

**Foraminiferal biostratigraphy of the post mid-Miocene in two boreholes in the Danish North Sea**

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## Abstract

Cutting samples from two exploration wells, Cleo-1 and Kim-1, in the Central Trough area in the northwestern part of the Danish North Sea, have been investigated for foraminiferal content in the section above the prominent mid-Miocene event. Benthonic foraminifera have been used to produce a stratigraphic subdivision by reference to the standard NSB zonation of King. The NSB 12 to NSB 17 zones (Middle Miocene to Middle Pleistocene) have been identified above the event. These zones can be related to the paleo water depth zonation. Paleoenvironmental reconstruction shows that sediments from the subject interval from Cleo-1 were deposited in a shallower situation than equivalent deposits in Kim-1. A conspicuous hiatus is identified in Cleo-1 at the Pliocene-Pleistocene boundary.

## Introduction

The following is an extended abstract of an ongoing research project on the foraminiferal faunas of the interval above the mid-Miocene event in the Danish sector, North Sea. The mid-Miocene event is a geological event, which is expressed in several ways. In seismic investigations in the North Sea, it is seen as a marker horizon or prominent unconformity (Cameron *et al.*, 1993). It is also registered in log sequence analyses as the base of usually two distinct gamma ray peaks (Kristoffersen & Bang, 1982). In the microfossils, the event is seen as a change in the faunas between the NSB 11 and NSB 12 zones (King, 1989, fig. 9.12), and especially evidenced by the occurrences of *Uvigerina* species (von Daniels, 1986) and of *Bolboforma* species (Spiegler and von Daniels, 1991).

The present study is concerned with the two exploration wells Cleo-1 and Kim-1 (Fig. 1) and is based on cutting samples stored at the archives of the Geological Survey of Denmark. The samples were washed on 0.1 mm and 0.063 mm screens. From the residue on the 0.1 mm screen a minimum of 300 foraminifera were picked, if possible, and counted. In samples with abundant inorganic material, the foraminifera were concentrated by means of a heavy liquid with the specific gravity of 1.8 g/ccm, and the residues were checked for remaining foraminifera.

Ditch cutting samples only allow the first downhole occurrence of species to be used in biostratigraphic interpretations (King, 1983). In this paper the term "first occurrence" is used in the sense of first downhole occurrence. Therefore "tops" of specific foraminiferal species together with *Bolboforma* spp. are used to divide the intervals into zones in accordance with the NSB zonation of King (1983,1989).

King (1989) revised the NSB 16 and NSB 17 zones of his 1983 paper into a NSB 16x zone for the North Sea north of 57° N. Apparently, he also includes his NSB 16 zone of 1983 in his NSB 15b zone of 1989. For that reason King's updated zonation of 1989 is used, except for the NSB 15b and NSB 16x zones, where the NSB 15b, NSB 16 and NSB 17 zones of 1983 are used. The Pliocene-Pleistocene boundary is placed in accordance with Thompson *et al.* (1992), which is equivalent to the base of NSB 15b subzone (King, 1989, fig. 9.7).

Ecological interpretation of the faunas is based on Murray (1991).

The investigated strata are equivalent to the major sequence stratigraphic unit 7 of Michelsen *et al.* (1994).

## Cleo-1

The Cleo-1 well is situated at 56° 23'N and 4° 25'E in the Central Trough area, just west of the Ringkøbing-Fyn High to the northwest of the Danish Sector.

A total of 124 species are identified. A summary of the foraminiferal investigations are given in Fig. 2 as percentage distributions of selected species, with information about the number of species, faunal dominance and the diversity (Walton, 1964).

The correlation of the investigated strata to the NSB-zonation is based on the following. The NSB 17 zone is indicated by the fauna sampled in the interval 480' to 1110'. Most faunas have low diversity and are dominated by *Elphidium excavatum* (Terquem). Other species are the cold water species *Elphidium asklundi* Brotzen and *Nonion orbiculare* (Brady) suggesting shallow water, and in one sample the presence of *Elphidium albiumbilicatum* (Weiss) indicates lowered salinity.

The NSB 16b subzone is found in the interval from 1170' to 1380', based on the first occurrence of *Elphidiella hannai* (Cushman and Grant). The faunas continue to have low abundances and diversity. The assemblages are dominated by *Elphidium excavatum* and other species include *Buccella tenerrima* (Bandy) and a few *Cassidulina laevigata* d'Orbigny and *Elphidium ustulatum* Todd. This fauna is indicative of a littoral and cold environment. The NSB 16b and NSB 17 zones are equivalent to the Pleistocene.

The sample at 1470' yielded a fauna with few specimens. The presence of *Ammonia beccarii* (Linne) and *Elphidium albiumbilicatum* indicate shallow water and reduced salinity. This restricted fauna could be an inner littoral facies or be reworked. It can not be referred to any zone with certainty.

The NSB 15 zone is not identified in this well and a hiatus must exist at this level.

The NSB 14b subzone is identified in the interval from 1530' to 1740', characterized by the first occurrence of *Monspeliensina pseudotepida* (van Voorthuysen) and *Nonion crassesuturatum* van Voorthuysen from the top. The faunas have low diversities in the upper part and are dominated by *Elphidium excavatum*. Other species include *Elphidiella hannai*, *Cassidulina laevigata* and *Buccella* spp. The faunal dominance is high and the environment is interpreted to be outer littoral.

The NSB 14a subzone is represented in the interval from 1800' to 1980' based on the first occurrence of *Cassidulina pliocarinata* van Voorthuysen, *Cibicidoides limbatusuturalis* (van Voorthuysen) and *Florilus boueanus* (d'Orbigny) from the top. The faunas are dominated by *Elphidium excavatum* and *Monspeliensina pseudotepida*, and other species include *Cassidulina laevigata*, *Nonion affine* (Reuss) and *Buccella* spp. The dominance decreases downhole, whereas the diversity is slightly increased. These faunas indicate an outer littoral to inner shelf environment.

The top of the interval is characterized by a notable change in the fauna which probably indicates a hiatus.

The NSB 13b subzone is found in the interval 1980' to 2550' based on the occurrence of *Criboelphidium vulgare* Voloshinova in the top of the zone and from 2280' *Uvigerina venusta saxonica* von Daniels and Spiegler. Other species associated are *Cassidulina laevigata*, *C. pliocarinata*, *Nonion affine*, *Florilus boueanus*, *Bulimina aculeata* d'Orbigny, *Globocassidulina subglobosa* (Brady) and *Cibicides* spp. The shallow water species *Elphidium excavatum* and *Monspeliensina pseudotepida* decrease downhole as planktonic specimens increase in number. The diversity increases strongly at the top of the interval. The fauna indicates an increasing water depth from inner to middle shelf environment downhole.

The top of the Miocene is placed at 2280' where *Valvulineria complanata* (d'Orbigny) has its first appearance (Doppert, 1980).

The NSB 13a subzone is indicated in the interval 2610' to 3450' based on the first occurrence of *Uvigerina pygmaea langeri* von Daniels and Spiegler at the top of the interval and *Bulimina elongata* d'Orbigny from 3180'. Other species include *Cassidulina laevigata*, *Nonion*

*affine*, *Bulimina aculeata*, *Globocassidulina subglobosa*, *Hoeglundina elegans* (d'Orbigny) and *Cibicides spp.* The fairly constant presence (2% to 4%) of the shallow water species *Elphidium excavatum* and *Monspeliensina pseudotepida* in all the samples from this interval may indicate reworking of shallow water sediments in the basin. The number of planktonic specimens increases downhole. The environment is considered to be middle shelf.

The NSB 12c subzone is not recorded in this borehole.

The NSB 12b subzone is identified in the interval 3510' to 4020' based on the occurrence of *Elphidium antoninum* (d'Orbigny) from the top. Other species in the interval are *Cassidulina laevigata*, *Nonion affine*, *Bulimina aculeata*, *Globocassidulina subglobosa* and *Cibicides spp.* The planktonic foraminiferal content is high, and in the samples below 3900' *Bolboforma metzmacheri* (Clodius) is found. The diversity is high and the dominance is low, except in the lowermost sample. The environment is interpreted as open marine, middle to outer shelf.

The NSB 12a subzone is indicated in the samples from the interval 4020' to 4170' based on the first occurrence of *Elphidium ungeri* (Reuss) at the top. An additional species characteristic of this subzone is *Trifarina gracilis* (Reuss). Other common species are *Cassidulina laevigata*, *Nonion affine*, *Bulimina aculeata*, *Bulimina elongata*, *Oridorsalis umbonatus* (Reuss), *Pullenia bulloides* (d'Orbigny) and *Cibicides spp.* Furthermore, the interval is characterized by the occurrence of *Bolboforma clodiusi* von Daniels and Spiegler and abundant planktonic specimens. This faunal assemblage indicates an open marine, outer shelf environment. This subzone partly have low frequencies in the faunas probably indicating a benthonic environment that was unfavorable for the fauna or for the preservation of tests.

The samples from 4170' to 4230' did not yield calcareous microfossils and represent a barren interval.

The NSB 11 zone is not identified in this well and a hiatus must exist at this level.

The NSB 10 zone is represented by the lowermost sample investigated from this borehole (4260') situated immediately below the mid-Miocene event. The fauna is characterized by the occurrence of *Uvigerina tenuipustulata* van Voorthuysen, *Elphidium inflatum* (Reuss) and *Asterigerina guerichi staeschei* (ten Dam and Reinhold).

## Kim-1

The well Kim-1 is situated at 56 07' N and 3 30' E in the Central Trough above the Lindesnes Ridge in the western part of the Danish sector.

A total of 144 species were identified. A summary of the foraminiferal investigations is shown in Fig. 3 as a percentage distribution of selected species together with the number of species, faunal dominance and the diversity (Walton, 1964).

The subdivision of the investigated interval into the NSB-zonation is based on the following.

The NSB 17 zone is found in the upper part of the borehole above 1380'. The faunas are characterized by *Elphidium ustulatum* and are dominated by *Elphidium excavatum* and high numbers of *Nonion orbiculare* indicating littoral facies. The occurrence of *Elphidium asklundi* suggests a cold water environment and *Elphidium albumbilicatum* indicates periods with reduced salinity. The interval 1050' to 1140' is characterized by the presence of *Elphidium gorbunovi* Stschedrina, which has a very restricted stratigraphic range in the upper part of the Early Pleistocene in this part of the North Sea (Pedersen, 1995) where it has been found in several wells.

A NSB 16b subzone fauna is recognized in the samples from 1440' to 2280'. It is indicated by the first occurrence of *Elphidiella hannai* and is dominated by *Elphidium excavatum*. In the

upper part of the interval *Nonion orbiculare* reflects a shallower water depth. In the lower part *Cassidulina teretis* and *C. reniforme* constitute important components of the fauna indicating inner shelf, cold environment.

The NSB 16b and NSB 17 zones are equivalent to the Pleistocene.

The NSB 15b subzone is identified in the interval from 2310' to 2880' based on the first occurrence of common *Cibicides grossus* (ten Dam and Reinhold) from the top and the influx of *Elphidiella hannai*. The fauna is dominated by *Elphidium excavatum*. In the upper part and at the base of the interval *Cassidulina teretis* and *C. reniforme* also constitute a significant part of the fauna indicating greater water depth than in the middle of the zone. The fauna indicates fluctuation in sea level from inner shelf to littoral environment.

The NSB 15a subzone is represented by two samples at 2910' and 3030' as indicated by the first occurrence of *Cibicides pseudoungerianus* (Cushman) in the latter sample. The upper sample is included in the subzone based on the conspicuous faunal change to the next sample uphole. The fauna includes *Elphidium excavatum*, *Cassidulina teretis*, *C. laevigata*, *C. carinata*, *Nonion affine* and *Epistominella vitrea* Parker. The faunal dominance has dropped notably and the diversity increases downhole. The fauna indicates an inner to middle shelf environment.

The abrupt faunal change at the top of the zone probably indicates a hiatus.

The NSB 14b subzone is indicated the sample at 3150' by the first occurrence of *Monspeliensina pseudotepida*. The fauna further includes *Elphidium excavatum*, *Cassidulina teretis*, *C. laevigata*, *C. carinata*, *Bulimina aculeata* and planktonic species. The environment is interpreted to be middle shelf.

The NSB 14a subzone is found in the interval 3210' to 3330' where the top is characterized by first occurrences of *Cassidulina pliocarinata* and *Florilus boueanus*. Other species include *Elphidium excavatum*, *Monspeliensina pseudotepida*, *Cassidulina teretis*, *C. laevigata*, *C. carinata*, *Bulimina aculeata*, *Nonion affine* and *Globocassidulina subglobosa*. The planktonic component together with the diversity increase downhole. This fauna indicates a middle shelf environment.

The NSB 13b subzone, in the interval 3450' to 3870', is characterized by the first occurrence of *Uvigerina venusta saxonica* from the top. Other species include *Elphidium excavatum*, *Monspeliensina pseudotepida*, *Cassidulina teretis*, *C. laevigata*, *C. carinata*, *Bulimina aculeata*, *Nonion affine*, *Globocassidulina subglobosa*, *Trifarina fluens* and planktonic species. The diversity is high and the fauna represents a middle to outer shelf environment.

The top of the Miocene is placed at first occurrence of common *Valvulineria complanata* at 3570'.

The NSB 13a subzone is recognised in the interval 3930' to 4720' based on the first occurrence of *Uvigerina pygmaea langeri* from the top and of *Bulimina elongata* from 4090' depth. The fauna includes *Monspeliensina pseudotepida*, *Cassidulina laevigata*, *C. carinata*, *Bulimina aculeata*, *Nonion affine*, *Globocassidulina subglobosa*, *Uvigerina venusta saxonica* and *Cibicides spp.* The samples from 4180' to 4600' have impoverished faunas or are barren probably due to either unfavorable benthonic conditions or poor preservation of the tests. *Bolboforma costairregularis* (Toering and van Voorthuysen) is recorded in the uppermost part of the interval. *Bolboforma metzmacheri* and *Bolboforma laevis* von Daniels and Spiegler occur in the lowermost sample from 4720' depth. The planktonic foraminifera are common and the diversity is generally high. This fauna indicates an open marine, middle to outer shelf environment.

The NSB 12 zone is identified in the interval 4780' to 4960' based on a characteristic high content of *Trifarina gracilis* and of *Bolboforma clodiusi*. The index species *Elphidium antoninum* is absent in this well. The faunas include *Bulimina aculeata*, *B. elongata*, *Nonion affine*, *Globocassidulina subglobosa*, *Oridorsalis umbonatus* and *Cibicides spp.* The planktonic component is high. The fauna indicates an open marine, outer shelf environment.

The NSB 11 zone is represented by the samples from 4980' to 5200' based on the first occurrence of *Asterigerina guerichi staeschei*, *Uvigerina acuminata* Hosius, *Uvigerina macrocarinata* Papp and Turnovsky and of *Bolboforma reticulata* von Daniels and Spiegler from the top. Other species are *Nonion affine*, *Bulimina elongata*, *Oridorsalis umbonatus*, *Trifarina gracilis* and *Pullenia bulloides*. The interval has a fairly large planktonic component and *Bolboforma spp.* are common. The samples in the middle part of the interval have somewhat impoverished faunas. The assemblages indicate an open marine, outer shelf environment. The NSB 10 zone is identified in the lowermost sample investigated from this well, at 5280', based on the occurrence of *Uvigerina tenuipustulata*.

### Comparison between the wells

The faunal assemblages of the biostratigraphic zonation in the two investigated wells clearly reflects the depositional environmental settings related to water depth.

In both wells the NSB 10 zone is identified in the lowermost investigated sample.

The NSB 11 zone is only identified in Kim-1 with a thickness of 220'.

In Cleo-1, the NSB 12 zone has a thickness of 570' and can be subdivided into two subzones NSB 12a and NSB 12b, whereas in Kim-1 the NSB 12 zone can not be subdivided and has a thickness of 150'. An impoverished fauna is found in the NSB 12a subzone in Cleo-1. An equivalent interval is not identified in Kim-1. The existence of *Elphidiidae* in Cleo-1 indicates a shallower water depth than at the Kim-1 site. A seismic section between the two wells shows that the major sequence stratigraphic unit is made up of several lensoid shaped sequences building out into the basin from the northeast to the southwest. At the time of the NSB 12 zone, the major sedimentation took place around the Cleo-1 site, whereas the Kim-1 site was situated further out into the basin.

The NSB 13 zone in both wells is subdivided into 13a and 13b subzones. In Cleo-1, the thicknesses of the subzones are 840' and 570' respectively and in Kim-1 790' and 420'. At the time of NSB 13 zone deposition the sedimentation rate was somewhat higher at the Cleo-1 site compared to the Kim-1 site. In Kim-1, an interval with an impoverished or missing fauna is found in the lower half of the NSB 13a subzone. An equivalent interval is not identified in Cleo-1. The faunas also in this zone indicate a shallower water depth at the Cleo-1 site than at the Kim-1 site. The Miocene-Pliocene boundary is placed in the NSB 13b subzone, in Cleo-1 well at 2190' depth and in Kim-1 well at 3480' depth.

The thickness of the NSB 14 zone in the Cleo-1 well is 450' and in the Kim-1 well 210'. Again, the faunas indicate a shallower water depth at the Cleo-1 site. In both wells, this zone can be subdivided into a 14a subzone and a 14b subzone. In the Cleo-1 well there is a conspicuous change in the fauna to a more littoral facies between the two subzones indicating a possible hiatus at this level. A comparable faunal change is not seen in the Kim-1 well.

At the Cleo-1 site, the NSB 15 zone is not identified indicating a hiatus here. This zone in the Kim-1 well has a thickness of 720' and is subdivided into the NSB 15a and NSB 15b subzones. In the latter subzone the faunas suggest a fluctuation in sea level. A faunal change at the top of the NSB 15a subzone indicates a hiatus at this level.

The NSB 16b subzone is 210' thick in Cleo-1 and is deposited in a littoral facies. In Kim-1, the subzone is 840' thick and displays a shallowing water depth.

The NSB 17 zone is represented by 630' of sediment in the Cleo-1 well and by 900' in the Kim-1 well. At both sites the faunas indicate a cold environment, but in Cleo-1 they are impoverished showing a more extreme environment perhaps due to proximity to the coast.

## Conclusion

Based on investigations of the foraminiferal fauna assemblages the exploration wells Cleo-1 and Kim-1 can be subdivided according to the NSB zonation of King (1983, 1989) above the mid-Miocene. The sediments are of Miocene, Pliocene and Early to Middle Pleistocene age. The Miocene-Pliocene boundary is placed in the NSB 13b subzone and the Pliocene-Pleistocene boundary is placed at the base of the NSB 16b subzone.

At the Cleo-1 site the sediments were deposited at a shallower water depth than at the Kim-1 site, which was situated further out in the basin. Moreover, the main sedimentation took place earlier at Cleo-1 than at Kim-1, as the sediments were building out into the basin.

At Cleo-1, a considerable hiatus is identified in the Middle Miocene and at the Pliocene-Pleistocene boundary. At Kim-1, a fluctuation in water depth is seen in the latest Late Pliocene. Hiati are also indicated in Cleo-1 between the NSB 14a and 14b subzones and at Kim-1 between the NSB 15a and 15b subzones.

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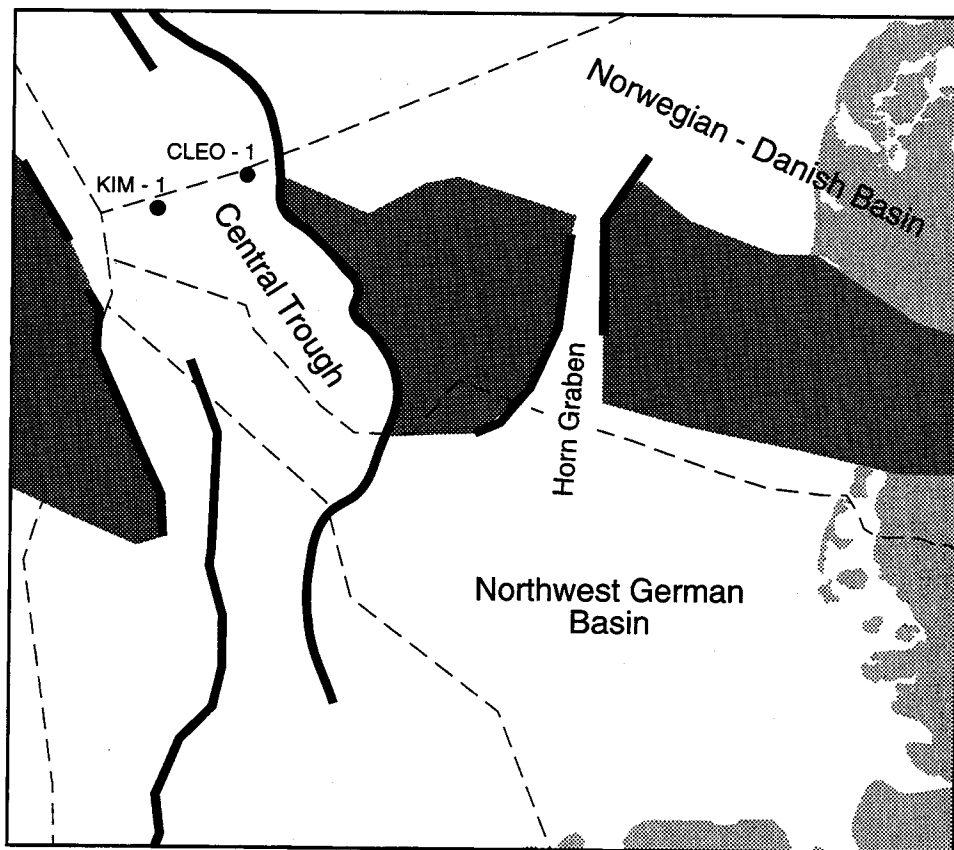


Fig. 1 Position of the wells Cleo-1 and Kim-1 in the Danish North Sea.

Fig. 2 Range chart of selected calcareous microfossils in the Cleo-1 well, Danish North Sea.

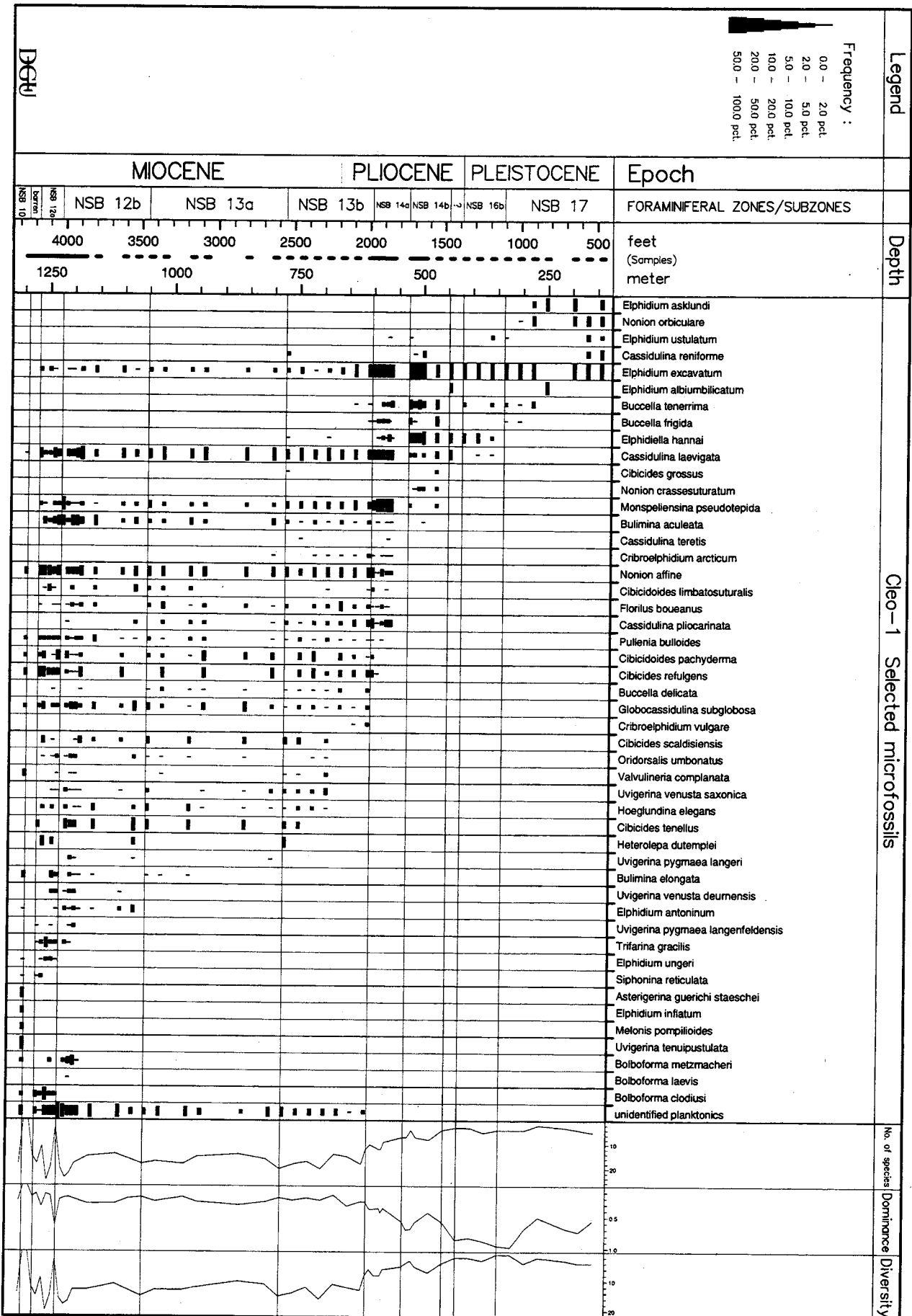


Fig. 3 Range chart of selected calcareous microfossils in the Kim-1 well, Danish North Sea.

