A SUMMARY CHART OF NEOGENE NANNOFOSSIL MAGNETOBIOSTRATIGRAPHY

Jeremy R. Young, Palaeontology Dept., The Natural History Museum, London SW7 5BD
Jose-Abel Flores, Univ. de Salamanca, Spain
Wuchang Wei, Scripps Inst. of Oceaography, Univ. of California, San Diego, USA
Incorporating workshop discussion contributions from:
Jan Backman, Bohumil Hamršmid, Shirley E. van Heck, Jan Krhovský, Isabella Raffi, Agata di Stefano, Giuliana Villa, Woody Wise

Introduction

This chart has been produced following discussion of Tertiary nannofossil zonations at the workshop on Tertiary Nannofossils during the VIth INA Conference, Salamanca 1993. Wei & Peleo-Alampay (1993) produced a table correlating the standard zonations of Martini (1971) and Okada & Bukry (1980) with the geomagnetic polarity time scale (GPTS) of Cande & Kent (1992), using recalibrated datum ages from Berggren *et al.* (1985), with some amendments. For the workshop this chart was extended to include various other nannofossil zonation schemes that have been proposed in the past 10 years, and some additional events. Workshop members discussed the details of the emended Wei & Peleo-Alampay chart and made various comments, particularly on the Neogene part, since we had most expertise in that part of the time scale. These comments were recorded by Shirley van Heck and are given below.

Workshop members noted that the correlations of Miocene nannofossil events with the geomagnetic record have been strongly revised in the last few years. These revisions have been systematically incorporated, as a result this is essentially a new chart and the zonal ages are often very different to those of Wei & Peleo-Alampay (1993). This chart only covers the Neogene. It is hoped to produce a similar chart for the Palaeogene later.

Warnings

- Within the zonations some names have been changed to modern forms, and secondary zonal markers are generally omitted.

- The correlation of Miocene nannofossil events to the GPTS is under active research and review. Changes of up to +/- 0.5 Ma in correlations are quite likely for most events. Revised ages for some Middle and Late Miocene nannofossil events will be given in the ODP Leg 138 Scientific Results (Raffi, Shackleton and others). Authoritative syntheses of Neogene nannofossil magnetostratigraphy are in preparation by Aubry and co-workers (as part of a revision of the Berggren *et al.* 1985 synthesis) and by Backman, Raffi and Rio (to be presented at the 1994 ODP Meeting in Aberystwyth).

- Even in good sections identification of magnetic anomalies and precise placement of nannofossil events is frequently difficult, and somewhat subjective.

- All events will be diachronous on some scale. Backman & Shackleton (1983) demonstrated that nannofossil events can be synchronous over long distances with precisions <0.05Ma, but for most events on the chart such precision has not yet been demonstrated.

- The chart was produced graphically and the positioning of lines is not highly precise, this gives a maximum resolution of +/- 0.1 Ma.

- The GPTS of Cande & Kent (1992) is itself liable to revision, particularly the age control points used to calibrate the magnetic sequence. This could easily result in changes of +/- 0.5Ma in the Miocene ages.

Notes on sources

The chart has been constructed by combining data from various sources as explained below.

GPTS of Cande & Kent (1992)

Cande & Kent (1992) presented a thoroughly revised magnetic polarity sequence, based on re-examination of the primary data (i.e. ocean-floor anomaly patterns). In addition they recalibrated this polarity sequence using the best available radiochronological data for selected time points. The resultant GPTS differs substantially the most widely used alternative, Berggren *et al.* (1985).

N.B. Cande & Kent (1992) use the nomenclature system for geomagnetic polarity intervals based on the sea-floor record - chron numbers C1-C7 on the chart. This sytem can extended by the use of suffixes to precisely refer to any interval, see Cande & Kent (1992, p. 13948-9). Older systems based on terrestial sequences use chron names (e.g. Brunhes) and numbers without a prefix (5-11 on the chart). These are included on the chart since they are used in many publications. For a longer explanation see Berggren *et al.* (1985, p.213).

Nannofossil event - magnetostratigraphy correlations

-Pleistocene and Late Pliocene: good correlations for most nannofossil events in this interval were available to Berggren *et al.* (1985) and these have not been revised here. Takayama (1993) and Raffi *et al.* (1993) give updated details of sources for these correlations.

-Early Pliocene and Miocene: When Berggren *et al.* (1985) produced their GPTS and stratigraphic chart virtually no Early Pliocene or Miocene sections were available with both a good geomagnetic record and good planktonic microfossil records. Subsequently a limited body of much better data has become available giving reliable nannofossil to magnetic anomaly correlations

(see table). This new data is used here to position the nannofossil events against the GPTS. N.B. In most cases the original authors correlated their events against the GPTS of Berggren *et al.* (1985) and so gave different numerical ages, Wei & Peleo-Alampay (1993) give an equation for precisely recalculating such ages.

The source for a magnetobiostratigraphic assignment is indicated on the chart by a reference number on the event line. Two reference numbers are only given when the data comes from different sites. When two or more authors have correlated an event at the same site only the *most recent* publication is indicated.

-*Uncorrelated events.* Nannofossil events for which no magnetic correlation data is available are only included here when they form zonal boundaries, and are shown by dotted lines.

-*Other syntheses:* Similar syntheses of magnetostratigraphy and nannofossil events have been made by e.g. Gartner (1990) and Takayama (1993). These do not include the data in Gartner (1992), and are calibrated to the Berggren *et al.* (1985) GPTS. New syntheses will doubtless be produced frequently, especially in ODP volumes.

Summary of DSDP & ODP Sites with good Miocene magnetostratigraphy

LEG	SITES	REFERENCES
DSDP 73	519, 521, 522	Poore *et al.* 1984, Tauxe *et al.* 84, Hsu *et al.* 84, Gartner 1990 (table integrating Miocene events), Olafsson & Villa 1992, also others on Palaeogene. *South Atlantic.*
DSDP 94	608	Takayama & Sato 1987, Baldauf *et al.* 1987 (synthesis), Olafsson 1991, Gartner 1992. *North Atlantic.*
ODP 115	710	Rio *et al.* 1990, Fornaciari *et al.* 1990, Backman *et al.* 1990. *Indian Ocean*

Integrated Miocene Nannofossil Zonation of Theodoridis (1984)

This is an alternative Miocene zonation scheme, based on Mediterranean, Atlantic and Indian Ocean sections and intended to be of general use. It is included here in order to facilitate use of Theodoridis (1984), which is one of the few monographs on Miocene nannofossils. Also it is noteworthy that the new data on placing of nannofossil events ("Other Events" column) strongly supports the qualitative sequence proposed by Theodoridis (1984), and the zonation includes several markers which deserve wider attention. N.B. Theodoridis (1984) used the genera *Eu-discoaster* and *Helio-discoaster* in place of *Discoaster*, his zones have been re-named here.

Notes on the chart - primarily from workshop discussion

(WD) - observation made during workshop discussion, as far as possible cited references have been used instead of this. Extensive discussions and notes on Neogene zonations are made by Theodoridis (1984), Rio *et al.* (1990), Fornaciari *et al.* (1990, 1993), Gartner (1992). Perch-Nielsen (1985) is the most widely used reference, and these notes are meant to supplement/update it.

NN 19-21

Pleistocene zonations are shown for comparison purposes only, and much additional data is omitted from the chart. For more details see e.g. Takayama & Sato (1987), Rio *et al.* (1990a), Young (1991), Takayama (1993), Raffi *et al.* (1993).

-Base CN14a, CN13b; there is some ambiguity as to where these events should be placed depending on the interpretation of *Gephyrocapsa* species adopted. Note that *G.caribbeanica* is an inappropriate name (Gartner 1991).

NN17

-*Discoaster pentaradiatus* LO; this may be somewhat diachronous, occurring earlier in high productivity environments (WD).

NN16

-*D. surculus* and *D. tamalis* LOs; these are both reliable events (WD).

NN15

-*Reticulofenestra pseudoumbilicus* LO; this is an abrupt event with simultaneous disappearance of specimens from 5μm to 10μm - Backman (1980), and Young (1990) give biometric data. Using >7μm as a size definition of *R. pseudoumbilicus* is convenient for biostratigraphy, but slight changes in the size definition do not change the location of the event.

NN14

-*Pseudoemiliania lacunosa* FO, *Gephyrocapsa* FO; these usually occur within NN14 (e.g Driever 1988) but they are gradational events and unsuitable for high resolution zonations (WD).

-Zone CN10D; this was added by Bukry (1981).

NN13-14

-Ambiguous ceratoliths; ceratoliths with optical properties intermediate between *Amaurolithus* and *Ceratolithus* are sometimes observed during this time interval (WD).

-*D. asymmetricus* and *D. tamalis* FOs; these can be useful, but in both cases are strictly first common occurrence events since rare specimens occur throughout the range of *D. brouweri*.

NN12

-*Ceratolithus acutus* range; some workshop members reported finding *C. acutus* above (co-occurring with *C. rugosus*, see also Rio *et al.*, 1990) or below (co-occurring with *D. quinqueramus*) the limits conventionally reported.

NN11

-*D. quinqueramus* LO; this can be problematic, due to rare or ambiguous specimens toward the top of its distribution. It is probably a diachronous event (WD).

-*Amaurolithus amplificus*; the restricted range within the upper part of NN11 reported by Bergen (1984) is confirmed by Rio *et al.* (1990), and is proving a useful event (WD).

-*Reticulofenestra rotaria*; this is a circular variant of *R. pseudoumbilicus*, it is distinctive but has rarely been reported. Flores *et al.* (1992) record its occurrence at the level described by Theodoridis (1984).

-*Minylitha convallis*; Rio *et al.* (1990) and Gartner (1992) report similar magnetobiostratigraphic correlations for both the FO and LO of *M. convallis*, and these agree with the sequential position of Theodoridis (1984). However, the abundance of *M. convallis* is, highly variable, probably due to ecological control and so it seems unsuitable as a standard marker species (WD).

-*D. quinqueramus* and *D. berggrenii* FOs;these appear to be synchronous. *D. berggrenii* is perhaps best regarded as a sub-species or variety of *D. quinqueramus* - distinguished by having a larger central area: free ray ratio. At the base of NN11 it is more common than typical *D. quinqueramus* and so makes a better marker. The uncertainty in the timing of this event at least partly reflects a lack of good sections. Rio *et al.* (1990) suggest that *D. quinqueramus/berggrennii* evolved gradationally from *D. bellus* and that this causes problems in event definition.

NN10

-small *Reticulofenestra* interval/ *R. pseudoumbilicus* paracme; Rio *et al.* (1990) and Young (1990) documented an event in mid NN10 during which large specimens of *Reticulofenestra* (>about 5µm) abruptly disappear. This event has been further documented by Gartner (1992) and Takayama (1993), and it is apparent in the data of Poore *et al.* (1984). Poore *et al.* (1984), Rio *et al.* (1990) and Gartner (1992) all correlate this event with the top of chron C4A, it is thus one of the best calibrated Miocene events.

This event is followed by an interval with assemblages dominated by small *Reticulofenestra* specimens. The reappearance of large specimens, in NN11, is a gradualistic process and it is not yet clear whether it can be used reliably for biostratigraphy. Rio et al. (1990) suggested use of the FO of *R. pseudoumbilicus* specimens >7µm long, this allows precise definition of a paracme (i.e. disappearance interval). The top of the small *Reticulofenestra* interval (Young 1990) is undefined but the term is slightly clearer, and so is used on the chart.

-*D. neorectus* FO; this event was used by Bukry (1973) to subdivide zone CN8 but it has rarely been used and its presence seems to inconsistent. The alternative marker, *D. loeblichii* FO, appears to be slightly more consistent, but this is not a common species (WD).

-*D. pentaradiatus* FO; this certainly occurs within NN10, but does not seem to be a good event for high resolution zonation since initial abundances are very low. (N.B. Theodoridis (1984) used the name *D. misconceptus* instead of *D. pentaradiatus*).

NN9

-CN7A,B subdivision; Bukry (1973) used the FO of *Catinaster calyculus* to divide CN7 into two subzones (CN7A & B). This does not seem to be consistently possible, and several authors have recorded *C. calyculus* occurring below the *D. hamatus* FO (Rio *et al.* 1990).

-*D. hamatus* FO; The age assignment of Gartner (1992) is used since the magnetostratigraphy of Site 608 was less ambiguous than that of Site 710, and since it agrees well with the *C. coalitus* FO record of Poore *et al.* (1984). Olafsson (1991) shows that *D. hamatus* is only abundant in the latter part of its range resulting in serious problems in defining its first occurrence, this may explain some of the discrepancies between reported levels.

-*D. bellus* FO; this occurs at or just below the *D. hamatus* FO (Theodoridis 1984, Rio *et al.* 1990, Gartner 1992 etc.).

NN6-8

A detailed revision of Mediterranean nannofossil zonation for this interval is in preparation by Agata di Stefano and co-workers.

NN7

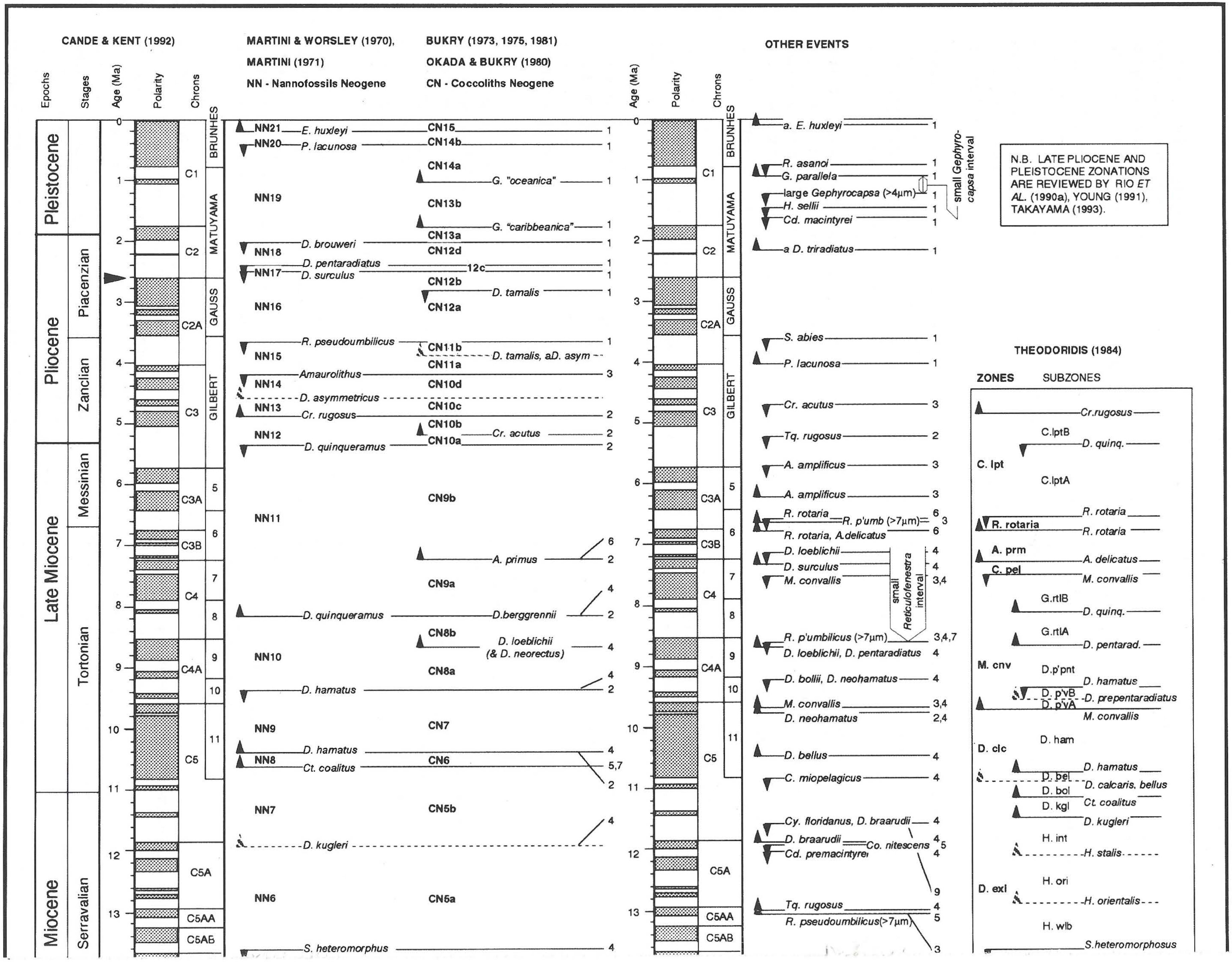
-*D. kugleri* FO; this is a difficult event to use since *D. kugleri* is usually rare and sporadic in distribution (WD, Rio *et al.* 1990). The level suggested by Gartner (1992) was based on very few specimens and so is a minimum age estimate, and has not been adopted on the chart.

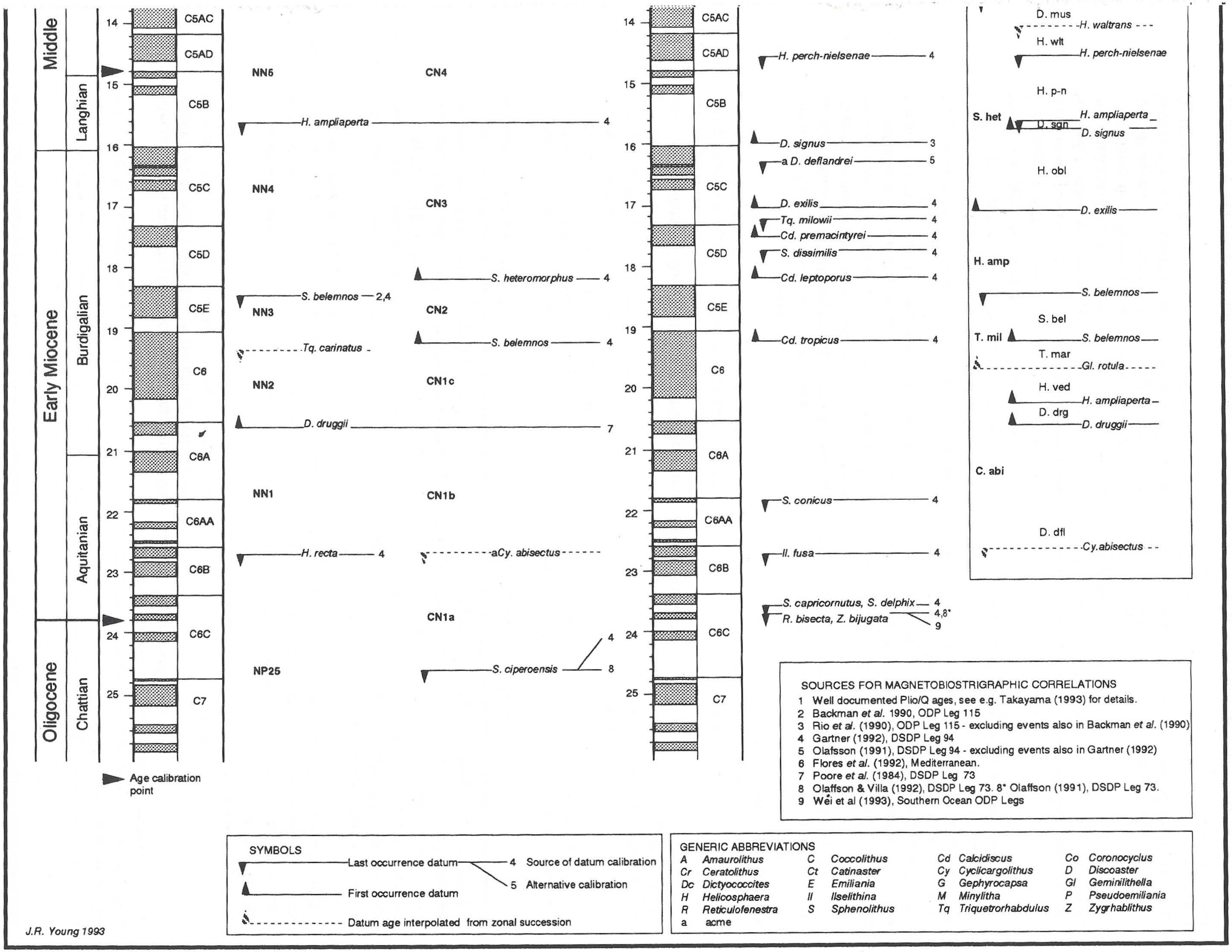
-*Cyclicargolithus floridanus* LO; Bukry (1973) , and Theodoridis (1984) used this as an alternative marker synchronous with the *D. kugleri* FO. The data of Gartner (1992) supports this but much lower FOs have been recorded by e.g. Fornaciari *et al.* (1993) and Wei *et al.* (1993). Evidently this event is strongly diachronous, occurring at widely varying levels within NN6.

NN6

-*Coronocyclus nitescens* LO; this may be a good alternative indicator of the NN7 base, Fornaciari *et al.* (1990) provide quantitative data.

-*R. pseudoumbilicus* (>7µm) FO this has been documented occurring near the NN5/6boundary by Rio *et al.* (1990), Olafsson (1991), Fornaciari *et al.* (1993) and Takayama (1993), it is, however, a gradational event and appears to be somewhat diachronous (Fornaciari *et al.* 1993).


CANDE & KENT (1992)
Epochs
Stages
Age (Ma)
Polarity
Chrons
MARTINI & WORSLEY (1970), MARTINI (1971)
NN - Nannofossils Neogene
BUKRY (1973, 1975, 1981) OKADA & BUKRY (1980)
CN - Coccoliths Neogene
OTHER EVENTS
Pleistocene
Pliocene
Late Miocene
Miocene
Piacenzian
Zanclian
Messinian
Tortonian
Serravalian
BRUNHES
MATUYAMA
GAUSS
GILBERT
C1
C2
C2A
C3
C3A
C3B
C4
C4A
C5
C5A
C5AA
C5AB
NN21
NN20
NN19
NN18
NN17
NN16
NN15
NN14
NN13
NN12
NN11
NN10
NN9
NN8
NN7
NN6
E. huxleyi
P. lacunosa
D. brouweri
D. pentaradiatus
D. surculus
R. pseudoumbilicus
Amaurolithus
D. asymmetricus
Cr. rugosus
D. quinqueramus
D. hamatus
Ct. coalitus
D. kugleri
S. heteromorphus
CN15
CN14b
CN14a
CN13b
CN13a
CN12d
12c
CN12b
CN12a
CN11b
CN11a
CN10d
CN10c
CN10b
CN10a
CN9b
CN9a
CN8b
CN8a
CN7
CN6
CN5b
CN5a
G. "oceanica"
G. "caribbeanica"
D. tamalis
D. tamalis, aD. asym
Cr. acutus
A. primus
D.berggrennii
D. loeblichii (& D. neorectus)
a. E. huxleyi
R. asanoi
G. parallela
large Gephyrocapsa (>4µm)
H. sellii
Cd. macintyrei
a D. triradiatus
small Gephyrocapsa interval
S. abies
P. lacunosa
Cr. acutus
Tq. rugosus
A. amplificus
A. amplificus
R. rotaria
R. p'umb (>7µm)
R. rotaria, A.delicatus
D. loeblichii
D. surculus
M. convallis
small Reticulofenestra interval
R. p'umbilicus (>7µm)
D. loeblichii, D. pentaradiatus
D. bollii, D. neohamatus
M. convallis
D. neohamatus
D. bellus
C. miopelagicus
Cy. floridanus, D. braarudii
D. braarudii
Co. nitescens
Cd. premacintyrei
Tq. rugosus
R. pseudoumbilicus(>7µm)
N.B. LATE PLIOCENE AND PLEISTOCENE ZONATIONS ARE REVIEWED BY RIO ET AL. (1990a), YOUNG (1991), TAKAYAMA (1993).
THEODORIDIS (1984)
ZONES
SUBZONES
Cr.rugosus
C.lptB
D. quinq.
C. lpt
C.lptA
R. rotaria
R. rotaria
R. rotaria
A. prm
A. delicatus
C. pel
M. convallis
G.rtlB
D. quinq.
G.rtlA
D. pentarad.
M. cnv
D.p'pnt
D. hamatus
D. p'vB
D. p'vA
D. prepentaradiatus
M. convallis
D. ham
D. clc
D. hamatus
D. bel
D. calcaris, bellus
D. bol
Ct. coalitus
D. kgl
D. kugleri
H. int
H. stalis
D. exl
H. ori
H. orientalis
H. wlb
S.heteromorphosus



Middle
Langhian
Early Miocene
Burdigalian
Aquitanian
Oligocene
Chattian
C5AC
C5AD
C5B
C5C
C5D
C5E
C6
C6A
C6AA
C6B
C6C
C7
NN5
NN4
NN3
NN2
NN1
NP25
CN4
CN3
CN2
CN1c
CN1b
CN1a
H. ampliaperta 4
S. heteromorphus 4
S. belemnos 2,4
S. belemnos 4
Tq. carinatus
D. druggii 7
H. recta 4
aCy. abisectus
S. ciperoensis 4 8
H. perch-nielsenae 4
D. signus 3
a D. deflandrei 5
D. exilis 4
Tq. milowii 4
Cd. premacintyrei 4
S. dissimilis 4
Cd. leptoporus 4
Cd. tropicus 4
S. conicus 4
Il. fusa 4
S. capricornutus, S. delphix 4
R. bisecta, Z. bijugata 4,8* 9
D. mus
H. waltrans
H. wlt
H. perch-nielsenae
H. p-n
S. het
D. sgn
H. ampliaperta
D. signus
H. obl
D. exilis
H. amp
S. belemnos
S. bel
T. mil
S. belemnos
T. mar
Gl. rotula
H. ved
H. ampliaperta
D. drg
D. druggii
C. abi
D. dfl
Cy.abisectus
Age calibration point
SOURCES FOR MAGNETOBIOSTRIGRAPHIC CORRELATIONS
1 Well documented Plio/Q ages, see e.g. Takayama (1993) for details.
2 Backman et al. 1990, ODP Leg 115
3 Rio et al. (1990), ODP Leg 115 - excluding events also in Backman et al. (1990)
4 Gartner (1992), DSDP Leg 94
5 Olafsson (1991), DSDP Leg 94 - excluding events also in Gartner (1992)
6 Flores et al. (1992), Mediterranean.
7 Poore et al. (1984), DSDP Leg 73
8 Olaffson & Villa (1992), DSDP Leg 73. 8* Olaffson (1991), DSDP Leg 73.
9 Wei et al (1993), Southern Ocean ODP Legs
SYMBOLS
Last occurrence datum
4 Source of datum calibration
5 Alternative calibration
First occurrence datum
Datum age interpolated from zonal succession
GENERIC ABBREVIATIONS
A Amaurolithus
Cr Ceratolithus
Dc Dictyococcites
H Helicosphaera
R Reticulofenestra
a acme
C Coccolithus
Ct Catinaster
E Emiliania
Il Ilselithina
S Sphenolithus
Cd Calcidiscus
Cy Cyclicargolithus
G Gephyrocapsa
M Minylitha
Tq Triquetrorhabdulus
Co Coronocyclus
D Discoaster
Gl Geminilithella
P Pseudoemiliania
Z Zygrhablithus
J.R. Young 1993

NN4

-*Helicosphaera ampliaperta* LO; this is often problematic since *H. ampliaperta* is very often absent from open ocean samples (eg. Rio *et al.* 1990). The FO of *D. signus* and *D. tuberi* occur just below this level, and are often better markers (Rio *et al.* 1990). Also *D. deflandrei* becomes much less abundant, ceasing to dominate discoaster assemblages (Rio *et al.* 1990, Olafsson 1991, Fornaciari *et al.* 1993). *D. tuberi* Filewicz (1985) is arguably a junior synonym of *D. petaliformis* Moshkovitz (1980), and *E. signus* Bukry (1971) emend Theodoridis (1984) is also very similar.

-FO *D. exilis;* it is very hard to produce a consistent definition of *D. exilis,* or to use it in zonations (WD). Gartner (1992) suggests that since the LO of *Triquetrorhabdulus milowii* occurs just below the FO of *D. exilis* the two may constitute a useful joint level.

-*Calcidiscus tropicus* FO. This is essentially the FO of *Calcidiscus* - Gardner (1992) suggests that *Cd. macintyrei* should be restricted to the large Pliocene forms, whilst the smaller Miocene circular *Calcidiscus* specimens are placed in *Cd. tropicus.* This also resolves the taxonomic problem of the priority of *Cd. tropicus* discussed by Gartner *et al.* (1984).

NN3/4

Quantitative data on the distribution of *Sphenolithus heteromorphus* and *S. belemnos* is given by Olafsson (1989) and Fornaciari *et al.* (1993).

-*Triquetrorhabdulus carinatus* LO; this seems to be a very unreliable event, with distribution of *T. carinatus* being sporadic. Quantitative data on the distribution of *Triquetrorhabdulus* spp. is given by Olafsson (1989) and Fornaciari *et al.* (1990, 1993).

NN1

-*D. druggii* FO; this can be difficult to use and is only poorly correlated with the magnetostratigraphy, but it remains one of the very few markers within this interval (WD). Rio *et al.* (1991) and Fornaciari *et al.* (1993) record a sharp acme of *Sphenolithus delphix* just below the *D. drugii* FO.

-*Cyclicargolithus abisectus* LO; this is a size reduction event, with specimens over about 11µm disappearing, it is not sharp. Olafsson (1992) documents it in detail and suggests it unsuitable as a zonation event.

-*Helicosphaera recta* LO; Gartner (1992) notes that *H. recta* is rare toward the end of its range, but unmistakable. His record of a LO significantly above that of *S. ciperoensis* is in line with other workers experience (WD). Fornaciari *et al.* (1993) suggest that the NN1/NP25 boundary should be formally redefined at the LO of *S. ciperoensis.*

-*H. carteri*; this is gradational and unsuitable for high resolution work but occurrence of *H. carteri* is a good indicator of Neogene age, typical specimens do not occur in the Palaeogene (WD).

NP25

-*Reticulofenestra bisecta* (syn *Dictyococcites scissura*) LO; this is a less distinct event than the *S. ciperoensis* LO (Fornaciari *et al.* 1990) but is observable at higher latitudes (Wei *et al.* 1993), and in worse preserved samples (WD).

Taxonomic references for species not in Perch-Nielsen (1985)

Calcidiscus premacintyrei Theodoridis (1985).
Calcidiscus tropicus Kamptner (1956) emend Gartner (1992).
Discoaster tuberi Filewicz (1985).
Helicosphaera stalis Theodoridis (1984).
Helicosphaera waltrans Theodoridis (1984).
Reticulofenestra asanoi Sato & Takayama (1992)
Reticulofenestra bisecta (Hay, Mohler & Wade 1966) Roth (1970).
Reticulofenestra rotaria Theodoridis (1984).

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