PALEOGENE SEQUENCE BOUNDARIES: GLOBAL EVENTS?

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Introduction

An essential assumption of the sequence stratigraphic paradigm is that sequence boundaries are time lines that resulted from eustatic events. Unconformable sequence boundaries separate older from younger strata but the ages of the bounding strata commonly change from section to section because erosion has differentially removed rock below and deposition of the younger sequence resumed at different times. Elaborate charts of proposed global events have been constructed based on sections in many basins (de Graciansky *et al.* 1998). The individual sequences are identified in different basins by their associated fossil zones.

Two challenges confront the application of the global chart. First is the correct identification of a sequence in a section, and second is testing its global synchroneity by the precise correlation of a sequence from basin to basin to. The standard procedure is to identify a sequence by its zonal content and to compare with a chart. However, some sequences have durations of less than one million years and most fossil zones are longer than a million years. Furthermore, in a given section it is difficult to determine where within the fossil range a sequence contact lies. Consequently a different technique is required to measure precisely the age of strata at a contact and to accurately determine the equivalency of sequence contacts between sections. Graphic correlation utilizing a global multidisciplinary integrated data base is such a proven technique (Mann and Lane 1995).

Methodology

The Paleogene Composite Standard (CS) data base consists of biostratigraphic, magnetostratigraphic, geochemical, and sequence stratigraphic data assembled by graphic correlation into a mega-annum scale from thirty-one reference outcrop and core hole sections published by recognized experts. The software, GraphCor©, was used to conduct the graphic correlation experiments.

The data base spans the Paleogene Period beginning within the Campanian and ending in the top of the Early Miocene. The epochs have been included because the data provide complete ranges of fossils and other types of chronostratigraphic markers so that the calibration with radiometric time can be much more certain.

The selection of reference sections (Pal.n) was based mainly on the experience of experts in the Paleogene. Sections were chosen that have no or few unconformities and have a diverse set of chronostratigraphic marker events that result in a multidisciplinary data base. The standard reference section is the chronostratigraphic and magnetochronostratigraphic chart of Berggren *et al.* (1995).

The basic assumption of the Paleogene CS data base is that the ages of the magnetochrons presented by Berggren *et al.* (1995) are accurate. Theirs is the most recent geomagnetic polarity time scale and it has benefited from the most current evaluations of reference sections, radiometric tie points, and careful interpolation of chron ages between the tie-points. The Berggren scale is tied at the Cretaceous-Tertiary boundary by an age of 65.00 Ma and at the beginning of the Thvera Subchron C3n.4n by an age of 5.23 Ma, which was derived by astrochronlogical analysis. The ages of the intervening magnetochrons were interpolated by a cubic spline function (Berggren *et al.* 1995). These ages are the bases of the time scale of the Paleogene CS, and fossil ranges were set in the CS by graphing chrons in the fossiliferous sections to the chron ages in the Berggren scale. In many graphs the LOC follows exactly the chrons, but in some cases the LOC segments spanned more than two chrons in order to simplify the interpretations. Consequently, the intervening chrons fall to the right of the LOC. It is clear that interpretation of the magnetic data in many DSDP-ODP sections has been affected by the coring process and by the sampling scale. An additional problem is that the identification of the chrons is not everywhere unequivocal. In fact, in some sites more than one interpretation of the chron identities is provided. However, the graphing process attempted to maintain the chron ages within the same range as given by Berggren; only a few have been extended into a slightly younger age. To test the accuracy and precision of the Paleogene CS age scale eight radiometric dates in five sections were graphed into the CS. These tie points confirm that the scale is correct within the error bar of the radiometric date.

Tops and bases of more than 1200 fossil planktic and benthic foraminifers, nannofossils, and dinoflagellates were taken from reports published by the DSDP-ODP scientific staff and from selected published outcrop and drill hole sections. Tops either well above the consistent occurrence or present in trace amounts were not used in the case they were re-worked. Likewise, bases well below the consistent occurrence were generally not used. Following the initial graphing process, three additional graph experiments of each section were evaluated in order to stabilize range changes and to test for unexpectedly high or low range extensions. In some sections, unconformities were suggested by the graph data to prevent unusually great extensions, and these breaks were generally substantiated by lithological data.

The ranges of some key fossils defined in the Paleogene Composite Standard (CS) differ from the ages presented by Berggren *et al.* (1995). Previous workers have noted that ranges of some taxa are diachronous in various sections. About one-third of the planktic foram tops/bases are essentially the same as published and more than half of the nannofossil tops/bases are the same. Also, bioevents defined in a reference section may actually have longer ranges in other sections. Thus, utilization of zonal concepts will result in diachronous correlations. In each section the line of correlation (LOC) has been carefully evaluated to ensure that ranges have not been artificially extended by the process of graphic correlation. In some sections the position of an unconformity has been carefully placed between closely spaced samples so that bases and tops are not extended.
A relatively stable fossil range can be achieved by its inclusion in a minimum of four sections. This standard is reached by 52% of the nannofossil taxa, by 46% of the planktic foraminifers, by 17% of the benthic foraminifers.

Results
Depositional cycles represent genetically related strata in transgressive-regressive phases separated by regional subaerial or submarine erosional unconformities or by marine condensed sections. Numerous such contacts were recognized in key sections by the original investigators of the sections and graphed into the Paleogene CS (Table 1). The contacts of depositional sequences in the southwest Alabama composited section (Pal.25) and the two sections on the Isle of Wight (Pal.26 & .27) have been defined in the CS as marker beds (MB). Their ages are defined by the LOC of each section. In some sections the hiatus of the unconformity was indicated on the graph by a shift on the X-axis time scale but in other sections no shift was defined. The age span of each hiatus was compared with hiatuses in other sections to determine the minimum age span, if any, of each hiatus. In each section the hiatus represents a contact of erosion or of non-deposition bracketed by the ages of underlying and overlying strata. The age of the cycle boundary is the age of the oldest strata overlying the defining unconformity.

The Alabama Paleogene section defines eighteen traceable sequence boundaries (SB) calibrated by foraminifers and nannofossils and defined by abrupt lithological changes and facies shifts. The sixteen Paleogene sequences range in duration from 0.14-4.30 m.y. and the mean is 1.51 m.y.

In southern England five sequence boundaries divide the Eocene Bracklesham Formation. Sequence boundary T1 spans from 51.50-51.30 Ma, which in Alabama correlates within the age span of SB TE2.1 between the Hatchetigbee and Tallahatta Formations. SB T2 and T3 in the Bracklesham span 50.83-49.80 Ma and 48.26-48.58 Ma respectively and correlate within the conformable Tallahatta. SB T4 spanning 47.00- 45.90 Ma is within the duration of SB TE2.2 at 45.95-45.29 Ma between the Tallahatta and the Lisbon Formation in the Gulf Coast. SB T5 spanning 43.15-42.98 Ma is slightly older than SB TE2.4 at the base of the upper Lisbon at 42.75 Ma. Twenty-one unconformities within the Paleogene correlate globally confirming that they record global changes in sea level or oceanic water mass conditions.

These sequence cycles are named by the first initial of the series and numbered from older to younger. In graphs of future sections these cycle ages can be projected into the new section by the LOC to test the time equivalency of contacts in the new section. This procedure provides an objective and testable method to identify global cycles in new sections.

The $d^{18}O$ and $d^{13}C$ isotopic shifts (relative to PDB) measured on planktic foraminifers in the ODP 748 core hole (Pal.9) were set as geochemical marker events. These geochemical events together with paleo-biological and sedimentological criteria signal the development of continental Antarctic glaciers (Wise *et al.* 1991). Prothero (1994) called it the 'Oligocene deterioration' implying climatic change. These isotopic markers of global climatic change are dated at 32.24 Ma by GC. This geochemical shift is within the depth interval of ice-rafted debris (IRD) of quartz and feldspar sand in ODP 748, which is dated at 32.26-32.22 Ma by GC. Prothero (1994) reported this isotopic shift in Chron 13n, which Berggren *et al.* (1995) dated at 33.058-33.545 Ma. This shift is actually within Chron 12r in ODP 748 and is about 1.5 m.y. younger than the Eocene-Oligocene boundary at 33.7 Ma. IRD also was reported in the basal Oligocene section in ODP 744 (Pal.10) within the basal interval of Chron 13n and is dated by GC to be 33.73-33.68 Ma. Thus the onset of Antarctic glaciation spanned at least a period of 1.5 m.y.

Two closely spaced iridium anomalies are known from Upper Eocene sections in DSDP Site 592 and in the Italian pelagic succession near Gubbio (Montanari 1990). In the Massignano section (Pal.22) the anomalies of 199 ppt Ir at 5.61 m above base of section and of about 36 ppt at 6.12-6.19 m are likely of impact origin (Eoc iridium anomalies 1 and 2 respectively) (Montanari *et al.* 1993). They are dated by GC at 35.81 and 35.67-35.65 Ma, which is slightly older than the ages of 35.7 and 35.0 Ma interpolated by Montanari *et al*. (1993). In ODP 689B

(Pal.20) an Ir anomaly of 160+ ppt is at 128.8 mbsf in Chron C16n (Montanari *et al*. 1993). This position on the LOC indicates a decreased rate of sediment accumulation and an age of 35.81 Ma for the Ir spike, which correlates it with Eoc iridium anomaly 1.
Tektite layers are consistently associated with the iridium anomalies. Stratigraphic and chemical data suggest that two to four layers can be distinguished. In the Paleogene CS database the microtektite layer in DSDP 612 (Pal.23) at a depth of 181.37-181.31 mbsf is dated by GC at 35.70 Ma. Obradovich *et al.* (1989) dated tektite fragments from this layer at 35.5±0.3 Ma by the $^{40}Ar/^{39}Ar$ method.

Conclusions

Graphic correlation is a technique that has the precision and accuracy required for the consistent identification and correlation of sequences to test their synchroneity and thus their potential as records of eustatic events.

Twenty-one unconformities within the Paleogene correlate globally confirming that they record global changes in sea level or oceanic water mass conditions.

The $d^{18}O$ and $d^{13}C$ isotopic shifts that signal the development of continental Antarctic glaciers spanned at least a period of 1.5 m.y. beginning at 33.73-33.68 Ma and continuing to 32.26-32.22 Ma.

Two closely spaced Late Eocene iridium anomalies are dated by GC at 35.81 Ma and 35.67-35.65 Ma. One of the several associated tektite layers is dated by GC at 35.70 Ma.

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Table 1. Mega-annums and designations of global depositional sequences based on sections in Alabama (Ala) by Mancini and Tew (1992) (Pal.25), in the Isle of Wight, southern UK (IOW) by Plint (1989) (sections Pal.26 & 27), and other sections.

Depositional Cycles	Sequence Ages
Recognized elsewhere	SB - 23.30 - M1
Recognized elsewhere	SB - 25.00 - O4
Recognized elsewhere	SB - 27.30 - O3
Recognized elsewhere	SB - 30.00 - O2
Ala Sequence TO1.1	SB - 33.20 - O1
Ala Sequence TE3.3	SB - 34.85 - E11
Ala Sequence TE3.2	TS - 37.50 - E10
Ala Sequence TE3.1	SB - 39.70 - E9
Ala Sequence TE2.4	local 42.75
IOW Transgressive contact T5	SB - 43.00 - E8
Ala Sequence TE2.3	SB - 44.10 - E7
Ala Sequence TE2.2	local 45.95-45.29
IOW Transgressive contact T4	SB - 45.90 - E6

IOW Transgressive contact T3	SB - 48.60 - E5
IOW Transgressive contact T2	local 50.83-49.80
Ala Sequence TE2.1	SB - 50.30 - E4
IOW Transgressive contact T1	SB - 51.30 - E3
Ala Sequence TE1.1	SB - 53.00 - E2
Ala Sequence TP2.3	SB - 55.50 - E1
Ala Sequence TP2.2	SB - 57.20 - P6
Ala Sequence TP2.1	SB - 58.45 - P5
Ala Sequence TP1.5	local 58.56
Ala Sequence TP1.4	SB - 60.65 - P4
Ala Sequence TP1.3	SB - 62.00 - P3
Ala Sequence TP1.2	SB - 63.65 - P2
Ala Sequence TP1.1	SB - 65.00 - P1