Biostratigraphic investigation of well 35/2-1

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Abstract

Microfossil stratigraphical analyses were carried out on ditch cutting samples in well 35/2-1 (61º53'26.68"N, 03º20'34.36"E) from 546 to 711 m below the drill table. No conventional cores were drilled in this well. Foraminiferal assemblages indicate an undifferentiated Pleistocene age above the upper regional unconformity (URU) at 621 m. Below the URU, the sediments are Late Pliocene in age.

Material and methods

Well 35/2-1 (61º53'26.68"N, 03º20'34.36"E) was sampled from 546 to 711 m (RKB) with ditch cutting samples with approximately three metre intervals. In this investigation we have analysed samples with approximately ten metre intervals, except just above and below the Upper Pliocene/Pleistocene boundary where three metre intervals were used.

Between 50 to 100 g of material were used for the analyses. The fossil identification was performed in the 106-500 µm sediment fraction. In some cases the fraction larger than 500 µm and the fraction less than 106 µm were also studied. Approximately 300 foraminiferal tests were picked out from the 106-500 µm fraction. In order to optimise the identification of the foraminiferal assemblages the 106-500 µm fraction was gravity-separated in heavy liquid. However, this operation was hampered by the fact that a large proportion of particles of light material, in the 106-500 µm fraction, was mixed in the drilling mud. In heavy liquid separation, these particles have the same buoyancy as foraminifera. This dilutes the fossil assemblages to the extent that the foraminifera are difficult to retrieve. These particles also hampered the study of the lithology of the dissolved and fractionated sediments.

Correlation

The foraminiferal assemblages are correlated with the Cainozoic micropaleontological zonations for the North Sea of King (1989) and the similar zonation of Gradstein & Bäckström (1996) for the North Sea and Haltenbanken area. The benthic foraminiferal zonation for Neogene deposits in the Netherlands of Doppert (1980) was also used. The planktonic foraminifera were, in addition, correlated with the zonations of planktonic foraminifera in the North Atlantic (DSDP Leg 94) of Weaver & Clement (1986) and on the Vøring Plateau (ODP Leg 104) of Spiegler & Jansen (1989).

Benthic foraminiferal assemblages

NONION LABRADORICUM – ISLANDIELLA NORCROSSI ASSEMBLAGE
Definition: The top of the assemblage extends to the uppermost investigated sample (546 m). The base is marked by the highest/youngest occurrence of consistent occurrence of *Elphidiella hannai.*

Depth range: 546-621 m
Material: Nine ditch cutting samples.
Age: Pleistocene.
Lithostratigraphic units: Nordland Group and Peon sandstone member (informal).
Correlation: Subzone NSB 16x of King (1989) and Zone NSR 13 of Gradstein & Bäckström (1996).
In-place assemblage: This interval contains a rich benthic fauna of mainly calcareous foraminifera in the upper part. In the lower part there are somewhat fewer taxa and the fauna is moderately rich. *Ephidium excavatum, Bulimina marginata* and *Islandiella norcrossi* occur most frequently, and these are common in the upper part. Other characteristic taxa include *Nonion labradoricum, Haynesina orbiculare, Cassidulina teretis* and *Elphidium albiumbilicatum*. In addition characteristic species in the upper part include *Nonion affine, Virgulina loeblichi, Cassidulina reniforme, Bolivina skagerakkensis* and *Bolivina pygmea*, and characteristic species in the lower part include *Cibicides scaldisiensis* and *Ammonia beccarii* (Fig. 1).
Reworked assemblage: A few worn tests of *Cibicides grossus* are recorded sporadically throughout the unit, and a few worn tests of *Elphidiella hannai* are recorded in two samples in the lower part. These taxa are probably reworked from Upper Pliocene deposits (King, 1989). *C. dutemplei* is known from Upper Eocene to Miocene deposits (Kaasschieter, 1961; Skarbø & Verdenius, 1986).
Remarks: Nearly all the benthic foraminifera here regarded as *in situ* are extant species typically associated with Upper Pliocene to Pleistocene deposits on the Norwegian margin. However, *N. labradoricum* appears to be restricted to Pleistocene deposits on the Norwegian shelf, and King (1989) employs this species as the nominate taxa for the Pleistocene Subzone NSB 16x of the northern North Sea.

ELPHIDIELLA HANNAI ASSEMBLAGE
Definition: The top of the assemblage is taken at the highest/youngest consistent occurrence of *E. hannai*. The base of the assemblage is not defined.
Depth range: 621-711 m.
Material: 13 ditch cutting samples.
Age: Late Pliocene.
Lithostratigraphic group: Nordland Group.
Correlation: Subzone NSB 15a of King (1989) and Zone FA of Doppert (1980).
In-place assemblage: This unit contains a rich benthic fauna of mainly calcareous foraminifera. *E. excavatum* is common throughout. Other important species include *E. hannai, N. affine, E. albiumbilicatum, B. marginata, H. orbiculare, Cibicides lobatulus, Cibicides scaldisiensis, Angulogerina fluens, Elphidium groenlandicum* and *Quinqueloculina seminulum*. *C. grossus* is also recorded in a few samples in the upper part, and *Textularia decrescens* (agglutinated), *Cibicidoides pachyderma* and *Loxostomoides lammersi* are recorded in a few samples in the lower part of the unit (Fig. 1).
Reworked assemblage: A few specimens of *Turrilina alsatica* and *Gyroidina soldanii girardana* are recorded in the upper part of the unit. These forms are probably derived from Oligocene deposits (King, 1989).
Remarks: With the exception of *E. hannai, C. grossus, C. pachyderma* and *L. lammersi* all the *in situ* taxa are extant species. According to King (1989) *L. lammersi* is known from Early to Late Pliocene deposits in the North Sea area. *C. pachyderma* is described from Early Miocene to Late Pliocene sediments in the same area. *E. hannai* is known from the Upper Pliocene to the lowermost Pleistocene in the same area (King, 1989) and from the Upper Pliocene in the Netherlands (Doppert, 1980). *C. grossus* is described from Upper Pliocene to lower

Pleistocene sediments in the northern North Sea and from Upper Pliocene in the southern North Sea (King, 1989).

Planktonic foraminiferal assemblages

NEOGLOBOQUADRINA PACHYDERMA (SINISTRAL; ENCRUSTED) ASSEMBLAGE
Definition: The top of the assemblage extends to the uppermost investigated sample (546 m). The base is marked the lowest/oldest occurrence of *N. pachyderma* (sinistral, encrusted).
Depth range: 546-591 m.
Material: Five ditch cutting samples.
Age: Pleistocene.
Lithostratigraphic units: Nordland Group and Peon sandstone member.
Correlation: *Neogloboquadrina pachyderma* (sinistral) Zone of Spiegler & Jansen (1989).
Description: The upper part of this interval contains a moderately rich planktonic foraminiferal fauna, while its lower part contains a sparse planktonic assemblage. *N. pachyderma* (sinistral, encrusted) occurs throughout and is common in the upper part. *Globigerina bulloides* is recorded in one sample in the upper part and in one sample in the lower part. *Neogloboquadrina pachyderma* (sinistral; unencrusted), *Neogloboquadrina pachyderma* (dextral) and *Turborotalia quinqueloba* are recorded in a few samples in the upper part of the unit (Fig. 1).
Remarks: The encrusted variety of the sinistral coiled *N. pachyderma* has its first frequent occurrence at 1.8 Ma in the North Atlantic and the Norwegian Sea (Weaver & Clement, 1986; Spiegler & Jansen, 1989). This variety of *N. pachyderma* (sinistral) occurs only very sporadically in older sediments, but the unencrusted variety also occurs in Pliocene deposits. In the North Atlantic *G. bulloides* is known from deposits older than 2.2 Ma (Weaver & Clements, 1986), and in the warmest interglacials in the last 0.5 Ma (Kellogg, 1977). *T. quinqeloba* is known from the Miocene to the Pleistocene on the Vøring Plateau (Spiegler & Jansen, 1989).

UNDEFINED INTERVAL
Depth range: 591-627 m.
Material: Five ditch cutting samples.
Age: Late Pliocene to Pleistocene (based on benthic foraminiferal evidence).
Lithostratigraphic units: Nordland Group and Peon sandstone member.
Description: This interval is nearly barren of planktonic foraminifera. Just one specimen of *G. bulloides* and one specimen of *Hedbergella* sp. are recorded.
Remarks: *Hedbergella* sp. is reworked from Cretaceous deposits. *G. bulloides* is probably caved or reworked.

NEOGLOBOQUADRINA PACHYDERMA (DEXRAL) ASSEMBLAGE
Definition: The top of the unit is taken at the down hole reappearance of *N. pachyderma* (dextral). The base is marked by the highest/youngest occurrence of *Neogloboquadrina atlantica* (sinistral).
Depth range: 627-684 m.
Material: Seven ditch cutting samples.
Age: Late Pliocene.
Lithostratigraphic unit: Nordland Group.
Correlation: *N. pachderma* (dextral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989) and Subzone NSP 16a of King (1989).

Description: This assemblage is characterized by a quite sparse fauna of planktonic foraminifera. *N. pachyderma* (dextral) and *N. pachyderma* (sinistral; unencrusted) occur throughout. A few specimens of *G. bulloides, T. quinqueloba, Globorotalia inflata, Globigerinita glutinata* and *Heterohelix* sp. are also recorded in some samples (Fig. 1).
Remarks: A latest Pliocene *N. pachyderma* (dextral) Zone is described by King (1989) from the North Sea, by Weaver & Clement (1986) from the North Atlantic and by Spiegler & Jansen (1989) from the Vøring Plateau. On the Vøring Plateau the zone is dated to 1.9-1.8 Ma. The zone is characterized by common *N. pachyderma* (dextral). However, *N. pachyderma* (dextral) is also recorded, in smaller numbers, in Pleistocene sections in these areas, and is quite numerous in the warmest interglacials of the last 0.5 Ma (Kellogg, 1977; Spiegler & Jansen, 1989).

NEOGLOBOQUADRINA ATLANTICA (SINISTRAL) ASSEMBLAGE
Definition: The top of the assemblage is taken at the highest/youngest occurrence of *N. atlantica* (sinistral). The base of the assemblage is undefined.
Depth range: 684-711 m.
Material: Four ditch cutting samples.
Age: Late Pliocene.
Lithostratigraphic unit: Nordland Group.
Correlation: *N. atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).
Description: The assemblage is characterized by a sparse fauna of planktonic foraminifera. Characteristic species include *N. atlantica* (sinistral), *N. pachyderma* (dextral), *N. pachyderma* (sinistral; unencrusted). A few specimens of *G. bulloides*, *T. quinqueloba, G. inflata* and *Neogloboquadrina atlantica* (dextral) are recorded in some samples (Fig. 1).
Remarks: *N. atlantica* (sinistral) is known from the North Atlantic and on the Vøring Plateau in Late Miocene to Late Pliocene sediments. The LAD of this species is in both areas, approximately 2.4 Ma (Weaver & Clement, 1986; Spiegler & Jansen, 1989). *N. atlantica* (dextral) is known to occur in the uppermost Upper Pliocene and in the Upper Miocene on the Vøring Plateau (Spiegler & Jansen, 1992; Müller & Spiegler, 1993). Consequently, the sole specimen recorded here is either caved or reworked from Upper Miocene deposits.

Stratigraphical conclusion for well 35/2-1

Pleistocene (Nordland Group and Peon sandstone member)
The interval 621-546 m is given Pleistocene age based on the occurrence of the benthic foraminifer *N. labradoricum* and in addition the occurrence of the planktonic foraminifer encrusted form of *N. pachyderma* (sinistral; 591-546 m).

Upper Pliocene (Nordland Group)
The interval 711-621 m is given a Late Pliocene age based on the consistent occurrence of the benthic foraminifer *E. hannai*, the consistent occurrence of the planktonic foraminifer *N. pachyderma* (dextral; 684 to 627 m) and the occurrence of *N. atlantica* (sinistral) from 684 m and below. The occurrence of *N. pachyderma* (dextral) indicate a Late Pliocene age as young as approximately 1.8 Ma at 621 m, and the occurrence of *N. atlantica* (sinistral) indicate an age of approximately 2.4 Ma at 684 m.

According to Carstens (2005) Norsk Hydro places the upper regional unconformity (URU) and the top of Upper Pliocene deposits at 607 m. In our investigation we record consistent evidence for Late Pliocene sediments not higher than 621 m. There are sharp log breaks at approximately 618 m indicating sandy deposits above. We suggest that the base of the Peon sandstone member probably is slightly above 618 m. However, it is also possible that the ditch cuttings sampling is not quite correct.

Discussion

According to Carstens (2005) Norsk Hydro proved the Peon gas discovery in well 35/2-1 in a sandy glacimarine depositional system about 165 m below the sea bottom (574 m, RKB). The depositional system is situated directly on the base Pleistocene regional unconformity (URU). The well was drilled in the northern part of the Norwegian Channel and according to Carstens (2005) Norsk Hydro describes a situation where sub glacial rivers deposited delta like sediments in the area where the north flowing ice stream met deep water in the Norwegian Sea.

Approximately 126 km south of well 35/2-1 the geotechnical borehole (core 8903; 60º38.4’N, 3º43.4’E) was drilled on the Troll Field in the central part of the Norwegian Channel. This borehole was extensively corded with continuous cores in the upper part and with a large number of cores taken at varying interval in the lower part. Whole of the approximately 200 m Pleistocene sediment column was sampled, and the drilling penetrated down into Oligocene sediments below URU. An extensive analytical programme, including sedimentological, geochronological and biostratigraphical techniques has been carried out on the cores. This include among other things palaeomagnetic investigations and amino acid geochronology based on epimerization reaction in foraminiferal tests (Sejrup et al., 1995). This borehole is the only borehole in the Norwegian part of the North Sea which reveals a detailed depositional history the Pleistocene.

Sejrup et al. (1995) recorded a glacigenic diamicton named Fedje diamicton (Lithozone L6) immediately above URU, and the climatostratigraphic event corresponding to the glaciation during which this diamicton was deposited was denoted *Fedje Glaciation.* These sediments is accurately dated since two normal polarity zones occurring within the assumed Matuyama Chron were recorded from Lithozone L6 and from the lower part of the overlying Lithozone L5. It is suggested that these polarity zones represent the Jaramillo and Cobb Mountain events dated to between 0.98 and 1.07 and to 1.19 Ma respectively on the time scale of Berggren et al. (1995).

Sejrup et al. (1995) correlate the Fedje Glaciation with the Menapian Glaciation in the Netherlands. Deposits from the Menapian Glaciation contain the oldest evidence of a major expansion of the Fennoscandian ice sheet in form of rock fragments of Scandinavian origin (Zagwijn 1985, 1987). According to Lindner et al. (2004) is the Menapian Glaciation correlated with the Narevian Glaciation in Poland. From the central North Sea (Fladen area; British sector), Sejrup et al. (1987) have recorded a glacial event in a cored geotechnical borehole which also is correlated with these glaciations. In addition, the Vøring Plateau sediments document an increase in IRD at 1.2-1.1 Ma (Jansen & Sjøholm, 1991; Frondval & Jansen, E, 1996). According to Sejrup et al. (1995), this suggests that the Fedje Glaciation was a regional event with a magnitude similar to the Weichselian maximum in this region. If this presumption is correct, and if not there is a specially large local erosion in the 35/2-1-area, it is likely that the ice stream witch deposited the Fedje diamicton on the Troll Field is the same as the one which deposited the sandy glacimarine depositional system in the 35/2-1 area. Detailed seismic correlation may verify this.

Further investigations

Based on foraminiferal correlation we are only able to give a general Pleistocene age to the deposits above URU in well 35/2-1. Since no conventional cores are available, no palaeomagnetic investigations can be executed and no exact dating can be obtained. However, in core 8903 Sejrup et al. (1995) have performed amino acid geochronology. This investigation is based on measuring the degree of amino acid diagenesis in foraminiferal tests. Their investigation goes down to the Fedje Diamicton and includes their Litozone L5 (containing normal marine sediments) which also may be present above the Peon sandstone member in well 35/2-1. The same benthic foraminifera which Sejrup et al. (1995) have used on their analyses in core 8903 are common above the Peon sandstone member in well 35/2-1. Amino acid analyses of these foraminifera may prove to be an important tool for correlation with the Troll Field core. A problem is, however, that the ditch cutting samples in well 35/2-1 may contain caved foraminiferal tests which may hamper a correlation.

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Figure

Fig. 1 Range chart of the most important benthic and planktonic foraminifera and other fossils in the investigated interval of well 35/2-1. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. M RKB = meters below rig floor, m MSL = metres below mean sea level, gAPI = American Petroleum Institute gamma ray units, µs/f = microseconds per foot.

Overview map
with bathymetry and well locations

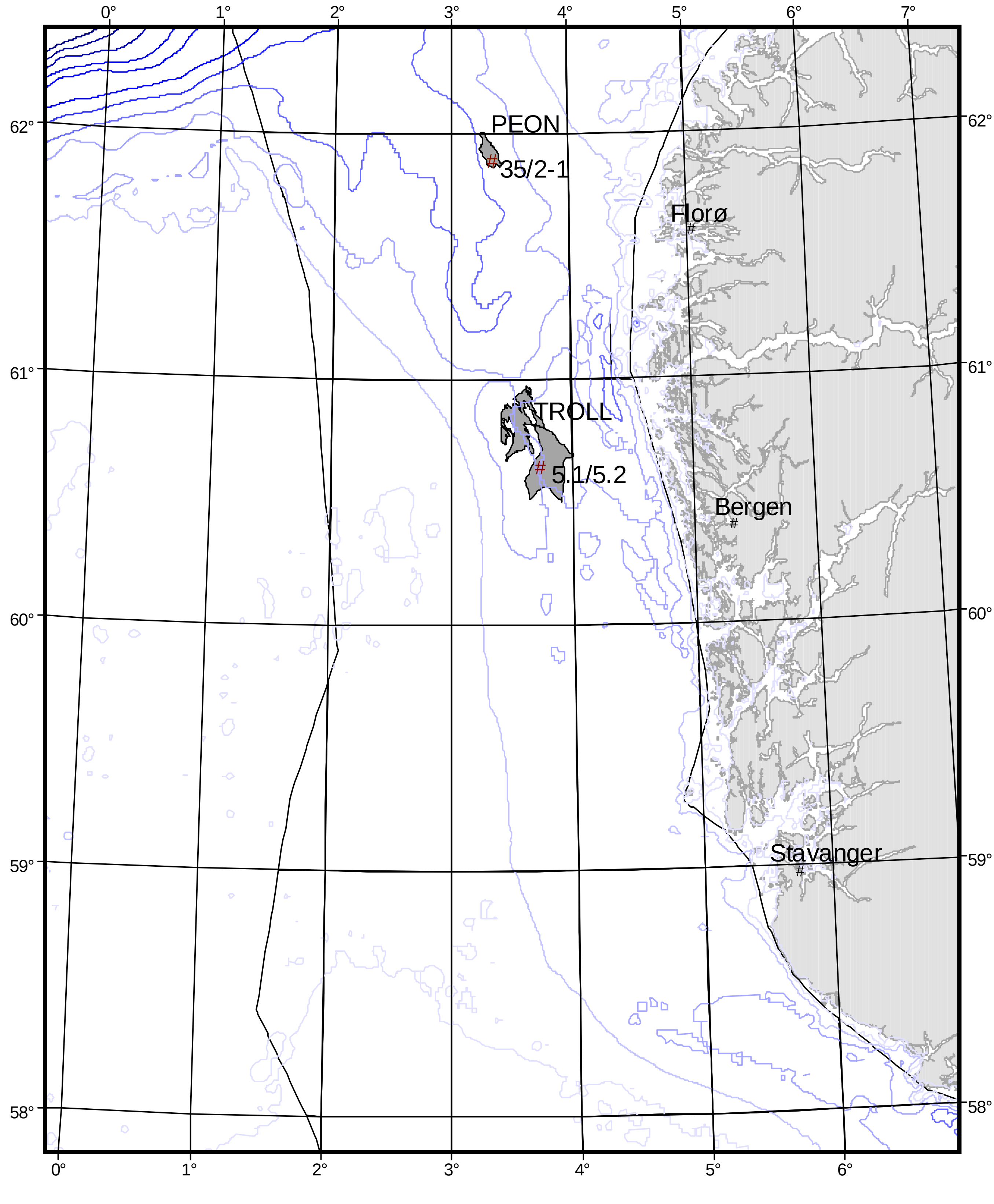
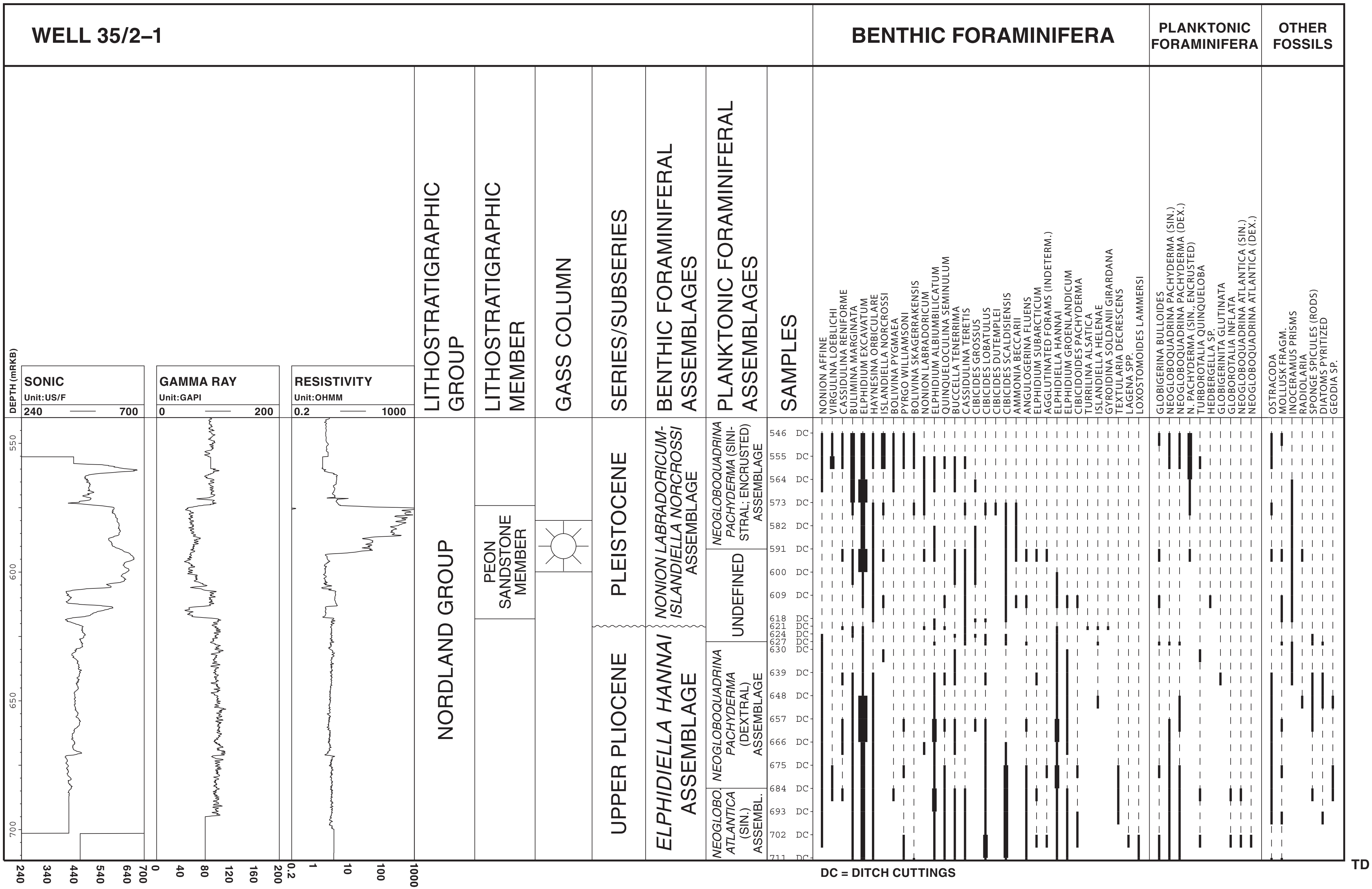


Figure 1



Water depth: 384 M (MSL)

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