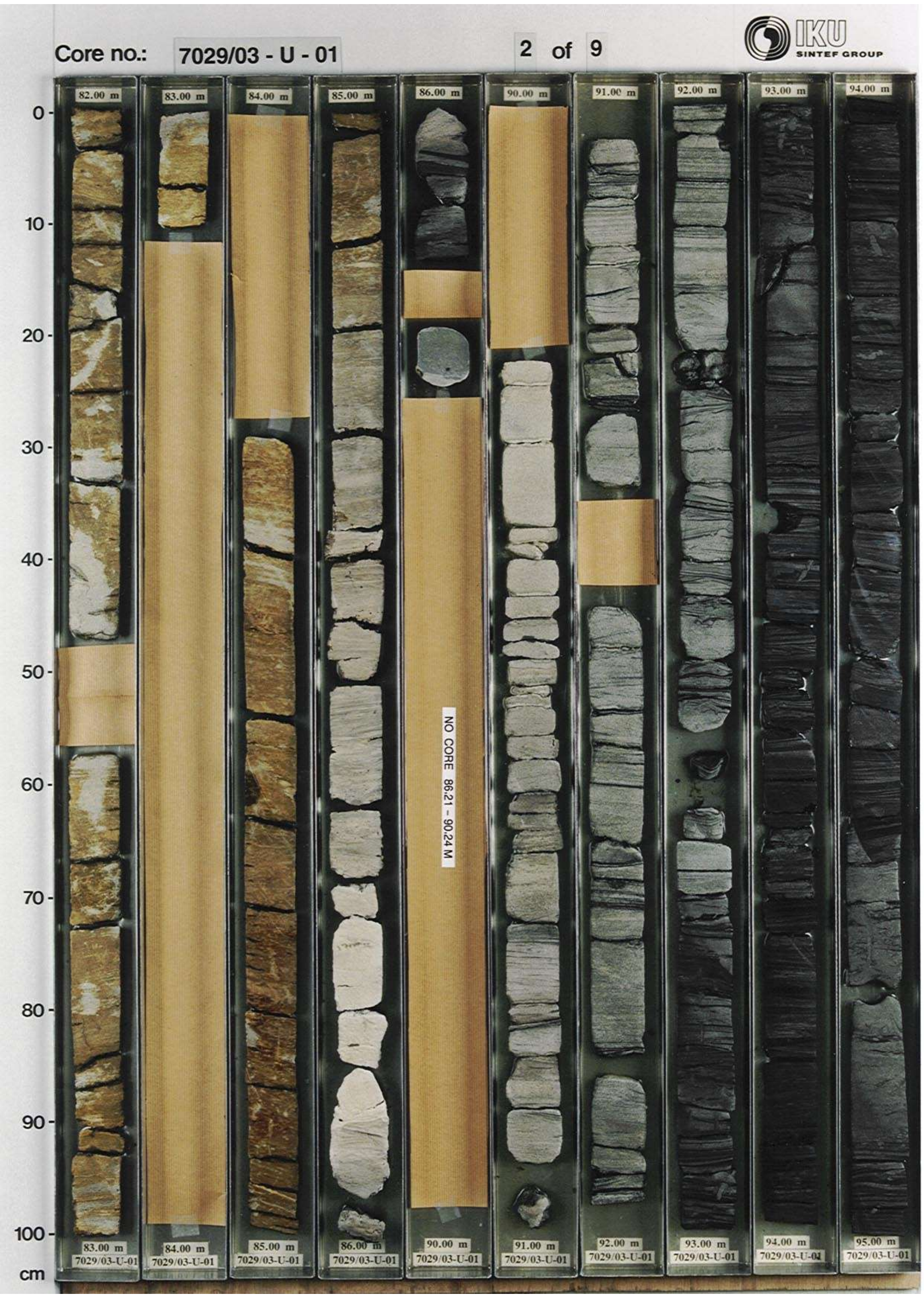

Well 7128/6-1
Depth
m RKB
2222
2225
2230
2235
2240
2245
2249,4
20 m to top formation
Tettegras Formation
108,6 m to base formation
C Si VF F M C VC Cgl

Fig. 17

# Shallow core 7029/03-U-01

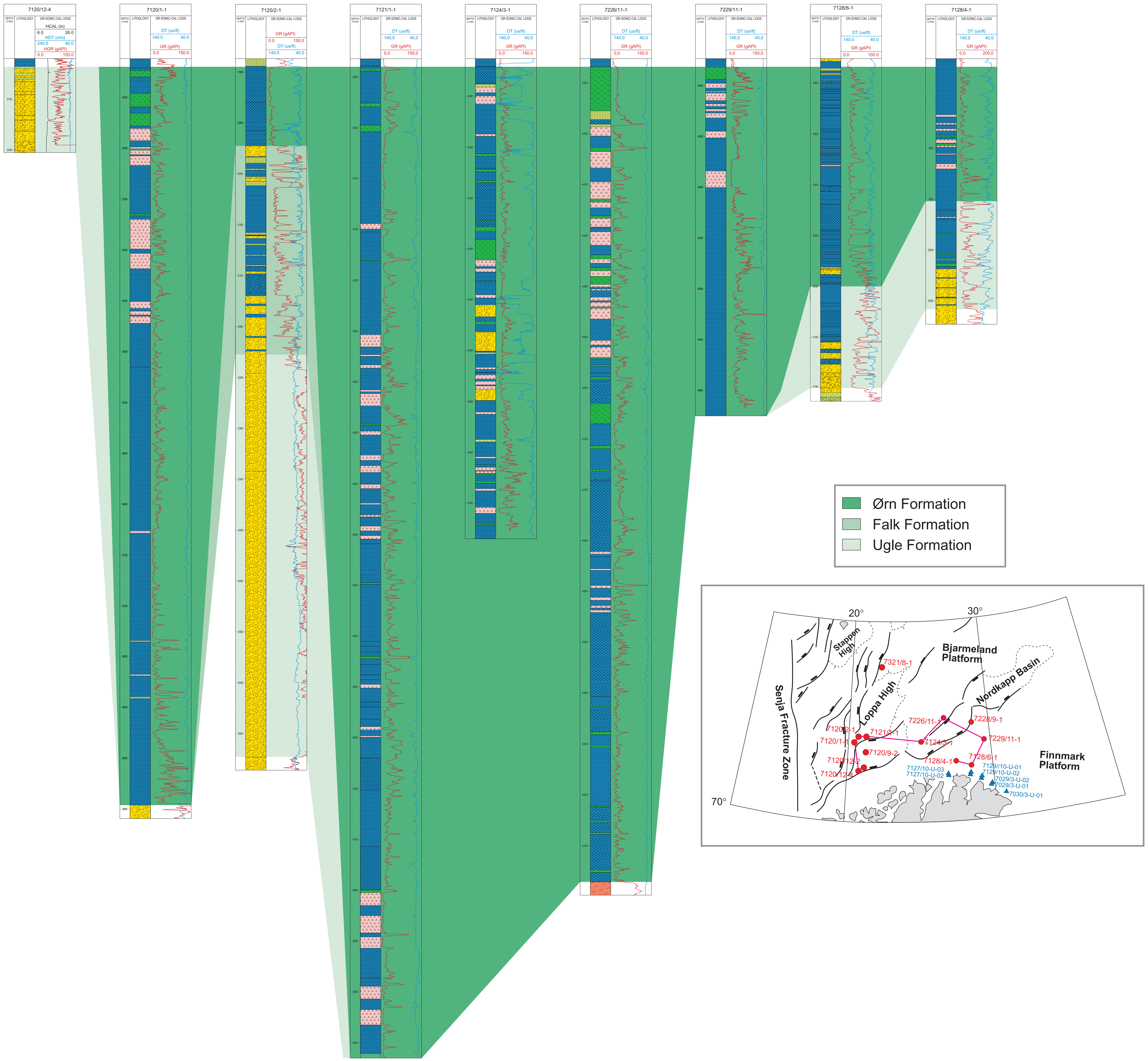




Core no.: 7029/03 - U - 01
2 of 9
IKU SINTEF GROUP
82.00 m
83.00 m
84.00 m
85.00 m
86.00 m
90.00 m
91.00 m
92.00 m
93.00 m
94.00 m
0
10
20
30
40
50
60
70
80
90
100
cm
NO CORE 86.21 – 90.24 M
83.00 m 7029/03-U-01
84.00 m 7029/03-U-01
85.00 m 7029/03-U-01
86.00 m 7029/03-U-01
90.00 m 7029/03-U-01
91.00 m 7029/03-U-01
92.00 m 7029/03-U-01
93.00 m 7029/03-U-01
94.00 m 7029/03-U-01
95.00 m 7029/03-U-01


Fig. 18

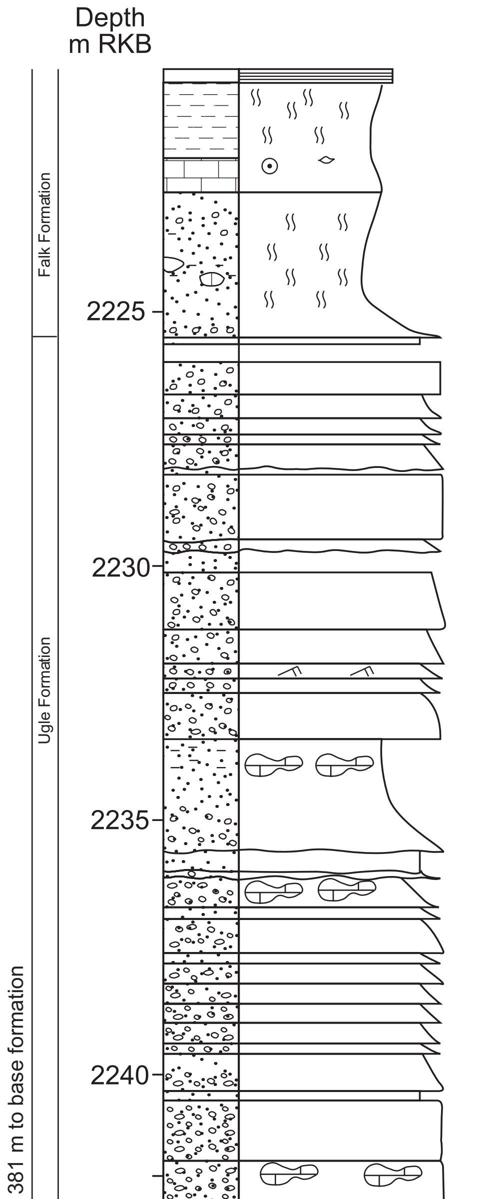
# Gipsdalen Group




7120/2-1
Norsk Hydro
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
GR (gAPI)
0.0 150.0
DT (us/ft)
140.0 40.0
NEUTRON-DENSITY LOGS
RHOB (g/cm3)
1.5 2.95
NPHI (m3/m3)
45.0 -15.0
Triassic
Carboniferous
Gipsdalen
Billefjorden
Ørn
Falk
Ugle
Undiff.
1950
2000
2050
2100
2150
2200
2250
2300
2350
2400
2450
2500
2550
2600
2650

Fig. 21

# Well 7120/2-1



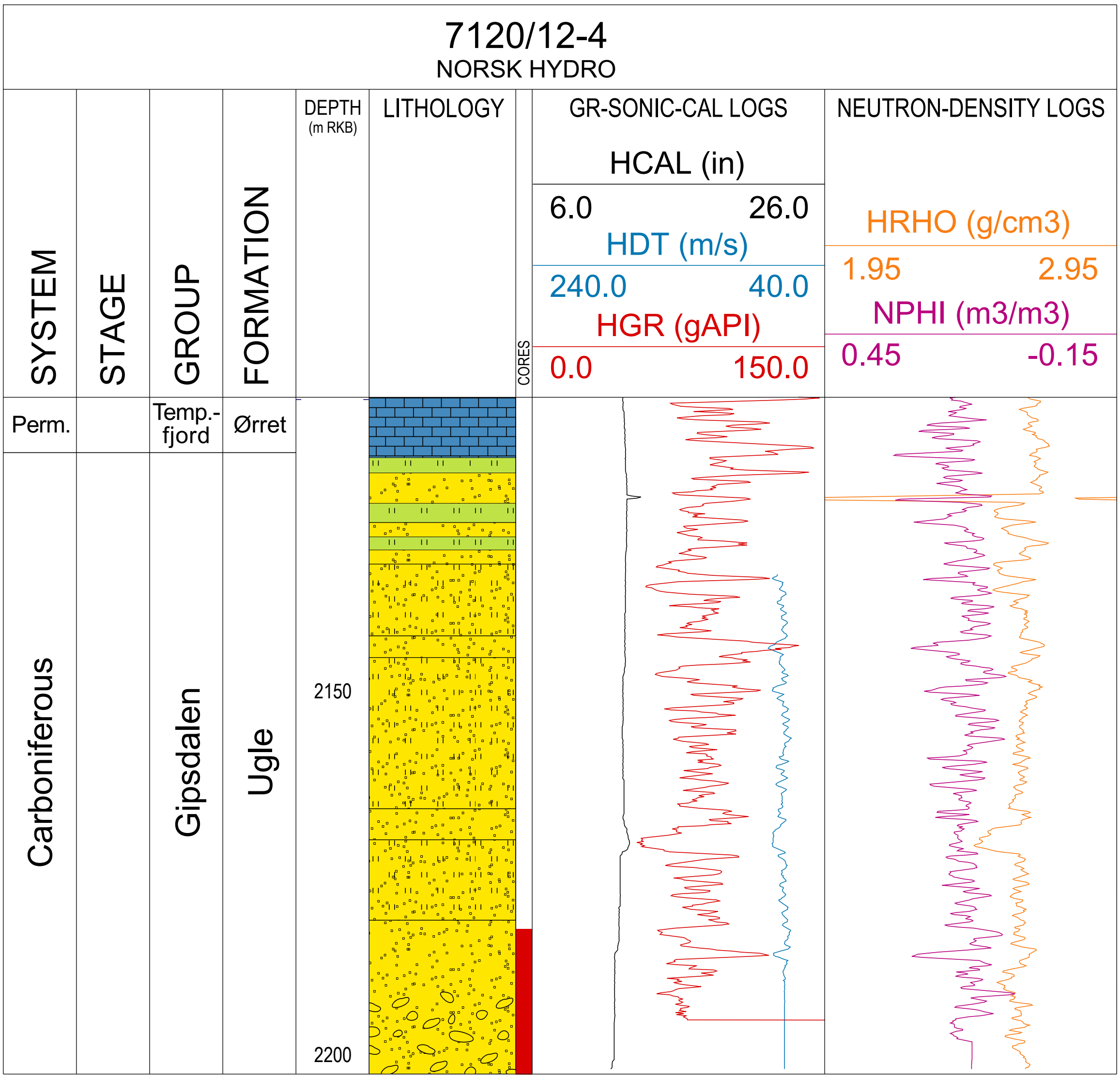

7120/12-4
NORSK HYDRO
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
HCAL (in)
6.0 26.0
HDT (m/s)
240.0 40.0
HGR (gAPI)
0.0 150.0
NEUTRON-DENSITY LOGS
HRHO (g/cm3)
1.95 2.95
NPHI (m3/m3)
0.45 -0.15
Perm.
Temp.-fjord
Ørret
Carboniferous
Gipsdalen
Ugle
2150
2200

Fig. 23

Shallow core 7029/03-U-02

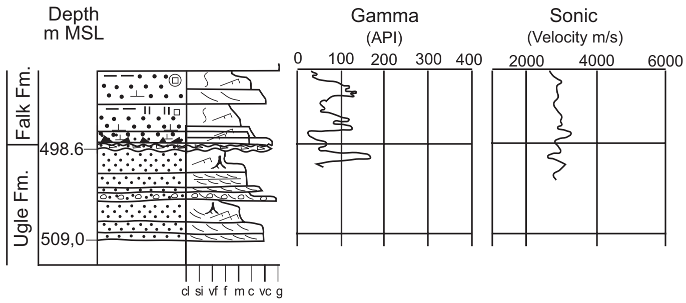
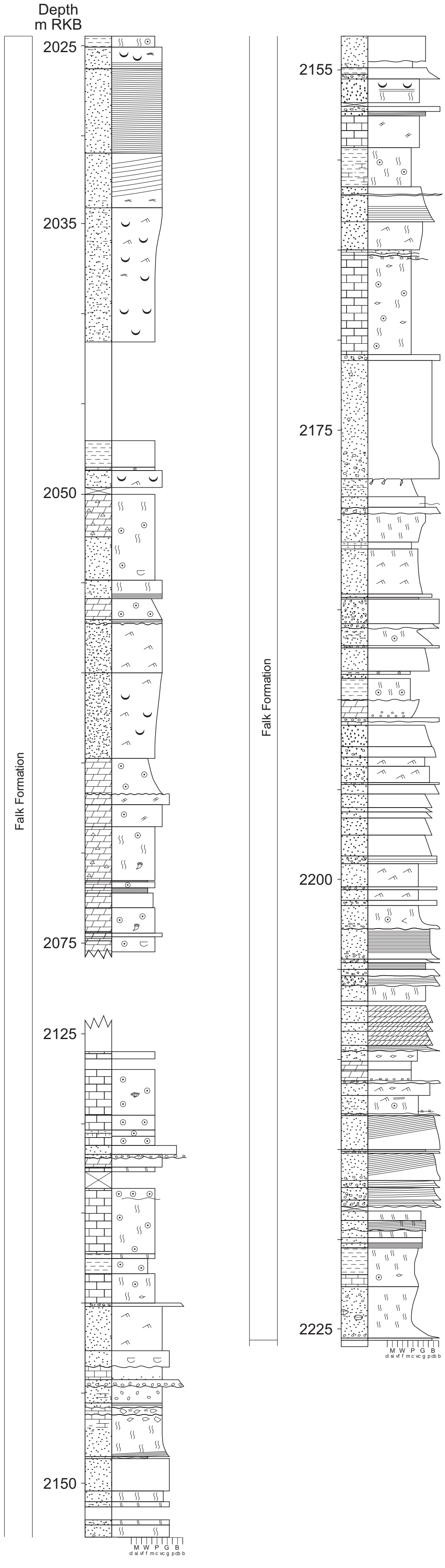
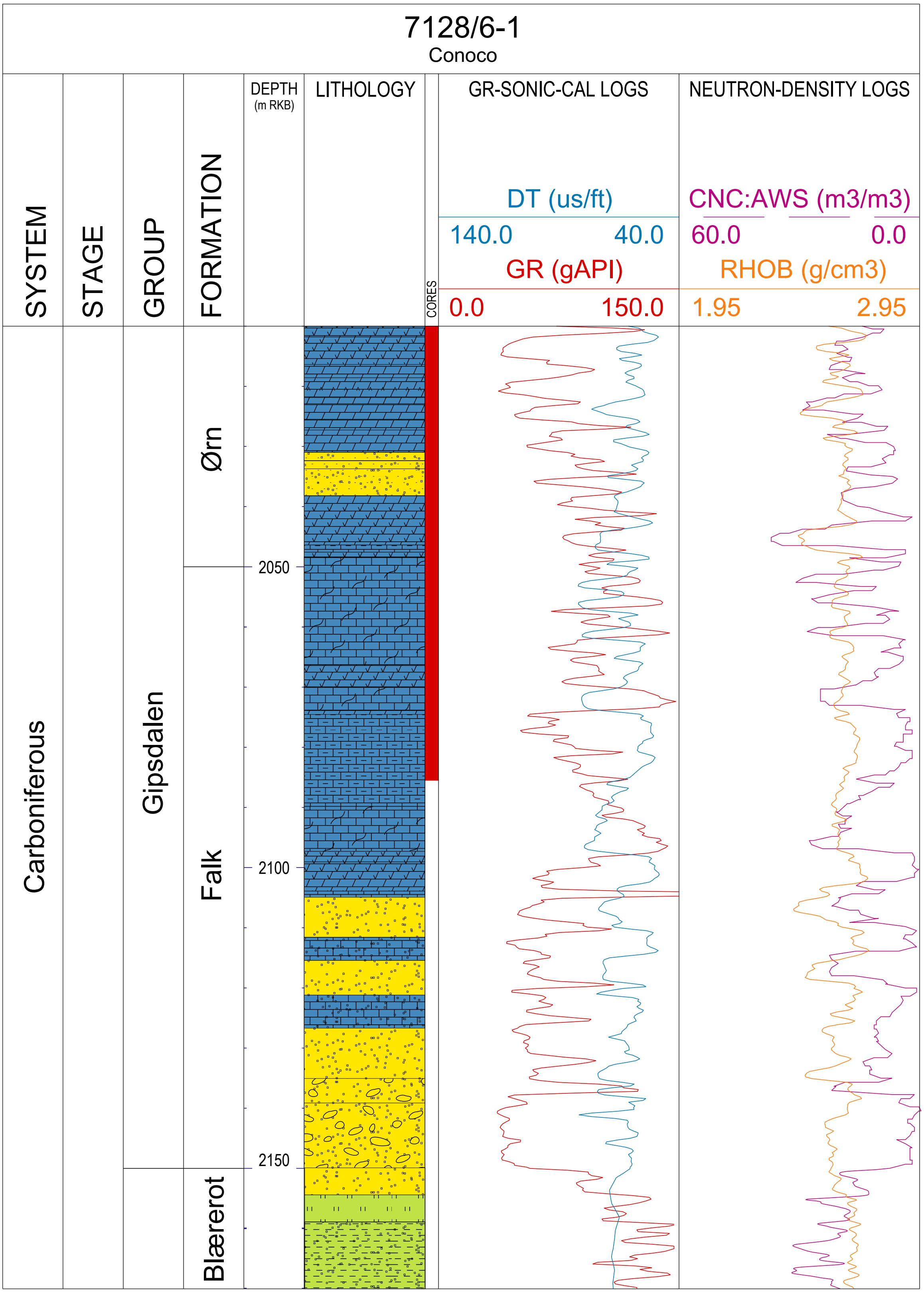
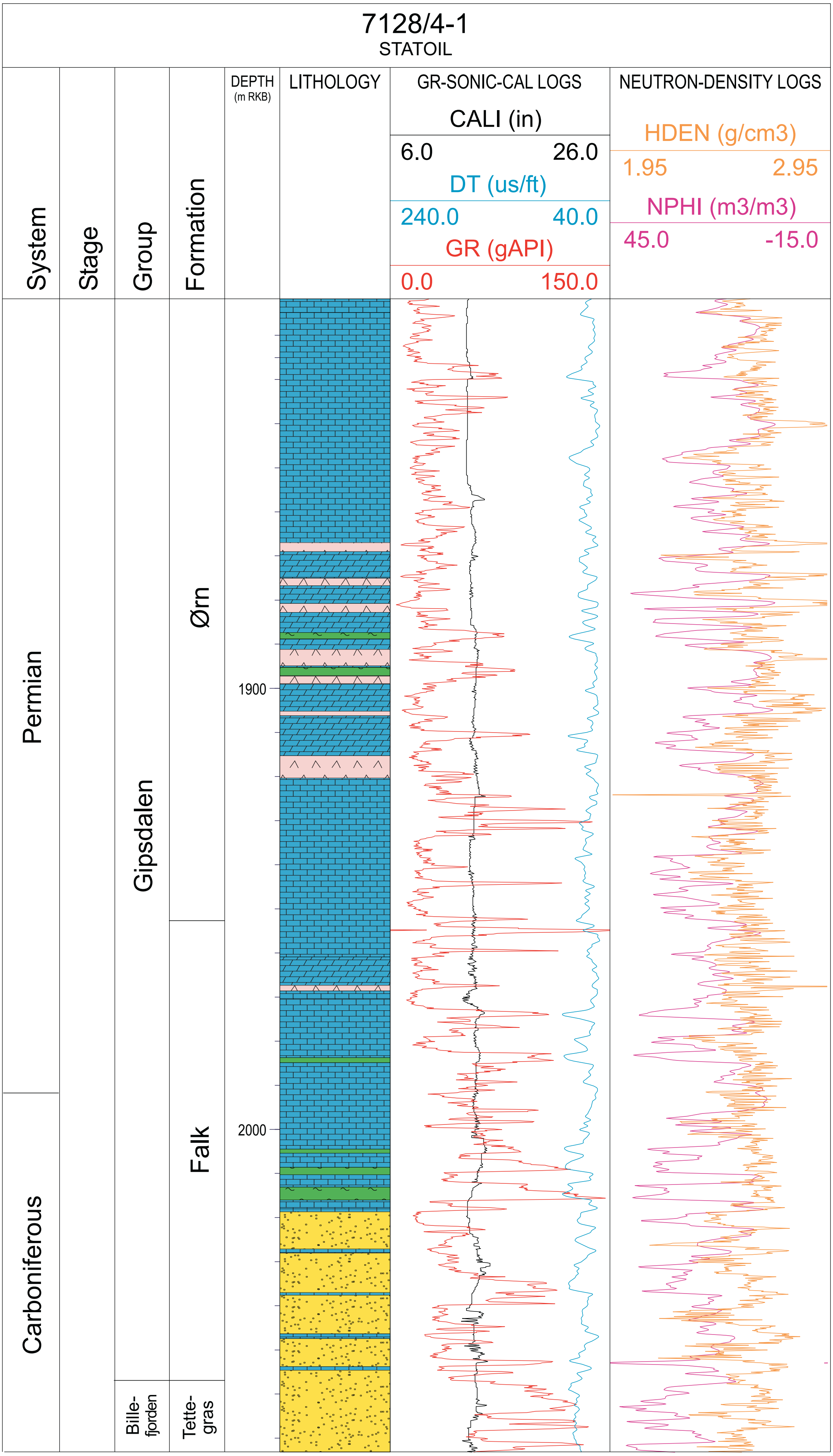


Fig. 24

# Well 7120/2-1




7128/6-1
Conoco
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
DT (us/ft)
140.0
40.0
GR (gAPI)
0.0
150.0
NEUTRON-DENSITY LOGS
CNC:AWS (m3/m3)
60.0
0.0
RHOB (g/cm3)
1.95
2.95
Carboniferous
Gipsdalen
Ørn
Falk
Blærerot
2050
2100
2150



7128/4-1
STATOIL
System
Stage
Group
Formation
DEPTH
(m RKB)
LITHOLOGY
GR-SONIC-CAL LOGS
CALI (in)
6.0
26.0
DT (us/ft)
240.0
40.0
GR (gAPI)
0.0
150.0
NEUTRON-DENSITY LOGS
HDEN (g/cm3)
1.95
2.95
NPHI (m3/m3)
45.0
-15.0
Permian
Carboniferous
Gipsdalen
Bille-fjorden
Ørn
Falk
Tette-gras
1900
2000

Fig. 27

# Shallow core 7029/03-U-02

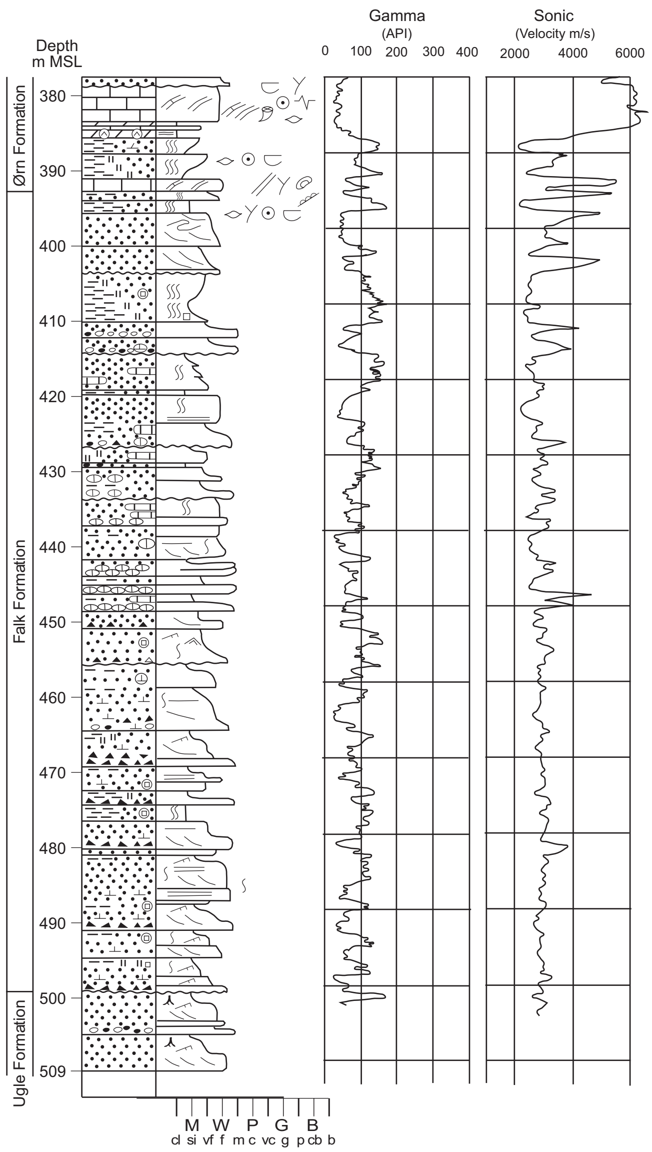


Fig. 28

Shallow core 7030/03-U-01

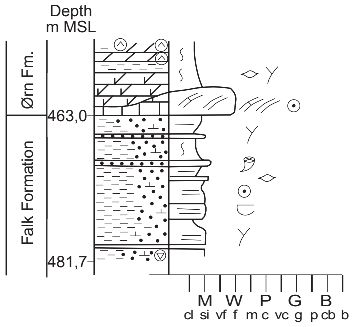
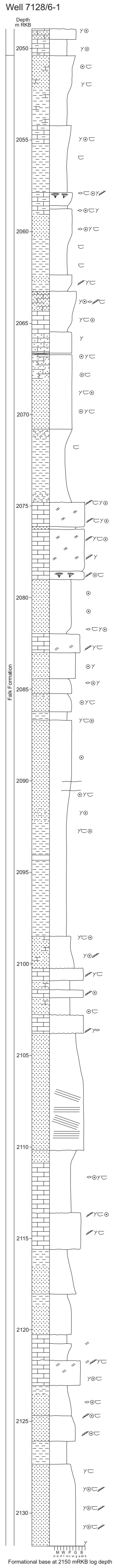


Fig. 29


Well 7128/6-1
Depth
m RKB
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
2105
2110
2115
2120
2125
2130
Falk Formation
M W P G B
cl si vf f m c vc g p cb b
Formational base at 2150 mRKB log depth

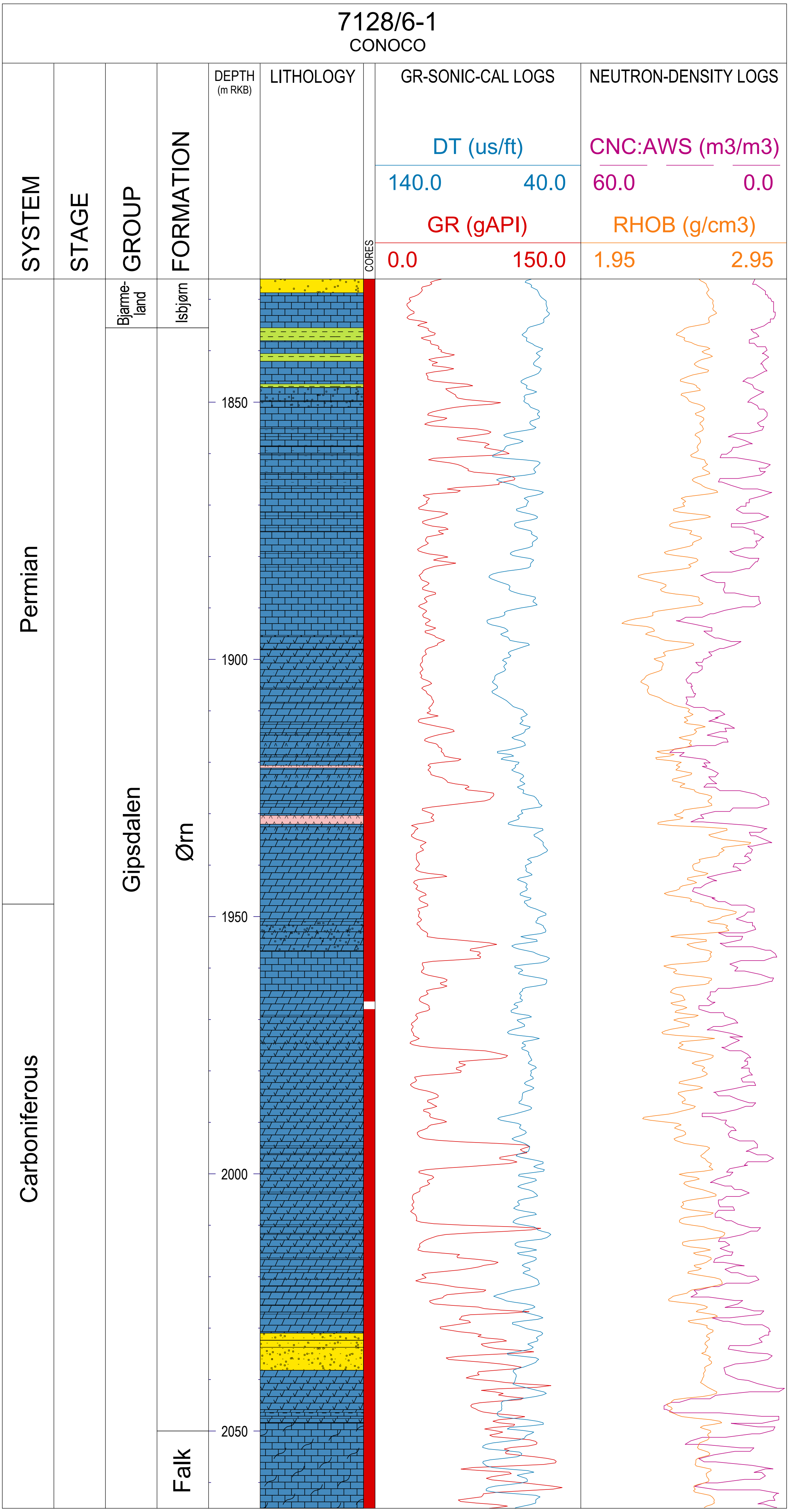
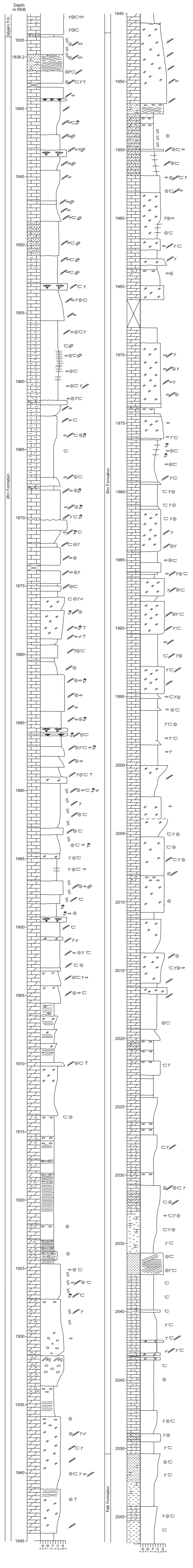

7128/6-1
CONOCO
SYSTEM
STAGE
GROUP
FORMATION
DEPTH
(m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
NEUTRON-DENSITY LOGS
DT (us/ft)
140.0
40.0
GR (gAPI)
0.0
150.0
CNC:AWS (m3/m3)
60.0
0.0
RHOB (g/cm3)
1.95
2.95
Permian
Carboniferous
Bjarme-land
Gipsdalen
Isbjørn
Ørn
Falk
1850
1900
1950
2000
2050

Fig. 31

Well 7128/6-1




7121/1-1 R
ESSO
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
GR-SONIC-CAL LOGS
HCAL (in)
6.0
26.0
HGR (gAPI)
0.0
150.0
HAC (ohm.m)
240.0
40.0
NEUTRON-DENSITY LOGS
HDEN (g/cm3)
1.95
2.95
HCNC (ohm.m)
45.0
-15.0
Bjarme-land
Polar-rev
Gipsdalen
Ørn
4000
4050
4100
4150
4200
4250
4300
4350
4400
4450
4500
4550
4600
4650
4700
4750
4800
4850
4900
4950

7226/11-1
STATOIL
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
GR-SONIC-CAL LOGS
HCAL (in)
6.0 26.0
HDT (m/s)
240.0 40.0
HGR (gAPI)
0.0 150.0
NEUTRON-DENSITY LOGS
HRHO (g/cm3)
1.95 2.95
NPHI (m3/m3)
0.45 -0.15
Gipsdalen
Ørn
4350
4400
4450
4500
4550
4600
4650
4700
4750
4800
4850
4900
4950
5000
5050
5100

Fig. 34

Shallow core 7030/03-U-01

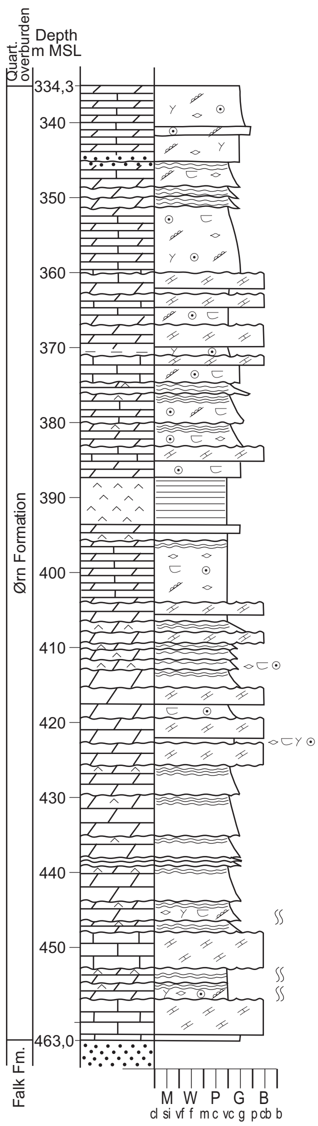


Fig. 35

Well 7029/03-U-02

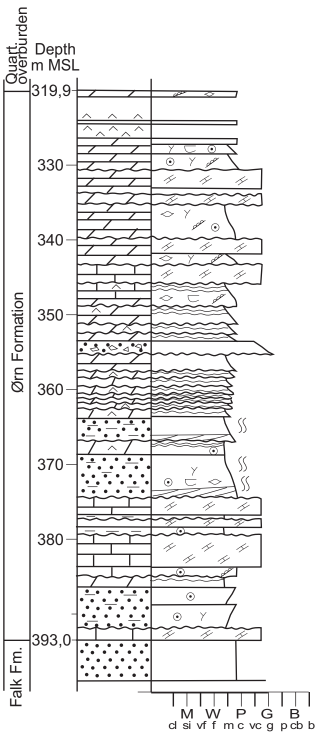


Fig. 36a

0 1cm

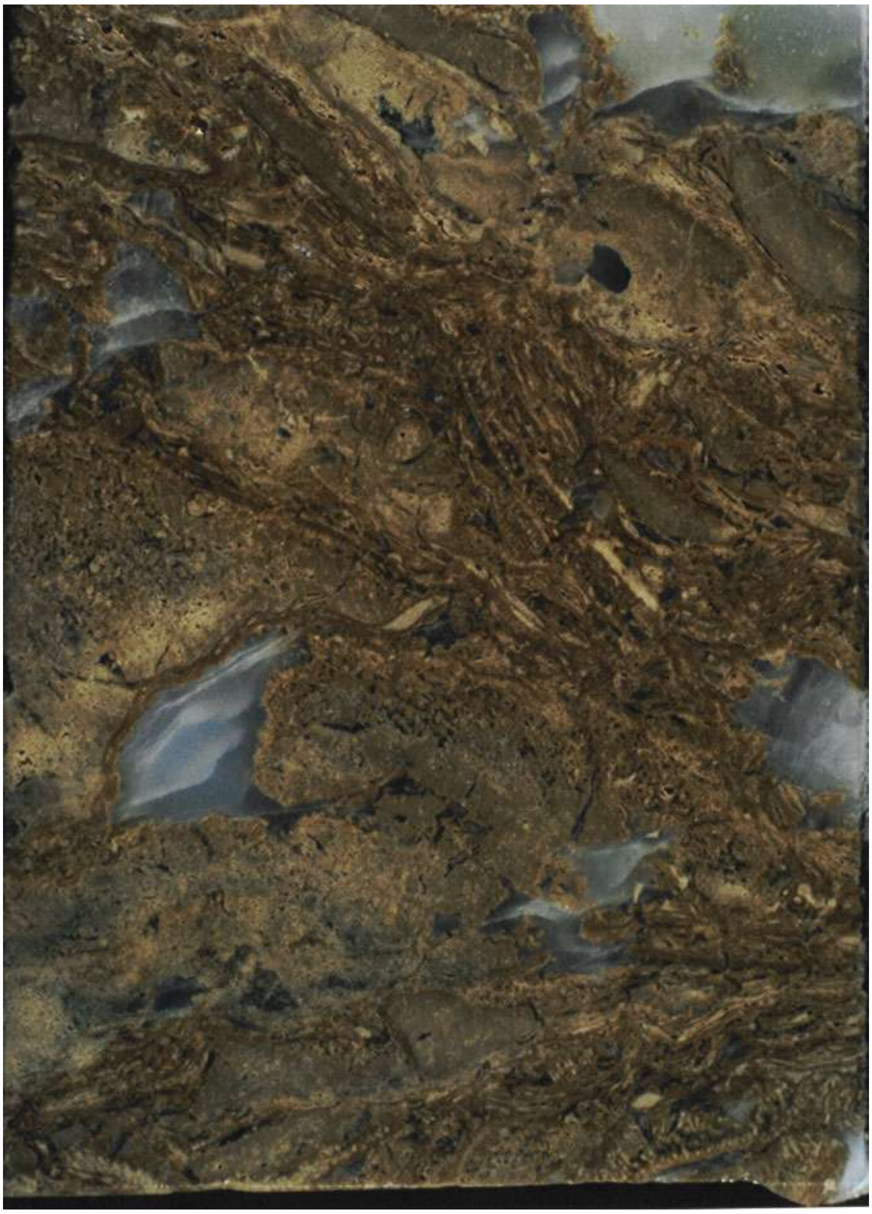


Fig. 36b

0 1cm

Fig. 36c

0 1cm

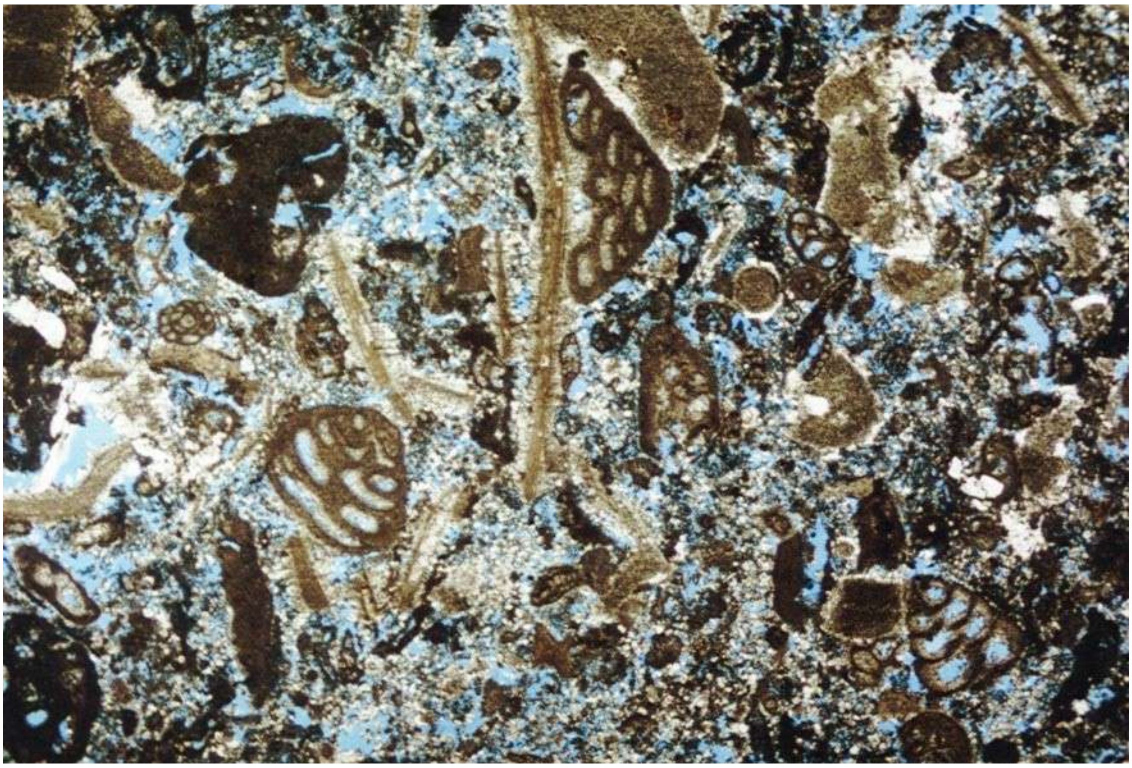
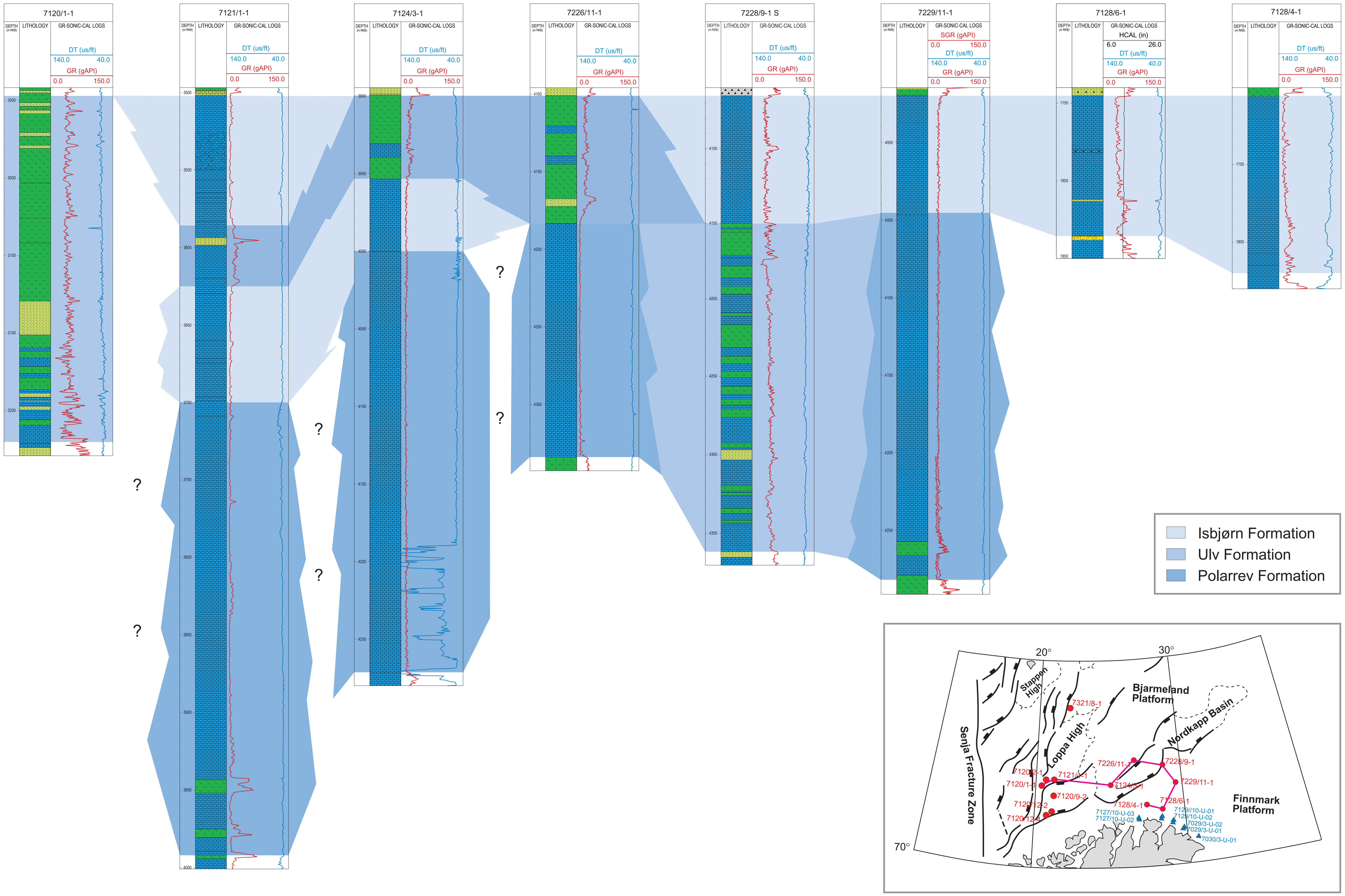


Fig. 37

# Bjarmeland Group



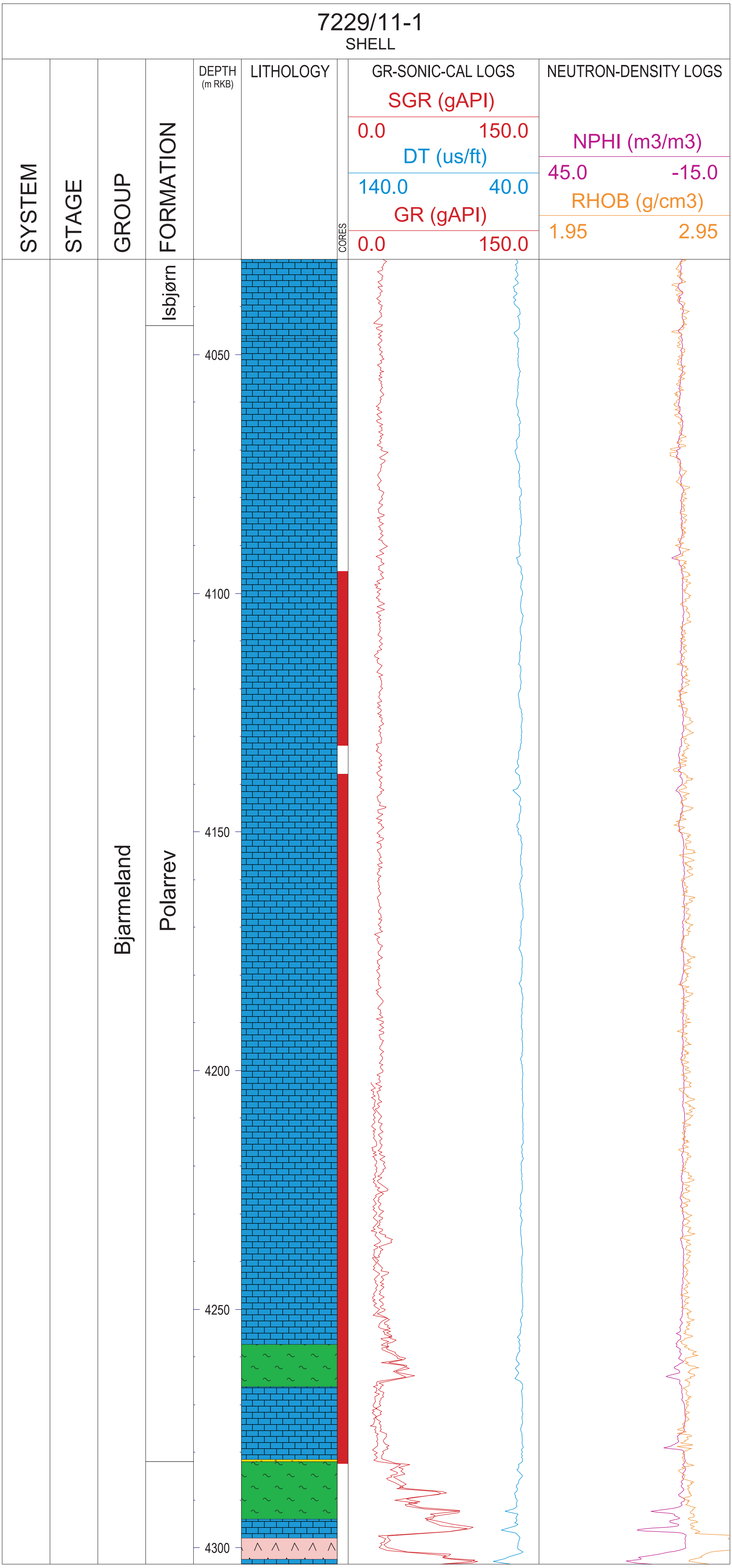
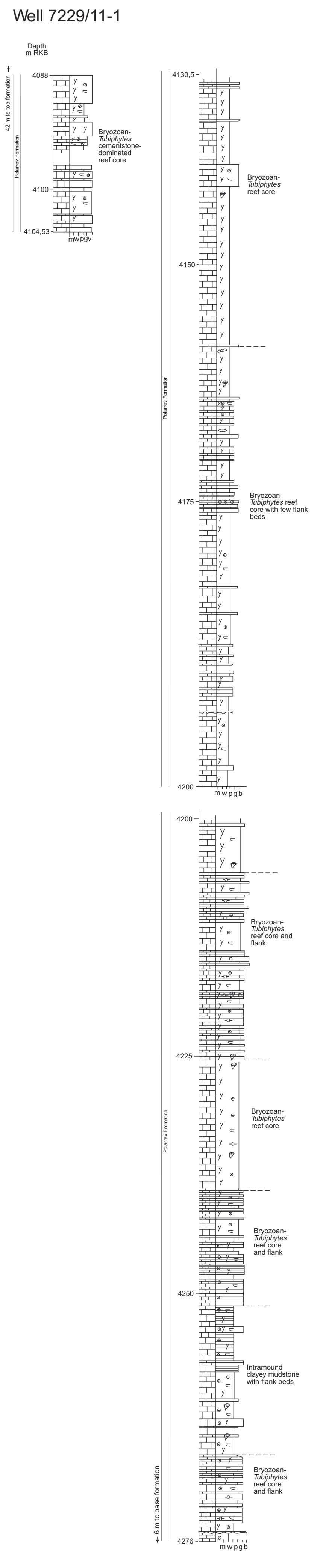
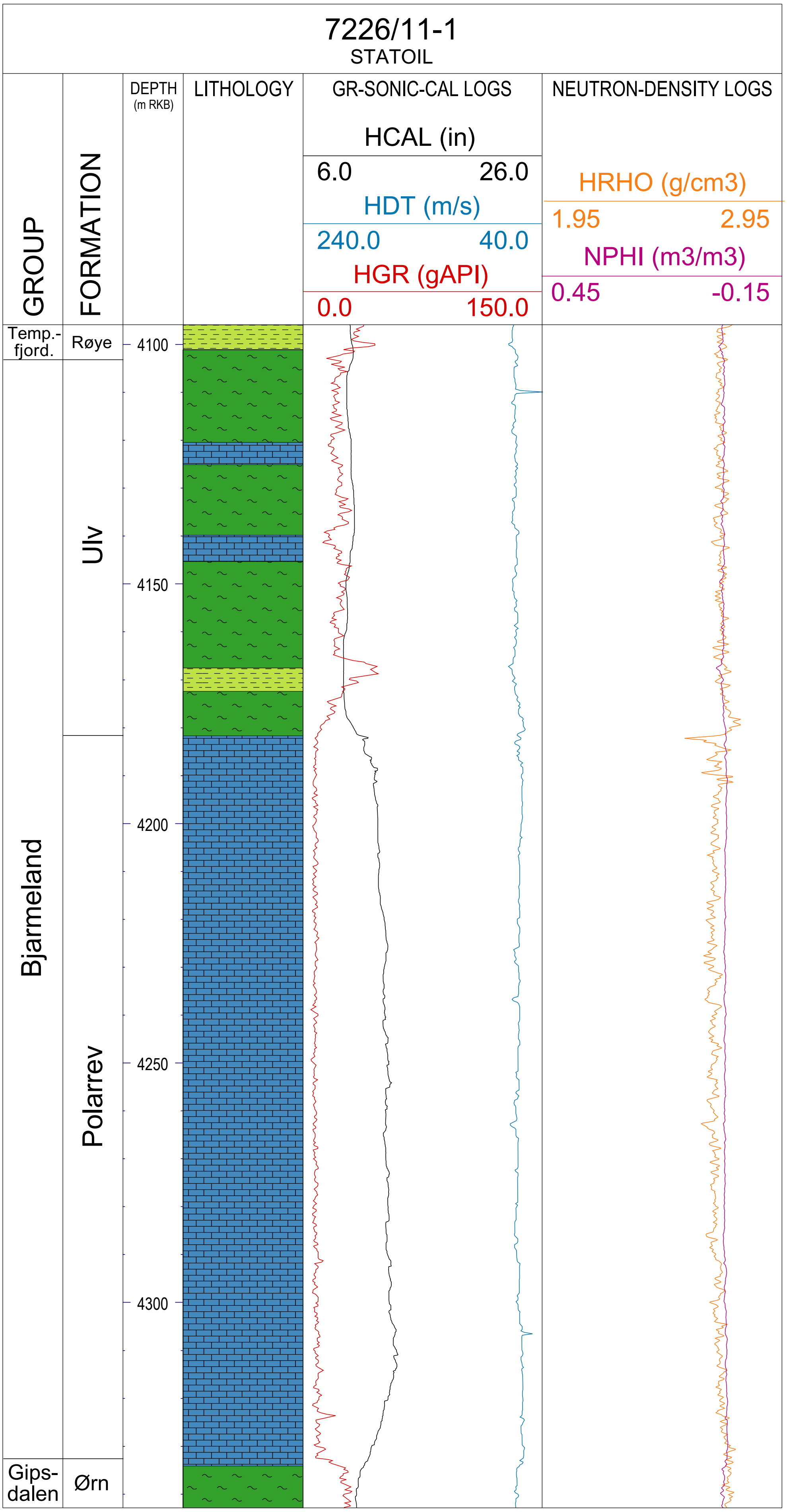
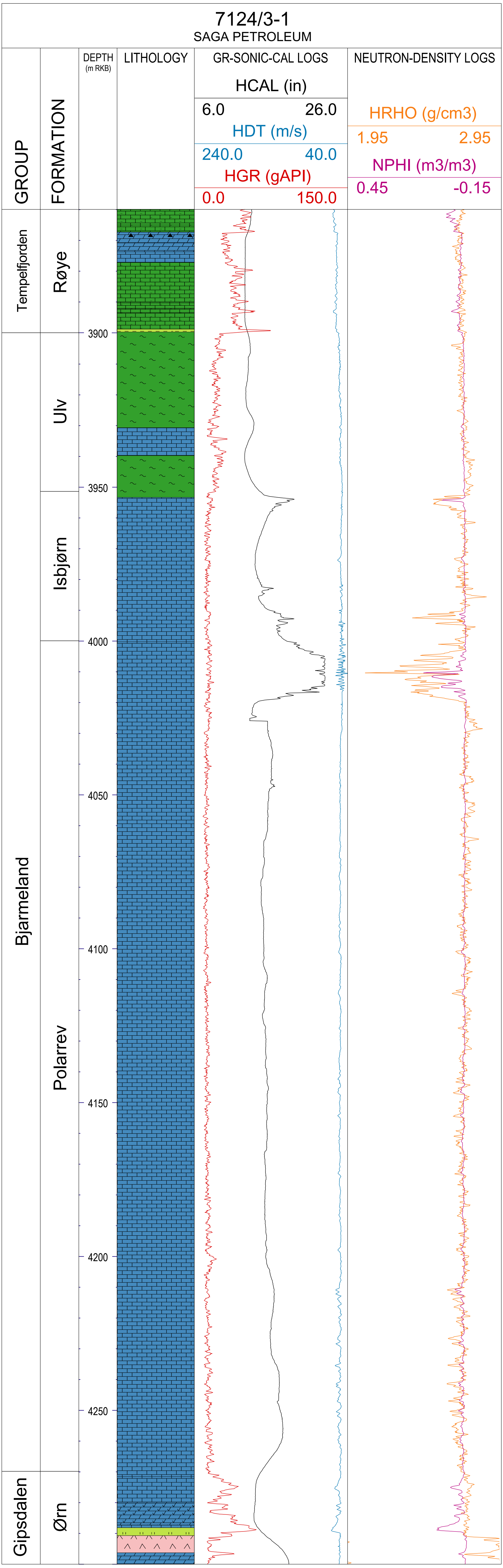

7229/11-1
SHELL
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
SGR (gAPI)
0.0 150.0
DT (us/ft)
140.0 40.0
GR (gAPI)
0.0 150.0
NEUTRON-DENSITY LOGS
NPHI (m3/m3)
45.0 -15.0
RHOB (g/cm3)
1.95 2.95
Isbjørn
Bjarmeland
Polarrev
4050
4100
4150
4200
4250
4300

Fig. 40

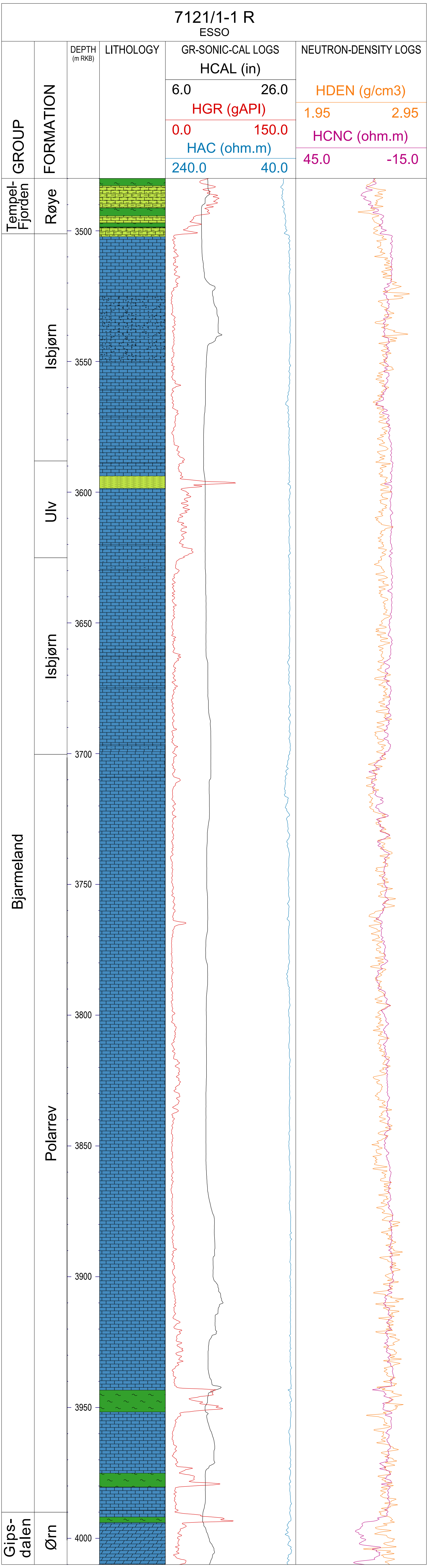


Well 7229/11-1
Depth
m RKB
42 m to top formation
Polarrev Formation
4088
4100
4104,53
mwpgv
Bryozoan-
Tubiphytes
cementstone-
dominated
reef core
4130,5
4150
4175
4200
mwpgb
Bryozoan-
Tubiphytes
reef core
Bryozoan-
Tubiphytes reef
core with few flank
beds
4200
4225
4250
4276
mwpgb
Bryozoan-
Tubiphytes
reef core and
flank
Bryozoan-
Tubiphytes
reef core
Bryozoan-
Tubiphytes
reef core
and flank
Intramound
clayey mudstone
with flank beds
Bryozoan-
Tubiphytes
reef core
and flank
6 m to base formation


7226/11-1
STATOIL
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
GR-SONIC-CAL LOGS
HCAL (in)
6.0 26.0
HDT (m/s)
240.0 40.0
HGR (gAPI)
0.0 150.0
NEUTRON-DENSITY LOGS
HRHO (g/cm3)
1.95 2.95
NPHI (m3/m3)
0.45 -0.15
Temp.-fjord.
Røye
Bjarmeland
Ulv
Polarrev
Gips-dalen
Ørn
4100
4150
4200
4250
4300



7124/3-1
SAGA PETROLEUM
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
GR-SONIC-CAL LOGS
HCAL (in)
6.0 26.0
HDT (m/s)
240.0 40.0
HGR (gAPI)
0.0 150.0
NEUTRON-DENSITY LOGS
HRHO (g/cm3)
1.95 2.95
NPHI (m3/m3)
0.45 -0.15
Tempelfjorden
Røye
Bjarmeland
Ulv
Isbjørn
Polarrev
Gipsdalen
Ørn
3900
3950
4000
4050
4100
4150
4200
4250



7121/1-1 R
ESSO
GROUP
FORMATION
DEPTH
(m RKB)
LITHOLOGY
GR-SONIC-CAL LOGS
HCAL (in)
6.0
26.0
HGR (gAPI)
0.0
150.0
HAC (ohm.m)
240.0
40.0
NEUTRON-DENSITY LOGS
HDEN (g/cm3)
1.95
2.95
HCNC (ohm.m)
45.0
-15.0
Tempel-Fjorden
Røye
Bjarmeland
Isbjørn
Ulv
Isbjørn
Polarrev
Gips-dalen
Ørn
3500
3550
3600
3650
3700
3750
3800
3850
3900
3950
4000

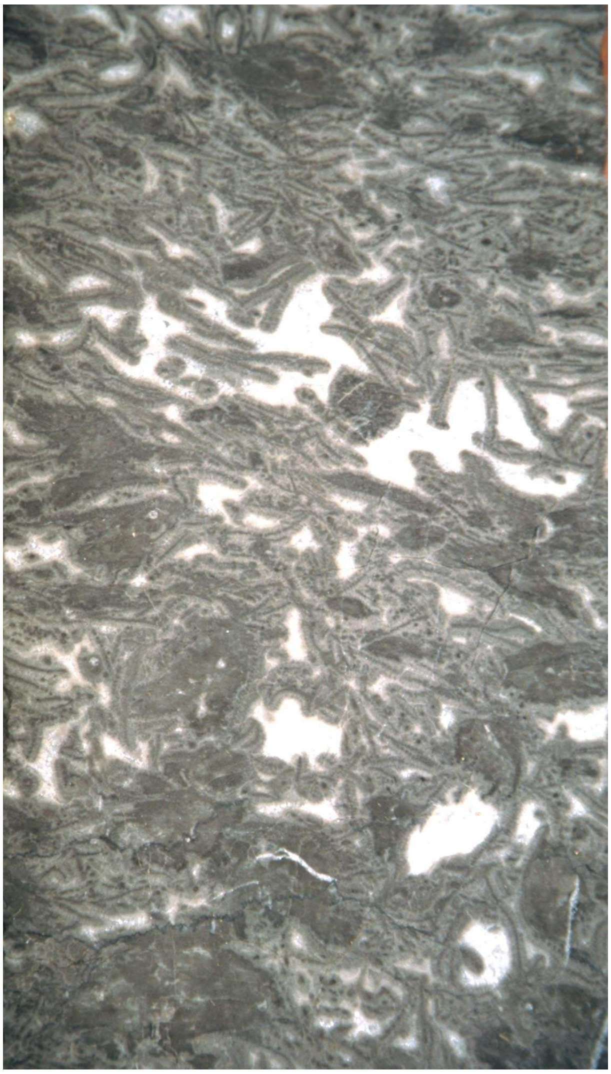
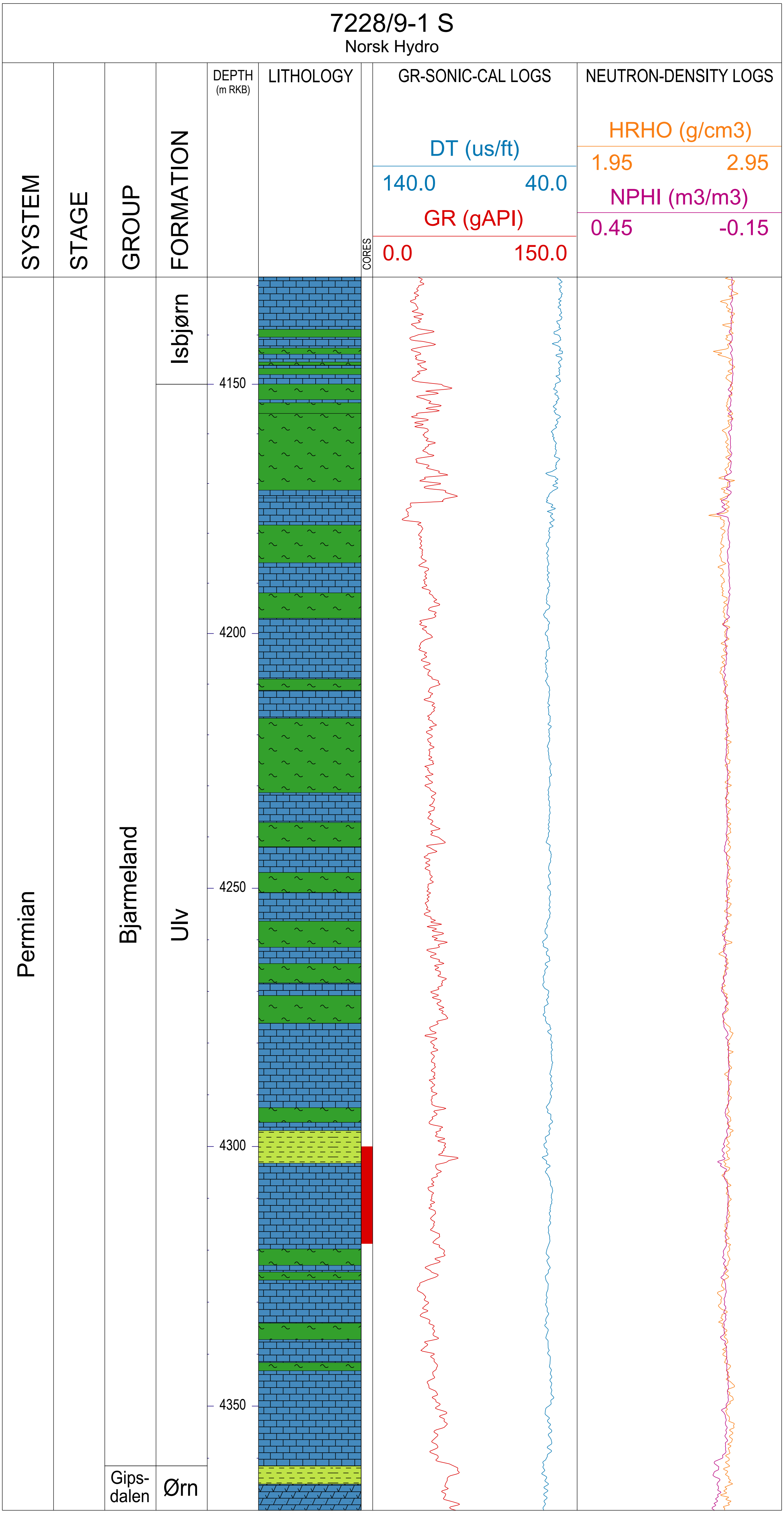


Fig. 44 0 5 cm


7228/9-1 S
Norsk Hydro
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
DT (us/ft)
140.0
40.0
GR (gAPI)
0.0
150.0
NEUTRON-DENSITY LOGS
HRHO (g/cm3)
1.95
2.95
NPHI (m3/m3)
0.45
-0.15
Permian
Bjarmeland
Gips-dalen
Isbjørn
Ulv
Ørn
4150
4200
4250
4300
4350

# 7120/1-1 R 2

SHELL

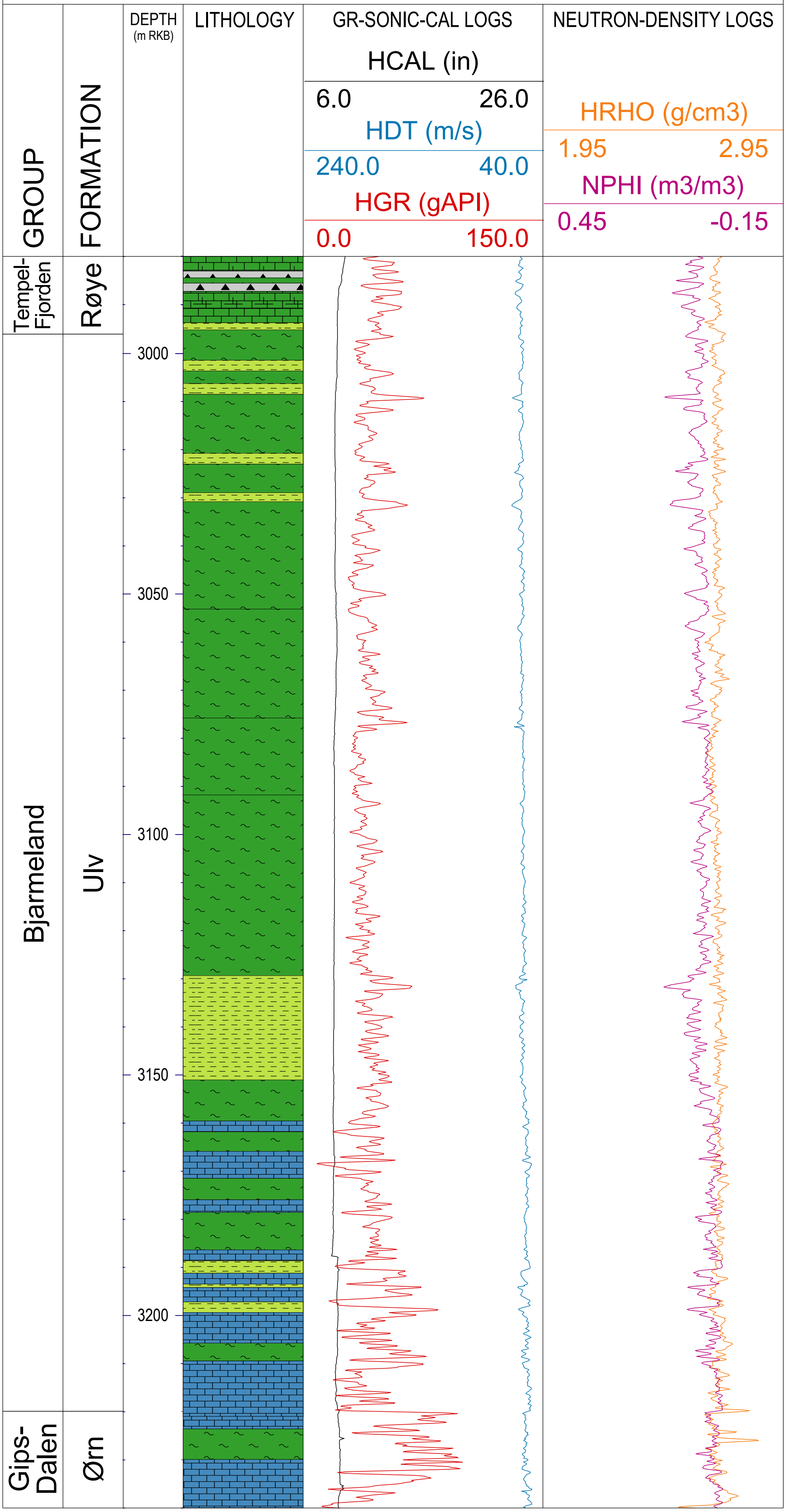
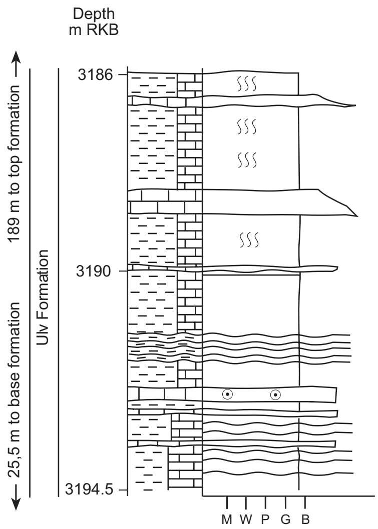
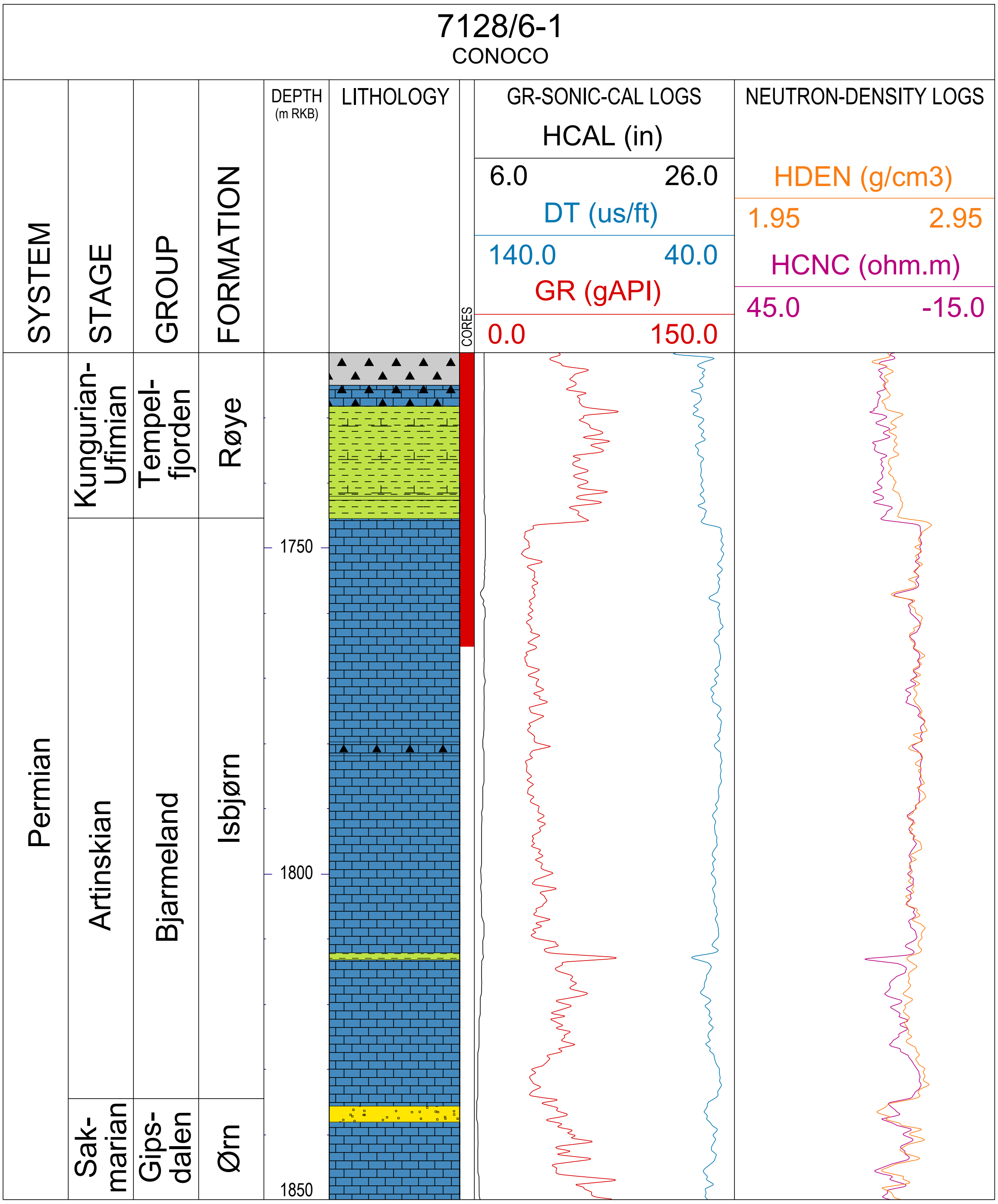


Fig. 47

Well 7120/1-1





7128/6-1
CONOCO
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
HCAL (in)
6.0 26.0
DT (us/ft)
140.0 40.0
GR (gAPI)
0.0 150.0
NEUTRON-DENSITY LOGS
HDEN (g/cm3)
1.95 2.95
HCNC (ohm.m)
45.0 -15.0
Permian
Kungurian-Ufimian
Artinskian
Sak-marian
Tempel-fjorden
Bjarmeland
Gips-dalen
Røye
Isbjørn
Ørn
1750
1800
1850

Fig. 49

Well 7128/6-1

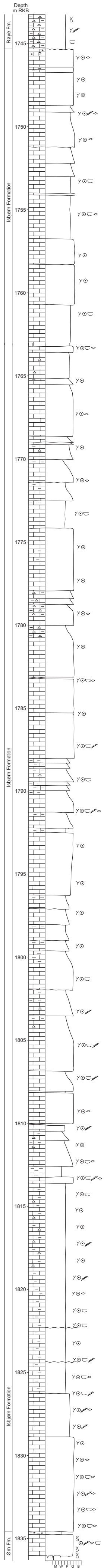
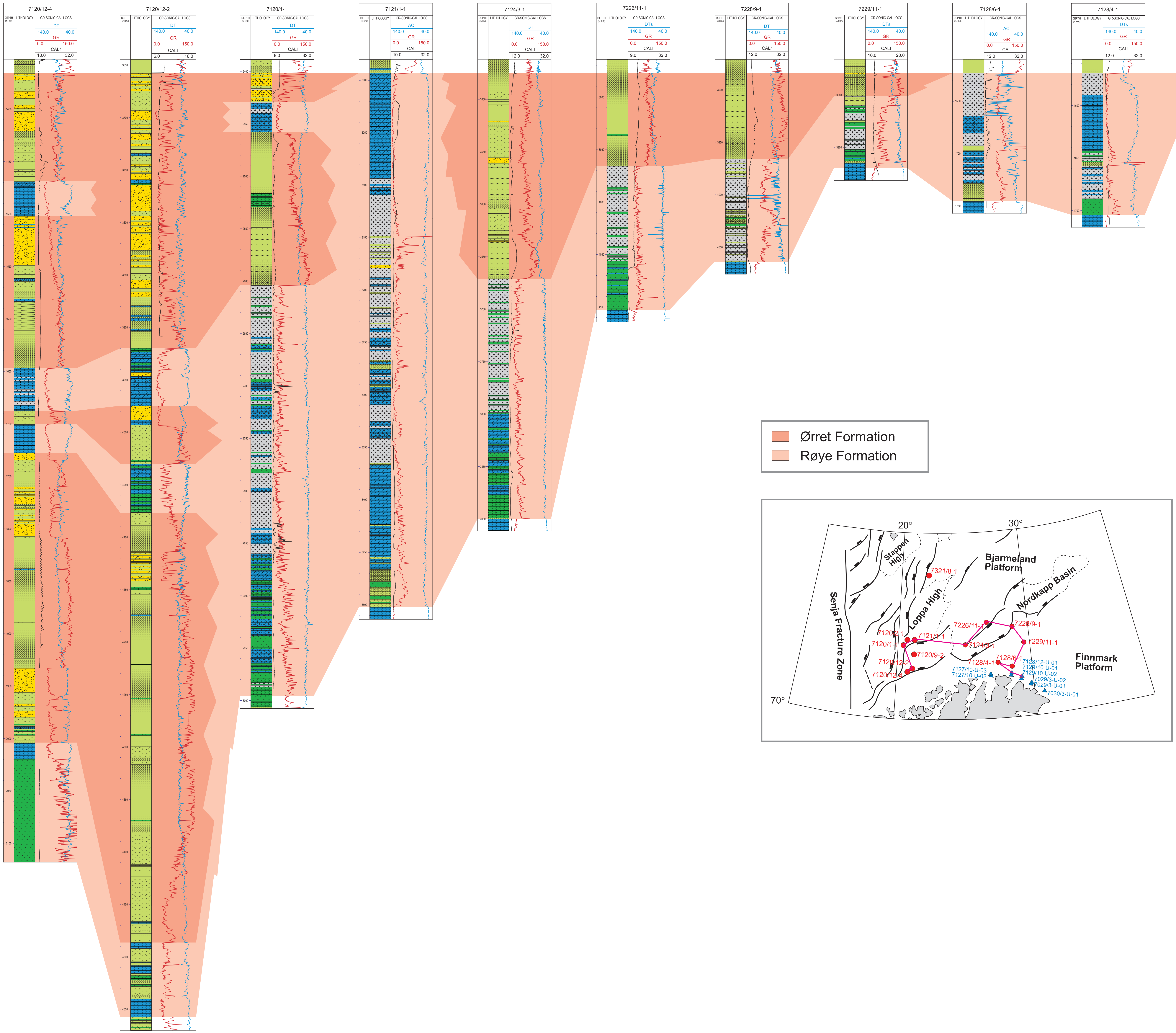


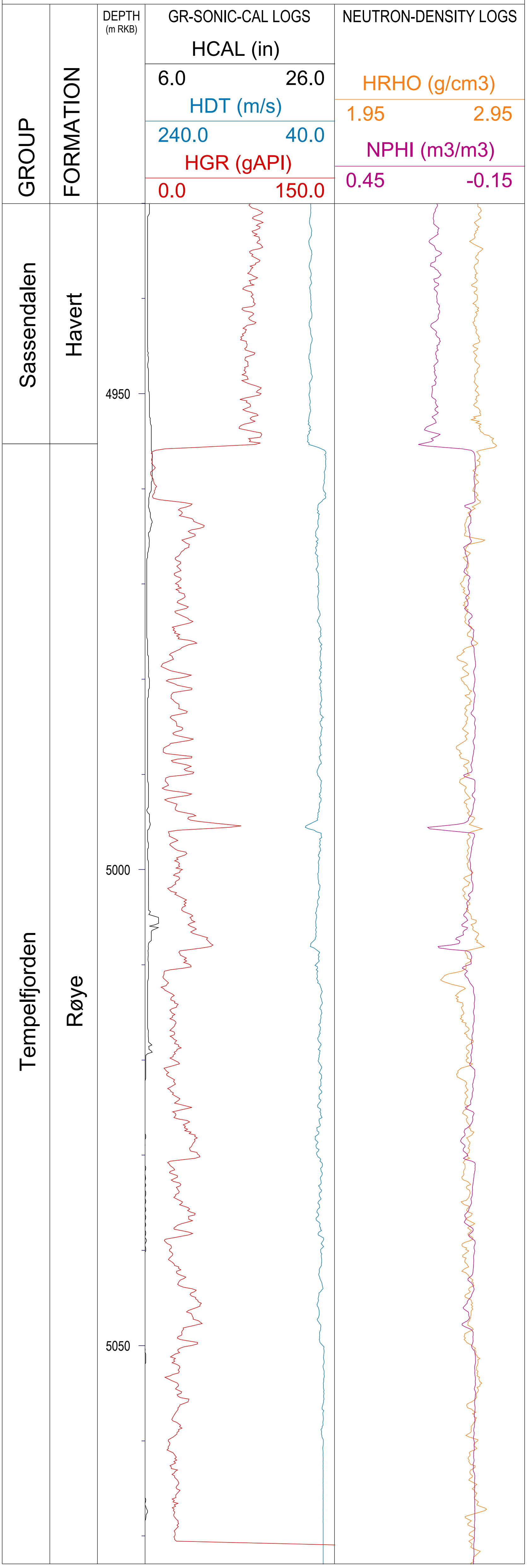
Fig. 50 0 1cm

# Tempelfjorden Group



# 7120/9-2 T2

NORSK HYDRO



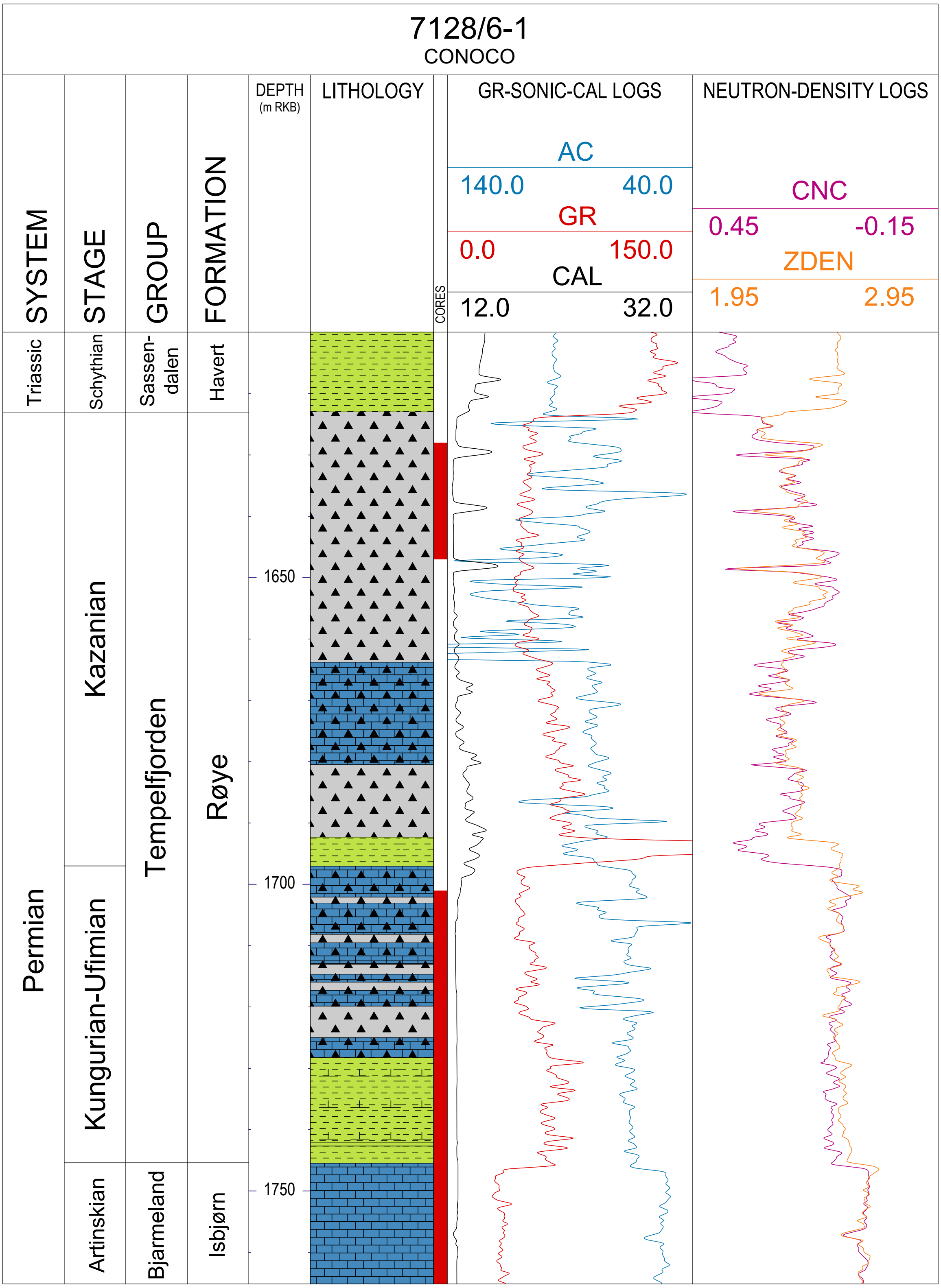
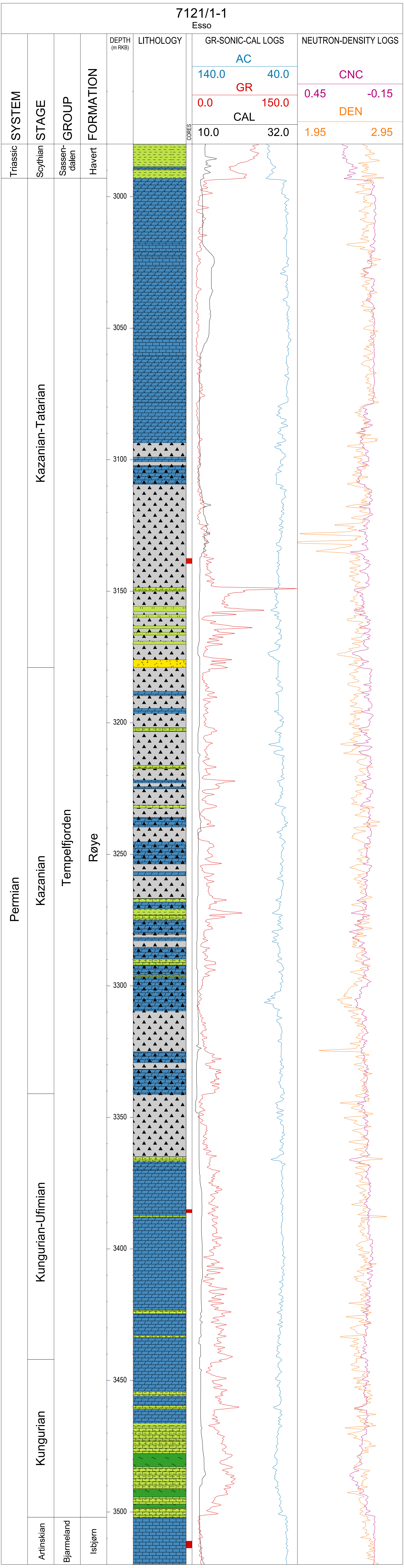

7128/6-1
CONOCO
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
AC
140.0
40.0
GR
0.0
150.0
CAL
12.0
32.0
NEUTRON-DENSITY LOGS
CNC
0.45
-0.15
ZDEN
1.95
2.95
Triassic
Schythian
Sassen-dalen
Havert
Permian
Kazanian
Kungurian-Ufimian
Artinskian
Tempelfjorden
Bjarmeland
Røye
Isbjørn
1650
1700
1750

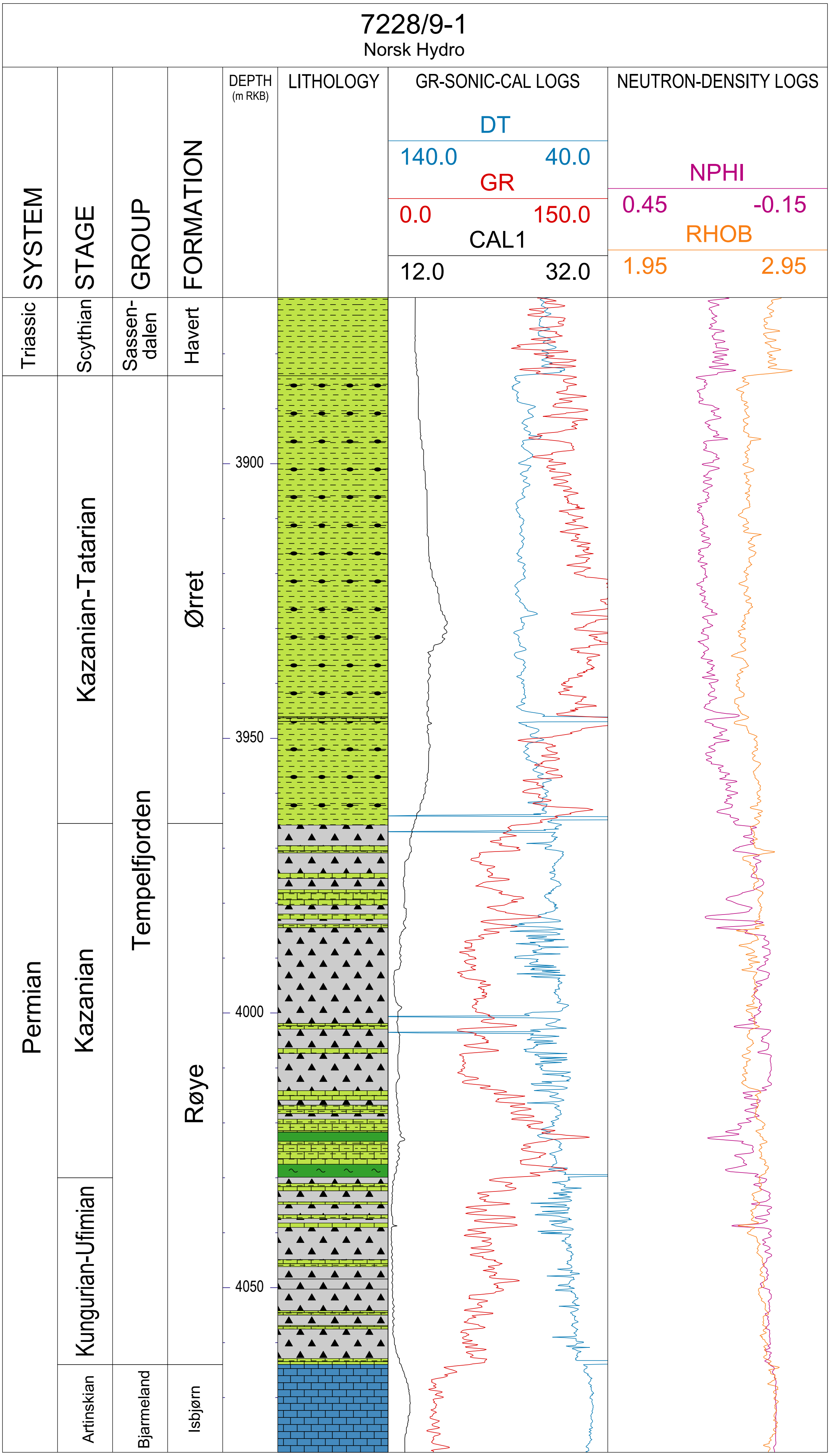
Fig. 54

0 5 cm

7120/1-1
SHELL
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CASING
GR-SONIC-CAL LOGS
DT
140.0
40.0
GR
0.0
150.0
CALI
8.0
32.0
NEUTRON-DENSITY LOGS
NPHI
0.45
-0.15
RHOB
1.95
2.95
Triassic
Permian
Scythian
Kazanian-Tatarian
Kazanian
Kungurian-Ufimian
Kungurian
Sassen-dalen
Tempelfjorden
Bjarmeland
Havert
Ørret
Røye
Ørret
Røye
Ulv
2400
2450
2500
2550
2600
2650
2700
2750
2800
2850
2900
2950
3000



7121/1-1
Esso
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
AC
140.0
40.0
GR
0.0
150.0
CAL
10.0
32.0
NEUTRON-DENSITY LOGS
CNC
0.45
-0.15
DEN
1.95
2.95
Triassic
Permian
Scythian
Kazanian-Tatarian
Kazanian
Kungurian-Ufimian
Kungurian
Artinskian
Sassen-dalen
Tempelfjorden
Bjarmeland
Havert
Røye
Isbjørn
3000
3050
3100
3150
3200
3250
3300
3350
3400
3450
3500



7228/9-1
Norsk Hydro
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
GR-SONIC-CAL LOGS
DT
140.0
40.0
GR
0.0
150.0
CAL1
12.0
32.0
NEUTRON-DENSITY LOGS
NPHI
0.45
-0.15
RHOB
1.95
2.95
Triassic
Scythian
Sassen-dalen
Havert
Permian
Kazanian-Tatarian
Kazanian
Kungurian-Ufimian
Artinskian
Tempelfjorden
Bjarmeland
Ørret
Røye
Isbjørn
3900
3950
4000
4050


7120/12-2
Norsk Hydro
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
CORES
GR-SONIC-CAL LOGS
DT
140.0
40.0
GR
0.0
150.0
CALI
6.0
16.0
NEUTRON-DENSITY LOGS
NPHI
0.45
-0.15
RHOB
1.95
2.95
Triassic
Permian
Scythian
Kazanian-Tatarian
Kazanian
Kungurian-Ufimian
Kungurian
Sassen-dalen
Tempelfjorden
Gipsd.
Havert
Ørret
Røye
Ørret
Røye
Ørret
Røye
Ugle
3650
3700
3750
3800
3850
3900
3950
4000
4050
4100
4150
4200
4250
4300
4350
4400
4450
4500
4550


Fig. 59

Fig. 60

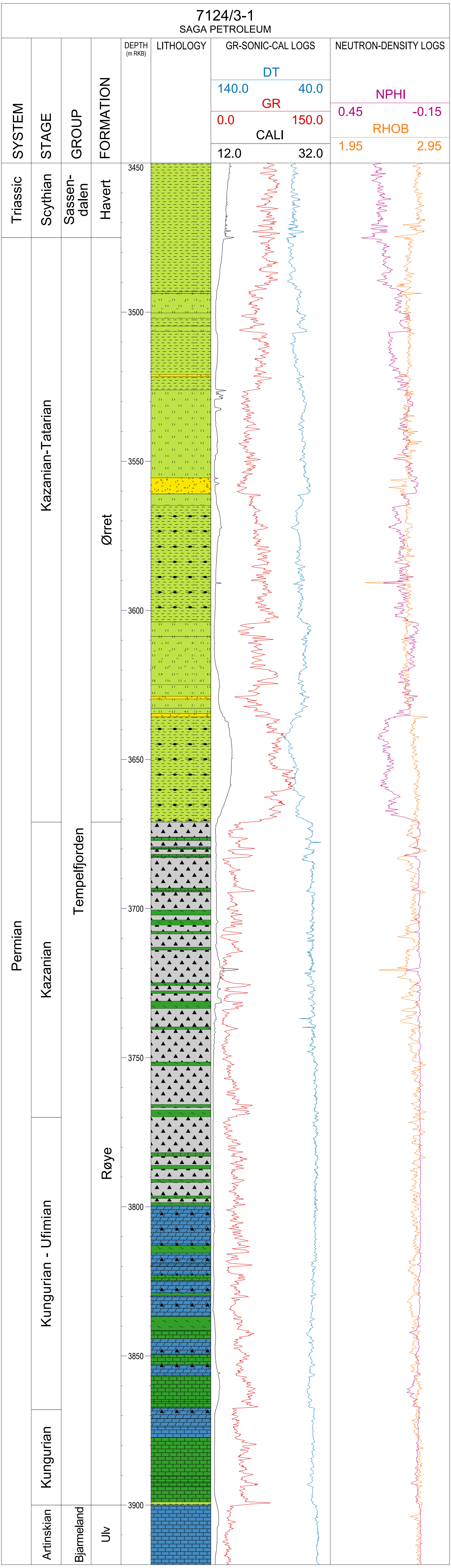
0 1 cm

Fig. 61a

0 1mm

Fig. 61b

0 1mm



7124/3-1
SAGA PETROLEUM
SYSTEM
STAGE
GROUP
FORMATION
DEPTH (m RKB)
LITHOLOGY
GR-SONIC-CAL LOGS
DT
140.0
40.0
GR
0.0
150.0
CALI
12.0
32.0
NEUTRON-DENSITY LOGS
NPHI
0.45
-0.15
RHOB
1.95
2.95
Triassic
Scythian
Sassen-dalen
Havert
Permian
Kazanian-Tatarian
Kazanian
Kungurian - Ufimian
Kungurian
Artinskian
Tempelfjorden
Bjarmeland
Ørret
Røye
Ulv
3450
3500
3550
3600
3650
3700
3750
3800
3850
3900

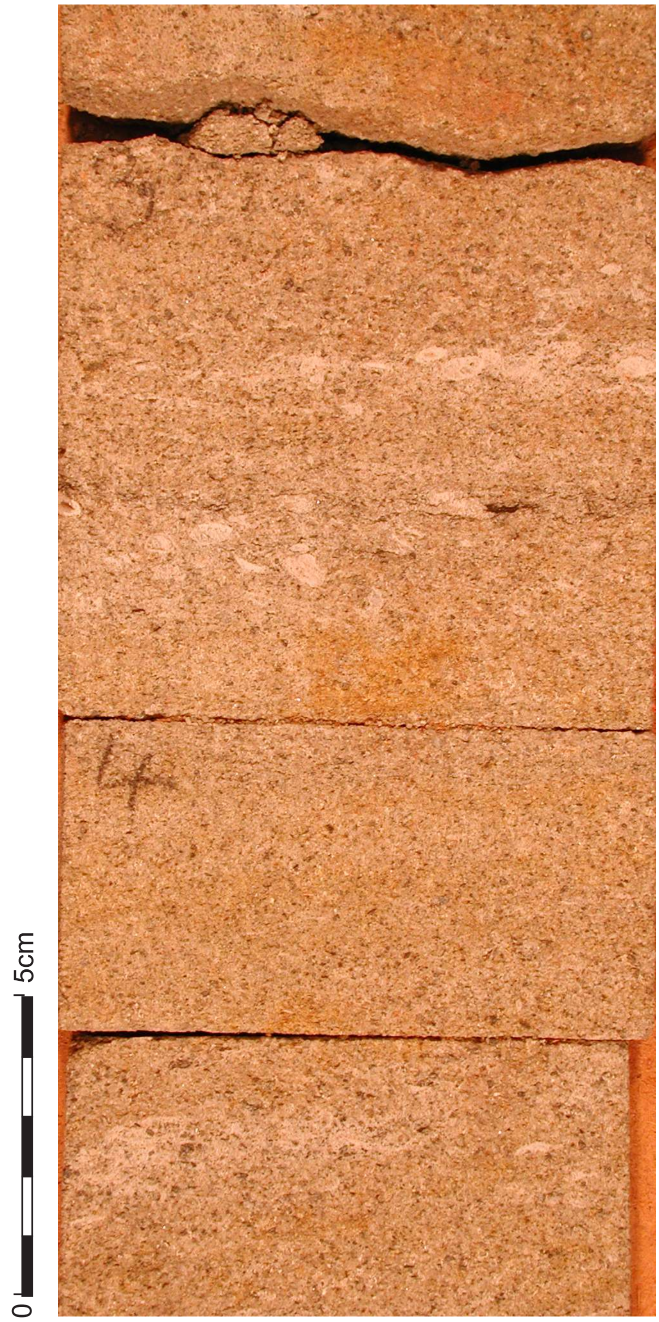


Fig. 63

| Group | Well No. | 7321/8-1 Hydro | 7120/12-4 Hydro | 7120/12-2 Hydro | 7120/9-2 Hydro | 7120/1-1 Shell | 7120/2-1 Hydro | 7121/1-1 Esso | 7124/3-1 Saga | 7226/11-1 Statoil | 7228/9-1S Hydro | 7229/11-1 Shell | 7128/6-1 Conoco | 7128/4-1 Statoil |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m RKB-msl | 23 | 23 | 25 | 23 | 25 | 23 | 26.8 | 22.5 | 24 | 23.5 | 24 | 23.5 | 24 |
| Tempel-fjorden | Ørret Fm | - | 1366-1469<br>1502-1648<br>1688-1700<br>1728-2003 | 3657-3920<br>3974.5-4030.5<br>4076-4485 | | 2403-2430<br>2458-2604 | - | - | 3475-3670 | 3877-3966 | 3884-3966 | 3879-3901 | - | - |
| | Røye Fm | 3398-3484 TD | 1469-1502<br>1648-1688<br>1700-1728<br>2003-2118 | 3920-3974.5<br>4030.5-4076<br>4485-4558 | 4956-5050<br>5072.6 (TD) | 2430-2458<br>2604-2997 | - | 2993-3502 | 3670-3900 | 3966-4103 | 3966-4065 | 3901-3970 | 1623.5-1745.4 | 1569-1704 |
| Bjarme-land | Isbjørn Fm | | - | - | | - | - | 3502-3586<br>3625-3700 | 3952-4000 | - | 4065-4150 | 3970-4046 | 1745.4-1834.5 | 1704-1820 |
| | Ulv Fm | | - | - | | 2997-3220 | - | 3586-3625 | 3900-3952 | 4103-4182 | 4150-4361 | - | - | - |
| | Polarrev Fm | | - | - | | | - | 3700-3990 | 4000-4271 | 4182-4334 | | 4046-4282 | - | - |
| Gipsdalen | Ørn Fm | | - | - | | 3220-3947 | 1945-2024 | 3990-5000 (TD) | 4271-4734.5 (TD) | 4334-5137 | 4361-4607 (TD) | 4282-4640 (TD) | 1834.5-2050 | 1820-1952 |
| | Falk Fm | | - | - | | | 2024-2221 | | | | | | 2050.4-2150 | 1952-2058 |
| | Ugle Fm | | 2118-2202 (TD) | 4558-4664 | | | 2221-2624 | | | | | | - | - |
| Bille-fjorden | Blærerot Fm | | | | | | Undiff Billefjorden Group 2624-3471 | | | | | | 2150-2202 | - |
| | Tettegras Fm | | | | | | | | | | | | 2202-2358 | 2058-2350.5 |
| | Soldogg Fm | | | | | | | | | | | | 2358-2533.5 | 2350.5-2503 |

| Group | Shallow drilling No. | 7127/10-U-02 IKU | 7127/10-U-03 IKU | 7128/12-U-01 IKU | 7029/03-U-01 IKU | 7029/03-U-02 IKU | 7129/10-U-01 IKU | 7129/10-U-02 IKU | 7030/03-U-01 IKU |
|---|---|---|---|---|---|---|---|---|---|
| | Water depth | 279m | 264m | 409m | 366m | 308m | 382m | 336m | 308m |
| Tempel-fjorden | Ørret Fm | | | | | | | | |
| | Røye Fm | | | 471.5-526 | | | 437.4-464 | | |
| Bjarmeland | Isbjørn Fm | | | 557.5-569.2 | | | 464.0-475.3 | | |
| | Ulv Fm | | | | | | | | |
| | Polarrev Fm | | | | | | | | |
| Gipsdalen | Ørn Fm | | | | | 319.9-393 | | 399.6-455.9 | 334.3-463.0 |
| | Falk Fm | | | | | 393-498.6 | | | 463.0-481.7 |
| | Ugle Fm | | | | | 498.6-509 | | | |
| Billefjorden | Blærerot Fm | | | | 437.2-503 | | | | |
| | Tettegras Fm | 348.0-479.2 | 338.9-417.0 | | | | | | |
| | Soldogg Fm | | | | 503-515.5 | | | | |

**Red:** Well Type section
**Green:** Well Reference section
**Depth:** Wells: m RKB (loggers depth)
Shallow cores: m MSL

Table 1