Biostratigrafi and Strontium Isotope Stratigraphy (SIS) of well 16/3-5 (Johan Sverdrup Field) including the Eir (informal) and Utsira formations

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For this investigation, micropalaeontological and Sr-isotope analyses for the interval 1180 to 750 m in well 16/3-5 are obtained. 44 ditch cutting samples were analysed (Table 1, Figs. 1 and 2).

Micropalaeontological analyses
Micropalaeontological investigations were based on analyses of planktonic and benthic foraminifera, *Bolboforma* and pyritized diatoms. The fossil assemblages are correlated with the micropalaeontological zonation for Cenozoic sediments of King (1989). The zonations of planktonic foraminifera (Spiegler and Jansen, 1989; Weaver and Clement, 1986) and *Bolboforma* (Spiegler and Müller, 1992; Müller and Spiegler, 1993) from ODP and DSDP drillings in the Norwegian Sea and the North Atlantic are also very important for the dating of the sediments since these zones are calibrated with both nannoplankton and palaeomagnetic data.

Lithological analyses
The lithological analyses are based on visual examination of the samples prior to treatment, and the dissolved and fractionated material after preparation.

Sr isotope analyses
Strontium isotope stratigraphy (SIS) is used as an additional control of the biostratigraphic correlations. The method has best resolution in sediments older than 15 Ma (Howard and McArthur, 1997). For samples with ages younger than eight Ma, the Sr isotope ages have to be treated with more caution. This is due to less variation in the Sr isotopic composition and a relatively flat curve between 2.5 and 4.5 Ma and also to some extent between 5.5 and 8 Ma (Hodell *et al*., 1991; Farrell *et al*., 1995; Howard and McArthur, 1997).

23 intervals were investigated for their Sr isotopic compositions with a total of 38 analysed samples (Table 1). The majority (34 samples) was conducted on mollusc fragments and the remainder on calcareous index foraminifera (two samples) and *Bolboforma* (two samples). As in well 26/10-1 to the north (Fig. 1), the Utsira and Skade formations, which usually are quite rich on mollusc fragments, are quite poor on such (Eidvin, 2018). The analytical work was carried out by the Mass Spectrometry Laboratory at the University of Bergen, Norway. Sr values were converted to age estimates using the strontium isotope stratigraphy look-up table of

Howard and McArthur (1997). This table is based on the time scale compiled by Berggren *et al*., (1995), which does not deviate significantly from the new time scale of Cohen *et al.* (2016). The most important difference is that the base Pleistocene has been moved from 1.85 Ma to 2.588 Ma. There exist no strontium isotope stratigraphy look-up table based on the time scale of Cohen *et al.* (2016). Please also note that the micropalaeontological zonation of King (1989) and the the planktonic foraminiferal zonation of Spiegler and Jansen (1989) are based on the time scale of Berggren *et al*. (1985), but we have converted the ages to the time scale of Berggren *et al*. (1995). The *Bolboforma* zonation of Spiegler and Müller (1992) and Müller and Spiegler (1993) is based on the time scale of Berggren *et al*. (1995).

Stratigraphy of well 16/3-5 (58° 46' 31.59'' N, 02° 42' 18.59'' E, Fig. 1)
There are recorded 30 m of Lower Miocene sediments, 140 m of Upper Oligocene deposits, 20 m of Lower Miocene deposits, 80 m of Middle Miocene deposits, 60 m of Upper Miocene sediments, 50 m of mainly Lower Pliocene deposits and 40 m of Upper Pliocene-Pleistocene sediments (mainly Pleistocene *sensu* Cohen *et al.,* 2016). The base on Lower Oligocene and the top of Upper Pliocene-Pleistocene are not sampled. There is an unconformity between the Lower and Middle Miocene. The ditch-cutting samples were investigated at ten metres intervals (Fig. 2).

Biostratigraphy

Lower Oligocene (1180-1150 m, Hordaland Group)

Benthic foraminifera of the *Rotaliatina bulimoides* assemblage and pyritized diatoms of the Diatom sp. 3 assemblage (lower part) together with one Sr isotope age date this unit to Early Oligocene (Fig. 2). The planktonic fossil assemblage also contains a few specimens of the planktonic foraminifera *Globigerina praebulloides*. In addition to the nominate species, the benthic foraminiferal assemblage also includes *Turrilina alsatica* and *Astigerina guerichi guerichi*. The benthic foraminiferal assemblage is correlated with Zone NSB 7 of King (1989), and the diatom assemblage is correlated with Subzone NSP 9c (lower part) of King (1989) from the North Sea.

Upper Oligocene (1150-1010 m, Hordaland Group)

Benthic foraminifera of the *Turrilina alsatica* assemblage and pyritized diatoms of Diatom sp. 3 (upper main part) together with one Sr isotope age give a Late Oligocene age to this unit (Fig. 2). The planktonic fossil assemblage also contains few specimens of the planktonic foraminifera *Globigerina angustiumbilicata* and *Globigerina praebulloides*. In addition to the nominate species, the benthic foraminiferal assemblage also includes *Rolfina arnei, Gyroidina soldanii girardana* and *Plectofrondicularia seminuda.* The benthic foraminiferal assemblage is correlated

with Zone NSB 8 of King (1989), and the diatom assemblage is correlated with NSP 9c (upper main part) of King (1989) from the North Sea.

Lower Miocene (1010-980 m, Hordaland Group)

Benthic foraminifera of the *Uvigerina tenuipustulata* assemblage and pyritized diatoms of the Diatom sp. 4 assemblage give an Early Miocene age to this unit (Fig. 2). The planktonic fossil assemblage also contains some specimens of the planktonic foraminifera *Globigerina angustiumbilicata* and *Globigerina praebulloides*. In addition to the nominate species the benthic foraminiferal assemblage also includes *Asterigerina guerichi staeschei* and *Ceratobulimina hauerii.* The benthic foraminiferal assemblage is correlated with Zone NSB 9 of King (1989), and the diatom assemblage is correlated with Zone NSP 10 of King (1989; North Sea).

Middle Miocene (980-900 m, Nordland Group including Eir formation (informal))

Bolboforma of the *Bolboforma badenensis* assemblage and benthic foraminifera of the *Trifarina gracilis* var. A assemblage give a Middle Miocene age to this unit (Fig. 2). In addition to the nominate species the *Bolboforma* assemblage also includes *Bolboforma clodiusi and Bolboforma reticulata* (common in one sample). The benthic foraminiferal assemblage also includes *Bulimina elongata* and *Elphidium antoninum*. Spiegler and Müller (1992) described a *B. badenensis* Zone and a *B. reticulata* Zone from the North Atlantic, and Müller and Spiegler (1993) described a *B. badenensis/B. reticulata* Zone from the Vøring Plateau (Norwegian Sea) in deposits with an age slightly older than 14 to 11.7 Ma. The benthic foraminiferal fauna is probably correlated with Zone NSB 11 and Zone NSB 12 of King (1989, North Sea).

Upper Miocene (900-840 m, Nordland Group including Utsira Formation (lower part)

Bolboforma of the *Bolboforma clodiusi* assemblage and benthic foraminifera of the *Uvigerina venusta saxonica* assemblage (lower main part) date this unit to the Late Miocene (Fig. 2). In addition to the nominate species the *Bolboforma* assemblage also includes *Bolboforma laevis* in one sample. The benthic foraminiferal assemblage also includes *Globocassidulina subglobosa, Globulina gibba myristiformis* and *Monspeliensina pseudotepida*. Qvale and Spiegler (1989) described *B. clodiusi* and *B. laevis* from the uppermost Middle and Upper Miocene from the Vøring Plateau (Norwegian Sea). King (1989) described *U. venusta saxonica* from the Upper Miocene to Lower Pliocene in the North Sea. The benthic foraminiferal fauna is correlated with Zone NSB 13 of King (1989).

Mainly Lower Pliocene (840-790 m, Nordland Group including Utsira Formation (upper part)

Benthic foraminifera of the *Uvigerina venusta saxonica* assemblage (uppermost part) and *Florilus boueanus* and planktonic foraminifera of *Neogloboquadrina atlantica* (sinistral) assemblage give likely an Early Pliocene age to this unit (Fig. 2). In addition to the nominate species, the benthic foraminiferal assemblage also includes *Eponides pygmeus, G. subglobosa, Plectofrondicularia advena* and *Sphaeroidina bulloides*. King (1989) described *U. venusta saxonica* from the Upper Miocene to Lower Pliocene and *P. advena* from the Lower to lowermost Upper Pliocene in the North Sea. The benthic foraminiferal fauna is correlated with Subzone NSB 13b and Subzone 14a of King (1989). Spiegler and Jansen (1989) described a *N. atlantica* (sinistral) Zone from the Vøring Plateau (Norwegian Sea) from Upper Miocene to Gelasian deposits.

Upper Pliocene (mainly Pleistocene sensu Cohen et al., 2016; 790-750 m, Nordland Group)

Benthic foraminifera of the *Cibicides grossus* assemblage and planktonic foraminifera of *Globigerina bulloides* assemblage and *Neogloboquadrina pachyderma* (dextral) assemblage give a Late Pliocene age (*sensu* Berggren *et al*., 1995; mainly Pleistocene *sensu* Cohen *et al*., 2016; Fig. 2). The benthic foraminiferal fauna is correlated with Zone NSB 15 of King (1989, North Sea). A *G. bulloides* Zone is described from the North Atlantic (DSDP Leg 94) in Plio-Pleistocene sediments as young as 2.2 Ma (Weaver and Clement, 1986). On the Vøring Plateau *G. bulloides* is common in Plio-Pleistocene sediments older than 2.4 Ma (Spiegler and Jansen, 1989) and in the warmest Pleistocene interglacials (Kellogg, 1977). Spiegler and Jansen (1989) also descried a *N. pachyderma* (dextral) assemblage from the Vøring Plateau from sediments with the age of 1.84 to 1.7 Ma.

Sr isotope stratigraphy

Most of the analysed samples in well 16/3-5 were mollusc fragments and were taken from the sandy Utsira Formation and the sandy to clayey lower part of the Nordland Group (including the sandy Eir formation (informal, see Eidvin *et al.,* 2013)). As for well 26/10-1 to the north (see Fig. 1; Eidvin, 2018), the obtained ages from the mollusc fragments (35 samples from 18 levels) show that an unusual large proportion of the material is caved.

The biostratigraphical correlations gave an Early Oligocene to Early Miocene age to the Hordaland Group, a Middle Miocene age to the Eir formation, a Late Miocene to Early Pliocene age to the Utsira Formation and a Late Pliocene to Pleistocene age to

the upper part of the Nordland Group (Fig. 2). Most of the Sr analyses of the mollusc fragments, from all parts, gave Late Miocene or younger ages and are probably caved. However, some analyses of mollusc fragments from the Utsira and Eir formations gave Early Miocene ages, and these are obviously based on reworked tests. We have listed the results of all the analyses in Table 1. In Fig. 2 and in the discussion below, we have only included Sr data from analyses of foraminiferal and *Bolboforma* index fossils which we have interpreted to be *in situ* or close to *in situ*.

The obtained $^{87}Sr/^{86}Sr$ ratios from 1180-1160 m (based on index foraminifera) gave an age of 28.3 Ma that support the Early Oligocene age given by the biostratigraphical correlation. The obtained $^{87}Sr/^{86}Sr$ ratios from 1140-1130 m (based on index foraminifera) gave an age 26.8 Ma, that also support the Late Oligocene age given by the biostratigraphical correlation (Table 1, Fig. 2).

Analyses of *Bolboforma badenensis* and *Bolboforma clodiusi* from 930 and 920 m gave 10.9 and 11 Ma respectively (Table 1, Fig. 2). These species are described from deep sea boreholes from the North-Atlantic and the North Sea in deposits with an age of approximately 14-11.7 and 14-10.2 Ma respectively (Qvale and Spiegler, 1989; Spiegler and Müller, 1992; Müller and Spiegler, 1993). The Sr ages support the ages obtained from the biostratigraphical correlations within the precision of the method.

Well 16/3-5

Litho. Unit	Sample (DC)	Corrected $^{87/86}Sr$	2S error	Age (Ma; H&M, 1997, 2004 mean values)	Comments	Analysed fossils
Utsira Fm	800 m	0.709086	0.000008	1.98, 1.97	Caved	One mollusc fragment
Utsira Fm	800 m	0.709068	0.000009	3.59, 2.58	Caved?	One mollusc fragment
Utsira Fm	810 m	0.709090	0.000009	1.84, 1.83	Caved	One mollusc fragment
Utsira Fm	810 m	0.709089	0.000008	1.87, 1.86	Caved	One mollusc fragment
Utsira Fm	820 m	0.708709	0.000008	16.65, 16.17	Reworked	One mollusc fragment
Utsira Fm	820 m	0.709082	0.000009	2.12, 2.12	Caved	One mollusc fragment
Utsira Fm	830 m	0.709073	0.000009	2.41, 2.39	Caved	One mollusc fragment
Utsira Fm	830 m	0.709080	0.000009	2.18, 2.19	Caved	One mollusc fragment
Utsira Fm	840 m	0.709082	0.000008	2.12, 2.12	Caved	One mollusc fragment
Utsira Fm	840 m	0.709065	0.000009	3.23, 2.72	Caved?	One mollusc fragment
Utsira Fm	850 m	0.709077	0.000008	2.27, 2.27	Caved	One mollusc fragment
Utsira Fm	850 m	0.708646	0.000009	17.45, 17.26	Reworked	One mollusc fragment
Utsira Fm	850 m	0.709097	0.000008	1.63, 1.65	Caved	One mollusc fragment
Utsira Fm	860 m	0.709066	0.000008	3.13, 2.67	Caved	One mollusc fragment
Utsira Fm	860 m	0.709070	0.000009	2.52, 2.50	Caved	One mollusc fragment
Nordland Gr	870 m	0.709043	0.000010	4.78, 4.74	Caved	One mollusc fragment
Nordland Gr	870 m	0.709077	0.000008	2.27, 2.27	Caved	One mollusc fragment
Nordland Gr	8.80 m	0.709063	0.000010	3.38, 2.84	Caved	One mollusc fragment
Nordland Gr	890 m	0.708635	0.000008	17.57, 17.42	Reworked	One mollusc fragment
Nordland Gr	890 m	0.709069	0.000009	2.57, 2.54	Caved	One mollusc fragment
Eir Fm (inform.)	910 m	0.709064	0.000008	3.31, 2.78	Caved	One mollusc fragment
Eir Fm (inform.)	910 m	0.709096	0.000009	1.66, 1.67	Caved	One mollusc fragment
Eir Fm (inform.)	920 m	0.708861	0.000009	10.98, 10.80		Ca 100 tests of *B. badenensis* and *B. clodiusi*
Eir Fm (inform.)	920 m	0.708644	0.000009	17.47, 17.29	Reworked	One mollusc fragment

Eir Fm (inform.)	930 m	0.708863	0.000009	10.93, 10.73		Ca 100 tests of *B. badenensis* and *B. clodiusi*
Eir Fm (inform.)	930 m	0.709049	0.000009	4.45, 4.42	Caved	One small mollusc fragment
Eir Fm (inform.)	940 m	0.709074	0.000009	2.37, 2.36	Caved	Two mollusc fragments
Eir Fm (inform.)	950 m	0.708454	0.000008	20.01, 19.77	Reworked	One mollusc fragment
Eir Fm (inform.)	950 m	0.708496	0.000010	19.37, 19.20	Reworked	One mollusc fragment
Eir Fm (inform.)	950 m	0.708762	0.000009	15.59, 15.53	Reworked	Two mollusc fragments
Nordland Gr	960 m	0.708647	0.000009	17.44, 17.24	Reworked	One mollusc fragment
Nordland Gr	960 m	0.708750	0.000009	15.88, 15.52	Reworked	One mollusc fragment
Nordland Gr	960 m	0.708914	0.000009	8.96, 9.12	Caved	Two mollusc fragments
Nordland Gr	970 m	0.708918	0.000009	8.79, 8.94	Caved	One mollusc fragment
Nordland Gr	970 m	0.708916	0.000008	8.87, 9.03	Caved	One mollusc fragment
Hordaland Gr	1010 m	0.709070	0.000009	2.52, 2.50	Caved	One mollusc fragment
Hordaland Gr	1010 m	0.708355	0.000009	21.80, 21.46	Reworked	One mollusc fragment
Hordaland Gr	1130, 1140 m	0.708107	0.000010	26.76, 26.51		28 tests of *T. alsatica*
Hordaland Gr	1160, 1170, 1180 m	0.708073	0.000009	28.25, 27.63		Ca 30 tests of *T. alsatica, R. bulimoides, G. soldanii girardana*

Table 1: Strontium isotope data from well 16/3-4

Lithology

Lower Oligocene to lower part of Upper Oligocene (1180 to approximately 1105 m (log), Hordaland Group)
Clay dominates the ditch cuttings. Minor sand and silt are also present throughout. Sand is slightly more common in the upper part. Quartz is the dominante mineral in the sand fraction. Minor glauconite is also present in the upper part (Fig. 2).

Upper Oligocene (main part) to Lower Miocene (approximately 1105 (log) to 980 m, Hordaland Group)
Clay dominates the ditch cutting samples also in this part of the Hordaland Group. Sand is minor to quite common throughout. Quartz and glauconite dominate the sand fraction (Fig. 2).

Middle Miocene to Upper Miocene (lower part; 980 to 870 m (log), Nordland Group including the Eir formation (informal))
The samples in this unit contain sand, silt and clay. Sand is dominant in the upper and lower part of the Eir formation. Sand is minor to quite common below and above the Eir formation and in the middle part of the Eir formation. Quartz is the dominant mineral with minor glauconite in the Eir formation. Below the Eir formation glauconite is the dominant minerale with minor quartz, and above the Eir formation both quartz and glauconite are common (Fig. 2).

Upper Miocene (upper part) to Lower Pliocene (870 m (log) to 790 m, Utsira Formation of the Nordland Group
Sand dominates this unit with minor silt and clay. The sand fraction is dominated by quartz, but some glauconite and mica are also recorded (Fig. 2).

Upper Pliocene to Pleistocene (mainly Gelasian; 790 to 750 m, Nordland Group (Naust Formation equivalent))
The ditch cutting samples in this unit contain a clay-rich diamicton with some sand, silt and minor pebbles. The sand fraction is dominated by quartz (Fig. 2).

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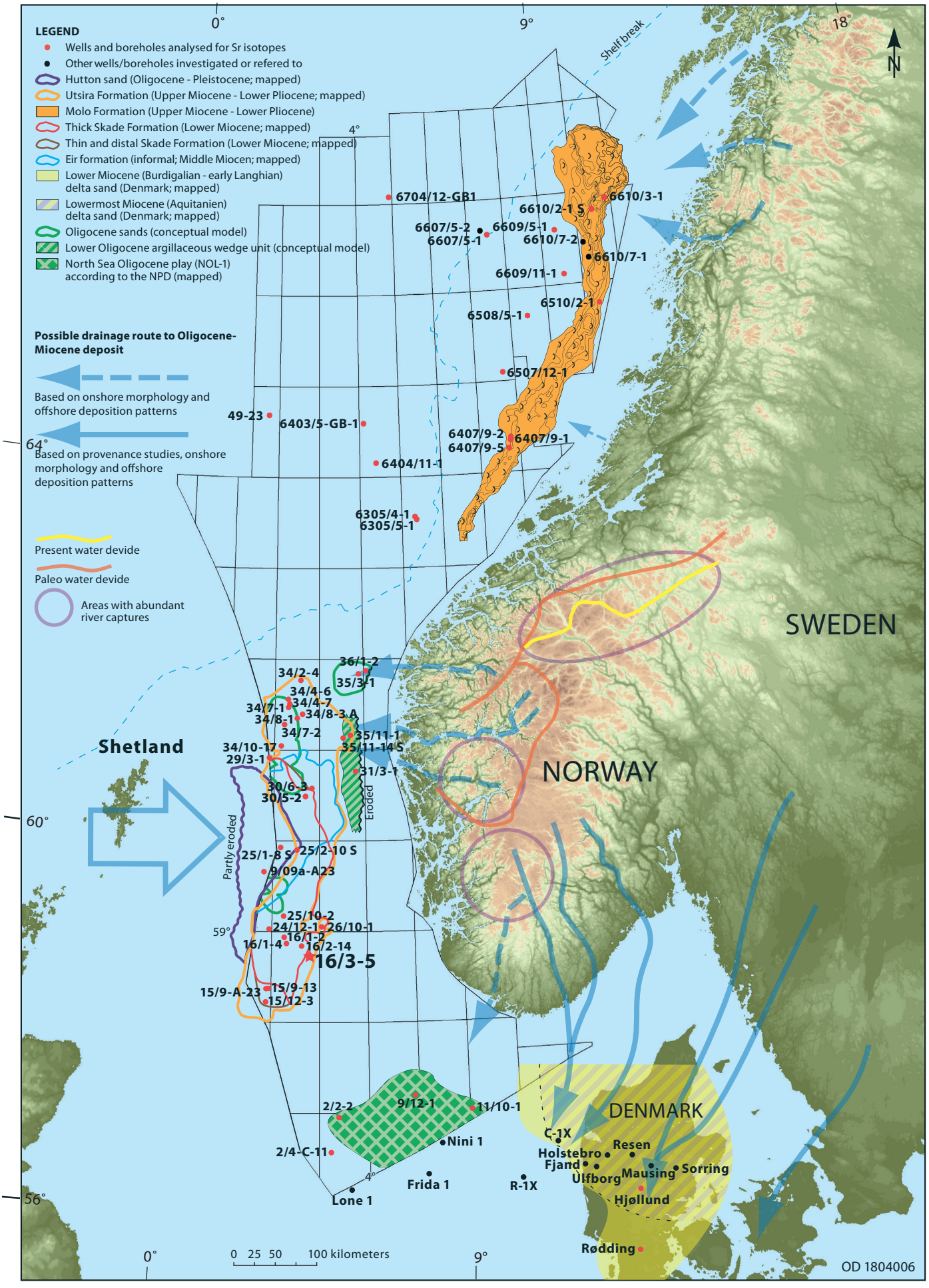
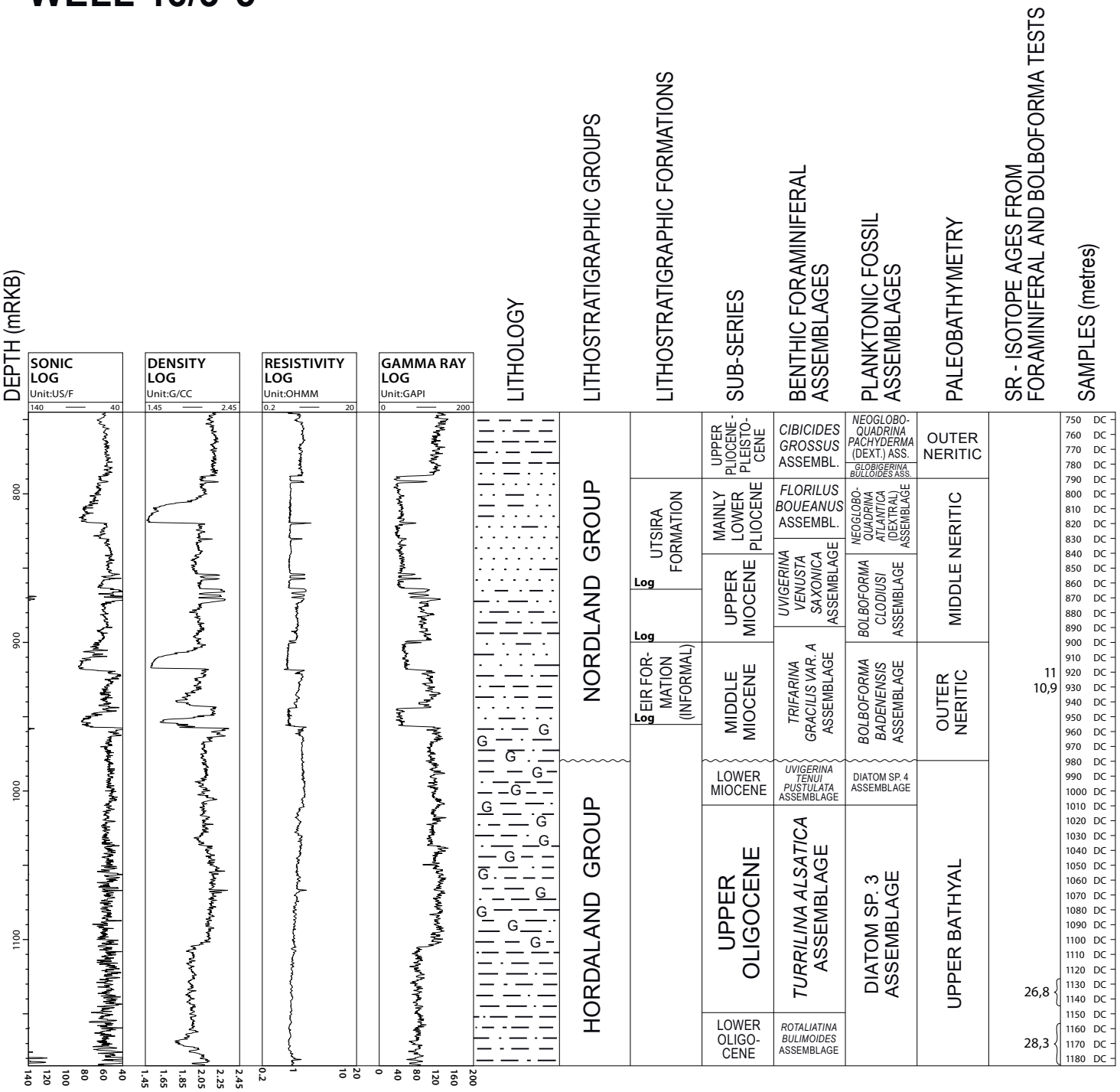


Fig. 1: The location of well 16/3-5 (Johan Sverdrup Field) shown on a map showing wells and boreholes containing Oligocene to Upper Pliocene - Pleistocene deposits (modified after Eidvin et al., 2013, 2014 and Eidvin and Riis, in prep.). The extent of the Utsira, Eir and Skade formations in the North Sea is according to NPD factpages. The extent of the Molo Formation is after Bullimore et al. (2005) and the extent of the Hutton sand (informal) is after Gregersen and Johannessen (2007). The extent of the North Sea Oligocene play (NOL-1) is according to the Norwegian Petroleum Directorate web page (www.npd.no). Provenance study is after Olivarius (2009) and topographic map is after Olesen et al. (2010).

WELL 16/3-5



Sea floor = 140 metres below rig floor (mRKB)
DC = Ditch cuttings
G = Abundant glauconite
gAPI = American Petroleum Institute gamma ray units
G/CC = Gram per cubic centimetres
US/F = Microseconds per foot

Fig. 2: Well summery figure including sonic, density, resistivety and gamma ray logs, lithostratigraphic units, series/subseries, benthic foraminiferal assemblages, planktonic fossil assemblages, paleobathymetry, strontium isotope ages and analysed samples for the investigated sequence in well 16/3-5 (Lower Oligocene to Upper Pliocene-Pleistocene (mainly Gelasian)).