DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2003/71

A stratigraphic study of the Palaeogene succession East of the Central Graben in the Danish North Sea sector: executive summary

P. Schiøler, J. Andsbjerg, K. Dybkjær,
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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

G E U S

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GEUS

Contents

Introduction

The results from the EFP 2000 project on the stratigraphy of the Palaeogene succession in the central and eastern North Sea is presented in this volume by four reports, three of which represent manuscripts at various stages of preparation for submission to international journals. This introductory summary outlines the main results obtained and provides an overview of the project.

Aims

The main aim of the project was to improve existing knowledge of Palaeogene hydrocarbon prospects in the Danish North Sea sector through a multidisciplinary geological study of the stratigraphic succession East of the Central Graben. Fulfilment of the main aim required an improved understanding of the nature, morphology and distribution of the Palaeogene sediment bodies as well as an improved biostratigraphic framework to determine their age relationship. Therefore, the project has focussed on a lithostratigraphic description of the succession encountered, with special emphasis on the morphology and distribution of sand bodies, and on the creation of a consistent and robust biostratigraphical framework for the Palaeogene. Hence, the establishment of a revised lithostratigraphy for the Danish North Sea sector became a unifying aim for the project.

The subject areas within the project were:

1) The creation of an improved biostratigraphical framework
2) A detailed log interpretation and correlation
3) The establishment of a revised lithostratigraphic scheme

The results are summarised overleaf. As the well coverage East of the Central Graben is scattered, it has been necessary to build on data from Central Graben wells also in order to meet the aims of the study.

As the revised lithostratigraphy presented in report 2003/72 encompasses confidential well data the summary of the revised lithostratigraphic framework below is necessarily generalised.

Material and methods

Biostratigraphy

Biostratigraphic consultancy reports on 29 selected North Sea wells have been reassessed in order to create a biostratigraphic platform for the Palaeogene interval. A database has been created encompassing the results of the reassessment. Further biostratigraphic sample material from 11 North Sea well has been prepared for palynology and microfossils at GEUS in order to cast further light on the biostratigraphic event succession. When available and needed, core material was prepared and study result incorporated. These data have also gone into the database.

Wells reassessed (see Fig. 1a for well location):

Alma-1
Bertel-1/1a
Cleo-1 (partly, Lark Formation only)
Diamant-1
Elna-1
Frida-1
Gert-1
Gulnare-1
Gwen-2
Ibenholt-1
Ida-1
Inez-1
Karl-1
Kim-1
Lone-1 (partly, Lark Formation only)
Mona-1
Nini-1
Nora-1 (partly, only microfossils)
Rigs-1
Roxanne-1
S-1x
Sandra-1
Saxo-1
Siri-2
Tabita-1
Tordenskjold-1
Vanessa-1
Wessel-1 (partly, only palynology)
Westlulu-3

Additional well material prepared at GEUS (see Fig. 1a for well location):

Alma-1 (palynology)
Francisca-1 (palynology and microfossils)
Frida-1 (palynology and microfossils)
Ida-1 (palynology)
Inez-1 (palynology)
Karl-1 (palynology)
Roxanne-1 (palynology and microfossils)
S-1x (palynology and microfossils)
Sandra-1 (palynology)
Ugle-1 (palynology and microfossils)
Wessel-1 (palynology)

Lithology and sedimentology

Inspection of cuttings samples from the following 16 key wells has formed the basis for the lithological study (see Fig. 1a for well location):

Alma-1
Bo-1
Cecilie-1
Cleo-1
Gert-1
Inez-1
Karl-1
Kim-1
Lone-1
Mona-1
Nora-1
Rigs-1
Saxo-1
Siri-2
Tabita-1
Westlulu-3

Detailed sedimentological studies have been carried out on the Francisca-1 core by GEUS staff and on cored sections from 20 wells drilled in the Siri submarine Canyon system by DONG E&P staff.

Petrophysical data

Petrophysical logs from all seventy wells shown in Fig. 1a have been studied and correlated. Five key correlation panels was constructed and served as the backbone of the well correlation. The correlation panels illustrate the morphology and extent of individual units in the Palaeogene sediment package. The five correlation panels are enclosed with report 2003/72 as Enclosures 1–5, the location of the 5 correlation lines is shown on Fig. 1b herein. The panels encompass the wells:

Saxo-1, Lone-1, Gert-1, Mona-1, Westlulu-1, Cleo-1, Siri-1, Sandra-1, Ibenholt-1, Ida-1, Inez-1 (Enclosure 1)

Westlulu-3, Tabita-1, Gulnare-1, Adda-1, G-1x, Alma-1x, Tove-1 (Enclosure 2)

Lone-1, Sten-1, Diamant-1, Ravn-1, Falk-1, Edna-1, John Flanke-1 (Enclosure 3)

Nini-3, Nolde-1, Sandra-1, Siri-1, Frida-1, L-1x, V-1x, Alma-1x, John Flanke-1 (Enclosure 4)

K-1x, F-1x, Inez-1, R-1x, S-1x (Enclosure-5)

Seismic interpretation

Seismic profiles from the surveys CGD85, DK-1, RTD81-RE94, UCG96 and UCGE97 were interpreted in the present project. The interpreted profiles were used to further guide the petrophysical well correlation and to determine the spatial distribution of stratigraphic units in areas with only scattered well coverage.

Results

Biostratigraphy

The palynological and micropalaeontological studies undertaken in this project has resulted in the establishment of a robust, yet detailed, succession of key palynological and microfossil events (Fig. 2a–c). The majority of samples dealt with in the project are cuttings samples which are notoriously subject to downhole contamination. Therefore, focus has been on first downhole occurrence (FDO =highest stratigraphic occurrence) of taxa. The downhole event succession established has been correlated with the major zonation schemes covering the area, with international chronostratigraphy and with geochronology (Fig. 2a–c, 3a–c).

The FDO succession established has been used to support the petrophysical log correlation of the present project and to date the lithostratigraphic units in a more precise and consistent way than previously possible.

Lithostratigraphy

A revised lithostratigraphic scheme for the siliciclastic Palaeogene succession of the Danish North Sea sector has been established based on the results from the log correlation and examination of cuttings samples, supported by new biostratigraphy and seismic interpretation (Fig. 4). The revised lithostratigraphy builds on the initial lithostratigraphic subdivision by Deegan and Scull (1977), and takes advantage of the subsequent improvements of that subdivision by Hardt *et al.* (1989), and Knox and Holloway (1992) (see Fig. 5 for correlation between the revised lithostratigraphy and the lithostratigraphy of other authors).

The lithostratigraphy presented in Fig. 4 has its genetic base at the top Chalk Group surface. Although the uppermost formation of the Chalk Group, the Ekofisk Formation, is of Early Palaeocene (Danian) age and therefore belongs to the Palaeogene Period by definition, the present study does not deal with that formation. The reason for this omission is that the Ekofisk Formation, like the rest of the Chalk Group, represents an entirely different sedimentary regime, far from that of the overlying siliciclastic sediments both by nature, depositional mechanism and host basin configuration. The top of the study section is constituted by the Mid-Miocene Unconformity, a basin-wide erosional surface that separates two thick and very different sediment packages, the Oligocene to mid-Miocene Hordaland Group and the Mid-Miocene to Recent Nordland Group.

The study section has been subdivided into 7 formation containing 11 new members. Vaale, Lista, Sele, Fur, Balder, Horda and Lark Formations of previous lithostratigraphic schemes are adequate for a subdivision of the Danish sector at formation level and are retained herein largely unchanged. Bor is a new sandstone member of the Vaale Formation. The Lista Formation is subdivided into the three mudstone members Vile, Ve and Bue and the three new sandstone members Gerd, Idun and Rind. Sif is a new sandstone member of the Sele Formation. Nana is a new sandstone member of the Horda Formation. The two new sandstone members Freja and Dufa are established in the Lark Formation. Type and reference sections are erected for the new members, and Danish reference sections are established for the formations. Isochore maps have been produced for each unit and detailed sedimentological descriptions are provided whenever core material has been available.

The revised lithostratigraphy is correlated with Danish onshore stratigraphic units and with the sequence stratigraphic scheme for the Eastern North Sea of Michelsen et al. (1998).

Conclusion

The EFP 2000 project on the stratigraphy of the Palaeogene succession in the central and eastern North Sea has resulted in:

1) A revised and refined, integrated biostratigraphic scheme based on first downhole occurrence of microfossils and dinoflagellate cysts. The scheme is calibrated with geochronology.

2) A revised lithostratigraphic subdivision of the Palaeogene siliciclastic sediments in the Danish North Sea sector that include the establishment of eleven new members.

3) An improved understanding of the distribution and age-relationship of the lithological units of the Palaeogene sediment package, in particular its sandstone bodies.

References

Deegan, C.E., Scull, B.J., 1977. A standard lithostratigraphic nomenclature for the Central and northern North Sea. Institute of Geological Sciences Report 77/25, NPD Bulletin 1, pp. 36.

Hardt, T., Holtar, E., Isaksen, D., Kyllingstad, G., Lervik, K.S., Lycke, A.S., Tonstad, K., 1989. Revised Tertiary Lithostratigraphic Nomenclature for the Norwegian North Sea. In: Isaksen, D., Tonstad, K. (Eds), A revised Cretaceous and Tertiary lithostratigraphic nomenclature for the Norwegian North Sea. NPD Bulletin 5, 35–55.

Knox, R.W.O'B., Holloway, S., 1992. 1. Paleogene of the Central and Northern North Sea. In: Knox, R.W.O'B., Cordey, W.G. (Eds), Lithostratigraphic nomenclature of the UK North Sea. British Geological Survey, Nottingham. pp. 133.

Michelsen, O., Thomsen, E., Danielsen, M., Heilmann-Clausen, C., Jordt, H., Laursen, G., 1998. Cenozoic sequence stratigraphy in the eastern North Sea. In: de Graciansky, P.-C, Hardenbol, J., Jacquin, T., Vail, P.R., Farley, M.B. (Eds), Mesozoic and Cenozoic sequence stratigraphy of European Basins. SEPM Special Publication 60, Tulsa, pp. 91–118.

Figures

Fig. 1a. Well location map showing all wells used in the study.

Fig. 1b. Position of log panels shown as enclosures 1–5 of GEUS Report 2003/72 (this Volume).

Fig. 2a. Paleocene chronostratigraphy and biostratigraphy. The chronostratigraphy is based on the scheme of Berggren *et al.* (1995). The majority of the selected microfossil and dinoflagellate events are chronologically placed according to the age estimates by Hardenbol *et al.* (1998, chart 3). In the microfossil event column, the planktic foraminiferid events have been written in normal, benthic foraminiferids in italics and diatoms and radiolarians are underlined. The microfossil events are correlated with the biostratigraphic zonation of King (1989), and - together with the dinoflagellate events - further correlated with the main lithostratigraphic units (full references may be found in the reference list of GEUS Report 2003/72, this Volume).

Fig. 2b. Eocene chronostratigraphy and biostratigraphy. Explanation as in Fig. 2a.

Fig. 2c. Oligocene and Lower to Middle Miocene chronostratigraphy and biostratigraphy. Explanation as in Fig. 2a.

Fig. 3a. Correlation of selected Paleocene biostratigraphic standard biozones and North Sea biozones. The standard biozones are adopted from Berggren and Miller (1988) with later revisions of Berggren *et al.* (1995) (planktic foraminiferids) and from Martini (1971) (nannoplankton). The correlation follows the scheme by Hardenbol *et al.* (1998). The North Sea biozones, which serve as a biostratigraphical base for the present paper, are adopted from King (1989) (foraminiferids) and Costa and Manum (1988), Köthe (1990) and Mudge and Bujak (1996) (dinoflagellates) (full references may be found in the reference list of GEUS Report 2003/72, this Volume).

Fig. 3b. Correlation of selected Eocene biostratigraphic standard biozones and North Sea biozones. Explanation as in Fig. 3a.

Fig. 3c. Correlation of selected Oligocene and Lower to Middle Miocene biostratigraphic standard biozones and North Sea biozones. Explanation as in Fig. 3a.

Fig. 4. Revised stratigraphic column for the Palaeogene of the Danish North Sea sector.

Fig. 5. Stratigraphic correlation between key lithostratigraphic schemes for the Central and Eastern North Sea, formations and members.

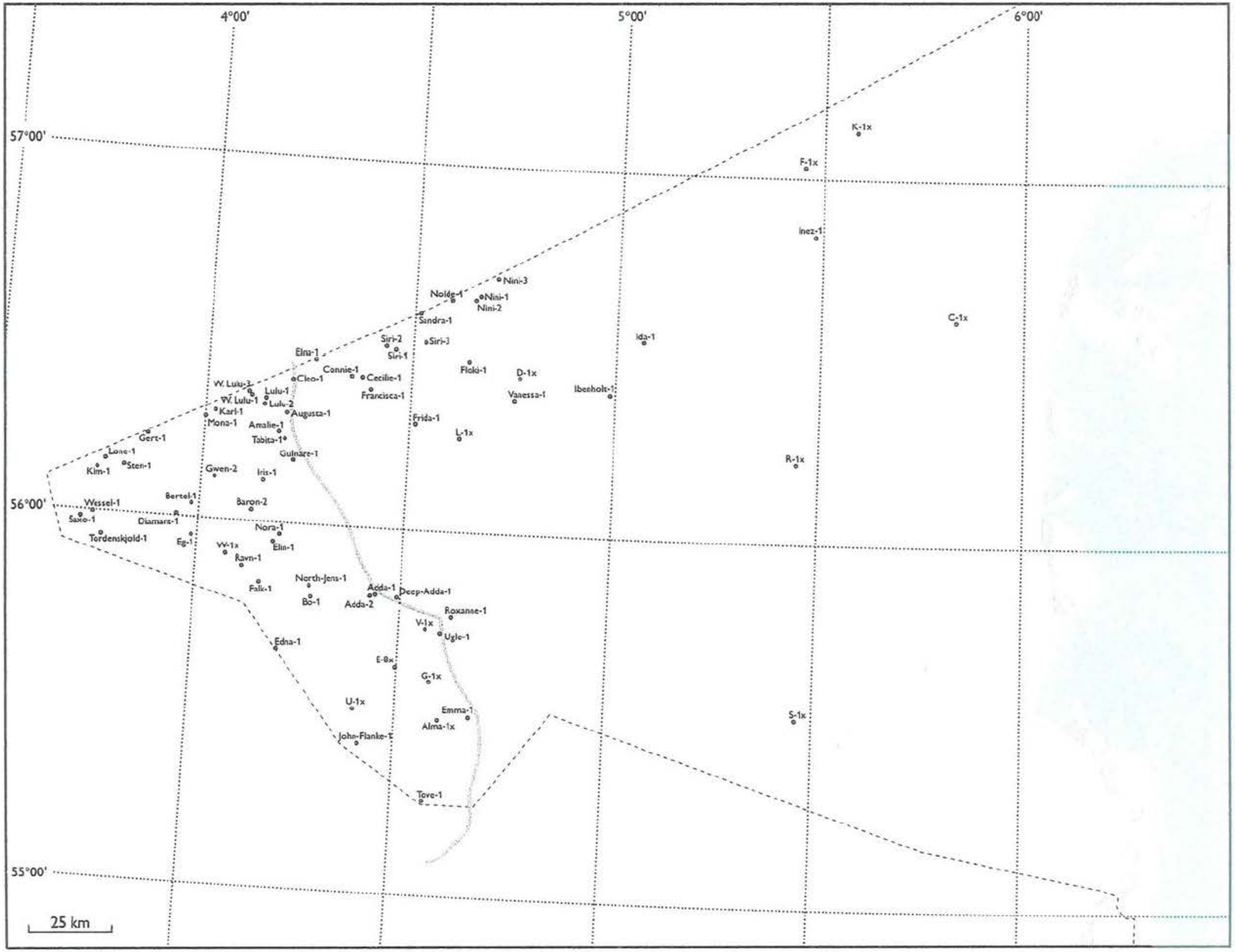

4°00'
5°00'
6°00'
57°00'
56°00'
55°00'
25 km
K-1x
F-1x
Inez-1
Nini-3
Nolde-1
Nini-1
Nini-2
Sandra-1
C-1x
Ida-1
Siri-2
Siri-1
Siri-3
Elna-1
Connie-1
Cleo-1
Cecilie-1
Floki-1
D-1x
W. Lulu-3
W. Lulu-1
Lulu-1
Lulu-2
Francisca-1
Vanessa-1
Ibenholt-1
Karl-1
Augusta-1
Mona-1
Amalie-1
Frida-1
L-1x
Gert-1
Tabita-1
Lone-1
Gulnare-1
Kim-1
Sten-1
Gwen-2
Iris-1
R-1x
Bertel-1
Wessel-1
Baron-2
Saxo-1
Diamant-1
Nora-1
Tordenskjold-1
Eg-1
W-1x
Elin-1
Ravn-1
North-Jens-1
Falk-1
Adda-1
Deep-Adda-1
Bo-1
Adda-2
Roxanne-1
V-1x
Ugle-1
Edna-1
E-8x
G-1x
U-1x
Emma-1
Alma-1x
S-1x
John-Flanke-1
Tove-1

Fig.1a

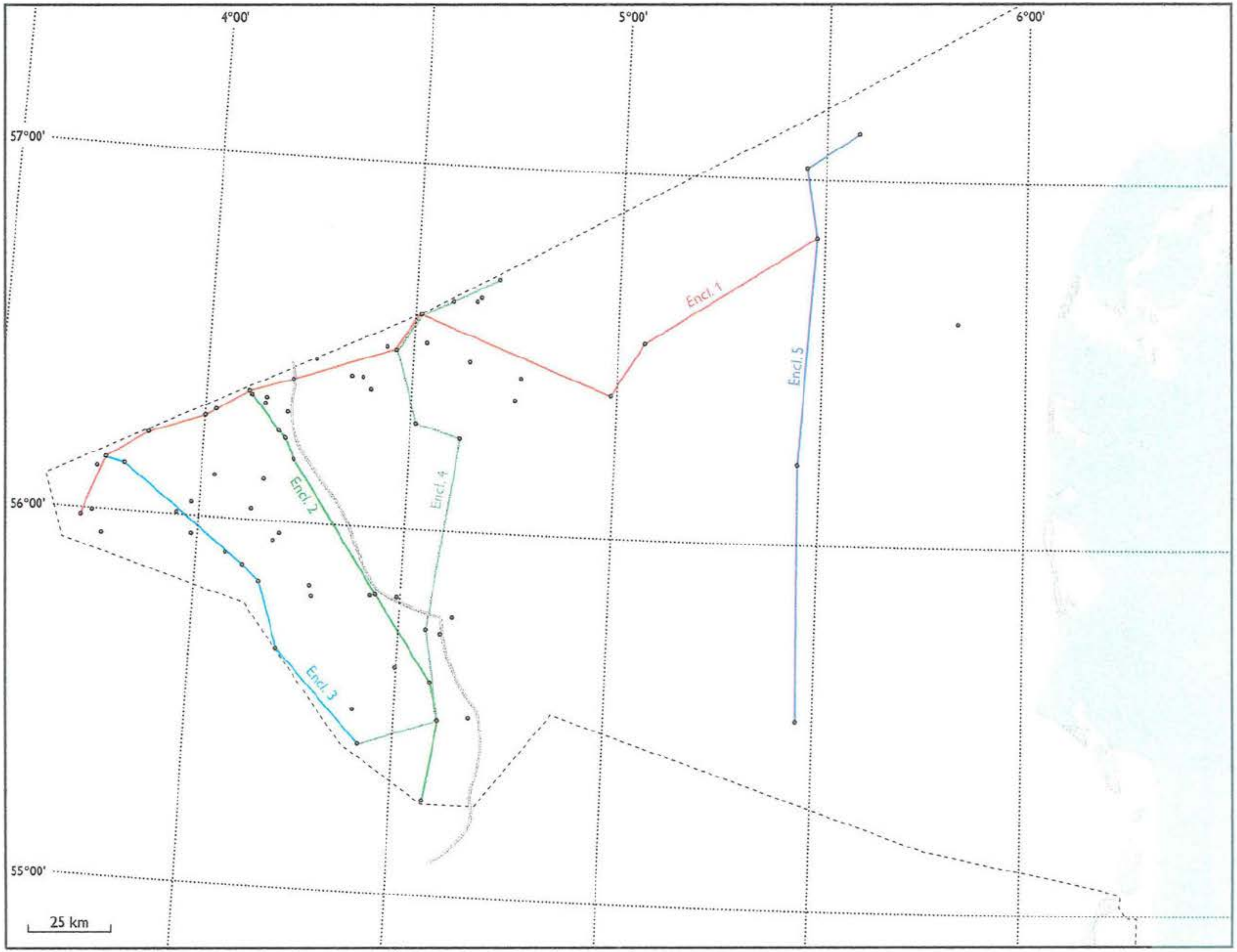
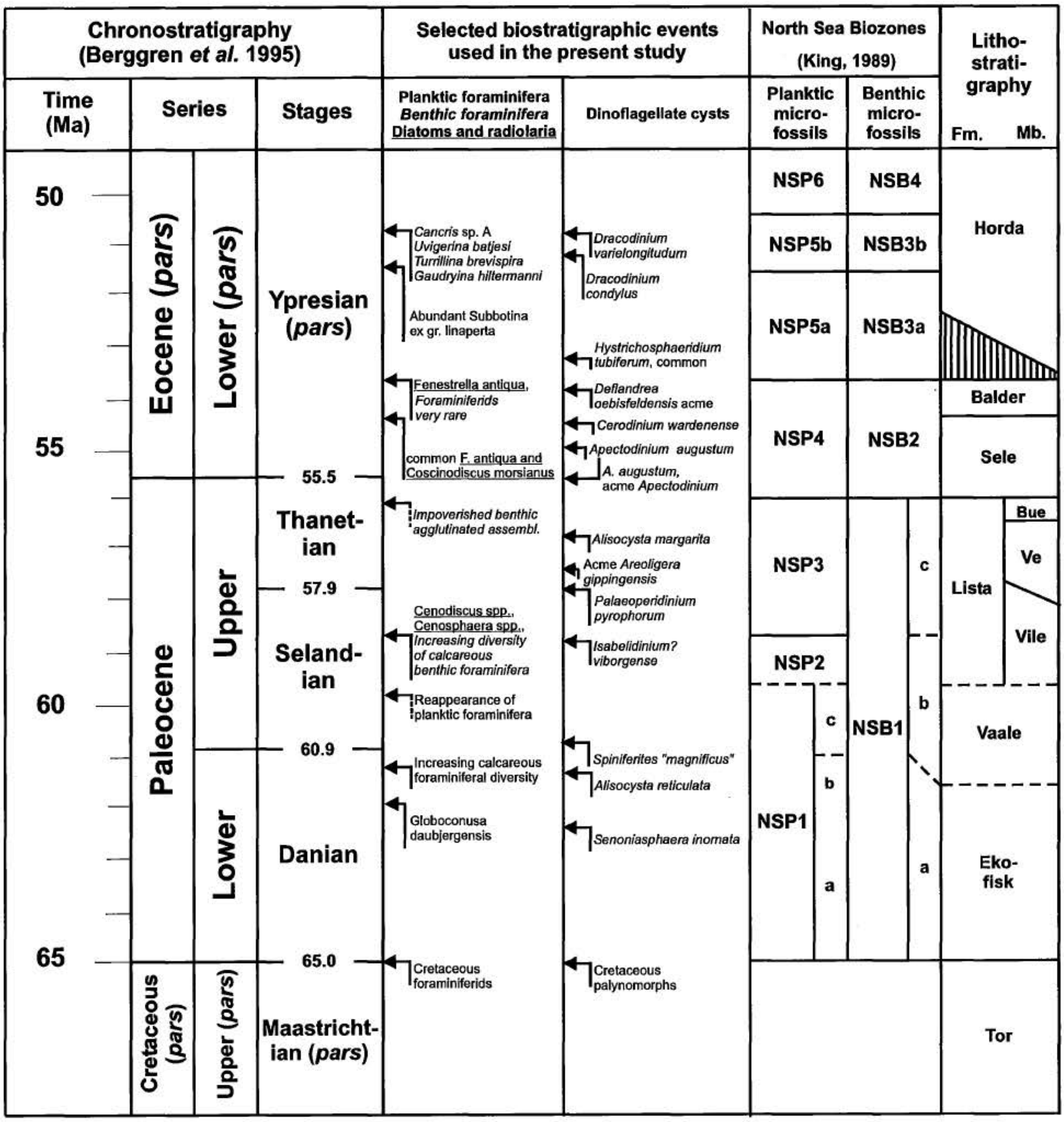
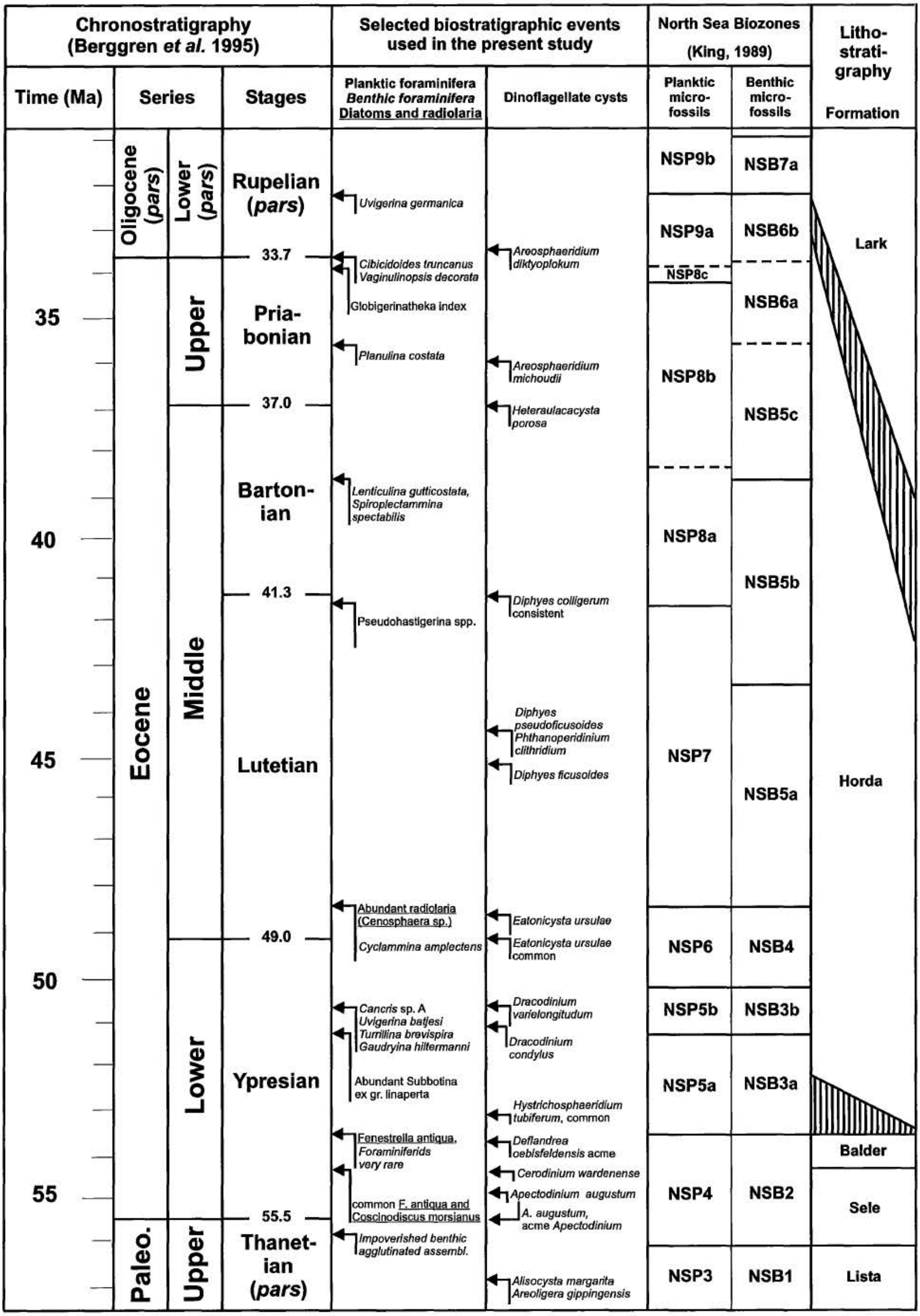

4°00'
5°00'
6°00'
57°00'
56°00'
55°00'
Encl. 1
Encl. 2
Encl. 3
Encl. 4
Encl. 5
25 km

Fig.1b



Chronostratigraphy (Berggren et al. 1995)
Selected biostratigraphic events used in the present study
North Sea Biozones (King, 1989)
Litho-strati-graphy
Time (Ma)
Series
Stages
Planktic foraminifera
Benthic foraminifera
Diatoms and radiolaria
Dinoflagellate cysts
Planktic micro-fossils
Benthic micro-fossils
Fm.
Mb.
50
55
60
65
Eocene (pars)
Lower (pars)
Paleocene
Upper
Lower
Cretaceous (pars)
Upper (pars)
Ypresian (pars)
55.5
Thanet-ian
57.9
Seland-ian
60.9
Danian
65.0
Maastricht-ian (pars)
Cancris sp. A
Uvigerina batjesi
Turrilina brevispira
Gaudryina hiltermanni
Abundant Subbotina ex gr. linaperta
Fenestrella antiqua, Foraminiferids very rare
common F. antiqua and Coscinodiscus morsianus
Impoverished benthic agglutinated assembl.
Cenodiscus spp., Cenosphaera spp., Increasing diversity of calcareous benthic foraminifera
Reappearance of planktic foraminifera
Increasing calcareous foraminiferal diversity
Globoconusa daubjergensis
Cretaceous foraminiferids
Dracodinium varielongitudum
Dracodinium condylus
Hystrichosphaeridium tubiferum, common
Deflandrea oebisfeldensis acme
Cerodinium wardenense
Apectodinium augustum
A. augustum, acme Apectodinium
Alisocysta margarita
Acme Areoligera gippingensis
Palaeoperidinium pyrophorum
Isabelidinium? viborgense
Spiniferites "magnificus"
Alisocysta reticulata
Senoniasphaera inornata
Cretaceous palynomorphs
NSP6
NSB4
NSP5b
NSB3b
NSP5a
NSB3a
NSP4
NSB2
NSP3
NSP2
NSP1
a
b
c
NSB1
Horda
Balder
Sele
Lista
Bue
Ve
Vile
Vaale
Eko-fisk
Tor

Fig. 2a



Chronostratigraphy (Berggren et al. 1995)
Selected biostratigraphic events used in the present study
North Sea Biozones (King, 1989)
Litho-strati-graphy
Time (Ma)
Series
Stages
Planktic foraminifera
Benthic foraminifera
Diatoms and radiolaria
Dinoflagellate cysts
Planktic micro-fossils
Benthic micro-fossils
Formation
35
40
45
50
55
Oligocene (pars)
Lower (pars)
Eocene
Upper
Middle
Lower
Paleo.
Upper
Rupelian (pars)
33.7
Pria-bonian
37.0
Barton-ian
41.3
Lutetian
49.0
Ypresian
55.5
Thanet-ian (pars)
Uvigerina germanica
Cibicidoides truncanus
Vaginulinopsis decorata
Globigerinatheka index
Planulina costata
Lenticulina gutticostata, Spiroplectammina spectabilis
Pseudohastigerina spp.
Abundant radiolaria (Cenosphaera sp.)
Cyclammina amplectens
Cancris sp. A
Uvigerina batjesi
Turrilina brevispira
Gaudryina hiltermanni
Abundant Subbotina ex gr. linaperta
Fenestrella antiqua, Foraminiferids very rare
common F. antiqua and Coscinodiscus morsianus
Impoverished benthic agglutinated assembl.
Areosphaeridium diktyoplokum
Areosphaeridium michoudii
Heteraulacacysta porosa
Diphyes colligerum consistent
Diphyes pseudoficusoides
Phthanoperidinium clithridium
Diphyes ficusoides
Eatonicysta ursulae
Eatonicysta ursulae common
Dracodinium varielongitudum
Dracodinium condylus
Hystrichosphaeridium tubiferum, common
Deflandrea oebisfeldensis acme
Cerodinium wardenense
Apectodinium augustum
A. augustum, acme Apectodinium
Alisocysta margarita
Areoligera gippingensis
NSP9b
NSP9a
NSP8c
NSP8b
NSP8a
NSP7
NSP6
NSP5b
NSP5a
NSP4
NSP3
NSB7a
NSB6b
NSB6a
NSB5c
NSB5b
NSB5a
NSB4
NSB3b
NSB3a
NSB2
NSB1
Lark
Horda
Balder
Sele
Lista

Fig. 2b

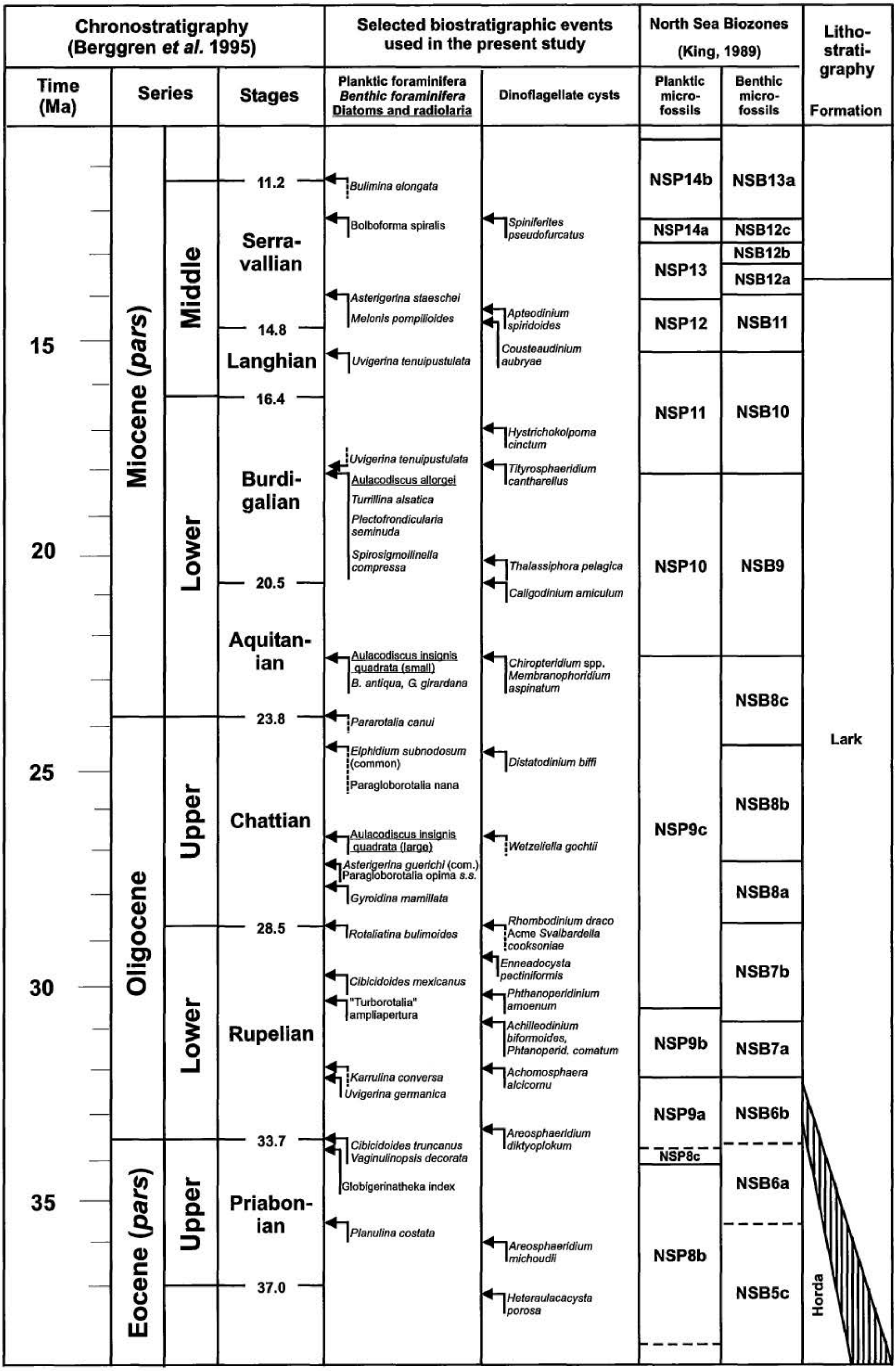
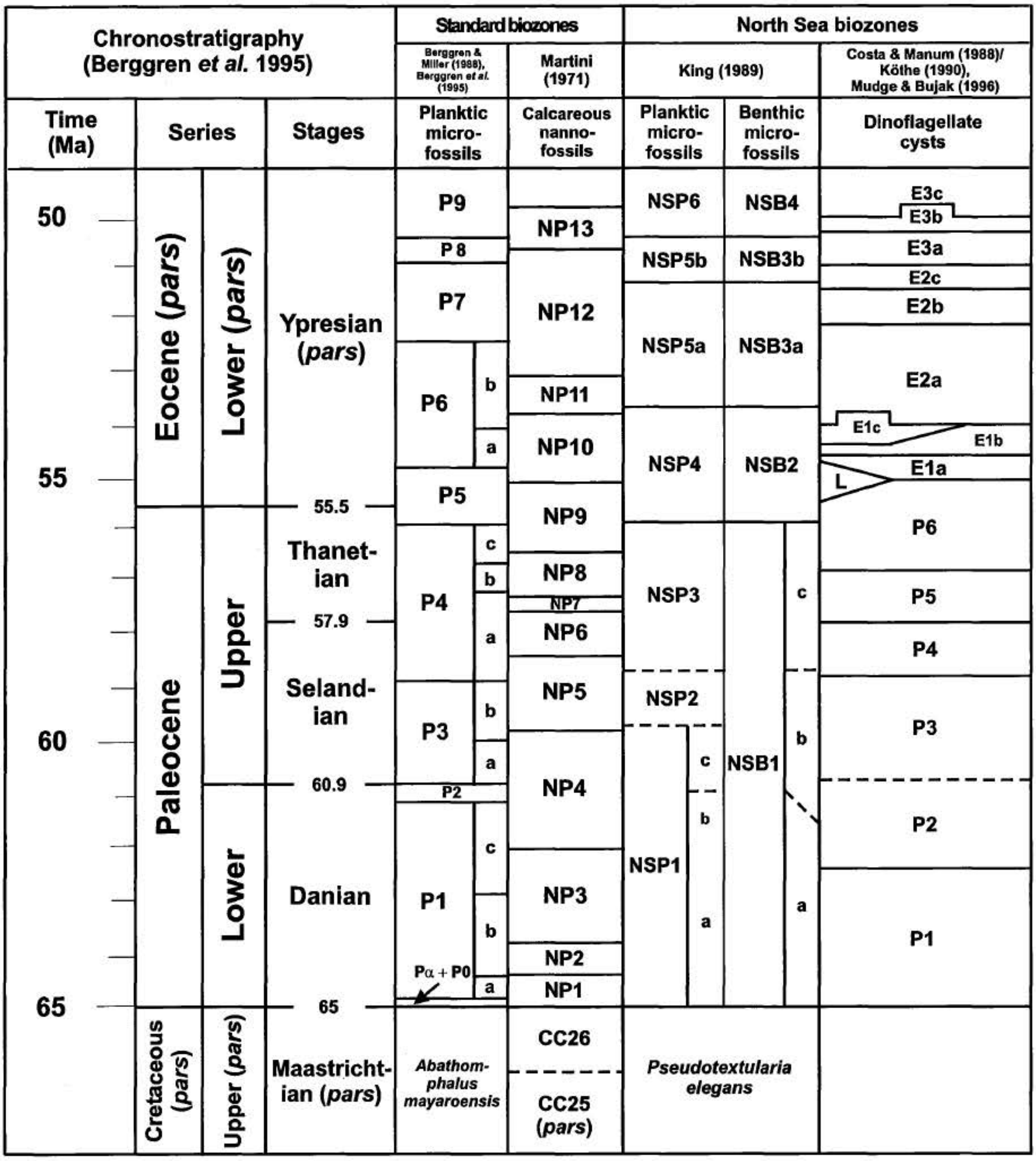

Chronostratigraphy (Berggren et al. 1995)
Selected biostratigraphic events used in the present study
North Sea Biozones (King, 1989)
Litho-strati-graphy
Time (Ma)
Series
Stages
Planktic foraminifera
Benthic foraminifera
Diatoms and radiolaria
Dinoflagellate cysts
Planktic micro-fossils
Benthic micro-fossils
Formation
15
20
25
30
35
Miocene (pars)
Oligocene
Eocene (pars)
Middle
Lower
Upper
Lower
Upper
11.2
Serra-vallian
14.8
Langhian
16.4
Burdi-galian
20.5
Aquitan-ian
23.8
Chattian
28.5
Rupelian
33.7
Priabon-ian
37.0
Bulimina elongata
Bolboforma spiralis
Asterigerina staeschei
Melonis pompilioides
Uvigerina tenuipustulata
Uvigerina tenuipustulata
Aulacodiscus allorgei
Turrilina alsatica
Plectofrondicularia seminuda
Spirosigmoilinella compressa
Aulacodiscus insignis quadrata (small)
B. antiqua, G. girardana
Pararotalia canui
Elphidium subnodosum (common)
Paragloborotalia nana
Aulacodiscus insignis quadrata (large)
Asterigerina guerichi (com.)
Paragloborotalia opima s.s.
Gyroidina mamillata
Rotaliatina bulimoides
Cibicidoides mexicanus
"Turborotalia" ampliapertura
Karrulina conversa
Uvigerina germanica
Cibicidoides truncanus
Vaginulinopsis decorata
Globigerinatheka index
Planulina costata
Spiniferites pseudofurcatus
Apteodinium spiridoides
Cousteaudinium aubryae
Hystrichokolpoma cinctum
Tityrosphaeridium cantharellus
Thalassiphora pelagica
Caligodinium amiculum
Chiropteridium spp.
Membranophoridium aspinatum
Distatodinium biffi
Wetzeliella gochtii
Rhombodinium draco
Acme Svalbardella cooksoniae
Enneadocysta pectiniformis
Phthanoperidinium amoenum
Achilleodinium biformoides,
Phtanoperid. comatum
Achomosphaera alcicornu
Areosphaeridium diktyoplokum
Areosphaeridium michoudii
Heteraulacacysta porosa
NSP14b
NSP14a
NSP13
NSP12
NSP11
NSP10
NSP9c
NSP9b
NSP9a
NSP8c
NSP8b
NSB13a
NSB12c
NSB12b
NSB12a
NSB11
NSB10
NSB9
NSB8c
NSB8b
NSB8a
NSB7b
NSB7a
NSB6b
NSB6a
NSB5c
Lark
Horda

Fig. 2c


Chronostratigraphy (Berggren et al. 1995)
Standard biozones
North Sea biozones
Berggren & Miller (1988), Berggren et al. (1995)
Martini (1971)
King (1989)
Costa & Manum (1988)/ Köthe (1990), Mudge & Bujak (1996)
Time (Ma)
Series
Stages
Planktic micro-fossils
Calcareous nanno-fossils
Planktic micro-fossils
Benthic micro-fossils
Dinoflagellate cysts
50
55
60
65
Eocene (pars)
Lower (pars)
Paleocene
Upper
Lower
Cretaceous (pars)
Upper (pars)
Ypresian (pars)
Thanet-ian
Seland-ian
Danian
Maastricht-ian (pars)
55.5
57.9
60.9
65
P9
P8
P7
P6
P5
P4
P3
P2
P1
Pα + P0
Abathom-phalus mayaroensis
NP13
NP12
NP11
NP10
NP9
NP8
NP7
NP6
NP5
NP4
NP3
NP2
NP1
CC26
CC25 (pars)
NSP6
NSP5b
NSP5a
NSP4
NSP3
NSP2
NSP1
NSB4
NSB3b
NSB3a
NSB2
NSB1
Pseudotextularia elegans
E3c
E3b
E3a
E2c
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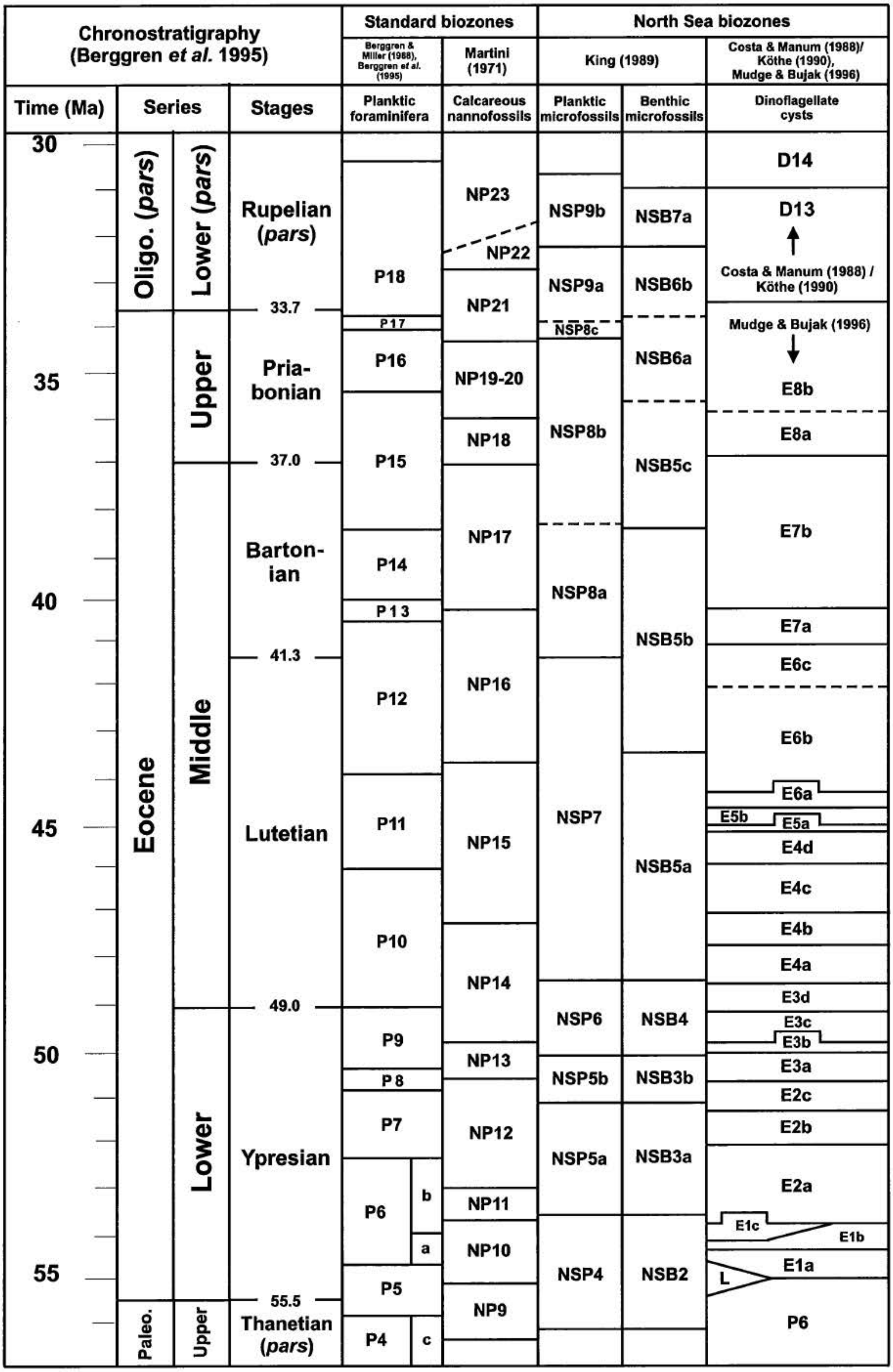
E2a
E1c
E1b
E1a
L
P6
P5
P4
P3
P2
P1

Fig. 3a



Chronostratigraphy (Berggren et al. 1995)
Standard biozones
North Sea biozones
Berggren & Miller (1988), Berggren et al. (1995)
Martini (1971)
King (1989)
Costa & Manum (1988)/ Köthe (1990), Mudge & Bujak (1996)
Time (Ma)
Series
Stages
Planktic foraminifera
Calcareous nannofossils
Planktic microfossils
Benthic microfossils
Dinoflagellate cysts
30
35
40
45
50
55
Oligo. (pars)
Lower (pars)
Eocene
Upper
Middle
Lower
Paleo.
Upper
Rupelian (pars)
33.7
Pria-bonian
37.0
Barton-ian
41.3
Lutetian
49.0
Ypresian
55.5
Thanetian (pars)
P18
P17
P16
P15
P14
P13
P12
P11
P10
P9
P8
P7
P6
b
a
P5
P4
c
NP23
NP22
NP21
NP19-20
NP18
NP17
NP16
NP15
NP14
NP13
NP12
NP11
NP10
NP9
NSP9b
NSP9a
NSP8c
NSP8b
NSP8a
NSP7
NSP6
NSP5b
NSP5a
NSP4
NSB7a
NSB6b
NSB6a
NSB5c
NSB5b
NSB5a
NSB4
NSB3b
NSB3a
NSB2
D14
D13
Costa & Manum (1988) / Köthe (1990)
Mudge & Bujak (1996)
E8b
E8a
E7b
E7a
E6c
E6b
E6a
E5b
E5a
E4d
E4c
E4b
E4a
E3d
E3c
E3b
E3a
E2c
E2b
E2a
E1c
E1b
E1a
L
P6

Fig. 3b

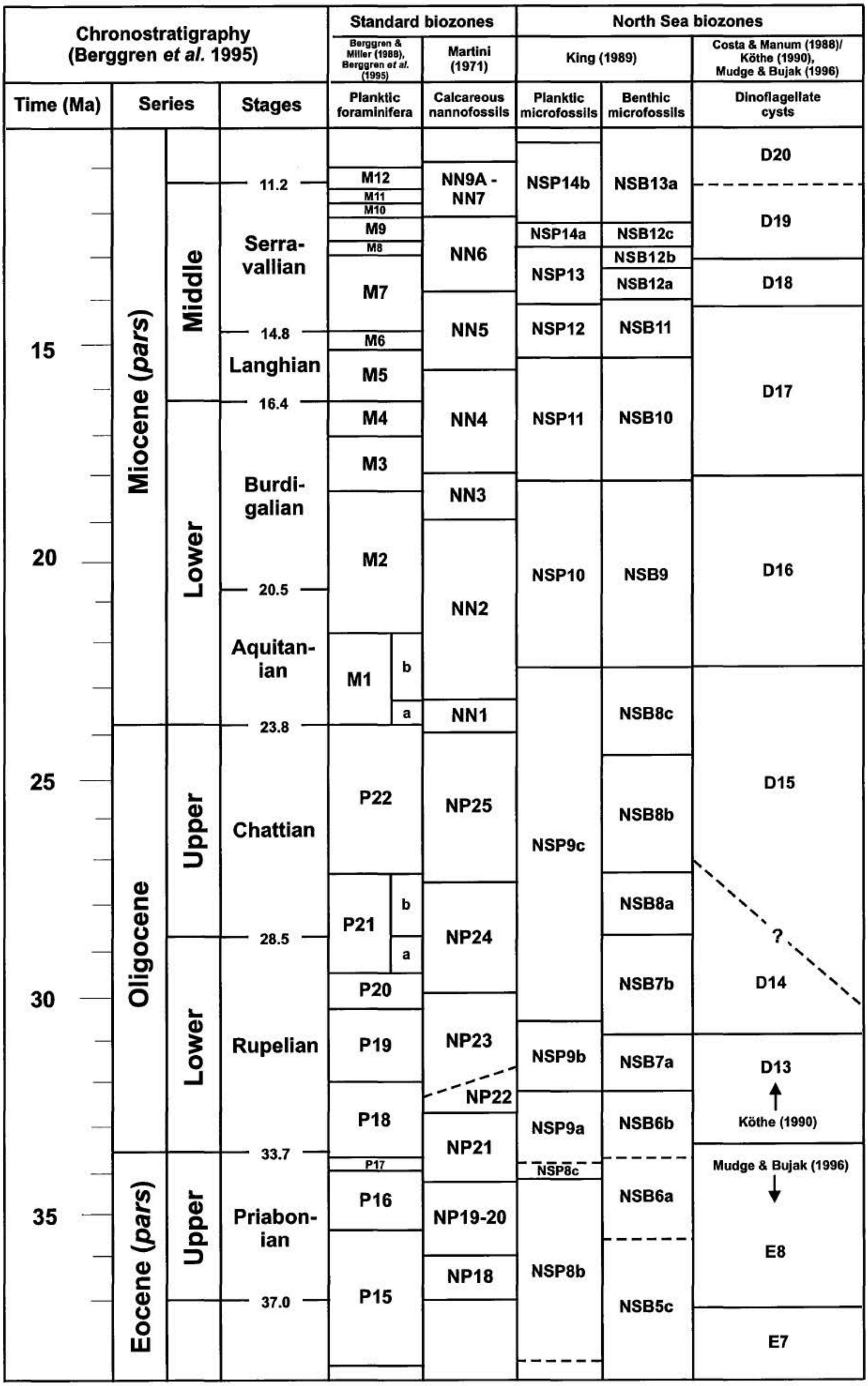
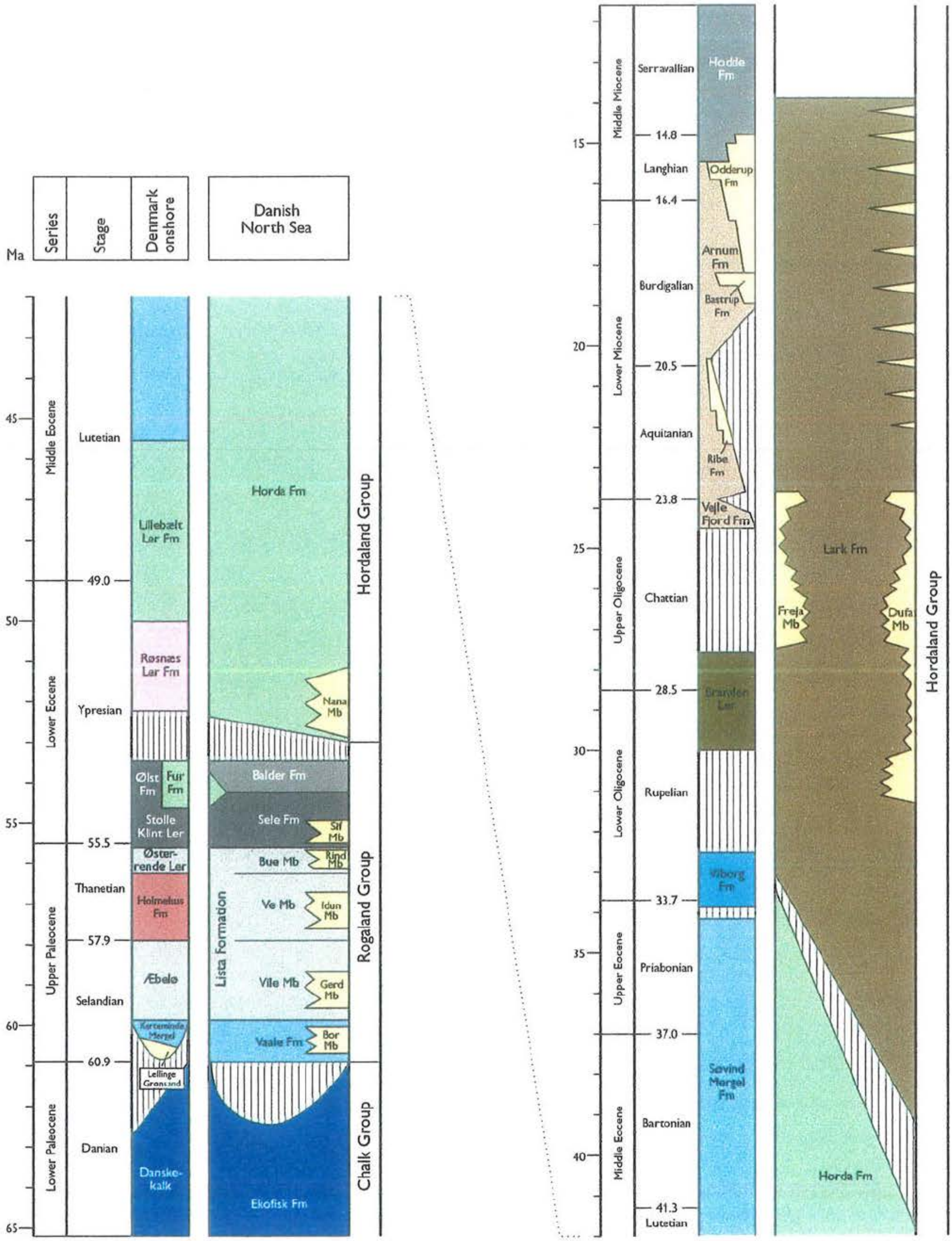

Chronostratigraphy (Berggren et al. 1995)
Standard biozones
North Sea biozones
Berggren & Miller (1988), Berggren et al. (1995)
Martini (1971)
King (1989)
Costa & Manum (1988)/ Köthe (1990), Mudge & Bujak (1996)
Time (Ma)
Series
Stages
Planktic foraminifera
Calcareous nannofossils
Planktic microfossils
Benthic microfossils
Dinoflagellate cysts
15
20
25
30
35
Miocene (pars)
Oligocene
Eocene (pars)
Middle
Lower
Upper
Lower
Upper
11.2
Serra-vallian
14.8
Langhian
16.4
Burdi-galian
20.5
Aquitan-ian
23.8
Chattian
28.5
Rupelian
33.7
Priabon-ian
37.0
M12
M11
M10
M9
M8
M7
M6
M5
M4
M3
M2
M1
b
a
P22
P21
b
a
P20
P19
P18
P17
P16
P15
NN9A - NN7
NN6
NN5
NN4
NN3
NN2
NN1
NP25
NP24
NP23
NP22
NP21
NP19-20
NP18
NSP14b
NSP14a
NSP13
NSP12
NSP11
NSP10
NSP9c
NSP9b
NSP9a
NSP8c
NSP8b
NSB13a
NSB12c
NSB12b
NSB12a
NSB11
NSB10
NSB9
NSB8c
NSB8b
NSB8a
NSB7b
NSB7a
NSB6b
NSB6a
NSB5c
D20
D19
D18
D17
D16
D15
?
D14
D13
Köthe (1990)
Mudge & Bujak (1996)
E8
E7

Fig. 3c



Ma
Series
Stage
Denmark onshore
Danish North Sea
45
50
55
60
65
Middle Eocene
Lower Eocene
Upper Paleocene
Lower Paleocene
Lutetian
Ypresian
Thanetian
Selandian
Danian
49.0
55.5
57.9
60.9
Lillebælt Ler Fm
Røsnæs Ler Fm
Ølst Fm
Fur Fm
Stolle Klint Ler
Øster-rende Ler
Holmehus Fm
Æbelø
Kerteminde Mergel
Lellinge Grønsand
Danske-kalk
Horda Fm
Nana Mb
Balder Fm
Sele Fm
Sif Mb
Bue Mb
Rind Mb
Ve Mb
Idun Mb
Vile Mb
Gerd Mb
Lista Formation
Vaale Fm
Bor Mb
Ekofisk Fm
Hordaland Group
Rogaland Group
Chalk Group
15
20
25
30
35
40
Middle Miocene
Lower Miocene
Upper Oligocene
Lower Oligocene
Upper Eocene
Middle Eocene
Serravallian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
14.8
16.4
20.5
23.8
28.5
33.7
37.0
41.3
Hodde Fm
Odderup Fm
Arnum Fm
Bastrup Fm
Ribe Fm
Vejle Fjord Fm
Branden Ler
Viborg Fm
Søvind Mergel Fm
Lark Fm
Freja Mb
Dufa Mb
Horda Fm
Hordaland Group

Fig.4

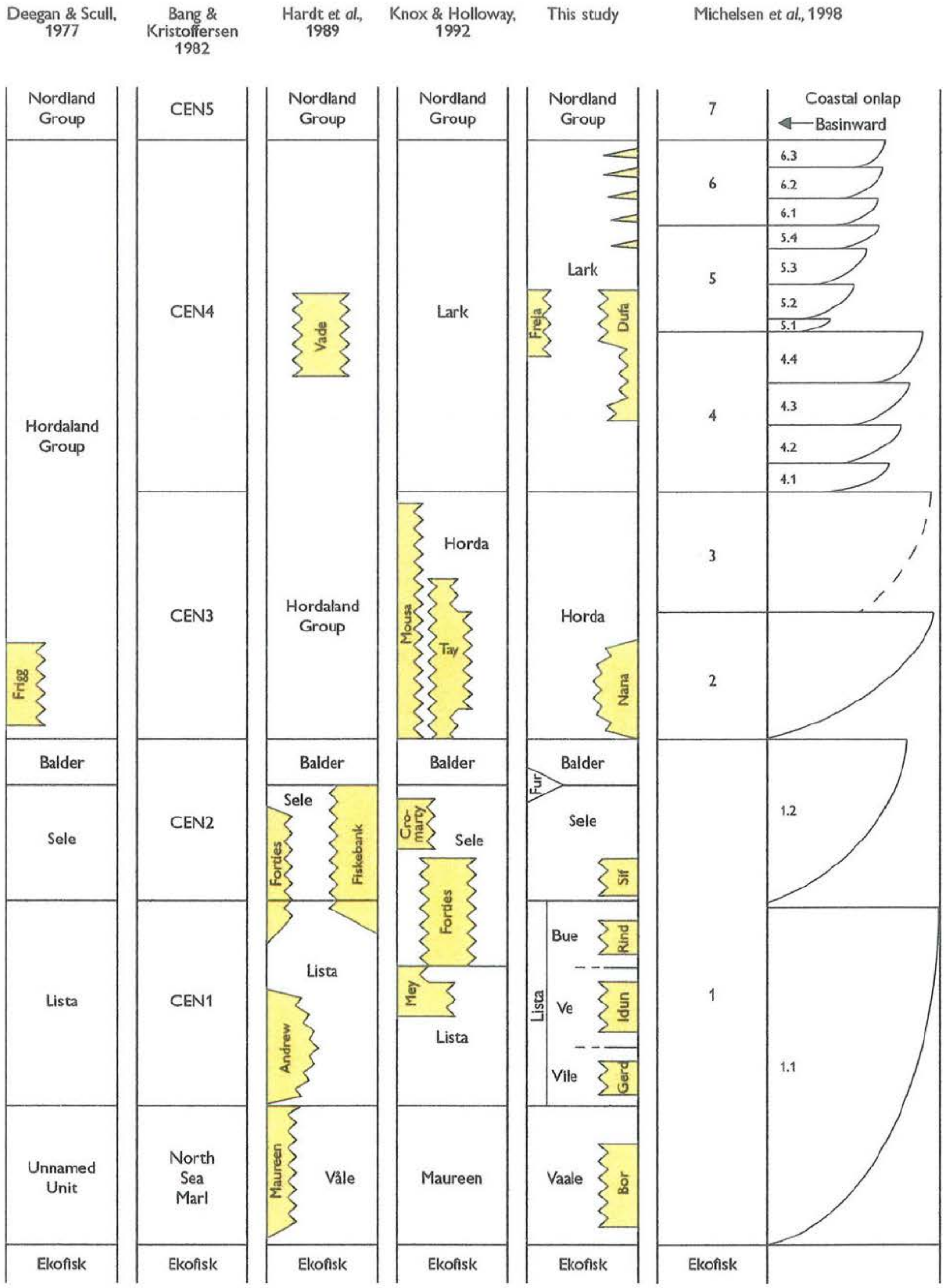

Deegan & Scull, 1977
Bang & Kristoffersen 1982
Hardt et al., 1989
Knox & Holloway, 1992
This study
Michelsen et al., 1998
Nordland Group
CEN5
Nordland Group
Nordland Group
Nordland Group
7
Coastal onlap
Basinward
6.3
6
6.2
6.1
5.4
Lark
5.3
5
5.2
5.1
4.4
CEN4
Vade
Lark
Freja
Dufa
4.3
4
Hordaland Group
4.2
4.1
Horda
3
Mousa
Tay
CEN3
Hordaland Group
Horda
2
Frigg
Nana
Balder
Balder
Balder
Balder
Sele
Fur
Cro-marty
Sele
Sele
CEN2
Forties
Fiskebank
Sele
1.2
Sif
Forties
Bue
Rind
Lista
Lista
CEN1
Mey
Lista
Ve
Idun
1
Andrew
Lista
Vile
Gerd
1.1
Unnamed Unit
North Sea Marl
Maureen
Våle
Maureen
Vaale
Bor
Ekofisk
Ekofisk
Ekofisk
Ekofisk
Ekofisk
Ekofisk

Fig.5