Revised Chronology of Neogene DSDP Holes from the World Ocean

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Abstract

After nearly 30 years of growth in geochronologic knowledge, the originally published age models for many older deep sea marine sections have become badly outdated. In this report we present newly revised age models for Neogene sediments from 94 DSDP holes. Biostratigraphic data for planktonic foraminifers, calcareous nannofossils, diatoms and radiolarians, paleomagnetic and other stratigraphic data were compiled from the original Initial Reports volumes of DSDP. The Berggren et al. (1985) scale was used for the age of magnetic reversals, and a variety of recent papers were used to establish a standard modern set of calibrations for marine microfossil events to the magnetic reversal scale. New age vs depth plots were made for each hole, and for each a new line of correlation was created. All tabulated stratigraphic data, new age models, and age depth plots are given as appendices to the report.

Introduction

Geochronology of deep-sea sediments has been one of the most rapidly advancing specialties within the general field of geochronology. Three decades of deep sea drilling, first by the Deep Sea Drilling Project (DSDP) and later by its successor, the Ocean Drilling Program (ODP), have provided a wealth of material for continual improvements in marine micropaleontology, isotope stratigraphy, and more recently magnetostratigraphy. Sucessive new fossil species, biostratigraphic zones, magnetochronologic scales, and standard stable isotope curves have been developed to improve the precision and accuracy of deep-sea sediment dating. The availability of high quality age models for numerous deep-sea sections has been a key component in the development of the science of paleoceanography, permitting rate calculations, correlation and synthesis of global data sets for the study of oceanographic processes.

Precisely because of this success, it has become imperative to review the geochronology of previously drilled deep-sea holes, particularly those drilled by DSDP many years ago. Although a selected few individual holes have been re-examined by subsequent authors, funding constraints and the continued flow of new sections needing primary study have so far prevented any reasonably systematic review of older materials. As a result, it is not possible to directly compare, with an acceptable degree of accuracy, the reported age of materials from older holes with the supposedly equivalent aged material in newer holes. Both our understanding of biostratigraphy, and its calibration to the geochronologic time scale, have altered too much to make this feasible. In this report, we begin to address this problem by re-appraising and revising the chronology of Neogene sediments from nearly 100 of the more important DSDP holes. Although this effort is, even for the Neogene, incomplete, and is itself subject to eventual obsolecensce, we believe it represents a useful source of updated chronologic information which will be useful to any scientist wishing to work with these sections. A more comprehensive revision of DSDP (and ODP) hole chronologies, including many more holes, and older time intervals such as the Paleogene, is also much needed, but unfortunately beyond the scope of our initial effort.

Development of such a large number of new age models has been a major effort, and has been motivated in part by the needs of another, even more ambitious project to develop a computer database of marine micropaleontological and chronostratigraphic data. This database holds the complete microfossil range chart data for numerous deep sea sections (both DSDP and ODP), and uses the age models presented here, together with additional information on microfossil taxonomy, to retrieve and report microfossil stratigraphic and biogeographic data using a single, consistent taxonomic and chronologic framework. In our initial work we have entered into the database only data from the four main groups of marine microfossil plankton - diatoms, planktonic foraminifers, calcareous nannofossils, and radiolarians. The database itself is described by Lazarus (1994), while initial applications of research using the database are given by Spencer-Cervato et al. (1993), Spencer-Cervato et al. (1994), and Thierstein et al. (in prep.).

Material and Methods

The work described here proceeded through several different steps: hole selection; compilation of a standard set of calibrated biostratigraphic, magnetostratigraphic and other events; compilation of stratigraphic data from each hole; creation of a new age model for each hole; evaluation and final compilation of results.

Hole Selection - We began our work by searching through the Initial Reports of the Deep Sea Drilling Project and Scientific Results volumes of the Ocean Drilling program (through Leg 120, the latest Leg to be published when our project began) to locate holes that met our selection criteria. These criteria included good core recovery, relatively continous coring, several stratigraphic intervals recovered, and good microfossil preservation. Given our longer-range goal of using the newly developed age models in a database of marine microfossil range chart and geographic data, we gave preference to holes with extensive range chart data for microfossils, and to including the equilavent at least one complete Neogene section for each biogeographic region in the modern plankton. These selection criteria were frequently in conflict, as it was often the case that only older holes with relatively incomplete recovery had detailed range chart data available; holes often had good paleontological data for only one fossil group, etc. We also had to keep our selection to a managable upper limit of about 100 or so holes. More would be desirable, but we did not have time or resources to handle them. The result of our survey was a ranked list of 94 DSDP and 33 ODP holes (Figure 1). There are many additional Neogene holes, some of considerable importance, which we could not include due to the above limitations, for this we must ask the reader's indulgence. In the interest of saving space, time, and also in consideration of their relatively modern data set, we do not include any data or age-model results in this report for the ODP holes selected. These may be included in a later report.

Compilation of stratigraphic event ages - One of the primary goals of our effort was to produce a set of age models to a single, internally consistent standard chronologic scale. Such scales are complex entities, comprising several linked correlation steps. For marine microfossils, the two most important are the correlation between biostratigraphic events and the paleomagnetic reversal sequence; and the correlation of the paleomagnetic reversal sequence to geochronology. The former is based on joint biostratigraphic/paleomagnetic studies, and for most individual biostratigraphic events tends to change with advancing knowledge only infrequently, although (see below) if an event is diachronous, calibrations based in one geographic area may later be found to be systematically incorrect when applied outside this area. Calibration between the geomagnetic reversal sequence and absolute chronology in millions of years is a more complex endeavour, and has altered more frequently with the publication of new scales. At the time the project began, the Berggren et al. (1985) scale was very widely used, and was chosen as the standard for our project. Newer scales have since become available (Cande and Kent, 1992; Berggren et al., in prep). Although eventually all of our work will need revision, so long as the calibration between biostratigraphic events and the geomagnetic polarity sequence has not changed, one can in most cases convert our data - both stratigraphic data files and the age models created from them - to the newer scales by a direct conversion based on the differences in ages for geomagnetic events given by the Berggren et al. (1985) scale and the newer scale of interest.

Diachony of biostratigraphic events presents a particular problem to which, as yet, we do not have entirely adequate solutions. Indeed, it has only been in the last few years that marine biostratigraphers have become aware of the full extent of the problem. Spencer-Cervato et al. (1994) for example recently concluded that at least one third of the biostratigraphic events used in this study are systematically diachronous by more than 1 m.y. At the time of this writing, no general solution to the problem has been developed, although it would seem that a set of several regional calibrations for biostratigraphic events would substantially reduce the severity of the problem. For the diatoms and radiolarians regional zonations and calibrations have in fact long been the norm, and separate regional calibrations of biostratigraphic events to the magnetic reversal sequence were used in the present study. These included for the diatoms: Barron (1981, 1985a, 1985b), Berggren et al.

(1985), Gersonde and Burckle (1990), Harwood and Maruyama (1992), Koizumi and Tanimura (1985), Mikkelsen (1990); and for the radiolarians: Goll (1989), Hays (1970), Hays and Opdyke (1967), Johnson and Nigrini (1985), Morley (1985), Lazarus (1992b), Nigrini (1991), Riedel and Sanfilippo (1978), Spencer-Cervato et al. (1993), Theyer et al. (1978). For a variety of reasons, including the difficulty in obtaining long paleomagnetic reversal sequences in high sedimentation rate, low latitude carbonate sections, and the relatively cosmopolitan geographic extent of many taxa, similar regional calibrations are not yet available for carbonate microfossil groups. We have therefore generally used (with occasional exceptions noted in individual holes) the tropical calibrations given by Berggren et al. (1985) for the planktonic foraminifers and calcareous nannofossils. We can only hope that sufficient stratigraphic data was available from each section to limit the effect of individual event diachrony on the development of the age model itself.

Compilation of biostratigraphic data from individual holes - The various biostratigraphic event lists with their numerical age estimates, together with a geomagnetic reversal list with ages, were stored as a set of spreadsheet templates. Copies of the templates were then filled in with actual occurrences for each hole. For each hole selected, taxonomic specialists went through the published range chart data in the Initial Reports volumes and located all biostratigraphic events listed in our template files. This compilation included all species listed in the Initial Report under older taxonomic synonymns of the modern name. Each event was normally recorded as occuring between two samples within the stratigraphic section. Samples were recorded either in meters below sea floor (mbsf), or as actual sample names, in core-section-interval within section in centimeters format. These sample names were automatically converted to depth in mbsf by the plotting software. It should be noted that no systematic attempt was made to search the general literature for additional stratigraphic data for these holes, although each specialist could, at his/her own discretion, update the Initial Report data with newer data published elsewhere.

There were some differences in recording conventions used by the different specialists. For radiolarians, the sample spacing recorded included a subjective estimate of the additional uncertainty suggested by discontinuous occurrences within the range of the species, based on a discussion of biostratigraphic gap analysis by McKinney (1986). In other words, if a species was often not present within its range for up to 3 samples in succession, then the top or bottom of its range was recorded as being between the uppermost or lowermost sample in which it was actually seen, and the third sample above or below the sample in which it occurred. For the other microfossil groups first and last occurrences were recorded as occuring between the 2 closest samples listed in the range chart. Also for radiolarians, taxa occuring only in a single sample were either ignored, or, if little or no other biostratigraphic data was available for that depth interval, the occurrence was recorded as an age range for a single sample, based on the known calibrated age range of the species. On an exceptional basis, typically when no detailed range chart data was available for a microfossil group, but zonal assignments were made in the Site chapter itself, the information was recorded as a set of zones, or converted from zones to their equivalent events using the zonal definitions given by the authors of the report. Calcareous nannofossil stratigraphy was the type of data most often recorded in this way.

Paleomagnetic stratigraphy was recorded as a set of paleomagnetic polarity interval identifications, as given by the original author. In some cases, it became neccessary to revise the identification scheme originally provided in order to achieve an optimal fit between the biostratigraphy and paleomagnetic polarity pattern.

Age model creation - While there are a variety of methods available to process stratigraphic event data, including Shaw Plots, Probabilistic Stratigraphy and Unitary Associations (Edwards, 1991), the method by far most frequently used by DSDP and ODP marine stratigraphers is the age vs depth plot method. A plot is made of the depth occurences within one section of previously age calibrated events, and a line of correlation drawn relating depth in section to age. Although various types of higher order curve fitting methods can, and occasionally have, been used, the more usual method is to fit a set of straight line segments of varying slopes to the data, with allowance for hiatuses as seems appropriate. We have adopted these latter conventions for our own work. The age models so produced are by no means as integrative as some of the above cited methods, as they proceed on a hole by hole basis, and are rather dependent on the accuracy of the primary calibrations. However, given the many imperfections of the data, as well as methodological limitations which exclude useful information in other age modelling procedures, we do not believe our results would be substantially improved by a more complex methodology.

In order to handle the large volume of data plotting and analysis in this project, a special purpose age-depth plotting program was written. This program is described in Lazarus (1992a), and is available from the senior author. The program reads stratigraphic data files and produces an age vs. depth plot of the data points. The line of correlation is not produced automatically, but drawn by the user interactively on the computer screen. Automatic methods, including spline curve fitting, were initially tried, but proved unsatisfactory. They were too readily affected by data outliers, and unable to incorporate external information, such as change in preservation, which are important in evaluating data on an age-depth plot. Our age models are thus subjective, and, except for a few holes where there was virtually no data scatter, often only one of 2 or more possible interpretations of the data. A few general guidelines however can be given here.

First, although a very common procedure among micropaleontologists, we have not tried to pick, *a priori*, 'good' events from 'bad' ones. Generally, when faced with an interval with data scatter, we have drawn a simple straight line through the cloud of data points, rather than to select 'good' points for tying the line of correlation, and thereby ignoring the remainder of the data. We have adopted this procedure in the belief that there are as yet no sufficiently objective criteria available for the routine *a priori* identification of biostratigraphic event reliability. Assessment of event reliability remains an extremely important priority for future research. Unfortunately, the most common criteria which seems to have been used previously is the taxonomic expertise of the creator of the age models: there have been many age models published in Biostratigraphic Synthesis or Site Summary chapters based entirely or mostly on the biostratigraphy of a single fossil group, despite the availability, often in the same DSDP volume, of apparently good biostratigraphic data from other groups of microfossils. We have made a special effort to avoid this situation, although we have perhaps been only partially successful in that we have excluded stratigraphic data from benthic foraminifers, dinoflagellates, and silicoflagellates. In defense of this decision, we can only say that stratigraphic data from these latter groups were only occasionally available, and event reliability and calibration in these groups much less well developed than is true for the four main plankton groups used in our study.

Evaluation and synthesis of results - Age modelling efforts were initially divided between the various authors of this report, in an attempt to distribute the workload. However, all initial age models were later reviewed by the group as a whole, and suggestions made for modification. In some few cases the scatter in the data was so large that the hole was rejected from further analysis. We have included these rejected holes in our compilation here, inasmuch as even a negative result

may be of some use to the community, either as a warning about the adequacy of chronology for a hole, or (hopefully) as a spur to new stratigraphic work on the hole. For most holes however an age-model was possible, though clearly there were major differences in the quality of the age model possible. We have subjectively classified each hole's age model into one of several categories - excellent, good, moderate, poor, very poor, or mixed - as an aid to searching through the report. These classes however hide a considerable degree of variation, often between intervals within a hole, and thus should be used with caution. The best way to judge the adequacy of the chronologic model for a hole is to examine the age depth plots themselves.

After a second round of revisions, all age models were then reviewed for consistency by the senior author. An effort was made to improve the consistency between individuals, to check for consistency between different holes at the same site, etc. Although the results of all these efforts undoubtedly still retain some inconsistencies and omissions, it is hoped that they nonetheless are a far more consistent, and updated, data set than was previously available.

Results

The chronologic data and age model results for each hole analysed are presented in this report in a set of tables and figures (Chapters 2-7). The various data sources used in the project - calibration data, primary stratigraphic reports for each hole, and other cited literature - are given as a cross-reference listing by Leg, and as a standard citation list in Chapter 2. While we do not discuss each hole individually in the text, any neccessary short comments and longer notes are given for each hole, as appropriate, as part of the summary table of information about each hole that comprises Chapter 3. This summary table also gives our selection criteria and our subjective ranking of the age model quality for each hole. Chapter 4 contains the master event calibration files used throughout the compilation effort, while Chapter 5 contains the compiled stratigraphic data for each hole. The age models are given in numerical form (a set of age-depth pairs defining the end-points of the line segments of the line of correlation) in Chapter 6. These are in the format used by the Age Depth Plot and Age Maker programs described in Lazarus (1992a). Lastly, Chapter 7 contains the actual age-depth plots for each hole. These have been reproduced in black and white, although the originals were created in color. Computer readable versions of all information (tables, text and figures) in this report may also be obtained from the NGDC via the World Wide Web, or upon special request from the senior author.

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CHAPTER 2 :
SOURCES OF STRATIGRAPHIC DATA AND MASTER REFERENCE LIST

In this chapter we list all literature cited in the preceding text, and in addition, all papers which provided the primary stratigraphic data for each hole analysed. Unless otherwise stated in the notes to each hole (Chapter 3), all data came from the Initial Reports volume for the hole. It was often the case that there was more than one shore-based microfossil report available for a hole. In such cases we used the report with the more detailed data for any given hole interval, and did not normally attempt to merge data sets between reports covering the same depth interval in a hole.

Two somewhat different zonations exist for nannofossils, which differ from each other not only in the choice of events used for zonation, but sometimes as well in taxonomic concepts for species. For consistency, we therefore used nannofossil stratigraphy from reports using the Martini (1971) zonation and taxonomy. Nannofossil data was recorded using the alternate zonation of Bukry (Bukry, 1971; Okada and Bukry, 1980) only when insufficient other stratigraphic data was available for the hole. In these cases we made use of the recent Indian Ocean calibrations of Neogene nannofossil events of Backman et al. (1990) to give age range error bars to individual events.

Also given in this chapter is a cross reference listing of primary data papers used, by Leg, to the alphabetically listed master refererence list. Use of this list allows one to quickly locate the in the reference list the stratigraphic reports used for a Leg, and, in combination with the 'Strat Events' columns of Chapter 3, to identify precisely which data reports were used for any one hole.

CHAPTER 3:
SUMMARY TABLE AND NOTES FOR ALL HOLES

The following table contains general information for each hole (Leg, latitude, longitude, etc.) and more specific information pertaining to this report (priority ranking of hole, age model (loc) version number (corresponding to the computer file name), number of age-depth plots included for each hole in Chapter 7). We have also included all hole specific comments in this table. Short comments are entered (in highly abbreviated form, to save space) in the table itself, longer comments are listed separately following the end of the table. Explanations of table coding conventions etc. are also given, as notes following the table.

CHAPTER 4:
MASTER LISTS OF CALIBRATED STRATIGRAPHIC EVENTS

The biostratigraphic and magnetostratigraphic events compiled here were obtained from the literature sources listed below. See also discussion in Chapter 1.

Planktonic Foraminifers: Berggren et al. (1985).

Calcareous Nannofossils: Backman (1990), Berggren (1985), Bukry (1971), Martini (1971), Okada and Bukry (1980).

Diatoms: Tropical and North Pacific - Barron (1981, 1985a, 1985b), Berggren et al. (1985), Koizumi and Tanimura (1985), Mikkelsen (1990); Antarctic - Gersonde and Burckle (1990), Harwood and Maruyama (1992),

Radiolarians: Tropical Pacific - Johnson and Nigrini (1985), Riedel and Sanfilippo (1978), Theyer et al. (1978); Tropical Indian - Nigrini (1991); North Pacific - Hays (1970), Morley (1985), Spencer-Cervato et al. (1993); Antarctic - Harwood et al. (1992), Hays and Opdyke (1967), Lazarus (1992b).

CHAPTER 5:
STRATIGRAPHIC DATA FILES FOR ALL HOLES

The following table gives all bio-, magneto- and isotope stratigraphic data used in the age-depth plots of Chapter 7. A header line or lines precedes the data for each hole. The header gives a date for the initial creation of the file, the initials of the person or persons who collated the data for this hole (provided by the individual taxonomic specialists), and, optionally, a short comment. Data lines include the Hole name, data type (normally, D-diatom, F-planktonic foraminifers, M-magnetostratigraphy, N-calcareous nannofossil, R-radiolarian), plotcode used to label the event on the age-depth plots, calibrated age or age range (from Chapter 4), and depths in section bracketing the event. Many events compiled from the stratigraphic range charts of the initial reports are entered in their original sample name format of Core-Section,interval. 'CC' refers to a core-catcher sample. Data can be either in event format (one, rarely 2, calibrated ages, followed by the samples bracketing the event) or in zonal format (2 age entries giving the age range of the zone or indicator species, followed by a single sample name). The computer program used to read these files and create age-depth plots automatically assigns symbols and colors in the order in which new group symbols are encountered. To maintain consistency in plotting, in most files at least one line was entered for each of the 5 standard data types most frequently encountered - D,F,M,N, and R. A blank data line was entered, with age and depth values of 0, for data types not available for the hole. For sources of data, see Chapter 2. Additional explanation of data formats can be found in Lazarus (1992a), and in the 'Users Guide to Age Depth Plot', included on the distribution disc of the ADP program.

CHAPTER 6:
LISTING OF AGE MODELS IN NUMERICAL FORM

Age model results for each hole are given here as a set of age-depth control points defining the ends of the line segments that make up the line of correlation (loc) for each hole. Hiatuses are identifiable as two successive lines with different ages but the same depth level. The creation date uniquely identifying each age model is given at the top of each individual listing, in YYYYMMDD (year,month,day) numerical format. The format of these listings are those used by the Age Maker program described in Lazarus (1992a), but presumably can also be adapted for use in other programs, including spreadsheets.

CHAPTER 7:
AGE DEPTH PLOTS FOR EACH HOLE

The following pages show age-depth plots for each hole analysed. At least one plot is given for a hole, and where the density of data requires it, several plots are given for expanded parts of the total section. All plots were created with the ADP program described in Lazarus (1992a), which gives additional details of plotting procedures, conventions, and usage. All plots were originally created in color, which adds considerably to their readability. For economy they are reproduced here in black and white, although the computer file versions retain all color information. In all plots, depth runs vertically down the page, age horizontally, increasing to the right. A paleomagnetic polarity scale (Berggren et al., 1985) is plotted on all figures along the bottom margin, regardless of whether paleomagnetic data was actually available or not. Paleomagnetic polarity data, when available, is entered as just another data type. In a few plots, the actually polarity pattern vs. depth in section is also plotted along the left hand margin. Cores are plotted vs depth on the right hand side of each plot. The actual recovery of each core was used, with incomplete recovery between cores thus leaving a visible gap. The short red lines within the cores are section marks, spaced at 1.5 meter intervals from the top of each core. Note that, due to a change in core labeling conventions by DSDP, the absolute total depth in mbsf of these section marks (and data points positioned relative to them) may not precisely correspond to the mbsf values used in older DSDP volumes (pre Leg 47), although the differences are usually less than 50 cm.

Labels along the top of the plot give the symbol type for each data type: D-diatoms, F-planktonic foraminifers, M-paleomagnetic polarity boundary, N-calcareous nannofossils, R-radiolaria. Additional special data types and symbols are usually noted in the comments line at the lower right corner of each plot. The file name/version number of the line of correlation (continous line on plot) is given at the lower left, while the loc creation date is at the upper right. Each data point plotted is labeled with a short combination of letters. The full name of each of these data points can be found in Chapters 4 and 5. Labels have been arranged so that in most cases the association between label and data point should be clear. However, the group to which a label belongs can also identified by conventions usually used for each group. Diatom event labels are 3 letters long, with the first letter and last letter in lowercase. Foram event labels are 4 letters long, first letter uppercase, the remaining letters usually lowercase. Magnetostratigraphic events are all caps, and include the number of the polarity chron. Nannofossil events are also 4 letters long, but the first two letters are usually uppercase and separated by a space. Lastly, radiolarian event labels are in all caps, 5 letters long, with no spaces between letters or numbers in the label.

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Subject:
Author:
Keywords:
Comments:
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