Biostratigraphy and Strontium Isotope Stratigraphy (SIS) of Lower Oligocene to Pleistocene in Well 9/09a-A 23 (Bruce Field, UK) including Hutton Sand (informal)

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For this investigation, micropalaeontological and Sr-isotope analyses for the interval 960 to 250 m in well 9/09a-A 23 (Bruce Field, UK sector) are obtained from the British Geological Survey (BGS) for the purpose of the research reported here. 30 ditch cutting samples were analysed (Table 1, Figs. 1-3).

Micropalaeontological analyses

Micropalaeontological investigations were based on analyses of planktonic and benthic foraminifera and *Bolboforma*. The fossil assemblages are correlated with the micropalaeontological zonation for Cenozoic sediments of King (1989). Gradstein and Bäckström's (1996) faunal zonation from the North Sea and Haltenbanken is also used. 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 is used as an additional control for the biostratigraphic correlations. The method has best resolution in sediments older than fifteen million years (15 Ma) (Howard and McArthur, 1997). For samples with ages younger than 8 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).

Eighty-eight samples based on mollusc fragments from 29 depths and nine samples based on foraminiferal tests from eight depths were analysed for their Sr isotopic compositions (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).

The stratigraphy of Well 9/09a-A 23 (59°44'37.720''N, 01°40'19.945''E, Figs. 2 and 3), is based on benthic and planktonic foraminifera, *Bolboforma* and Sr isotopes. We have recorded 180 m of Lower Oligocene sediments, 170 m of Upper Oligocene sediments, a 200 m-thick column with Lower Miocene deposits, 80 m of Middle Miocene sediments, 40 m of Upper Miocene-Lower Pliocene deposits, 10 m of Upper Pliocene deposits and 30 m of Pleistocene (*sensu* Berggren *et al*., 1995) deposits. The base of the Lower Oligocene is not investigated and the top of the Pleistocene is not sampled. The units were investigated with 30 ditch-cutting samples at approximately 10 to 50 metre intervals. A large number of the samples are amalgamated over 20 to 30 metres of sediments. For technical reasons, we have chosen to denote the lower level of these intervals in the stratigraphic Figs. 2 and 3. However, the entire intervals are in parentheses. The large intervals between the samples and the lack of wireline logs increased the margins of error for determining boundaries between stratigraphical units. The comparison of British and Norwegian lithostratigraphic units is based on Sr isotopic and biostratigraphic age.

All absolute ages are referred to Berggren *et al*. (1995). The main reason for this is that the Strontium Isotope Stratigraphy (SIS) Look-up table of Howard and McArthur (1997) has been used, and this is based on the time scale of Berggren *et al*. (1995). For the post-Eocene part, this time scale does not deviate to any great extent from the time scale of the International Commission on Stratigraphy (ICS, 2013). The most important difference is that the base Pleistocene has been moved from 1.85 Ma to 2.588 Ma. Please also note that the micropalaeontological zonation of King (1989) and the plantonic 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 micropalaeontological zonation of Gradstein and Bäckström (1996) is based on the time scale of Cande and Kent (1992) in which the absolute ages are identical to those 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). All depths are expressed as metres below the rig floor (m RKB).

Biostratigraphy

Both the benthic foraminiferal assemblages and the planktonic fossil assemblages are quite sparse throughout the investigated succession, especially in the Oligocene strata. Many of the important index fossils, known from the central part of the North Sea Basin, are missing in the 9/09a-A 23 area where mainly shallow marine environments have prevailed throughout the deposition period.

Lower Oligocene (960-780 m), Lark Formation and Hutton Sand (informal, lowermost part), probably equivalent to the Hordaland Group in the Norwegian North Sea (the uppermost part probably correspond to an unit suggested to be called the Ull Formation by Eidvin et al., 2013)

Benthic foraminifera of the *Gyroidina soldanii girardana* assemblage (lower part), together with a number of Sr isotope ages date this unit to the Early Oligocene (Fig. 2). In addition to the nominate species, the benthic foraminiferal assemblages also includes *Rolfina arnei* (one specimen). The benthic foraminiferal assemblage is correlated with Zone NSB 7 of King (1989) from the North Sea.

Upper Oligocene (780-610 m), Hutton Sand (informal), probably equivalent to unnamed sand of the Hordaland in the Norwegian North Sea (suggested to be called the Ull Formation by Eidvin et al., 2013)

Benthic foraminifera of the *Gyroidina soldanii girardana* assemblage (upper part), planktonic foraminifera of the *Globigerina praebulloides* assemblage, together with a number of Sr isotope ages date this unit to the Late Oligocene (Fig. 2). In addition to the nominate species, the benthic foraminiferal assemblage also includes *Turrilina alsatica* (one level) and *Elphidium subnodosum* (throughout). The benthic foraminiferal assemblage is correlated with Zone NSB 8 of King (1989, North Sea).

Lower Miocene (610-410 m), Hutton Sand (informal), probably equivalent to the Skade Formation in the Norwegian North Sea

Benthic foraminifera of the *Elphidium subnodosum* assemblage and the *Astigerina guerichi staeschei* assemblage (lower, main part), planktonic foraminifera *of Globigerina angustiumbilicata-Globigerina praebulloides* assemblage, together with a large number of Sr isotope ages give an Early Miocene age to this unit (Fig. 3). In addition to the nominate species, the benthic foraminiferal assemblage also include *Elphidium inflatum* (upper part), *Cibicides dutemplei*, *Ehrenbergina serrata* and *Elphidium antoninum*. The benthic foraminiferal assemblages are correlated with Zone NSB 9 and NSB 10 of King (1989, North Sea).

Middle Miocene (410-330 m), Hutton Sand (informal), probably equivalent to the lower part of the Nordland Group in the Norwegian North Sea (suggested to be called the Eir Formation by Eidvin et al., 2013)

Benthic foraminifera of the *Astigerina guerichi staeschei* assemblage (uppermost part) and *Florilus bouanus* (lower main part), *Bolboforma* of the *Bolboforma badenensis* assemblage, together with most of the Sr isotope ages indicate a Middle

Miocene age to this unit (Fig. 3). In addition to the nominate species the benthic foraminiferal assemblages also include *Bulimina elongata* and *Globocassidulina subglobosa*. In the uppermost sample (330 m) the *Bolboforma* assemblage also contains *Bolboforma reticulata, Bolboforma subfragori, Bolboforma clodiusi and Bolboforma laevis*. Spiegler and Müller (1992) and Müller and Spiegler (1993) described a *B. fragori/B. subfragori* Zone from deposits with an age of 11.7-10.3 Ma from the North Atlantic and the Vøring Plateau (Norwegian Sea), and a *B. badenensis* Zone and a *B. reticulata* Zone in deposits with an age of slightly older than 14 to 11.7 Ma. *B. clodiusi* and *B. laevis* have ranges including both time intervals. We suggest that *B. badenensis* and *B. reticulata* are *in situ* and that *B. subfragori* is caved. However, another interpretation could be that *B. subfragori* is *in situ* and that *B. badenensis* and *B. reticulata* are re-worked since the Sr data from the sample at 330 m show Late Miocene and Early Pliocene ages. The benthic foraminiferal faunas are correlated with Zone NSB 11, NSB 12 and lowermost part of Zone NSB 13 of King (1989, North Sea).

Upper Miocene-Lower Pliocene (330-290 m), Hutton Sand (informal), probably equivalent to the Utsira Formation in the Norwegian North Sea

The dating of this unit is mainly based on the Sr isotope ages from the interval 310-290 m (Fig. 2). The *Florilus bouanus* assemblage which with certainty reaches as high as 310 m, but may reach as high as 290 m since the sample denoted 310 m represents amalgamated sediments over 310-290 m (Fig. 2). According to King (1989) the last appearance datum (LAD) of *F. bouanus* is within the Early Pliocene. The planktonic foraminiferal assemblage nominate *Globigerina bulloides* is known from the Upper Miocene to the Pleistocene on the Vøring Plateau (Norwegian Sea, Spiegler and Jansen 1989).

Upper Pliocene (290-280 m), undifferentiated, probably equivalent to the Nordland Group in the Norwegian North Sea

Benthic foraminifera of the *Elphidium hannai* assemblage and planktonic foraminifera of the *Globigerina bulloides* assemblage (uppermost part) give a Late Pliocene age (on the time scale of Berggren *et al*., 1995) for this unit (Fig. 2). The benthic foraminiferal fauna is correlated with Subzone NSB 15a (1989, North Sea) and Zone NSR 12 of Gradstein and Bäckström (1996, North Sea and Haltenbanken area). A *G. bulloides* Zone is described from the North Atlantic (DSDP Leg 94) in Pliocene sediments as young as 2.2 Ma (Weaver and Clement, 1986). On the Vøring Plateau, *G. bulloides* is common in Pliocene deposits older than 2.4 Ma (Spiegler and Jansen, 1989). *G. bulloides* is also common in the warmest interglacials of the last 0.5 Ma in the North Atlantic (Kellogg, 1977). This unit may be of Pleistocene age *sensu* ICS (2013).

Pleistocene (280-250 m), undifferentiated, probably equivalent to the Nordland Group in the Norwegian North Sea

The benthic foraminifera of the *Elphidium excavatum-Haynesina orbiculare* assemblage are characteristic Pliocene-Pleistocene taxa. All the recorded taxa are extant. Knudsen and Asbjörndóttir (1991) have described an *Elphidium excavatum-Haynesina orbiculare* Zone (Jo 6) from the Josephine boring (30/13-2x) in the easternmost part of the British sector. Correlation based on benthic foraminifera between 30/13-2x and the BGS borehole BH 81/34 indicates that Zone Jo 6 is slightly older than the Brunhes/Matuyana boundary (Knudsen and Asbjörndóttir, 1991). BH 81/34 has been cored, and the cores have been magneto-stratigraphically investigated (Stoker *et al*., 1983).

A *Neogloboquadrina pachyderma* (sinistral) Zone is described by Weaver and Clement (1986) from the North Atlantic and by Spiegler and Jansen (1989) from the Vøring Plateau (Norwegian Sea) in sediments younger than approximately 1.8 Ma. At these open ocean sites, an encrusted variety of the sinistrally coiled *N. pachyderma* dominates over an unencrusted form.

Sr isotope stratigraphy

Nineteen analyses of mollusc fragments and two analyses of foraminiferal tests have been carried out for the lower part (960-780 m) of the unit which is of a general Oligocene age inferred from foraminiferal correlations. Nine of these samples obtained 87Sr/86Sr ratios that gave spurious ages indicating that the tests were caved. In the upper part of the interval (960-780 m), the probably *in situ* samples gave ages from 29.0 to 25.1 Ma. The samples in the lower part of the interval gave ages from 31.1 to 30.4 Ma (Table 1, Fig. 2). The Lower/Upper Oligocene boundary, on the timescale of Berggren *et al*. (1995), is at 28.4 Ma.

Fifteen analyses of mollusc fragments and three analyses of foraminiferal tests have been carried out for the upper part (780-610 m) of the Oligocene unit. Except for one obvious caved sample, the analyses gave ages from 28.1 to 24.3 Ma (Table 1, Fig. 2). The Oligocene/Miocene boundary is at 23.3 Ma.

Twenty-eight analyses of mollusc fragments and eight analyses of foraminiferal tests were taken from the interval 610-410 m giving an Early Miocene age by the foraminiferal correlations. Except for four obvious caved samples, samples in the upper part gave ages from 17.1 to 16.4 Ma and samples in the lower part gave ages from 23.6 to 20.4 Ma (Table 1, Fig. 3). The Lower/Middle Miocene boundary is at 16.4 Ma.

In the interval given a Middle Miocene age by fossil correlations, twelve Sr isotope analyses based on mollusc fragments and three analyses based on foraminiferal

tests have been carried out. It seems to that nearly half of these (seven samples) are based on caved materials. As mentioned above, all the analyses from the uppermost level (330 m) show Late Miocene and Early Pliocene ages. We choose to give weight to the biostratigrapical data for this level, but the top of the Middle Miocene is uncertain. The samples interpreted to be *in situ* gave ages from 14.6 to 13.0 Ma. The Middle/Upper Miocene boundary, on the timescale of Berggren *et al*. (1995), is at 11.2 Ma.

Three analyses based on mollusc fragments were carried out on the sample that represent amalgamated sediments over the interval 310-290 m. The foraminiferal correlations indicates a Late Miocene to Early Pliocene age for this part. The samples gave Sr isotope ages of 10.1, 10.0, 5.0 and 4.1 Ma (Late Miocene and Early Pliocene). This may indicate that the unit is a condensed sequence, and that the fragments giving Early Pliocene ages are not caved material since the sample immediately above (280 m) is of Late Pliocene age.

9/09a - A 23 (UK)

Litho. Unit	Sample (DC)	Corrected $^{87/86}Sr$	2S error	Age (Ma)	Comments	Analysed fossils
Hutton Sand	290-310 m	0.709054	0.000009	4.10		One mollusc fragment
Hutton Sand	290-310 m	0.709038	0.000008	4.97		One mollusc fragment
Hutton Sand	290-310 m	0.708890	0.000009	9.96		One mollusc fragment
Hutton Sand	290-310 m	0.708887	0.000009	10.08		One mollusc fragment
Hutton Sand	330 m	0.709058	0.000008	3.79	Caved	One mollusc fragment
Hutton Sand	330 m	0.709052	0.000009	4.21	Caved	One mollusc fragment
Hutton Sand	330 m	0.709046	0.000009	4.64	Caved	One mollusc fragment
Hutton Sand	330 m	0.709002	0.000009	5.80	Caved	One mollusc fragment
Hutton Sand	330 m	0.708902	0.000009	9.47	Caved	34 tests of *P. bulloides*
Hutton Sand	330 m	0.709058	0.000009	10.00	Caved	One mollusc fragment
Hutton Sand	330 m	0.708884	0.000009	10.19	Caved	One mollusc fragment
Hutton Sand	350 m	0.709079	0.000009	2.21	Caved	One mollusc fragment
Hutton Sand	350 m	0.708816	0.000009	13.03		One mollusc fragment
Hutton Sand	350 m	0.708802	0.000008	13.88		One mollusc fragment
Hutton Sand	370 m	0.708807	0.000009	13.45		One mollusc fragment
Hutton Sand	370 m	0.708806	0.000009	13.52		One mollusc fragment
Hutton Sand	370 m	0.708792	0.000009	14.56		One mollusc fragment
Hutton Sand	390 m	0.709155	0.000009	0.587	Caved	One mollusc fragment
Hutton Sand	390 m	0.709074	0.000009	2.37	Caved	One mollusc fragment

Hutton Sand	390 m	0.708829	0.000008	12.38		One mollusc fragment
Hutton Sand	390-410 m	0.708791	0.000010	14.61		16 tests of *F. bouanus*
Hutton Sand	410 m	0.709162	0.000008	0.427	Caved	One mollusc fragment
Hutton Sand	410 m	0.709035	0.000008	5.06	Caved	One mollusc fragment
Hutton Sand	410 m	0.708681	0.000009	17.05		One mollusc fragment
Hutton Sand	430 m	0.708725	0.000009	16.39		One mollusc fragment
Hutton Sand	430 m	0.708718	0.000007	16.51		51 tests of *F. bouanus*
Hutton Sand	430 m	0.708678	0.000009	17.08		One mollusc fragment
Hutton Sand	430 m	0.708674	0.000008	17.13		One mollusc fragment
Hutton Sand	430-460 m	0.708581	0.000009	18.17		One mollusc fragment
Hutton Sand	430-460 m	0.708577	0.000009	18.22		One mollusc fragment
Hutton Sand	430-460 m	0.708568	0.000008	18.33		52 tests of *A. guerichi staeschei*
Hutton Sand	460 m	0.708646	0.000009	17.45		One mollusc fragment
Hutton Sand	460 m	0.708545	0.000009	18.64		One mollusc fragment
Hutton Sand	460 m	0.708538	0.000008	18.73		36 tests of *F. bouanus*
Hutton Sand	480-500 m	0.708522	0.000010	18.96		One mollusc fragment
Hutton Sand	480-500 m	0.708520	0.000008	18.99		42 tests of *F. bouanus*
Hutton Sand	480-500 m	0.708488	0.000008	19.50		One mollusc fragment
Hutton Sand	480-500 m	0.708475	0.000008	19.74		30 tests of *A. guerichi staeschei*
Hutton Sand	480-500 m	0.708437	0.000008	20.33		One mollusc fragment
Hutton Sand	500-520 m	0.708522	0.000008	18.96		One mollusc fragment
Hutton Sand	500-520 m	0.708512	0.000008	19.11		One mollusc fragment
Hutton Sand	500-520 m	0.708493	0.000008	19.42		One mollusc fragment
Hutton Sand	500-520 m	0.708452	0.000008	20.12		21 tests of *A. guerichi staeschei*
Hutton Sand	500-520 m	0.708442	0.000009	20.26		One mollusc fragment
Hutton Sand	520-540 m	0.708793	0.000007	14.51	Caved	One mollusc fragment
Hutton Sand	520-540 m	0.708629	0.000008	17.63	Caved	One mollusc fragment
Hutton Sand	520-540 m	0.708571	0.000009	18.29		One mollusc fragment
Hutton Sand	520-540 m	0.708559	0.000009	18.45		One mollusc fragment
Hutton Sand	540-560 m	0.708444	0.000009	20.23		One mollusc fragment
Hutton Sand	540-560 m	0.708370	0.000008	21.46		One mollusc fragment
Hutton Sand	540-560 m	0.708355	0.000009	21.80		One mollusc fragment

Hutton Sand	560-580 m	0.708324	0.000009	22.60		One mollusc fragment
Hutton Sand	560-580 m	0.708285	0.000009	23.50		One mollusc fragment
Hutton Sand	560-580 m	0.708282	0.000008	23.56		One mollusc fragment
Hutton Sand	580-610 m	0.708436	0.000007	20.35		One mollusc fragment
Hutton Sand	580-610 m	0.708319	0.000009	22.74		One mollusc fragment
Hutton Sand	580-610 m	0.708299	0.000009	23.21		One mollusc fragment
Hutton Sand	640 m	0.708200	0.000009	24.87		One mollusc fragment
Hutton Sand	640 m	0.708197	0.000009	24.92		One mollusc fragment
Hutton Sand	640 m	0.708177	0.000009	25.26		One mollusc fragment
Hutton Sand	660 m	0.708240	0.000008	24.28		One mollusc fragment
Hutton Sand	660 m	0.708229	0.000009	24.45		One mollusc fragment
Hutton Sand	660 m	0.708225	0.000008	24.51		One mollusc fragment
Hutton Sand	660 m	0.708077	0.000009	27.64		23 tests of *E. subnodosum* and one test of *G. soldanii girardana*
Hutton Sand	680 m	0.708185	0.000009	25.11		One mollusc fragment
Hutton Sand	680 m	0.708178	0.000009	25.24		One mollusc fragment
Hutton Sand	680 m	0.708175	0.000009	25.30		One mollusc fragment
Hutton Sand	680 m	0.708062	0.000008	28.08		26 tests of *E. subnodosum*
Hutton Sand	700 m	0.708340	0.000009	22.14	Caved	One mollusc fragment
Hutton Sand	700 m	0.708144	0.000009	25.91		One mollusc fragment
Hutton Sand	700 m	0.708101	0.000007	26.93		One mollusc fragment
Hutton Sand	730 m	0.708174	0.000009	25.32		One mollusc fragment
Hutton Sand	730 m	0.708158	0.000009	25.63		One mollusc fragment
Hutton Sand	730 m	0.708110	0.000008	26.67		One mollusc fragment
Hutton Sand	780 m	0.708360	0.000008	21.68	Caved	One mollusc fragment
Hutton Sand	780 m	0.708184	0.000009	25.13		One mollusc fragment
Hutton Sand	780 m	0.708102	0.000009	26.90		One mollusc fragment
Hutton Sand	780 m	0.708087	0.000007	27.35		One mollusc fragment
Hutton Sand	780 m	0.708078	0.000009	27.61		11 tests of *G. soldanii girardana*
Hutton Sand	780 m	0.708022	0.000008	29.04		34 tests of *A. guerichi staeschei*
Hutton Sand	810 m	0.708313	0.000009	22.88	Caved	One mollusc fragment
Hutton Sand	810 m	0.708182	0.000009	25.17		One mollusc fragment
Hutton Sand	810 m	0.708196	0.000008	24.94		One mollusc fragment

Hutton Sand	810 m	0.708128	0.000009	26.25		One mollusc fragment
Hutton Sand	840 m	0.708490	0.000009	19.47	Caved	One mollusc fragment
Lark Fm	840 m	0.708334	0.000009	22.30	Caved	One mollusc fragment
Lark Fm	840 m	0.707984	0.000009	29.99		One mollusc fragment
Lark Fm	840-860 m	0.709068	0.000009	2.62	Caved	One mollusc fragment
Lark Fm	840-860 m	0.709059	0.000009	3.68	Caved	One mollusc fragment
Lark Fm	840-860 m	0.709037	0.000009	5.00	Caved	One mollusc fragment
Lark Fm	840-860 m	0.708314	0.000008	22.86	Caved	One mollusc fragment
Lark Fm	840-860 m	0.708026	0.000009	28.94		One mollusc fragment
Lark Fm	860-900 m	0.708604	0.000008	17.91	Caved	One mollusc fragment
Lark Fm	860-900 m	0.708443	0.000008	20.25	Caved	One mollusc fragment
Lark Fm	860-900 m	0.708017	0.000009	29.17		One mollusc fragment
Lark Fm	900-930 m	0.708319	0.000009	22.74	Caved	One mollusc fragment
Lark Fm	900-930 m	0.708009	0.000008	29.37		One mollusc fragment
Lark Fm	930-960 m	0.707968	0.000009	30.40		One mollusc fragment
Lark Fm	930-960 m	0.707946	0.000008	31.01		One mollusc fragment
Lark Fm	930-960 m	0.707941	0.000009	31.14		One mollusc fragment

Table 1: Strontium isotope data from well 09a - A 23 (UK; all samples are analysed at the University of Bergen). All Sr ratios were corrected to NIST 987 = 0.710248. Numerical ages derived from the SIS Look-up Table of Howard and McArthur (1997; based on the time scale of Berggren *et al*., 1995). NIST = National Institute for Standard and Technology. DC = ditch cuttings.

Lithology

Since no wireline logs were available, the lithological descriptions were based on visual examination of the samples prior to treatment, and of the washed, sieved and fractionated material after preparation of the microfossils.

Lower Oligocene (main part, 960 to approximately 820 m, Lark Formation), probably equivalent to the Hordaland Group in the Norwegian North Sea

The samples in this unit contain mostly fine grained material (mudstone) with some silt and sand. Some of the sand may be caved material from the overlying Hutton Sand (Fig. 2).

Lower Oligocene (uppermost part) to Upper Miocene-Lower Pliocene, approximately 820-290 m, Hutton Sand, probably equivalent to an unnamed sand of the Hordaland Group (suggested to be called the Ull Formation by Eidvin et al., 2013), the Skade Formation, the lower part of the Nordland Group (suggested to be called Eir Formation by Eidvin et al., 2013) and the Utsira Formation in the Norwegian North Sea

Coarse- to fine-grained, mainly quartzose sand, dominate throughout this succession. Glauconitic sand is common in the lowermost part. Proportions of mollusc fragments and lignite coal vary from very common to sparse throughout (Figs. 2 and 3).

Upper Pliocene to Pleistocene, 290 to 250 m (undifferentiated), probably equivalent to the Nordland Group in the Norwegian North Sea

The samples in this unit contain a clay-rich diamicton with some sand, silt and minor pebbles (Fig. 3).

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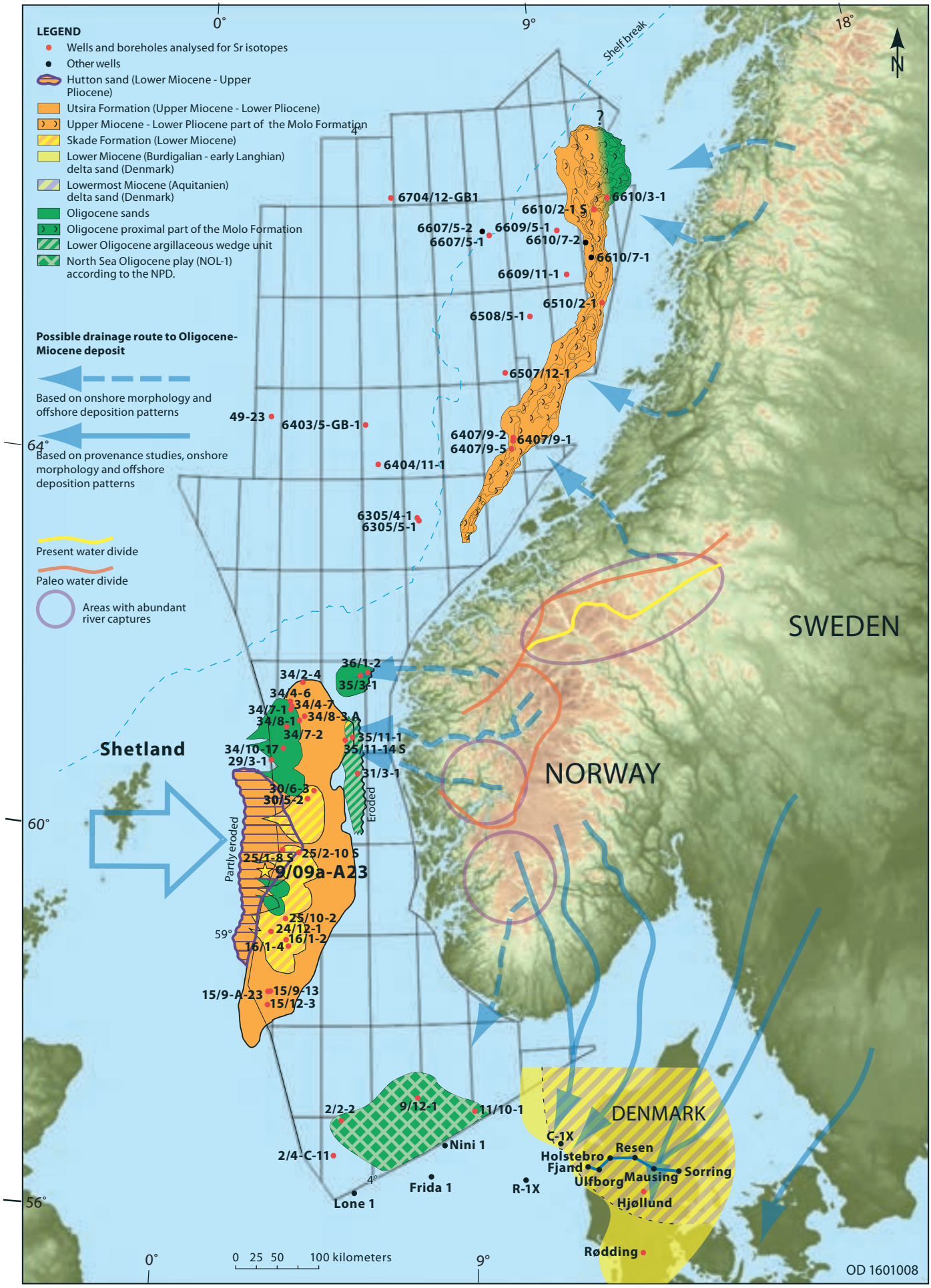
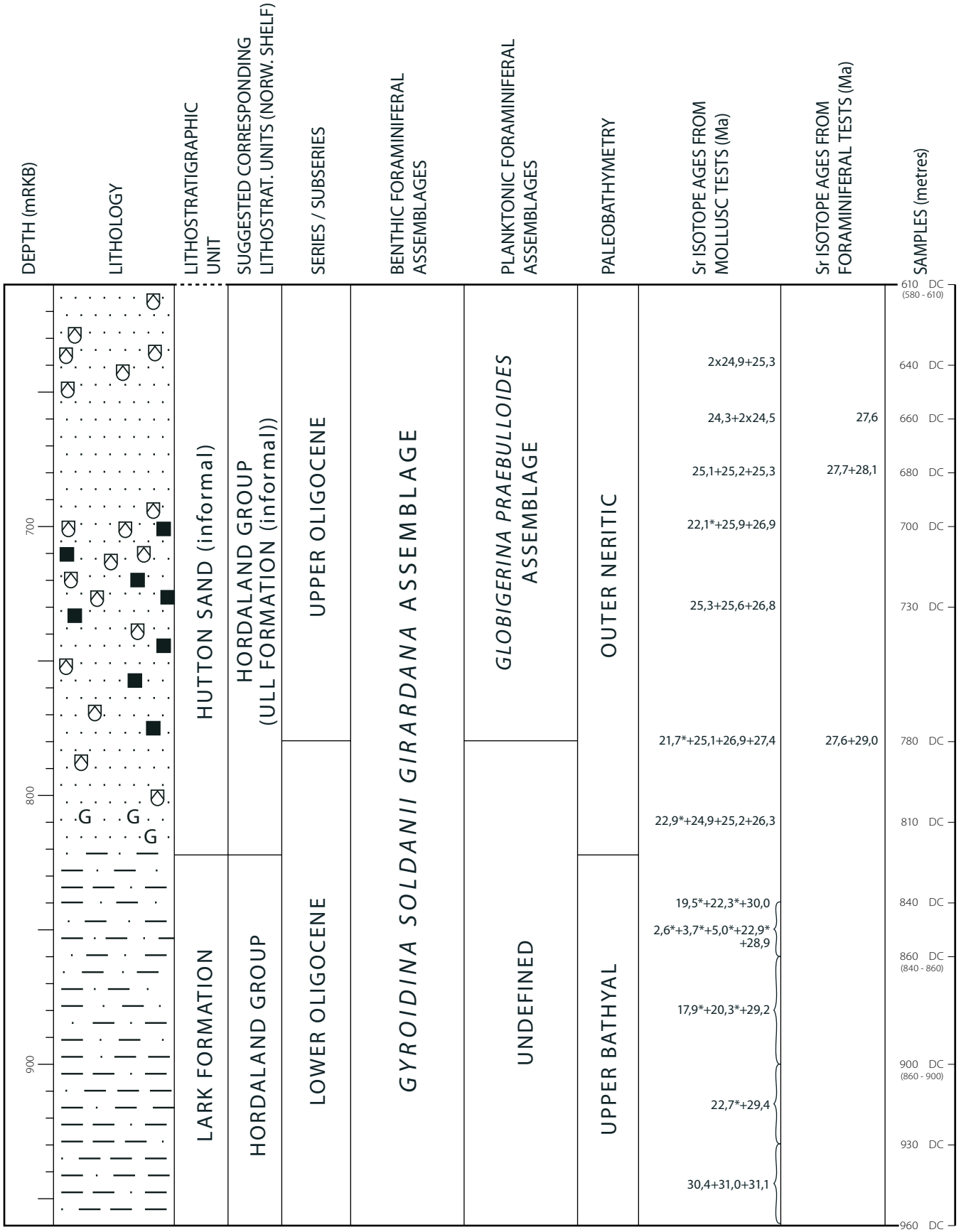


Fig. 1: The location of well 9/09a-A 23 (Bruce Field, UK sector) shown on a map showing wells and boreholes containing Oligocene to Lower Pliocene deposits (modified after Eidvin *et al.*, 2013 and Eidvin and Riis, in prep.). The extent of the Oligocene sands and wedge unit and the Utsira and Skade formations is according to Rundberg and Eidvin (2005). The extent of the Molo Formation is after Bullimore *et al.* (2005), Eidvin *et al.* (2007) and Grøsfjeld *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 9/09a-A 23 (UK)

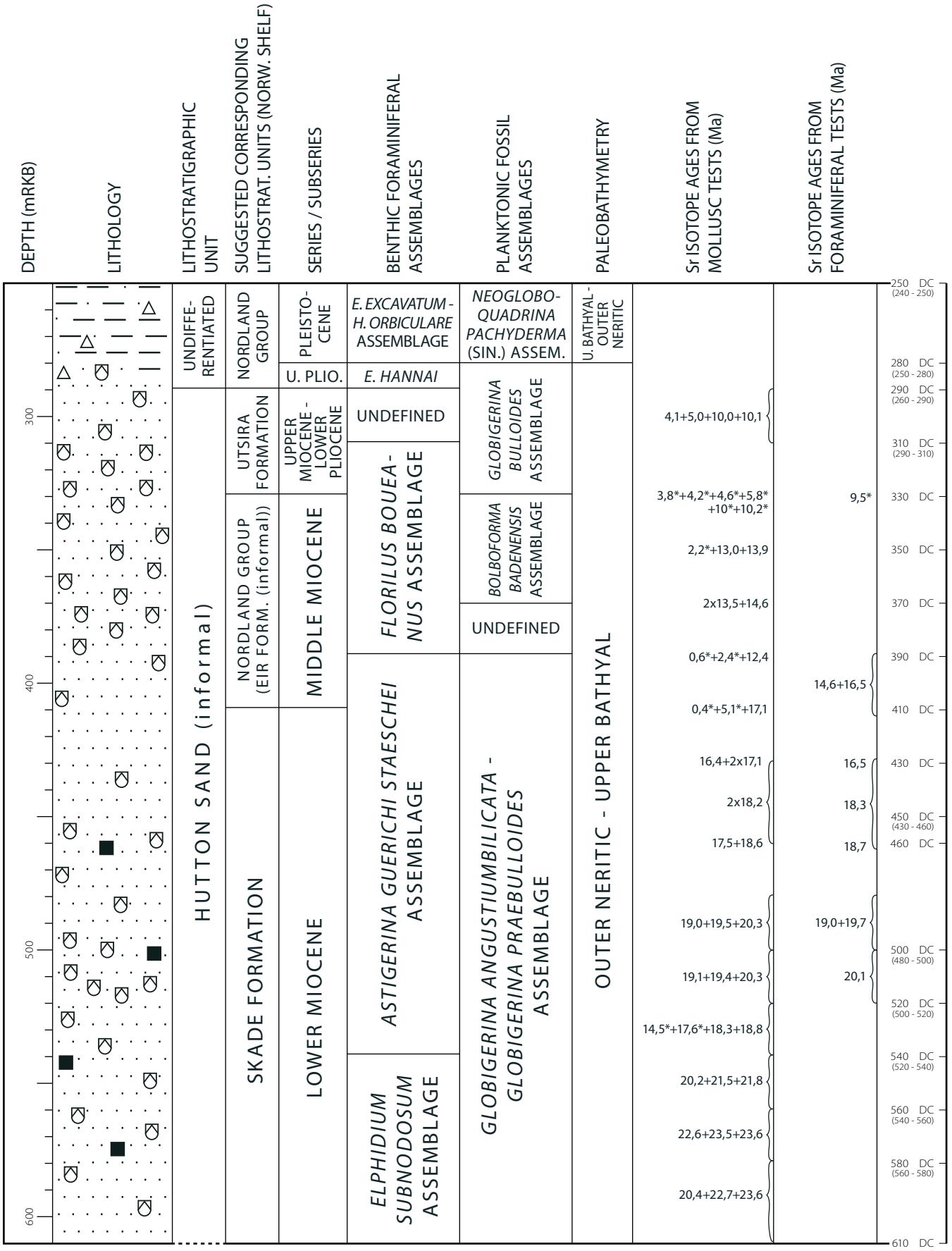


Sea floor = 173 metres below rig floor
DC = Ditch cuttings
* = Caved
■ = Lignite coal
⌀ = Abundant molluscs and mollusc fragments
G = Abundant glauconite

OD 1410003

Fig. 2: Well summery figure including lithology, lithostratigraphic units, series/subseries, benthic foraminiferal assemblages, planktonic foraminiferal assemblages, paleobathymetry, strontium isotope ages and analysed samples for the lower part of the investigated sequence in well 9/09a-A 23 (UK; Lower to Upper Oligocene).

WELL 9/09a-A 23 (UK; continued)



Sea floor = 173 meters below rig floor
DC = Ditch cuttings
* =Caved
■ = Lignite coal
◯ = Abundant molluscs and mollusc fragments
△ = Ice rafted pebbles

OD 1410004

Fig. 3: Well summery figure including lithology, lithostratigraphic units, series/subseries, benthic foraminiferal assemblages, planktonic fossil assemblages, paleobathymetry, strontium isotope ages and analysed samples for the upper part of the investigated sequence in well 9/09a-A 23 (UK; Lower Miocene to Pleistocene).