Biostratigraphy and Strontium Isotope Stratigraphy (SIS) of the upper part of the Brygge Formation, Kai and Naust formations in well 6507/5-1 and cored section of the Naust Formation in well 6507/5-J-1 H from the the Skarv Field (Revfallet Fault Complex, Norwegian Sea shelf)

NPD stratigraphic report 2019/01, updated 2020

Tor Eidvin, Norwegian Petroleum Directorate, P. O. Box 600, NO-4003 Stavanger, Norway

Well 6507/5-1

For the investigation of well 6507/5-1 (65º44'36.11''N, 07º39'4.6''E, Fig. 1), micropaleontological and Sr-isotope analyses for the interval 1900 to 1470 m are obtained. Forty-three ditch-cutting samples were analysed (Table 1, Figs. 1 and 2).

Micropaleontological analyses
Micropaleontological investigations were based on analyses of planktonic and benthic foraminifera, *Bolboforma* and pyritized diatoms. The fossil assemblages are correlated with the micropaleontological zonation for Cenozoic sediments of King (1989). The zonations of planktonic foraminifera (Spiegler and Jansen, 1989; Weaver and Clement, 1987) 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. 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).

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 is used as an additional control for 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 especially between 2.5 and 4.5 Ma but

also to some extent between 5.5 and 8 Ma (Hodell *et al*., 1991; Farrell *et al*., 1995; Howard and McArthur, 1997).

Seven samples from six intervals were investigated for their Sr isotopic composition. Three of these were conducted on benthic foraminiferal tests and four on *Bolboforma* tests (Table 1). 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, 2004). The look-up table of Howard and McArthur (1997) is based on the time scale of Berggren *et al*. (1995), and this time scale is used throughout the report. The look-up table of Howard and McArthur (2004) is based on the time scale of Gradstein *et al*. (2004). There is currently no SIS look-up table that is based on the new time scale of Cohen *et al*. (2013, updated 2018). The time scale compiled by Berggren *et al*., (1995) does not deviate significantly from the new time scale of Cohen *et al.* (2013, updated 2018). The most important difference is that the base of Pleistocene has been moved from 1.85 Ma to 2.588 Ma. Of that follows that according to Berggren *et al*. (1995), the Gelasian is in the uppermost part of Pliocene, and according to Cohen *et al*. (2013, updated 2018) the Gelasian is in the lowermost part of Pleistocene.

Stratigraphy of well 6507/5-1

There are recorded 50 m of Lower-Middle Eocene sediments, 10 m of Lower Oligocene deposits, 40 m with sediments from early part of Early Miocene, 70 m with sediments from early to middle part of Middle Miocene, 160 m with Upper Miocene deposits, approximately 15 m with Lower Pliocene deposits, approximately 75 m with mainly Gelasian sediments and 20 m with Calabrian sediments (Fig. 2). The base of the Lower-Middle Eocene and the top of the Calabrian are not investigated.

Biostratigraphy

Lower-Middle Eocene (1900-1850 m, Hordaland Group including the Brygge Formation)

Benthic agglutinated foraminifera of the *Bathysiphon eocenicus-Bathysiphon nodosariaformis* assemblage and radiolaria of the *Cenosphaera* sp. assemblage give an Early-Middle Eocene age to this unit (Fig. 2). In addition to the nominate species the benthic foraminiferal assemblage also includes a few specimens of *Cyclammina placenta* and *Ammodiscus cretaceous*. The benthic foraminiferal fauna is correlated with Zone NSA 4 of King (1989) from the North Sea, and the planktonic fossil (radiolaria) assemblage is correlated with Zone NSP 6 of King (1989; North Sea).

Lower Oligocene (1850-1840 m, Hordaland Group including the Brygge Formation)

Benthic foraminifera of the *Rotaliatina bulimoides* assemblage and diatoms of the Diatom sp. 3 assemblage date this unit to the Early Oligocene (Fig. 2). In addition to the nominate species the *Rotaliatina bulimoides* assemblage also includes *Turrilina alsatica* and *Gyroidina soldanii girardana*. The benthic foraminiferal fauna is correlated with Subzone NSB 7b of King (1989; North Sea) and the planktonic fossil (diatom) assemblage is correlated with Subzone NSP 9c of King (1989; North Sea).

Lower-middle part of Lower Miocene (1840-1810 m, Hordaland Group including the Brygge Formation)

Benthic foraminifera of the *Spirosigmoilinella compressa* assemblage and pyritized diatoms of the Diatom sp. 4-Diatom sp. 5 assemblage date this unit to the early to middle part of Early Miocene (Fig. 2). The *S. compressa* assemblage is correlated with Zone NSA 10 of King (1989; North Sea) and the diatom assemblage is correlated with Zone NSP 10 of King (1989, North Sea).

Lower-middle part of Middle Miocene (1810-1740 m, Hordaland Group including the Brygge Formation)

Bolboforma of the *Bolboforma reticulata* assemblage and benthic foraminifera of the *Trifarina gracilis* assemblage date this unit to the early to middle part of Middle Miocene (Fig. 2). From DSDP Sites 12-116, 49-408, 81-555 and 94-608 in the North Atlantic, Spiegler and Müller (1992) described a *Bolboforma reticulata* Zone from deposits with an age of slightly older than 14 to 12.3 Ma, a very short *Bolboforma danielsi* Zone from around 12.3 Ma and a *Bolboforma badenensis* Zone from 12.3 to 11.9 Ma. Müller and Spiegler (1993) have also investigated the boreholes ODP 104-624B and C and ODP 104-643A on the Vøring Plateau (Norwegian Sea), and this investigation shows that *B. reticulata* and *B. badenensis* occur together in the same samples in a *B. badenensis-B. reticulata* Zone. In this area they have not defined a *B. danielsi* Zone. Only one specimen of *B. badenensis* was recorded from the *B. reticulata* assemblage in well 6507/5-1, and we think it is most likely that the *B. reticulata* assemblage has an age slightly older than 14 to 12.3 Ma. According to Skarbø and Verdenius (1986), *T. gracilis* occurs in Oligocene to Middle Miocene sediments on the Norwegian continental shelf. A few specimens of *T. gracilis* var. A are also recorded in the *T. gracilis* assemblage.

Upper Miocene (1740-1580 m, Nordland Group including the Kai Formation)

Benthic foraminifera of the *Martinottiella communis* assemblage and *Uvigerina venusta saxonica* assemblage (lower main part), *Bolboforma* of the *Bolboforma compressispinosa* assemblage, *Bolboforma subfragori-Bolboforma fragori* assemblage and *Bolboforma laevis* assemblage and planktonic foraminifera of *Neogloboquadrina atlantica* (dextral) assemblage together with six Sr isotope ages give a Late Miocene age to this unit (Fig. 2). The benthic foraminiferal assemblages also include *Sphaeroidina bulloides* and *Globocassidulina subglobosa.* The *Martinottiella communis* assemblage is correlated with Subzone NSB 13a (lower part) of King (1989; North Sea) and tentatively Zone FC of Doppert (1980) from the Netherlands. The *Uvigerina venusta saxonica* assemblage is correlated with Subzone NSB 13b (upper part) of King (1989; North Sea). Spiegler and Müller (1992) and Müller and Spiegler (1993) described a *B. compressispinosa* Zone and *a B. fragori/B. subfragori* Zone from the North Atlantic and the Norwegian Sea (Vøring Plateau). In the North Atlantic these Zones is dated to 11.9-11.7 Ma and 11.7-10.3 Ma respectively. The same authors have recorded a *B. laevis/Bolboforma capsula* Zone from the North Atlantic and a *B. laevis* Zone from the Vøring Plateau from deposits with an age of 10.3-10.0 Ma. Spiegler and Jansen (1989) described a lower *N. atlantica* (dextral) Zone from Upper Miocene sediments on the Vøring Plateau, and Weaver and Clement (1987) reported a *N. atlantica/Neogloboquadrina acostaensis* Zone from Upper Miocene sediments in the North Atlantic.

Lower Pliocene (1580 to approximately 1565 m, Nordland Group including the Kai Formation)

Benthic foraminifera of the *Uvigerina venusta saxonica* assemblage (uppermost part) and planktonic foraminifera of the *Neogloboquadrina atlantica* (sinistral) assemblage (lower part) give an Early Pliocene age to this unit (Fig. 2). According to King (1989), *U. venusta saxonica* occur in the North Sea area from Late Miocene to Early Pliocene (upper part of Subzone NSB 13b and lower part of Subzone 14a). According to Spiegler and Jansen (1989), *N. atlantica* (sinistral) occur through the Upper Miocene and Pliocene and into the Gelasian on the Vøring Plateau (Norwegian Sea). The last occurrence datum (LAD) in that area is approximately at 2.4 Ma.

Mainly Gelasian (approximately 1565 to 1490 m, Nordland Group including the Naust Formation)

Benthic foraminifera of the *Cibicides telegdi* assemblage and *Cibicides grossus-Elphidiella hannai* assemblage and planktonic foraminifera of the *N. atlantica* (sinistral) assemblage (upper part) and *Globigerina bulloides* assemblage give a mainly Gelasian age (mainly Late Pliocene *sensu* Berggren *et al*., 1995 and mainly Pleistocene *sensu* Cohen *et al*., 2013, updated 2018) to this unit (Fig. 2). The

Cibicides telegdi assemblage also contains *Eponides pygmeus*. *C. telegdi* and *E. pygmeus* occur most common in Oligocene to Pliocene sediments but are recorded (*in situ*) in the Gelasian (Stratlab, 1988; Eidvin and Rundberg, 2007; Eidvin et al., 2013). The *C. telegdi* assemblage and the *C. grossus-E. hannai* assemblage are correlated with Zone NSB 15 of King (1989; North Sea) which is mainly of Gelasian to early Calabrian age. *A G. bulloides* Zone is described from the north Atlantic (DSDP Leg 94) in Neogene sediments as young as 2.2 Ma (Weaver and Clement, 1987). On the Vøring Plateau. *G. bulloides* is common in Neogene deposits older than 2.4 Ma (Spiegler and Jansen, 1989). *G. bulloides* is also known from the North Atlantic and Norwegian Sea in deposits from warm periods during the Pleistocene (Kellogg, 1977).

Mainly Calabrian (1490 to 1470 m, Nordland Group including the Naust Formation

Benthic foraminifera of the *Elphidium groenlandicum* assemblage and planktonic foraminifera of the *Neogloboquadrina pachyderma* (dextral) assemblage give a Calabrian age (early Pleistocene *sensu* Berggren *et al*., 1995 and middle Pleistocene *sensu* Cohen *et al*., 2013, updated 2018) to this unit (Fig. 2). The *E. groenlandicum* assemblage also contains *Elphidium albiumbilicatum* and *Elphidium excavatum*, and the assemblage probably correlates with the lower part of Zone NSB 16x of King (1989; North Sea) which is mainly of Calabrian age. A *N. pachyderma* (dextral) Zone is described by King (1989) for the North Sea, Weaver and Clement (1987) from the North Atlantic and by Spiegler and Jansen (1989) from the Vøring Plateau. On the Vøring Plateau the zone is dated to 1.9-1.8 Ma. *N. pachyderma* (dextral) also occured during warm periods in the Pleistocene.

Sr isotope stratigraphy

Analysis of three samples based on benthic foraminiferal tests and four samples based on *Bolboforma* tests have been carried out on the unit which was given a Late Miocene age by the foraminiferal and *Bolboforma* correlations. These are the only samples which contain enough calcareous index fossil tests for Sr analysis. The analyses of the three samples based on foraminiferal test in the upper part of the unit gave large standard deviations (Table 1). Consequently, the results are therefore somewhat uncertain, and the sample at 1610 m gave an age which is obvious too young and incorrect. Based on the look-up table of Howard and McArthur (1997), the samples from 1590 and 1600 m gave 5.8 and 4.3 Ma respectively (late Late Miocene and early Early Pliocene; Table 1, Fig. 2), which broadly supports the foraminiferal correlations. The analyses of the samples in the lower part of the unit gave 11.3 Ma for the sample at 1720 m, 10.5 Ma for the sample at 1710 m and 9.0 and 9.1 for the samples at the 1700 m interval (early Late Miocene; Table 1, Fig. 2). These results support the *Bolboforma* correlations.

Well 6507/5-1

Litho. Unit	Sample (DC)	Corrected $^{87/86}Sr$	2S error	Age (Ma; H&M, 1997, 2004 mean values)	Comments	Analysed fossil species
Kai Fm	1590 m	0.709003	0.000011	5.79, 5.84	High standard deviation	38 tests of *U. venusta saxonica*
Kai Fm	1600 m	0.709051	0.000011	4.30, 4.23	High standard deviation	23 tests of *U. venusta saxonica*
Kai Fm	1610 m	0.709130	0.000011	1.146, 1.131	High standard deviation	55 tests of *U. venusta saxonica*
Kai Fm	1700 m	0.708910	0.000009	9.13, 9.29		Approximately 60 tests of *B. subfragori* and *B. fragori*
Kai Fm	1700 m	0.708912	0.000009	9.04, 9.21		Approximately 70 tests of *B. subfragori* and *B. fragori*
Kai Fm	1710 m	0.708876	0.000008	10.48, 10.30		Approximately 60 tests of *B. subfragori* and *B. fragori*
Kai Fm	1720 m	0.708852	0.000008	11.27, 11.14		Approximately 70 tests of *B. subfragori* and *B. fragori*

Table 1: Strontium isotope data from well 6507/5-1. The samples were analysed at the University of Bergen. Sr ratios were corrected to NIST 987 = 0.710248. Numerical ages derived from the SIS Look-up Tables of Howarth and McArthur (1997, 2004). NIST = National Institute for Standard and Technology. DC means ditch-cuttings.

Lithology

Lower- Middle Eocene (1900-1850 m, Brygge Formation)

This unit consists of pelagic ooze (mainly siliceous) with some clay (Fig. 2).

Lower Oligocene to lower part of Middle Miocene (1850 to approximately 1770 m, Brygge Formation)

Clay dominates the sample, but the content of glauconitic sand is quite high in most of the section (Fig. 2).

Middle part of Middle Miocene to Lower Pliocene (approximately 1770 to approximately 1565 m, uppermost Brygge Formation and Kai Formation)

The ditch-cutting samples from this succession are also fine grained. Clay dominates the samples with minor silt and sand (quartzose and glauconitic; Fig. 2).

Mainly Gelasian (approximately 1565 m to 1490 m, Naust Formation)

The ditch-cutting samples from the mainly Gelasian unit also contain mostly fine-grained material, with some silt, sand (mainly quartzose, but also some glauconitic) and pebbles of crystalline rocks. Sand and pebbles are quite common in the uppermost 10 m of the unit, but occur throughout indicating a glaciomarine origin of the sediment in the unit (Fig. 2).

Jansen and Sjøholm (1991) and Fronval and Jansen (1996) reported the onset of major glaciations in northern Europe at around 2.75 million years ago on the basis of the IRD (Ice-Rafted Debris) record from the ODP boreholes 642, 643 and 644 located on the Vøring margin west of the major depocentre of the Naust Formation on the Norwegian Sea shelf and rise. Eidvin et al. (2000) correlated the start of the deposition of the Naust Formation with this large increase in the supply of ice-rafted material (Ottesen et al., 2009).

According to the previous operator (Amoco in 1998) for licence PL 212, the Kai/Naust formations boundary was set to 1381 m (i.e. almost 200 m higher than our interpretation).

Calabrian (1490 to 1470 m, Naust Formation)

The samples contain a mixture of clay, silt, sand and pebbles of crystalline rocks typical for glacial diamictons. The maximum age of the sediments is given by the fact that the onset of the major glaciations of Scandinavia started around 2.75 Ma.

Well 6507/5-J-1 H

In the production well 6507/5-J-1 H (65º44'17.17''N, 07º39'4.83''E) we have investigated four samples for micropaleontology and lithology (1572.10, 1584.80, 1590 m and 1610.10 m) and two samples for Sr isotope ratios (1572.10 and 1610.10 m) in a corded section in the lower part of the Naust Formation (1570-1613.3 m; Fig. 3). Inclination of the well is 32º at 1570 m and 32.5º at 1613 m. The operator for licence PL 212 in 2013 (BP) sets the Kai/Naust formations boundary at 1387.2 m (226 m above the base of the core). Aker/BP is operator for licence PL 212 in 2018. The NPD usually do not receive ditch-cuttings samples from production wells, mainly just conventional cores. This caused that we were not able to locate the actual Kai/Naust formations boundary as we did for well 6507/5-1 (see above).

Biostratigraphy

In the samples 1572.10 and 1610.10 m, we recorded a benthic foraminiferal *Cibicides grossus* assemblage. The assemblage also includes *Elphidium excavatum*, *Elphidium albiumbilicatum, Cassidulina teretis* and *Nonion affine.* We did not record any planktonic foraminifera in these samples. The sample at 1584.80 m is completely barren of foraminifera. The sample at 1595 m do not contain any *C. grossus*, but have *Elphidium excavatum*, *Elphidium albiumbilicatum, Cassidulina teretis* and *Nonion affine.* The sample also contains planktonic foraminifera including *Globigerina* *bulloides* (rare) and *Neogloboquadrina pachyderma* (dextral; common). The *C. grossus* assemblage correlates with Zone NSB 15 of King (1989; North Sea) which is of Gelasian to early Calabrian age. *G. bulloides* Zone is common in deep sea boreholes from the North Atlantic and the Norwegian sea in sediments from approximately 2.4 to 2.2 Ma and in sediments deposited during warm periods in the Pleistocene (Kellogg, 1977). *N. pachyderma* (dextral) is common in similar boreholes from the same areas in sediments from approximately 1.9 to 1.8 Ma (Weaver and Clement, 1987; Spiegler and Jansen, 1989; see above) and during warm periods in the Pleistocene.

The cored section in well 6507/5-J-1 H (Fig. 3) was extrapolated into the stratigraphical figure for well 6507/5-1 (based on log data; Fig. 2), and indicates that the *C. grossus* assemblage corresponds to the *C. grossus-E. hannai* assemblage in that well. The occurrence of *G. bulloides* and *N. pachyderma* (dextral) at 1595 m in well 6507/5-J-1 H corresponds to the *G. bulloides* and *N. pachyderma* (dextral) assemblages in well 6507/5-1.

Lithology

1610.10 to 1572.10 m (Naust Formation)

As for the upper part of the Naust Formation in well 6507/5-1, the samples contain a mixture of clay, silt, sand and pebbles of crystalline rocks typical for glacial diamictons. Sand and pebbles are most common in the uppermost and in the lowermost sample (Fig. 3). Core photos cores are available at the NPD factpages (npd.no/facts).

Sr isotope stratigraphy

Analysis of two samples based on benthic foraminiferal tests have been carried out on the cored section in well 6507/5-J-1 H. The sample from 1610.1 m gave 1,4 Ma (based on the look-up table of Howard and McArthur (1997)) and 1.5 Ma (based on of Howard and McArthur (2004)). A second analysis of the sample from 1610.1 m gave 1.7 Ma based on both look-up tables. The sample from 1572.10 m gave 1.3 Ma on both look-up tables, and a second analysis from 1572.10 m gave 1.5 Ma based on Howard and McArthur (1997) and 1.6 based on Howard and McArthur (2004; Table 2). All the Sr ages obtained from cored section in well 6507/5-J-1 H gave ages within the earliest Calabrian, and broadly supports the foraminiferal correlations.

The marine Sr isotope curves for the Pleistocene of Howard and McArthur (1997, 2004), in general, have lower gradients than the Oligocene and the Miocene parts. Small errors in the $^{87}Sr/^{86}Sr$ isotopic composition due to minor impurities in the calcareous tests, re-crystallization of the tests, errors introduced during sample preparation and the mass spectroscopy analysis process, etc., have much larger impact when calculating ages from low gradient parts of the strontium isotope seawater curves than from high gradient parts. However, $^{87}Sr/^{86}Sr$ isotopic compositions which give ages between 1.6 and 1.0 Ma plots on the steepest part of the Sr isotope curve for Pleistocene and consequently, theoretically, should provide the most reliable Pleistocene ages. It is planned to perform magnetostratigraphy on the 6507/5-J-1 H core.

Well 6507/5-J-1 H

Litho. Unit	Sample (core)	Corrected $^{87/86}Sr$	2S error	Age (Ma; H&M, 1997, 2004 mean values)	Analysed fossil species
Naust Fm	1572.10 m	0.709116	0.00007	1.312, 1.324	Approximately 30 tests of *C. teretis*
Naust Fm	1572.10 m	0.709100	0.00009	1.546, 1.591	Approximately 30 tests of *C. teretis*
Naust Fm	1610.10 m	0.709107	0.00009	1.423, 1.461	Approximately 30 tests of *C. teretis*
Naust Fm	1610.10 m	0.709096	0.00009	1.657, 1.672	Approximately 30 tests of *C. teretis*

Table 2: Strontium isotope data from well 6507/5-1. The samples were analysed at the University of Bergen. Sr ratios were corrected to NIST 987 = 0.710248. Numerical ages derived from the SIS Look-up Tables of Howarth and McArthur (1997, 2004). NIST = National Institute for Standard and Technology. DC means ditch-cuttings.

Acknowledgement

Many thanks to Rune Goa (NPD) for drawing the figures, Tone Tjelta Hansen (NPD) for executing the micropaleontological preparation, Peter Lucas (PetroStrat Ltd) for informing us about the IRD in the 1570-1613 m cored section in well 6507/5-J-1 H, Yuval Ronen (University of Bergen) for executing the strontium isotope analyses and Fridtjof Riis (NPD) and Robert Willams (NPD) for discussions.

References

Berggren, W. A., Kent, D. V, Swisher, C. C., III and Aubry, M.-P., 1995. A Revised Cenozoic Geochronology and Chronostratigraphy, in: Berggren, W. A. *et al*. (eds.), Geochronology Time Scale and Global Stratigraphic Correlation. *Society for Sedimentary Geology Special Pulication 54*, 129-212.

Berggren, W. A., Kent, D. V. and van Couvering, 1985. The Neogene. Part 2. Neogene geochronology and chronostratigraphy. In Snelling, N. J. (ed.), *The chronology of the geological record*. *Geol. Soc. Memoir 10*, 141-195.

Bullimore, S., Henriksen, S., Liestøl, F.M. and Helland-Hansen, W., 2005. Clinform stacking patterns, shelf-edge trajectories and facies associations in Tertiary coastal deltas, offshore Norway: Implications for the prediction of lithology in prograding systems. *Norwegian Journal of Geology 85*, 169-187.

Cohen, K. M., Finney, S. C., Gibbard, P. L. and Fan, J.–X., 2013 (updated 2018): The ICS International Chronostratigraphic Chart. *Episodes, 36*: 199-204. Available from the internet: http://stratigraphy.org/ICSchart/ChronostratChart2018-08.jpg

Doppert, J. W. C., 1980. Lithostratigraphy and biostratigraphy of marine Neogene deposits in the Netherlands. *Mededelingen Rijks Geologische Dienst 32-16, 2*, 3-79.

Eidvin, T. and Rundberg, Y., 2007. Post-Eocene strata of the southern Viking Graben, northern North Sea; intergrated biostratigraphic, strontium isotopic and lithostratigraphic study. *Norwegian Journal of Geology 87*, 391-450. Available from the internet: http://www.npd.no/Global/Norsk/3-Publikasjoner/Forskningsartikler/Eidvin_and_Rundberg_2007.pdf.

Eidvin, T., Jansen, E., Rundberg, Y., Brekke, H. and Grogan, P., 2000. The upper Cainozoic of the Norwegian continental shelf correlated with the deep-sea record of the Norwegian Sea and North Atlantic. *Marine and Petroleum Geology, 17,* 579-600.

Eidvin, T., Riis, F. and Rasmussen, E. S., 2014a. Correlation of Upper Oligocene to Lower Pliocene deposits of the Norwegian continental shelf, Norwegian Sea, Svalbard, Denmark and their relation to the uplift of Fennoscandia: a synthesis. Marine and Petroleum Geology 56, 184-221. Available from the internet: http://www.npd.no/Global/Norsk/3-Publikasjoner/Forskningsartikler/Eidvin_et_al_2014.pdf.

Eidvin, T., Riis, F., Rasmussen, E. S. and Rundberg, Y., 2013. Investigation of Oligocene to Lower Pliocene deposits in the Nordic area. *NPD Bulletin No 10*. Available from the internet: http://www.npd.no/engelsk/cwi/pbl/NPD_papers/Hyperlink-NPD-Bulletin-10.pdf.

Farrell, J., Clemens, S. C., Gromet, L. P., 1995. Improved chronostratigraphic reference curve of late Neogene seawater $^{87}Sr/^{86}Sr$. *Geology 23*, 403-406.

Fronval, T. and Jansen, E., 1996. Late Neogene paleoclimates and paleoceanography in the Iceland-Norwegian Sea: evidence from the Iceland and Vøring Plateaus. *In* Thiede, J., Myhre, A. M., Firth, J. V., John, G. L. and Ruddiman, W. F. (eds.), *Proceedings of the Ocean Drilling Program, Scientific Results 151*: College Station, TX (Ocean Drilling Program), 455-468.

Gradstein, F., Ogg, J., Smith, A., 2004. A Geological Time Scale. Cambridge University Press, Cambridge, U. K.

Gregersen, U. and Johannessen, P. N., 2007. Distribution of the Neogene Utsira Sand and Hutton Sand, and the succeeding deposits in the Viking Graben area, North Sea*. Marine and Petroleum Geology* 24, 591-606.

Hodell, D. A., Mueller, P. A. and Garrido, J. R., 1991 Variations in the strontium isotopic composition of seawater during the Neogene. *Geology 19*, 24-27.

Howarth, R. J. and McArthur, J. M., 1997. Statistics for Strontium Isotope Stratigraphy: A Robust LOWESS Fit to Marine Sr-Isotope Curve for 0 to 206 Ma, with Look-up table for Derivation of Numeric Age. *Journal of Geology 105*, 441-456.

Howarth, R. J., McArthur, J. M., 2004. Strontium Isotope Stratigraphy. In: F.M. Gradstein and J.G. Ogg (eds.), A Geological Time Scale, with Look-up Table Version 4: 08/04. Cambridge University Press, Cambridge, U.K., 96–105.

Jansen, E. and Sjøholm, J., 1991. Reconstruction of glaciation over the past 6 Myr from ice- borne deposits in the Norwegian Sea. *Nature 349*, 600-603.

Kellogg, T. B., 1977. Paleoclimatology and Paleo-oceanography of the Norwegian and Greenland Seas: The last 450,000 years. *Marine Micropalaeontology 2*, 235-249.

King, C., 1989. Cenozoic of the North Sea. In: Jenkins, D.G. and Murray, J.W. (eds.), Stratigraphical Atlas of Fossils Foraminifera, 418-489. Ellis Horwood Ltd., Chichester.

Müller, C. and Spiegler, D., 1993. Revision of the late/middle Miocene boundary on the Voering Plateau (ODP Leg 104). *Newsletter on Stratigraphy, 28 (2/3),* 171-178.

Norwegian Petroleum Directorate web page. Available from the internet: http://www.npd.no/en/.

NPD factpages. Available from the internet: http://factpages.npd.no/factpages/Default.aspx?culture=no.

Olesen, O., Gellin, J., Gernigon, L., Kihle, O., Koziel, J., Lauritsen, T., Mogaard, J.O., Myklebust, R., Skilbrei, J.R. and Usov, S., 2010. Magnetic anomaly map, Norway and adjacent areas, scale 1:3 millions. Geological Surway of Norway.

Olivarius, M., 2009. Provenance and facies of Miocene sand succession in western Denmark based on bulk geochemistry, heavy minerals and zircon dating. Master's thesis. Department of Geography and Geology, University of Copenhagen.

Ottesen, D., Rise, L., Sletten Andersen, E., Bugge, T. and Eidvin, T., 2009: Geological evolution of the Norwegian continental shelf between 61ºN and 68ºN during the last 3 million years. *Norwegian Journal of Geology, Vol. 89*, 251-265. Available from the internet: http://www.geologi.no/data/f/0/20/14/1_2401_0/NGT_4_09_Ottesen_scr.pdf.

Skarbø, O. and Verdenius, J. G., 1986. Catalogue of microfossils, Quaternary - Tertiary. *IKU Publication 113*, 19 pp, 187 pl.

Spiegler, D. and Jansen, E., 1989. Planktonic Foraminifer Biostratigraphy of Norwegian Sea Sediments: ODP Leg 104. In: Eldholm, O., Thiede, J., Tayler, E., *et al*. (eds.), Proceedings of the Ocean Drilling Program, Scientific Results 104: College Station, TX (Ocean Drilling Program), 681-696.

Spiegler, D. and Müller, C., 1992. Correlation of *Bolboforma* zonation and nannoplankton stratigraphy in the Neogene of the North Atlantic: DSDP sites 12-116, 49-408, 81-555 and 94-608. *Marine Micropaleontology 20*, 45-58.

Stratlab, 1988: Mid - Norway offshore Biozonation, Tertiary to Triassic. Fossil-atlas, bind 1 - 4, Stratlab a.s. (non-proprietary report).

Weaver, P.P.E. and Clement, B.M., 1987. Magnetobiostratigraphy of planktonic foraminiferal datums: Deep Sea Drilling Project Leg 94, North Atlantic. *In* Ruddiman, W. F., Kidd, R. B., Thomas, E., et al. (eds.): *Initial Reports of the Deep Sea Drilling Project 94*, 815-829.

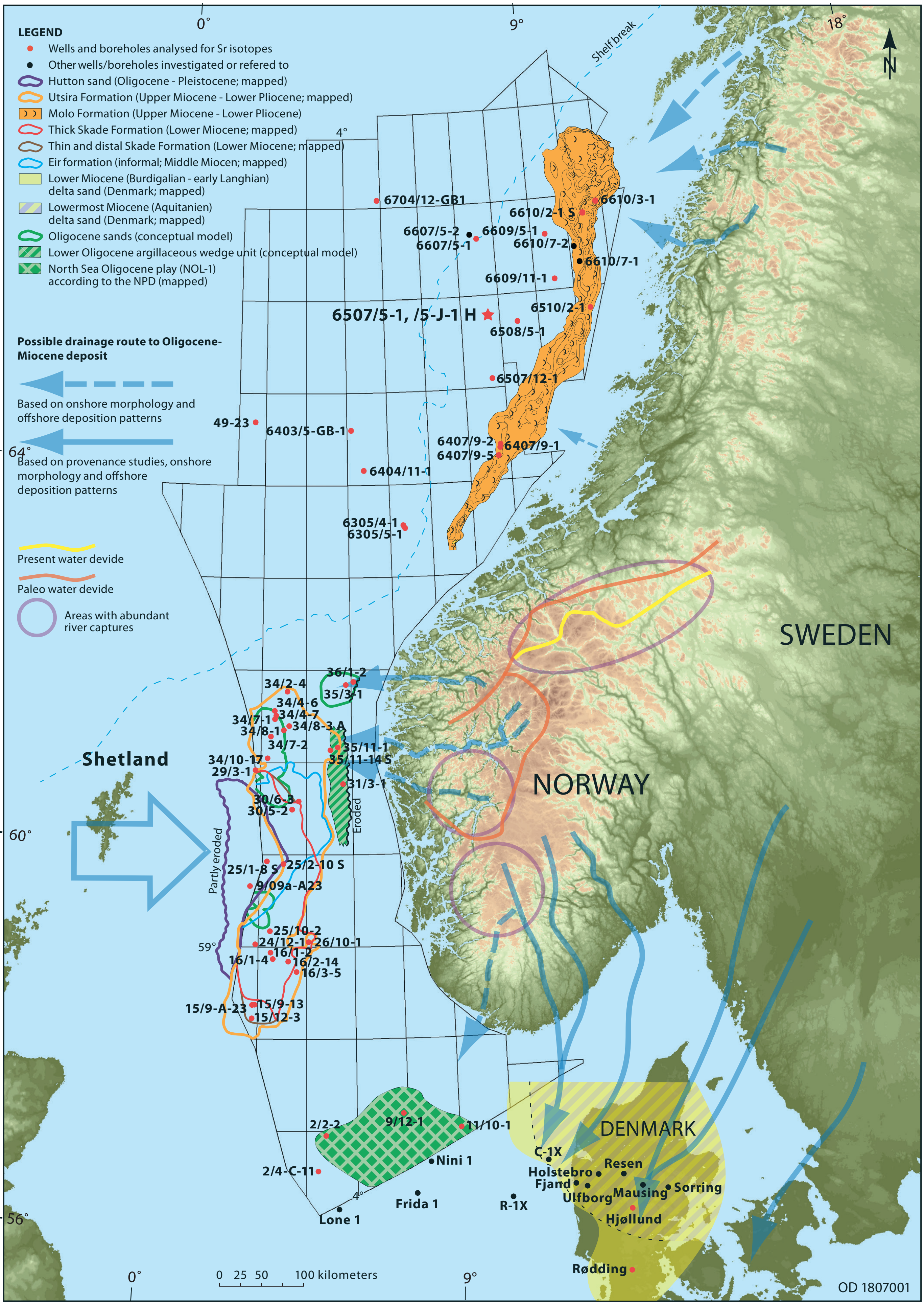
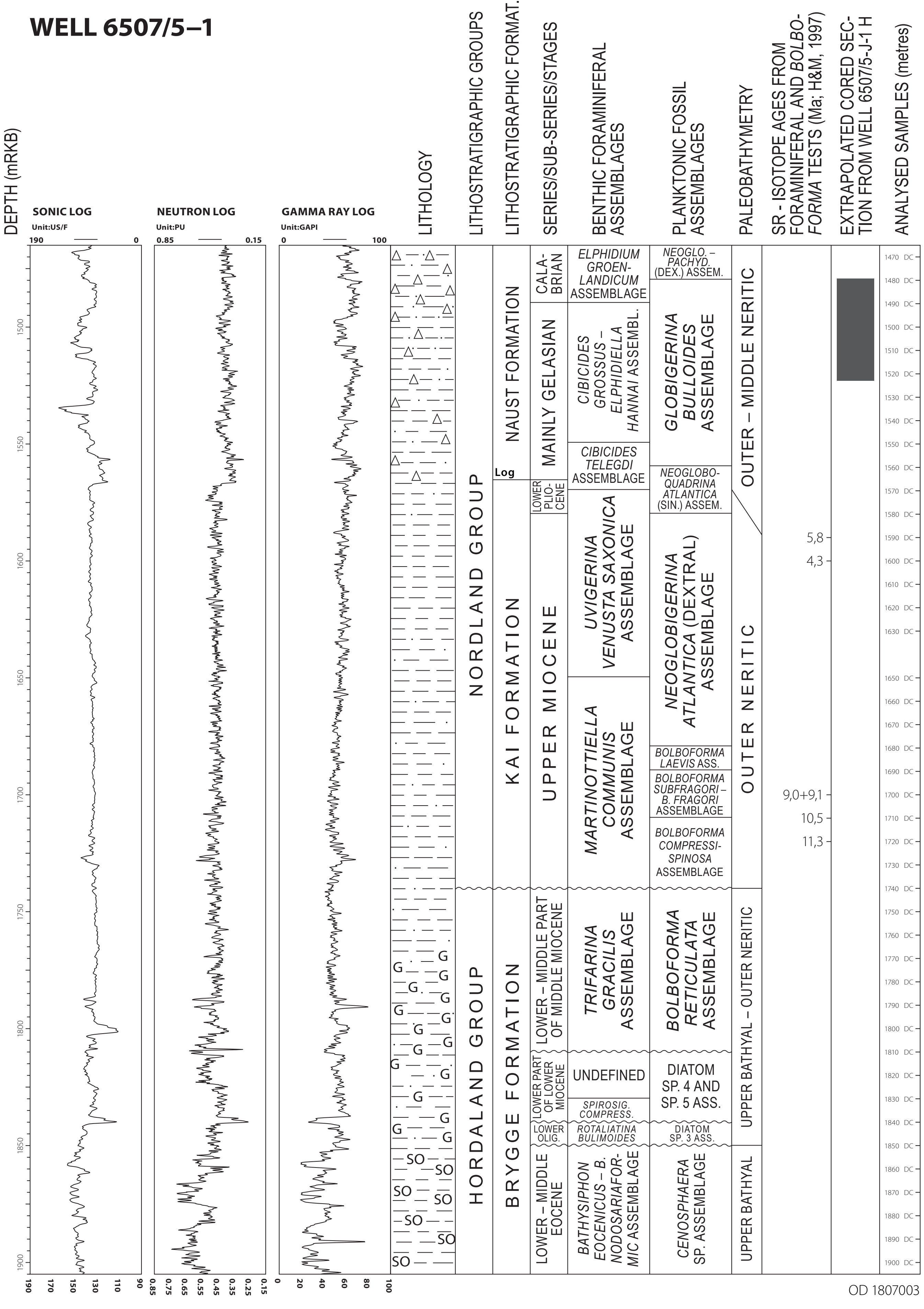


Fig. 1: The location of well 6507/5-1 and 6507/5-J-1-H shown on a map showing wells and boreholes containing Oligocene to Upper Pliocene - Pleistocene deposits (modified after Eidvin et al., 2013, 2014). The extent of the Utsira, Eir and Skade formations in the North Sea is according to NPD factpages. 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 6507/5–1

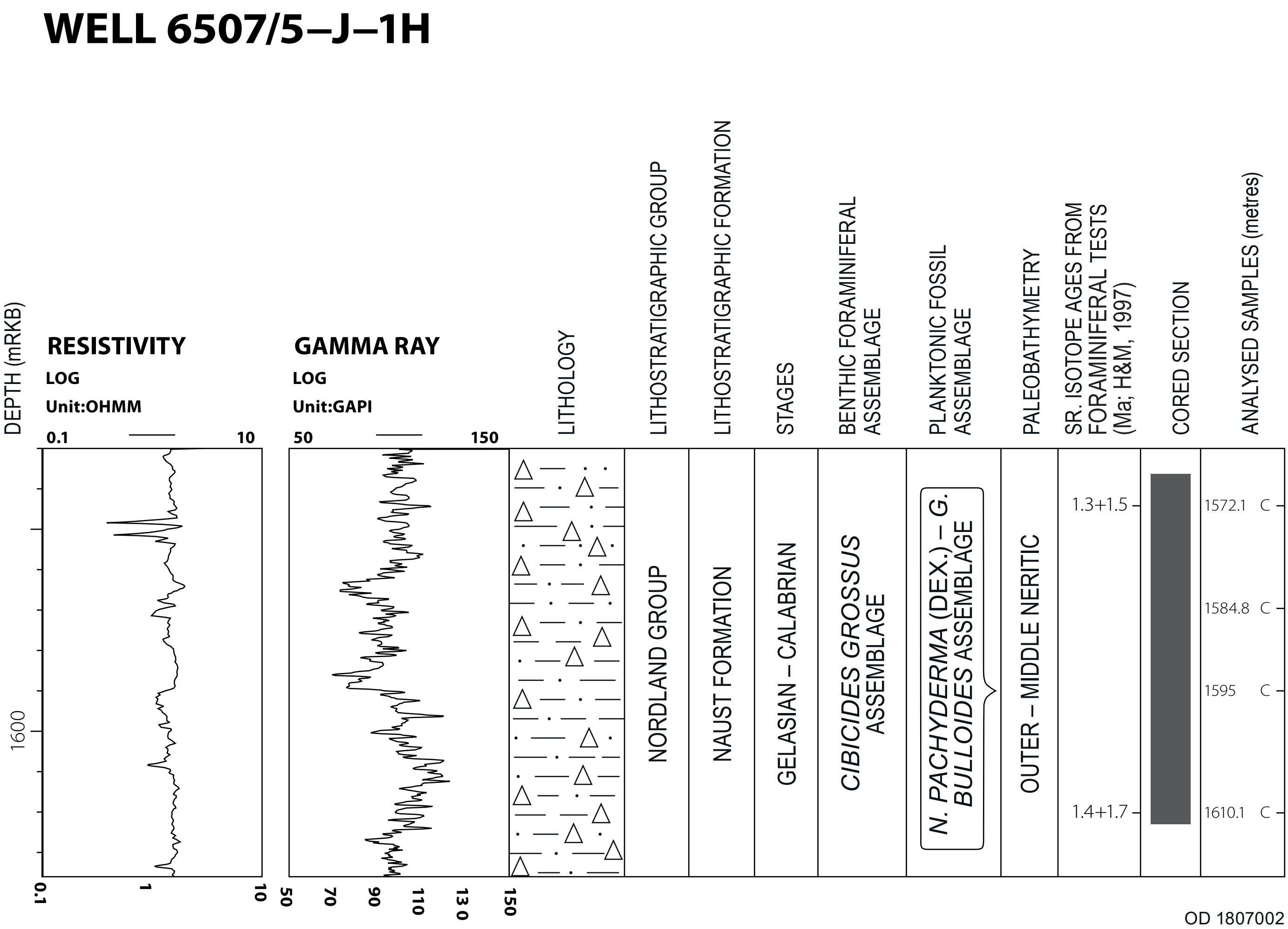


Sea floor = 345 metres below rig floor (mRKB)
DC = Ditch cuttings

SO = Abundant siliceous ooze
G = Abundant glauconite
△ = Ice rafted pebbles

US/F = Microseconds per foot
PU = Porosity units
gAPI = American Petroleum Institute gamma ray units

Fig. 2: Well summery figure including sonic, neutron and gamma ray logs, lithostratigraphic units, series/subseries/stages, benthic foraminiferal assemblages, planktonic fossil assemblages, paleobathymetry, strontium isotope ages and analysed samples for the investigated succession in well 6507/5-1 (Lower-Middle Eocene to Calabrian).



Sea floor = 348 metres below rig floor (mRKB)
C = Core
gAPI = American Petroleum Institute gamma ray units
△ = Ice rafted pebbles

Fig. 3: Well summery figure including resistivity and gamma ray logs, lithostratigraphic units, stages, benthic foraminiferal assemblages, planktonic foraminiferal assemblages, paleobathymetry, strontium isotope ages, cored section and analysed samples for the investigated section in well 6507/5-J-1 H (Gelasian to Calabrian). Please note that the inclination of the well is 32º at 1570 m and 32.5º at 1613 m.