THE CENOZOIC DEEP SEA MICROFOSSIL RECORD: EXPLORATIONS OF THE DSDP/ODP SAMPLE SET USING THE NEPTUNE DATABASE

Cinzia Spencer-Cervato

ABSTRACT

For 30 years the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP) have been drilling the ocean floors and retrieving sediment cores. This study presents a relational micropaleontological and stratigraphic database, Neptune, where a selection of the published studies made on these sediments is available. The selected sites and their stratigraphic extent represent a statistically reproducible subset of the whole DSDP and ODP data set as of 1995 (up to Leg 135). Cenozoic sediments from 165 globally distributed holes were dated with age/depth plots using biochronology of four marine plankton groups (diatoms, nannofossils, foraminifera, and radiolarians). Each hole's location is available with paleogeographic coordinates. A taxonomic revision of the 8000+ reported species names was also made. The database is searchable and a variety of routines are available. Data can be exported to produce age range charts, geographic distribution maps, and occurrence charts.

A rigorous evaluation of the database potentials and limitations is presented together with a summary of the published studies that have been carried on with the data. These include stratigraphic studies (diachrony of Neogene plankton, hiati distribution in Cenozoic sediments) and evolution studies (cladogenesis and evolution of one foraminiferal lineage). Unpublished data on macroevolutionary patterns (species longevity and richness, speciation and extinction rates) are presented as example of Neptune's potential for paleobiological research. Finally, some suggestions are presented as to how Neptune can be more fully exploited through the addition of sedimentologic and isotopic data. A variety of critical sedimentologic and paleoceanographic questions could be addressed with this extended database.

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KEY WORDS: Cenozoic, relational database, plankton, evolution, age models

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PLAIN LANGUAGE SUMMARY:

Marine sediments contain the most complete record of the evolution of life on Earth. After the mass extinction event of the Cretaceous/Tertiary boundary, 65 million years' worth of sediments have accumulated on the sea floor. The Deep Sea Drilling Project and its successor, the Ocean Drilling Program, have drilled, retrieved and analysed kilometers of cores, as well as described their paleontological content. The Neptune database was established to compile the most valuable and significant data, and to use them to study the evolution of marine plankton. The global geographic coverage (165 holes), the high number of species described (1400+) from four marine plankton groups, the improved age control on the sediments, and the relatively high sample resolution (a few hundred thousand years) make this relational database the most complete paleontological data set currently available.

The analysis of these data has shown different evolutionary patterns in different plankton groups. On average a plankton species ‘survives’ 7 to 10 millions of years. Siliceous plankton (diatoms and radiolarians) tend to speciate and become extinct at distinct climatic and oceanographic boundaries independently from their nutritional habits (photosynthetic algae or plankton feeders). On the other hand, calcareous plankton seems to be more independent from these conditions. The results also show that the total number of species preserved in the sediments as fossils (a subset of the total number of species that existed at each given time and location) has gradually increased through time, but has also fluctuated strongly in the last 65 million years perhaps in response to climatic changes. This database has the potential to allow paleontologists to study the complex interactions between marine life and environment at a geological scale.

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1. INTRODUCTION: THE SCOPE OF THE DATABASE AND ORIGINAL PLANNING

Last year (1998) marked the 30th anniversary of the first Deep Sea Drilling Project (DSDP) cruise and the collection of the first cores. The handful of scientists who conceived and initiated this gigantic enterprise in the early 1960s probably did not expect this international project to spur as many controversies and theories on the history of the Earth as it indeed did. At that time, Plate Tectonics, the fundamental theory that unifies most if not all of our geological (and not only geological) knowledge, was still just a controversial hypothesis accepted by only a few scientists. JOIDES (Joint Oceanographic Institute for Deep Earth Science), the program that initiated the DSDP and later the Ocean Drilling Program (ODP), deserves a lot of the credit for the collection and study of the evidence that today practically makes plate tectonics a widely accepted ‘truth’.

As a side effect of the wealth of knowledge acquired in these 30 years, scientists have produced an enormous amount of data, so large that I am not aware of any recent estimate after the one done for the first ten years of research (Revelle 1981). Up to recently, all results were first published in reports (also known as ‘blue books’). This procedure made most of the raw data available from a centralized and easily accessible printed source. In addition, JOIDES published a CD-ROM containing much of the data produced from the some 1000 holes during the progress of DSDP in electronic format. However, this multitude of data makes sense only to a limited number of scientists that have been involved in their production, and nobody has a concrete overview of what is available. Moreover, the competitiveness of the recent research climate does not encourage the re-evaluation of older data, but leads instead to the production of more new data.

With this background, a group of biostratigraphers at the ETH Zürich initiated the Neptune project in 1990. The group included some veterans from DSDP (Jean-Pierre Beckmann, Katharina von Salis Perch-Nielsen, Hans Thierstein), one participant of the more recent ODP cruises (Dave Lazarus), and some newcomers (Milena Biolzi, Jörg Bollmann, Heinz Hilbrecht, and myself). The project was funded by the Swiss National Science Foundation. The project was, in its initial stages, conceived and led by Dave Lazarus (Lazarus 1994; Lazarus et al. 1995a), while in the later, scientific analysis phase, the effort was carried out by this author (Spencer-Cervato et al. 1993, 1994; Spencer-Cervato and Thierstein 1997; Spencer-Cervato 1998).

The scope of the Neptune project was to evaluate and organize the existing DSDP and ODP data into a relational database that would be accessible to the research community. First, we planned to ‘rescue’ and compile the micropaleontological information. This information could be used first to establish an updated chronology for selected sites. The micropaleontological data themselves were then to be used for various studies of evolution. The established chronology would also be used to obtain age control on sedimentological and geochemical data.

This database would be substantially different from a mere compilation of existing data, as was assembled in the DSDP CD-ROM. The main difference would be in the ‘quality control’ of the data to be included. Suitable sites would be selected, based on criteria dictated by our experience in biostratigraphy and deep-sea drilling. We decided to limit the number of sites in the database to give preference to an accurate selection and analysis of the data available for each site. We initially planned to include some 100 holes, but this number has been substantially increased in a later phase of the project. The second innovative approach was represented by the search options. The data in the DSDP CD-ROM are not searchable, but are available as a series of gigantic tables with listings of data. As potential end users, we recognized the necessity to create links between the different data sets (e.g., by hole, by age, by geographic location, by fossil group) to optimize the research applications of the database.

In the next chapters, I will provide a description of what is in the Neptune database and how it got there. I will also discuss what we would have liked to do, and why we did not get to it. Some of the published (and in progress) applications of Neptune will be discussed in a separate chapter. I will conclude with some suggestions on possible additions and how Neptune can be used as a tool available to the research community.

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2. THE CONCEPTION OF NEPTUNE AS A STEPPING STONE TOWARD THE MICROPALEONTOLOGIST'S DREAM OF THE IDEAL WORLD

2.1. Stratigraphic and geographic coverage

Marine sediments provide more or less continuous, laterally extensive and correlatable geological archives. The first choice that we made was to limit the database to deep-sea sediments, thereby excluding land sections. Hence the name given by D. Lazarus to the database: Neptune, the Roman god of the sea. The largest amount of data on deep-sea sediments come from ocean drilling, and we began our work by systematically searching through the **Initial Reports of the Deep Sea Drilling Project** (DSDP) and the Initial and the **Proceedings of the Ocean Drilling Program, Scientific Results**. Based on a variety of criteria, we rated the holes drilled by DSDP and by ODP up to Leg 135 (the latest leg available in 1995, when I expanded the database to the whole Cenozoic). Ratings were given for each fossil group separately. No rating meant that biostratigraphy was not available, a rating of ‘M’ (medium) indicated the presence of biostratigraphy limited to a few markers and often the absence of detailed range charts. A rating of ‘H’ (high) was used for detailed biostratigraphic reports with extensive range charts. Comments on core recovery, preservation, etc. were also added at this point. Given our long-range goal of using the data for a micropaleontological database, we selected to include in Neptune mainly holes that were marked as high or medium priority for more than one biostratigraphic group. Other hole selection criteria included good core recovery, relatively continuous coring, the length of the stratigraphic interval covered, as well as good microfossil preservation. The recognition of magnetostratigraphy, which could be used for further age control, was also determinant in the selection.

To date, Neptune includes stratigraphic data for the whole Cenozoic (last 65 million years). Several reports are available on Cretaceous sediments and some on Jurassic sediments. However, the K/T boundary represents a major stratigraphic boundary that marks a dramatic faunal and floral assemblage turnover. I feel, therefore, justified in the choice of limiting the coverage to the Cenozoic. At the other end of the spectrum, upper Pleistocene and Holocene sediments are not well represented in DSDP and ODP reports and, therefore, in Neptune. This is mainly due to the limited resolution of marine biostratigraphy for recent sediments, the relatively coarse sampling used in most reports and to loss of the upper few meters of sediments in early coring work.

Final additions or changes to the list of holes were done after plotting the geographic location of the selected holes. We aimed to have a broad geographic coverage and at least one complete section for each biogeographic province (Figure 2.1). The coverage of shelf to abyssal sediments was equally considered: the range of water depths

Figure 2.1

Figure 2.1.

of the sediment/water interface represents a statistically representative subset of all the holes drilled by DSDP and ODP as of 1995 (Spencer-Cervato 1998). However, shallow water (shallower than 1000 m) sediments are underrepresented in the DSDP and ODP collection and are, therefore, underrepresented also in Neptune. In total, we did include 165 holes (Table 2.1). More holes would have been desirable and we have possibly excluded holes of considerable importance. This was due to time limitations and the project's goals of creating a 'micropaleontological database'.

2.2. Chronology

The next step consisted in establishing an internally consistent chronology for the selected holes. Because magnetostratigraphic data were available only for some of the holes, biochronology represented the best and often the only way to provide an age model for the holes. Biochronology provides a series of 'calibrated events' which essentially mark the first and last appearance of biostratigraphic markers (taxa). Ideally, these events have been correlated in several locations to an independent stratigraphic method, like magnetostratigraphy or oxygen isotope stratigraphy. These scales have in turn been calibrated to absolute chronology in millions of years through complex procedures. The magnetostratigraphic scale used initially for Neptune was Berggren et al. (1985). We subsequently updated our chronology to Berggren et al. (1995b), which is based on Cande and Kent's magnetostratigraphy (1992, 1995). Berggren et al.'s chronology was chosen because it is the most updated and most comprehensive time scale published to date - it includes biochronological data for several hundred Cenozoic events. Oxygen isotope stratigraphy (in turn calibrated to a magnetostratigraphic scale) was used for only a few of the calibrated events used in Neptune.

Through this two-step approach, numerical ages in million of years (Ma) are given to biostratigraphic events. We assumed that these events are geologically instantaneous and occur simultaneously throughout a given region of the globe (i.e., are globally synchronous and at least regionally widespread, and not dependent on local environment or sediment facies). Berggren et al. (1985) and its recent updates (Berggren et al., 1995a, b) were the source of biochronological events for planktic foraminifera and calcareous nannoplankton. Various regional calibrations were used for siliceous plankton (for radiolarians: Hays and Opdyke 1967; Hays 1970; Theyer et al. 1978; Johnson and Nigrini 1985; Sanfilippo et al. 1985; Goll and Bjørklund 1989; Nigrini 1991; Harwood et al. 1992; Caulet 1991; for diatoms: Barron 1981, 1985a, b; Berggren et al. 1985; Fenner 1984; Koizumi and Tanimura 1985; Gersonde and Burckle 1990; Mikkelsen 1990; and Harwood and Maruyama 1992). Paleogene siliceous plankton biochronology is less well established than the one for the Neogene, so most of the events used were biozonation boundary markers.

Published biochronological events were used to construct the chronology of each hole. Templates were assembled with all the events that we found in the cited references (Table 2.2). These templates (ASCII files to be used in MS Excel) contained the description of the event, an identification code, and the age interval of the calibration. An excerpt from one of these files is shown in Table 2.3.

2.3. Taxonomy

The articles published in the DSDP and ODP reports are an immense source of evolutionary and biostratigraphic data. Although we were aware of many discrepancies in the subjective nature of taxa and taxonomic names (e.g., Gradstein et al. 1985), we assumed that these factors would be manageable by use of simple synonymy lists in our study. A very extensive taxonomic literature is available for marine plankton, and taxa and nomenclature are quite well defined among the most common microfossil groups. This can be used to reasonably standardize taxonomic usage. Thus if taxon **Ab** is called **Ab** by one author but **Bb** by another, we could standardize the data by creating an equivalence **Bb** = **Ab** in the database. Moreover, the holes that we selected had been extensively studied for biostratigraphy and some of them represented classical micropaleontological studies. We, however, had to assume that taxon names in all the selected holes were uniformly used, in other words, that taxon **Ab** described in Hole 289 was identical to taxon **Ab** described in Hole 747A. More than 8800 taxon names have been used in the selected holes.

2.4. Biostratigraphy

Most micropaleontological studies are limited to one or perhaps two fossil groups. Biostratigraphic studies in DSDP and ODP reports include diatoms, radiolarians, calcareous nannoplankton, planktic and benthic foraminifera, dinoflagellates, silicoflagellates. We decided to consider only planktic organisms and out of the several groups described in the Reports, we selected the four groups that are most abundant in deep-sea sediments, most regularly described in the biostratigraphic literature, and for which extensive event calibration is available: diatoms, radiolarians, calcareous nannoplankton and planktic foraminifera. This selection includes two siliceous (diatoms and radiolarians) and two calcareous (nannoplankton and foraminifera) plankton groups, and at the same time two phytoplankton (diatoms and nannoplankton) and two zooplankton (radiolarians and foraminifera) groups. This approach has several advantages: it would allow us to compare evolutionary trends in multiple groups, but mainly it allowed us to have a better biochronological control on the age models. Planktic foraminifera are probably the most used microfossils for biostratigraphy, and with this approach we were able to compare their resolution and accuracy to the other groups.

The templates were filled in with actual occurrences of the events for each hole. We went through the published range charts or lists of markers and located the events present in the templates. The list of references to the individual reports is given in Table 2.4. Each event was normally recorded as occurring between two samples within the stratigraphic section. Samples were either recorded as meters below seafloor (mbsf) or as actual sample names, in core-section-interval within section in centimeter format. The sample names were then automatically translated into mbsf by the plotting software. No systematic attempt was made to search the general literature for additional stratigraphic data, although biostratigraphic data for some critical holes (e.g., DSDP 558 and 563) were extracted from charts published outside the DSDP reports. The creation of biostratigraphic files from the templates was initially subdivided among the project participants. In the later phase of the project, I was solely responsible for this task. This eliminated some of the discrepancies in the event identification due to subjective interpretations of range charts in terms of First Occurrence (FO) and Last Occurrence (LO).

The first and last occurrence of a taxon were identified when the taxon was not recorded in two or more samples above or below the first or last recorded occurrence. Because the precision of the actual FO or LO depends on the sample spacing, we recorded each event as the stratigraphic interval between the two samples bracketing the event.

Paleomagnetic stratigraphy was recorded as a set of paleomagnetic polarity interval identifications, as given by the original author. In some cases, it became necessary to revise the original identification scheme to achieve an optimal fit between biostratigraphy and paleomagnetic polarity patterns. However, this was usually apparent only when the events were plotted.

The biostratigraphic files prepared for each group were pasted together and used in the construction of age models. There is a varietyare several of methods available to process stratigraphic event data, including Shaw's plots (Shaw 1964) and Probabilistic Stratigraphy (Hay 1972). However, the most used method of stratigraphic correlation for deep-sea sediments is the age vs. depth plot method. A plot is made of the depth occurrences of previously age-calibrated events in each hole and a line is drawn to correlate depth to age. Although various curve-fitting methods can be used, we have chosen to manually fit a series of straight line segments of varying slopes to the data.

To handle the large volume of data plotting and analysis we used a special-purpose, age-depth plotting program written by Lazarus (1992). The program, written for Macintosh computers, reads the stratigraphic data files and produces an age- vs. versus-depth scatter plot of the data points. The program allows us to draw a line of correlation through the points interactively on the computer screen. Automatic correlation methods were attempted but proven unreliable because they were too easily affected by data outliersdata outliers too easily affected them. The manual construction of the line of correlation allows us to take into consideration recovery gaps and changes in preservation or lithology that may affect the reliability of the age vs. depth plot. The age models are thus subjective and, with a few exceptions, the scatter of data allows for two or more possible interpretations. The use of two or more biostratigraphic groups was intended to minimize the bias introduced by an **a priori** selection of 'good' or 'bad' events.

Age models were initially constructed by several project participants. To eliminate discrepancies in the selection of the line of correlation due to subjective preferences, all Neogene DSDP age models were subsequently revised by Dave Lazarus (Lazarus et al. 1995a) and later by myself (after the addition of Paleogene data and ODP holes, and the update of the chronology). A personal rating of the quality of the age models is given in Table 2.1. Although the results of all these efforts still do not guarantee that the age models are optimally reliable, I hope that they represent a far more consistent and updated data set than available prior to the beginning of the project.

The established chronology provided age control on the 30,000 samples described in the DSDP and ODP reports for the selected holes. Information on the micropaleontological content of these samples is available as range charts. These charts give information on the presence or absence of a taxon, and usually describe its abundance. Properly formatted MS Excel range charts were either extracted from the DSDP CD-ROM by the Neptune database program, typed by us, or provided directly from ODP (Table 2.4). These were then imported into Neptune and represent the bulk of data available. We planned to use this information for various studies (species occurrence patterns, longevity and diversity, identification of temporal distribution of biogeographic provinces) which are described in Chapter 4.

The age/depth plots and the age models (text files) are given in the Appendix A. The stratigraphic data files used to construct the age vs. depth plots, are not published here because of space considerations and the complexity of having such a large number of files and links. They are, however, available from the author.

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Figure 2.1. Location of DSDP and ODP holes in the Neptune database. Dots mark holes with one or more hiati, squares holes with a continuous stratigraphy, within the resolution of the chronology.

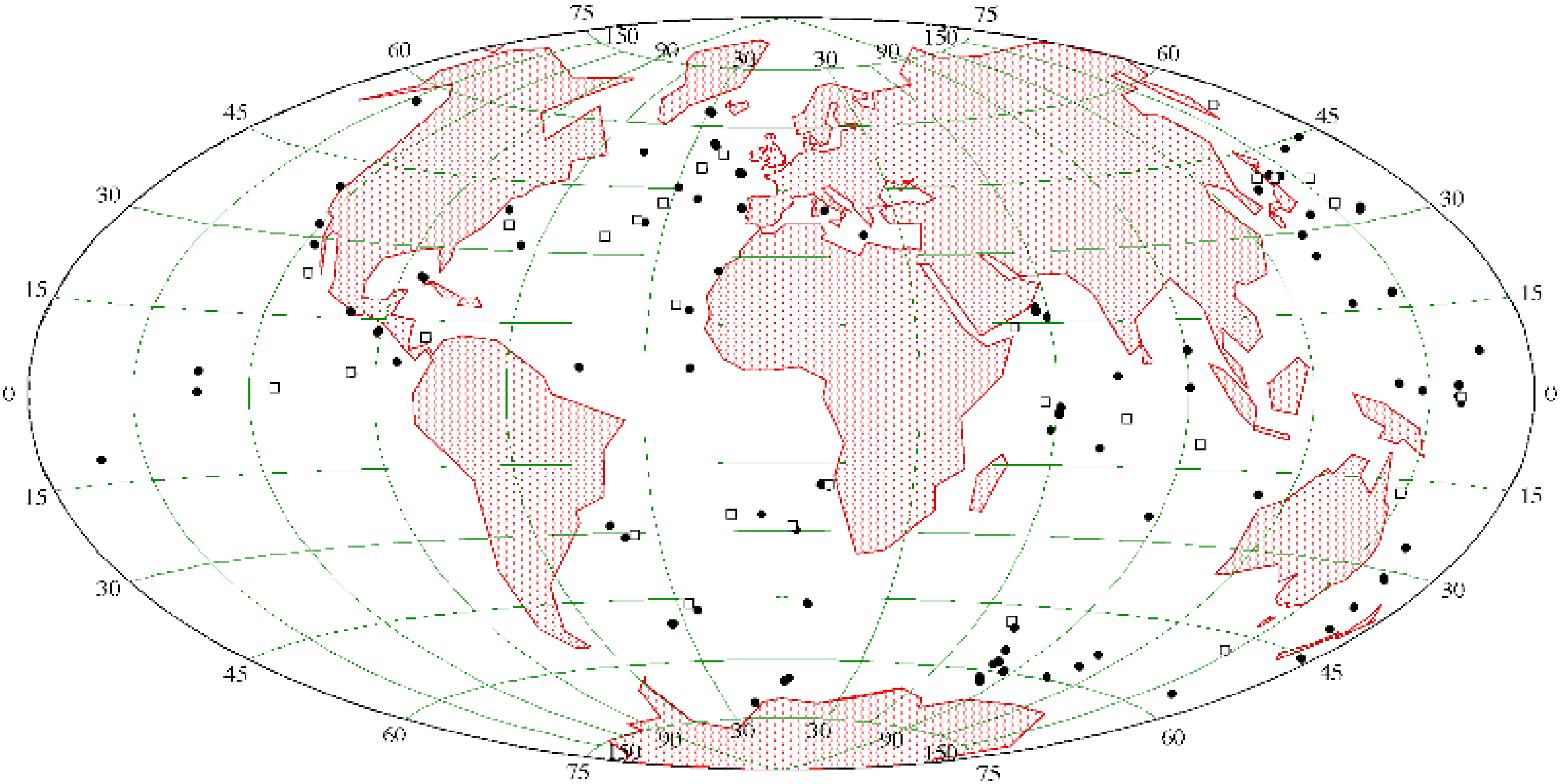

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Table 2.1.

					Priority					RCs exist:			
Leg	**Hole**	Latitude	Longitude	Pmag.	D	N	R	F	Loc Quality	D	N	R	F
7	62	1.9	141.9	N			H		P	-	Y	Y	Y
7	62A	1.9	141.9	N			H		P	-	Y	Y	Y
7	63	0.8	147.9	N			M		P	-	Y	Y	-
7	63A	0.8	147.9	N			M		P	-	Y	Y	-
7	63B	0.8	147.9	N			M		P	-	Y	Y	-
7	64	-1.7	158.6	N			M		M	-	Y	Y	Y
7	64A	1.5	158.4	N			M	H	M	-	Y	Y	Y
13	125	34.6	20.4	N				H	P	-	Y	-	Y
13	132	40.3	11.4	N				H	G	-	Y	-	Y
14	141	19.4	-24.0	N				H					

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Table 2.2. (Continued next 4 pages.)

Planktic Foraminifera			Berggren et al. 1995a,b						
Group	Event Name	Plotcode	Young Age	Old Age	Group	Event Name	Plotcode	Young Age	Old Age
F	TOP Globoquadrina pseudofoliata	Tpft	0.22		F	TOP Globorotalia miozea	Tmza	15.9	
F	BT G. hirsuta	Bhir	0.45		F	BT Praeorbulina circularis	BPcr	16	
F	BT G. flexuosa	Bflx	0.4		F	BT Praeorbulina glomerosa	BPgl	16.1	
F	BT Bolliella calida	BBca	0.22		F	BT Globigerinoides diminutus	Bdim	16.1	
F	TOP G. flexuosa	Bflx	0.068		F	BT Praeorbulina curva	BPcv	16.3	
F	TOP Globorotalia tosaensis	Ttos	0.65	1	F	BT Praeorbulina sicana (= G.es bispher.)	BPsc	16.4	
F	BT Pulleniatina finalis	BPfn	1.4		F	BT Globorotalia miozea	Bmza	16.7	
F	TOP Globigerinoides fistulosus	Tfst	1.6		F	TOP Globorotalia zealandica	Tzld	17.3	
F	TOP Globigerinoides obliquus extremus	Tobe	1.7		F	TOP Globorotalia pseudomiozea	Tpmz	16.6	
F	BT Globorotalia truncatulinoides	Btrc	2		F	BT Globorotalia birnageae	Bbng	16.7	
F	TOP Globorotalia exilis	Texl	2.15		F	TOP Catapsydrax stainforthi	TCst	17.2	
F	reappear.Pulleniatina (local)	RAPu	2.3		F	BT Globorotalia zealandica	Bzld	17.3	
F	TOP Globorotalia miocenica	Tmio	2.3		F	BT Globorotalia pseudomiozea	Bpmz	17.3	
F	TOP Neogloboquadrina atlantica	Tatl	2.41		F	TOP Globorotalia semivera	Tsmv	17.3	
F	TOP G. puncticulata	Tpun	2.41		F	TOP Globorotalia incognita	Tigt	16.4	
F	TOP Globorotalia pertenuis	Tprt	2.6		F	TOP Catapsydrax dissimilis	TCds	17.3	
F	TOP Globorotalia multicamerata	Tmtc	3.09		F	BT Globorotalia praescitula	Bpsc	18.5	
F	TOP Globoquadrina altispira	Talp	3.09		F	TOP Globoquadrina dehiscens f.spinosa	TGqds	17.9	

F	TOP Sphaeroidinellopsis seminulina	Tsem	3.12		F	BT Globigerinoides altiaperturus	Batp	20.5	
F	BT Globigerinoides fistulosus	Bfst	3.33		F	BT Tenuitella munda	Bmun	21.4	
F	TOP Spheroidinellopsis spp	TSdp	3.25		F	TOP Globorotalia kugleri	Tkgl	21.5	
F	BT Spheroidinella dehiscens s.s.	BSdd	3.25		F	BT Globoquadrina dehiscens f.spinosa	BGqds	22.2	
F	BT Globorotalia inflata	Bifl	3.25		F	TOP Globoquadrina globularis	TGqg	22.8	
F	TOP Globorotalia conomiozea	Tcmz	3.25		F	BT Globoquadrina dehiscens	BGqd	23.2	
F	BT Globorotalia tosaensis	Btos	3.35		F	BT Globorotalia incognita	Bigt	21.6	
F	BT Globorotalia crassula	Bcrl	3.3		F	TOP Globoturborotalita angulisuturalis	Tags	21.6	
F	TOP Pulleniatina (local)	TPlt	3.45		F	TOP Globorotalia pseudokugleri	Tpkg	21.6	
F	BT Globorotalia pertenuis	Bprt	3.45		F	BT Globigerina euapertura	Beua	23.8	
F	BT Globorotalia miocenica	Bmio	3.55		F	B Globorotalia kugleri	bGku	23.8	
F	TOP Globorotalia margaritae	Tmgt	3.58		F	T Globorotalia mendacis	tGme	23.8	
F	TOP Pulleniatina primalis	TPpr	3.65		F	B Globigerinoides primordius (common)	bGpr-c	24.3	
F	Pulleniatina s->d	sdP	3.95		F	B Globigerinoides primordius (rare)	bGpr-r	26.7	
F	TOP Globigerina nepentes	Tnep	4.2		F	T Globorotalia opima	tGop	27.1	
F	TOP Pulleniatina spectabilis	TPsp	4.2		F	B Globigerina angulisuturalis	bGas	29.4	
F	BT Globorotalia crassaformis s.s.	Bcrs	4.5		F	T Globigerina angiporoides	tGap	30	
F	TOP Globigerinoides seiglei	Tsgl	4.7		F	T Globigerina ampliapertura	tGam	30.3	
F	BT Globorotalia puncticulata	Bptc	4.5		F	T Globorotalia cerroazulensis	tGce	33.8	
F	TOP Globorotalia cibaoensis	Tcbn	4.4		F	T Hantkenina	tHan	33.7	
F	BT Spheroidinella dehiscens	BSdd	5.2		F	T Porticulasphaera semiinvoluta	tPsi	35.3	
F	BT Globorotalia sphericomiozea	Bsphc	5.6		F	T Morozovella spinulosa	tMsp	38.1	
F	BT Globorotalia pliozea	Bpli	5.6		F	B Porticulasphaera semiinvoluta	bPsi	38.4	

F	BT Globorotalia tumida	Btum	5.6		F	T Subbotina frontosa	tSfr	39.3	
F	BT Pulleniatina spectabilis	BPsp	5.6		F	T Globigerapsis beckmanni	tGbe	40.1	
F	BT Globigerinoides conglobatus	Bcgb	5.8		F	B Globigerapsis beckmanni	bGbe	40.5	
F	BT Globorotalia cibaoensis	Bcbn	7.8		F	T Acarinina bullbrooki	tAbu	40.5	
F	TOP Globoquadrina dehiscens	TGqd	5.8		F	B Globorotalia pomeroli	bGpo	42.4	
F	TOP Globorotalia lenguaensis	Tlng	6		F	B Globigerapsis index	bGin	42.9	
F	BT Globorotalia margaritae	Bmgt	6		F	B Morozovella lehneri	bMle	43.5	
F	BT Pulleniatina primalis	BPpr	6.4		F	T Morozovella aragonensis	tMar	43.6	
F	Neogloboquadrina acostaensis s->d	acsd	6.2		F	B Globorotalia possagnoensis	bGpg	46	
F	BT Globorotalia menardii form 5 (dext.)	Bmn5	6.4		F	B Planorotalites palmerae	bPpa	50.4	
F	Neogloboquadrina acostaensis d->s	acds	6.6		F	B Morozovella aragonensis	bMar	52.3	
F	Neogloboquadrina atlantica d->s	atds	6.8		F	B Morozovella formosa	bMfo	54	
F	BT Globorotalia conomiozea	Bcmz	7.12		F	T Morozovella velascoensis	tMve	54.7	
F	TOP Globorotalia menardii form 4 (sin.)	Tmn4	7.4		F	T Planorotalites pseudomenardii	tPps	55.9 (?)	
F	BT Globorotalia suterae	Bsut	7.8		F	B Morozovella velascoensis	bMve	60	
F	BT Globorotalia juanai	Bjua	8.1		F	B Morozovella pusilla	bMpu	61 (?)	
F	BT Candeina nitida	Bcnit	8.1		F	B Morozovella conicotruncata	bMco	60.9	
F	BT Globigerinoides extremus	BGex	8.3		F	B Morozovella angulata	bMan	61	
F	BT Globorotalia plesiotumida	Bplt	8.3		F	B Morozovella uncinata	bMun	61.2 (?)	
F	BT Neogloborotalia humerosa	Bhum	8.5		F	B Planorotalites compressus	bPco	63 (?)	
F	TOP Neogloboquadrina nympha	Tnym	10.1		F	T Globotruncana	tGtc	65	
F	BT Neogloboquadrina acostaensis	Bac	10.9						

Close Window

Table 2.3: Example of format used in the biostratigraphic templates. ‘Young age’ and ‘Old age’ allow entering two different values and obtain an age range for the event. The last two columns to the right are left blank and will be filled with depth information from each hole. B represents the first appearance datum (FAD), T the last appearance datum (LAD).

Hole	**2.00**	**dd/mm/yy**	**Author of file**	**Comments**		
Group	**Event name**	**Code**	**Young age**	**Old age**	**Top Depth**	**Bottom Depth**
N	B D. tamalis	B Dta	3.8			
N	B D. asymmetricus	B Das	4.2			
N	T A. primus	T Apr	4.8			
N	B C. rugosus	B Cru	5	5.23		

Close Window

Table 2.4. References to biostratigraphic files present in Neptune. The ‘Group’ column indicates the plankton group (D: diatoms; F: foraminifera; N: nannofossils; R: radiolarians) stratigraphy or magnetostratigraphic data (M) presented in the reference.

Vol.	Author(s)	Group
7	Brönnimann, P.; Resig, J., 1971	F
7	Martini, E.; Worsley, T., 1971	N
7	Riedel. W.R.; Sanfilippo, A., 1971	R
13	Gartner, S., Jr., 1973	N
13	Bukry, D., 1973	N
13	Ryan, W. B. F.; Hsü, K. J., 1973	F
14	Beckmann, J. P., 1972	F
14	Roth, P. H.; Thierstein, H. R., 1972	N
16	Kaneps, A. G., 1973	F
16	Dinkelman, M.G., 1973	R
16	Bukry, D.; Foster, J.H., 1973	D
18	Ingle, J. C., Jr., 1973	F
18	Kling, S. A., 1973	R
18	Schrader, H. J., 1973	D
18	Wise, S. W., 1973	N
19	Koizumi, I., 1973	D
19	Ling, H. Y., 1973	R
19	Worsley, T. R., 1973	N
19	Echols, R. J., 1973	F
19	Akiba, F., 1986 (vol. 87)	D
22	Johnson, D. A., 1974	R
22	Gartner, S., Jr., 1974	N
22	McGowran, B., 1974	F
22	Berggren, W.A.; et al., 1974	F
22	Schrader, H.-J., 1974 (vol. 24)	D
24	Sanfilippo, A.; Riedel, W. R., 1974	R
24	Roth, P. H., 1974	N
24	Schrader, H. J., 1974	D
24	Vincent, E.; et al., 1974	F
24	Heiman, M.E.; et al., 1974	F
26	Boltovskoy, E., 1974	F
26	Thierstein, H. R., 1974	N
28	McCollum, D. W., 1975	D
28	Chen, P. H., 1975	R
28	Burns, D. A., 1975	N
28	Kaneps, A. G., 1975	F
29	Edwards, A. R.; Perch-Nielsen, K., 1975	N

29 Petrushevskaya, M. G., 1975 R
29 Jenkins, D. G., 1975 F
29 Schrader, H. J., 1976 (vol. 35) D
30 Holdsworth, B. K., 1975 R
30 Shafik, S., 1975 N
31 Koizumi, I., 1975 D
31 Ellis, C. H., 1975 N
31 Ling, H.Y., 1975 R
33 Johnson, D. A., 1976 R
33 Martini, E., 1976 N
33 Takayanagi, Y.; Oda, M., 1976 F
39 Boersma, A., 1977 F
39 Perch-Nielsen, K., 1977 N
39 Sanfilippo, A.; Nigrini, C., 1995 R*
39 Fenner, J., 1978 (supplement) D
40 Jenkins, D. G., 1978 F
40 Proto Decima, F.; et al., 1978 N
40 Toumarkine, M., 1978 F
40 Pisias, N.G.; Moore, T.C. Jr., 1978 R
41 Bukry, D., 1978 N
41 Krasheninnikov, V. A.; Pflaumann, U., 1978 F
41 Krasheninnikov, V. A.; Pflaumann, U., 1978 F
41 Johnson, D. A., 1978 R
41 Schrader, 1978 D
43 Okada, H.; Thierstein, H.R., 1979 N
47 Blechschmidt, G., 1979 N
48 Murray, J.W., 1979 F
48 Müller, C., 1979 N
49 Poore, R. Z., 1979 F
49 Ling, H. Y., 1979 R
49 Steinmetz, J. C., 1979 N
49 Martini, E., 1979 N
49 Schrader, H. J., 1979 D
55 Takayama, T., 1980 N
55 Ling, H. Y., 1980 R
55 Koizumi, I., 1980 D
56/7 Thompson, P. R., 1980 F
56/7 Reynolds, R. A., 1980 R
56/7 Shaffer, B. L., 1980 N
56/7 Keller, G., 1980 F
56/7 Harper, H. E., Jr., 1980 D
56/7 Sakai, T., 1980 R
56/7 Barron, J. A., 1980 D
58 Okada, H., 1980 N
58 Sloan, J., 1980 R

59 Martini, E., 1981 N
59 Theyer, F.; Lineberger, P., 1981 R
59 Heiman, M.E., 1981 F
60 Ellis, C. H., 1982 N
60 Kling, S. A., 1982 R
61 Premoli Silva, I.; Violanti, D., 1981 F
61 Thierstein, H.R.; Manivit, H., 1981 N
61 Sanfilippo, A.; et al., 1981 R
63 Barron, J. A., 1981 D
63 Wolfart, R., 1981 R
63 Poore, R. Z., 1981 F
66 Stradner, H.; Allram, F., 1982 N
66 McMillen, K.J., 1982 R
67 Thompson, P. R., 1982 F
67 Muzylöv, N., 1982 N
67 Westberg, M. J.; Riedel, W. R., 1982 R
67 Harper, H. E., Jr.; et al., 1982 D
67 Jousé, A.P.; et al., 1982 D
68 Kent, D. V.; Spariosu, D. J., 1982 M
68 Riedel, W. R.; Westberg, M. J., 1982 R
68 Keigwin, L. D., Jr., 1982 F
68 Sancetta, C., 1982 D
68 Kent, D. V.; Spariosu, D. J., 1982 M
71 Krasheninnikov, V. A.; Basov, I. A., 1983 F
71 Salloway, J. C., 1983 M
71 Wise, S. W., 1983 N
71 Gombos, A.M.; Ciesielski, P.F., 1983 D
71 Weaver, F. M., 1983 R
71 Ciesielski, P. F., 1983 D
72 Berggren, W.A.; et al., 1983 M
72 Pujol, C., 1983 F
72 Berggren, W.A.; et al., 1983 F
72 Gombos, A.M., Jr., 1983 D
72 Pujol, C.; Duprat, J., 1983 F
73 Percival, S. F., Jr., 1984 N
73 Poore, R. Z., 1984 F
73 Smith, C.C.; Poore, R.Z., 1984 F
73 Tauxe, L.; et al., 1984 M
73 Gombos, A.M., Jr., 1984 D
74 Boersma, A., 1984 F
74 Jiang, M.-J.; Gartner, S., 1984 N
77 Lang, T.H.; Watkins, D.K., 1984 N
80 Snyder, S. W.; Waters, V. J., 1985 F
80 Müller, C., 1985 N
80 Townsend, H. A., 1985 M

80 Pujol, C.; Duprat, J., 1985 F
80 Pujos, A., 1985 N
80 Labracherie, M., 1985 R
81 Krumsiek, K.; Roberts, D. G., 1984 M
81 Backman, J., 1984 N
81 Huddlestun, P. F., 1984 F
81 Baldauf, J.G., 1984 D
81 Westberg-Smith, M.J.; Riedel, W.R., 1984 R
82 Parker, M.E.; et al., 1985 N
82 Bukry, D., 1985 N
82 Miller, K.G.; et al., 1985 N,F*
82 Miller, K.G.; et al., 1994 N,F,M*
85 Weinreich, N.; Theyer, F., 1985 M
85 Saito, T., 1985 F
85 Labracherie, M., 1985 R
85 Baldauf, J. G., 1985 D
85 Barron, J. A., 1985 D
85 Gartner, S.; Chow, J., 1985 N
85 Nigrini, C. A., 1985 R
85 Pujos, A., 1985 N
86 Koizumi, I.; Tanimura, Y., 1985 D
86 Heath, G. R.; et al., 1985 M
86 Bleil, U., 1985 M
86 Monechi, S., 1985 N
86 Morley, J. J., 1985 R
90 Martini, E., 1986 N
89/90 Lohman, W. H., 1986 N
90 Ciesielski, P. F., 1986 D
89/90 Jenkins, D. G.; Srinivasan, M. S., 1986 F
90 Barton, C. E.; Bloemendal, J., 1986 M
89/90 Caulet, J. P., 1986 R
92 Romine, K., 1986 F
92 Knüttel, S., 1986 N
93 Muza, J. P.; et al., 1987 N
93 Lang, T.H.; Wise, S.W., Jr., 1987 N
93 Applegate, J.L.; Wise, S.W., Jr., 1987 N
93 Ma'alouleh, K.; Moullade, M., 1987 F
93 Saint-Marc, P., 1987 F
93 Nishimura, A., 1987 R
93 Gombos, A.M., Jr., 1987 D
93 Canninga, G.; et al., 1987 M
94 Jenkins, D.G., 1987 F
94 Weaver, P. P. E., 1987 F
94 Clement, B. M.; Robinson, F., 1987 M
94 Baldauf, J. G., 1987 D

94 Takayama, T.; Sato, T., 1987 N
94 Westberg-Smith, M.J.; et al., 1987 R
95 Miller, K.G.; Hart, M.B., 1987 F*
95 Palmer, A.A., 1987 R
95 Valentine, P.C., 1987 N
95 Abbott, W.H., 1987 D
105 Knüttel, S.; et al., 1989 N
105 Firth, J.V., 1989 N
105 Aksu, A.E.; Kaminski, M.A., 1989 F
105 Baldauf, J.G.; Monjanel, A.-L., 1989 D
105 Lazarus, D.; Pallant, A., 1989 R
105 Clement, B.M.; et al., 1989 M
108 Manivit, H., 1989 N
108 Weaver, P.P.E.; Raymo, M.E., 1989 F
108 Tauxe, L.; et al., 1989 M
113 Spiess, V., 1990 M
113 Pospichal, J.J.; Wise, S.W., 1990 N
113 Wei, W.; Wise, S.W., 1990 N
113 Abelmann, A., 1990 R
113 Lazarus, D.B., 1990 R
113 Gersonde, R.; Burckle, L.H., 1990 D
113 Stott, L.D.; Kennett, J.P., 1990 F
114 Fenner, J., 1991 D
114 Crux, J.A., 1991 N
114 Madile, M.; Monechi, S., 1991 N
114 Nocchi, M.; et al., 1991 F
114 Hailwood, E.A.; Clement, B.M., 1991 M
114 Hailwood, E.A.; Clement, B.M., 1991 M
115 Okada, H., 1990 N
115 Rio, D.; et al., 1990 N
115 Premoli Silva, I.; Spezzaferri, S., 1990 F
115 Johnson, D.A., 1990 R
115 Fenner, J.; Mikkelsen, N., 1990 D
115 Vincent, E.; Toumarkine, M., 1990 F
115 Schneider, D.A.; Kent, D.V., 1990 M
117 Spaulding, S., 1991 N
117 Sato. T.; et al., 1991 N
117 Nigrini, C., 1991 R
117 Spaulding, S.A.; et al., 1991 F*
117 Hayashida, A.; Bloemendal, J., 1991 M
119 Huber, B.T., 1991 F
119 Wei, W.; Thierstein, H.R., 1991 N
119 Wei, W.; Pospichal, J.J., 1991 N
119 Caulet, J.P., 1991 R
119 Lazarus, D.B., 1992 (vol. 120) R

119 Baldauf, J.G.; Barron, J.A., 1991 D
119 Sakai, H.; Keating, B.H., 1991 M
119 Keating, B.H.; Sakai, H., 1991 M
120 Heider, F.; et al., 1992 M
120 Inokuchi, H.; Heider, F., 1992 M
120 Aubry, M.-P., 1992 N
120 Wei, W.; Wise, S.W., 1992 N
120 Berggren, W.A., 1992 F
120 Berggren, W.A., 1992 F
120 Harwood, D.M.; Maruyama, T., 1992 D
120 Takemura, A., 1992 R
120 Abelmann, A., 1992 R
120 Lazarus, D.B., 1992 R
122 Siesser, W.G.; Bralower, T.J., 1992 N
122 Galbrun, B., 1992 M
122 Zachariasse, W.J., 1992 F*
122 Tang, C., 1992 M
125 Ciampo, G., 1992 N
125 Xu, Y.; Wise, S.W., Jr., 1992 N
125 Milner, G.J., 1992 F
127 Rahman, A., 1992 N
127 Brunner, C.A., 1992 F
127 Alexandrovich, J.M., 1992 R*
127 Koizumi, I., 1992 D
127 Hamano, Y.; et al., 1992 M
130 Leckie, R.M.; et al., 1993 F*
130 Chaisson, W.P; Leckie, R.M., 1993 F
130 Takayama, T., 1993 N
132 Premoli Silva, I.; et al., 1993 N,F
132 Sager, W.W.; et al., 1993 M
133 Gartner, S.; et al., 1993 N
133 Kroon, D., 1993 F*
134 Zhao, X.; et al., 1994 M
134 Staerker, T.S., 1994 N
134 Perembo, R.C.B., 1994 F
134 Weinheimer, A.L.; et al., 1994 R
135 Nishi, H.; Chaproniere, G.C.H., 1994 F*
135 Quinterno, P.J., 1994 N*

* used only in biostratigraphy files, not available in Neptune

3. THE REALISATION OF NEPTUNE - THE REAL WORLD IS WORSE THAN WE THOUGHT

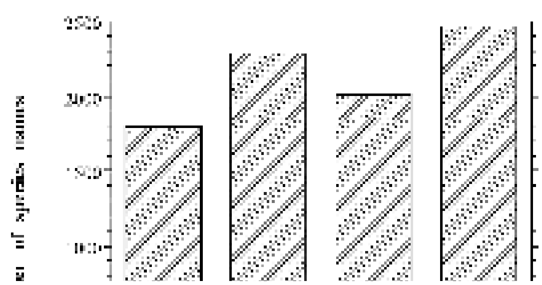
3.1. Stratigraphic and geographic coverage

The geographic distribution of the 165 holes included in Neptune is uneven. In some areas there is a very detailed coverage, like for example in some parts of the Antarctic Ocean (Fig. 2.1). On the other hand, no holes from the central north and southeastern Pacific Ocean are present in Neptune. (Holes from ODP Leg 145 now provide a transect across the north Pacific.) The mid- and high latitudes in the southern hemisphere and the tropical regions of the Atlantic Ocean are also not well represented. This is due in part to the uneven coverage of DSDP and ODP cruises and in part to the selection made for Neptune, which preferentially included holes with good biostratigraphy.

Each year, ODP organizes five to six drilling cruises which result in as many published **Scientific Results**. Although not all cruises retrieve micropaleontologically significant material, many of them provide a detailed biostratigraphy and data relevant to the scopes of Neptune. The present geographic coverage of holes in Neptune has been last updated in 1995 (Leg 135). Since then more than twenty-five volumes of **Scientific Results** have been published. From the beginning of the project, we were faced with the need to maintain a balance between keeping up with the new data produced by ODP and the need to analyze the data already in Neptune for biostratigraphic or micropaleontological studies. At present, I have decided to keep Neptune at its current, acceptable but not optimal, size in order to complete some of the studies that we had planned. If it will be decided to update Neptune in the future, it will be necessary to:

- select suitable holes from Leg 136 onward, and for the selected holes:
- compile biostratigraphic files and construct age models;
- import the core depth file and the age model file for each hole;
- download from ODP the available range charts;
- format the range chart files to make them compatible with Neptune;
- import the range chart file;
- update the species name list with the new names eventually present in the range charts.

Another limitation of the database is given by the often incomplete often-incomplete recovery of sediments (Fig. 3.1). Before the advent of hydraulic piston coring, few continuously recovered sections were available. Core recovery has drastically improved in the more recent ODP holes but



sediment loss at core breaks is still common even in continuously cored sections (Farrell and Janecek 1991).

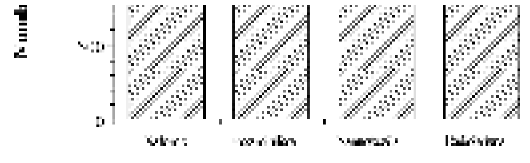


Figure 3.1.

In addition, there is an uneven distribution in the temporal coverage of the sections. Whilst Plio-Pleistocene sections are very well represented in Neptune (as they are in ODP holes overall), the detail of stratigraphic coverage decreases for older time periods, as naturally expected from the drilling procedure (Fig. 3.2, Spencer-Cervato 1998). This might be interpreted as a need to recover more Miocene and older sections, but this pattern actually reflects the number of **studied** sections and not simply the recovered sections. Therefore, I believe that the problem does not lie only in the 'quantity' of older sections drilled, but also in the 'quality' of their stratigraphy. The reliability of the stratigraphy provided for a section depends strongly on the availability of good calibrations, and these are currently available mainly for Neogene sediments. Figure 3.2 also shows that the number of well-studied sections does not decrease gradually and regularly with age, but shows peaks (around 2 Ma) and plateaus (e.g., between 20 and 32 Ma). This likely reflects the relative, unequal attention given to the Cenozoic stratigraphy through the history of DSDP and ODP.

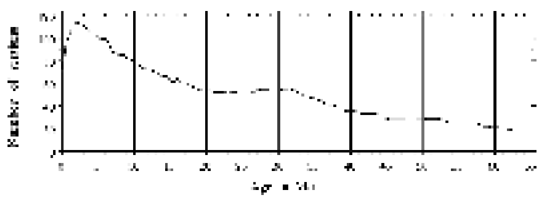


Figure 3.2.

3.2. Chronology

For the database, we have chosen to use a comprehensive biochronology based on deep-sea sections, therefore not considering land sections, which represent the type localities where stratigraphic series were first described. This may represent a limitation in the achieved biochronological calibration. The precision of the ages determined with the age models depends on various factors, some subjective and nonquantifiable, and some, like sample spacing, accuracy of biostratigraphic calibration, or core recovery, that can be quantified. A conservative estimate of the age model precision of 0.36 m.y. was determined for Neogene sediments (Spencer-Cervato et al. 1994). For Paleogene sediments it is about 0.66 m.y. (twice the average sample spacing).

Another important factor is the quality of the age model. The Neogene DSDP age/depth plots that we have published so far (Spencer-Cervato et al. 1993; Lazarus et al. 1995a) are a good example of the range of reliability of the line of correlation. The subjective ranking given in Table 2.2 varies from very poor or poor (wide scatter of events, straight line of correlation drawn across the middle of the cloud), to moderate (some scatter of a limited number of events, various possible lines of correlation), to good or excellent (40% of the holes: very good agreement of the event ages, abundant events to constrain the line of correlation, good agreement between magnetostratigraphy and biostratigraphy). Several factors can cause the scatter of events observed in most age/depth plots: reworking, downhole contamination, incorrect entry in the biostratigraphy file, typos in the range charts, diachrony of the calibrated event, , and sample spacing. Whilst most of these causes can be easily double-checked, diachrony is quite difficult to assess. The assumption of 'globally synchronous events' which is at the base of biochronology is validly established only for some selected, well documented events (e.g., Hays and Shackleton 1976; Thierstein et al. 1977; Backman and Shackleton 1983; Wei 1993; Spencer-Cervato et al. 1994). It is likely that more complete data collection and documentation would lead to the identification of more globally synchronous events. But in most cases, a calibration is valid only for the more or less restricted biogeographic province where it is done, and only a few events are truly globally synchronous, within the precision of the method adopted for calibration. The need for localized calibrations has long been known for siliceous plankton stratigraphy, but it is not widely accepted by biostratigraphers using calcareous plankton. To minimize this factor, we intentionally used multiple regional calibrations for diatoms and radiolarians. Even with this approach, the scatter is sometimes too large to provide a reliable line of correlation. For nannofossils and foraminifera only one general (low latitude) calibration is available (Berggren et al. 1985, 1995a, b). The advantage of this calibration is that it is based on several sites, while most of the regional calibrations are based only on one hole. An estimate of the diachrony/synchrony of Neogene events was done with a subset of the holes currently present in Neptune (Spencer-Cervato et al. 1994). This study indicated that calcareous nannofossils provide the most reliable biostratigraphic events, as they are mostly cosmopolitan and, if diachronous, the age margin is relatively small.

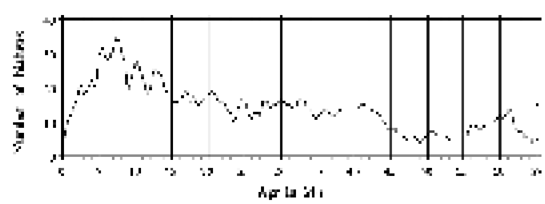


Figure 3.3.

Very few sections are actually continuous, and long stratigraphic gaps are common (Spencer-Cervato 1998) (Fig. 3.3). Two-thirds of the selected holes contain at least one hiatus, and on average they each contain three hiati of various lengths (Fig. 2.1). The presence of these hiati results in artificially older or younger ages for the samples adjacent to the gap. This does not allow one to automatically ('blindly') search the database for e.g.,such information as species ages, but requires that every output is be checked and compared with the age models.

The final and probably most necessary improvement of the chronology of Neptune is given by the life-timelifetime of the biochronology selected for the age model calibration. We initially based the age models on Berggren et al. (1985). An updated magnetostratigraphy was published later (Cande and Kent 1992) but it did not provide the combination of biochronology and magnetostratigraphy available from Berggren et al.'s (1985) work. We thus decided to continue using Berggren et al. (1985) throughout the first phase of the project (DSDP Neogene sediments). However, ten years after the first biochronology compilation, a new updated biochronology was published (Berggren et al. 1995b) and the chronology of Neptune became suddenly outdated. The iterations to update Neptune's chronology were greatly helped by additional programming of Neptune by Dave Lazarus and an auxiliary computer program (not part of Neptune and written **ad hoc** by Bernhard Brabec) which created a correlation function between the old and the new master biochronology. This function was applied to all age model files and new revised age models were created. . Then, all biostratigraphy files were updated using a 'find - replace' routine with lookup tables (i.e.: if code in column 3 is equal to xYwz, replace age in column 4 with corresponding value in lookup table). While we could directly use the new calibrations for calcareous plankton as lookup tables, it was necessary to recalibrate to the new time scale all regional templates used for siliceous plankton events. Finally, before the new age models could be imported into Neptune, all the age/depth plots were redone by myself and eventually adjusted to fit the new event ages.

3.3. Taxonomy

Among the other reasons mentioned above, if a bio-event recorded in a specific hole plots far outside the area where the line of correlation can be drawn, it could be due to its taxonomic identification. Many authors have put together the hundreds of range charts that were used for Neptune and not all agree in the detailed taxonomic identification of all the 8800+ taxa included in Neptune. Indeed, taxonomic identification is subjective. The time pressure under which biostratigraphers are during a leg is also an important limiting factor in the number of species described in a range chart, which is often limited to biostratigraphic markers. The extent to which this taxonomic problem has affected the data in Neptune can be judged by experts in particular cases but cannot be easily quantified.

Starting from the biostratigraphy filesbiostratigraphic records assembled for the chronology, we assumed that the taxon associated with one event and described in the range chart was the one we were looking for. Further, we needed to consider the occurrence of synonyms. It sometimes happens that the name used by one author for a taxon corresponds either to a different taxon according to another author, or that a different name is used by a second author for this specific taxon (synonymy). For example, the foraminifer species **Globorotalia truncatulinoides** has been also called **Truncorotalia truncatulinoides**. To account for this, we have used the literature, personal experience and extensive consultation with taxonomic experts to identify valid taxon names. Three thousand of the 8810 names listed in Neptune (Fig. 3.4) are considered valid (i.e., are legal names in the framework of the ICZN and ICBN, and are known to be real to at least one of the experts). Synonyms to these valid names were then identified (with the corresponding valid name). They constitute 31% of the total number of names. In several cases we could not unequivocally identify a specific name and marked it as 'unknown' (15% of all names). Only 43 names (0.5%) were considered invalid. This information is available in the 'Species Names' table of Neptune. The synonymizsation is subjective (the initials of the person who identified each species name is also given in the 'Species Names' table) and the names list does not at all pretend to be a thorough or complete taxonomic revision of marine plankton. It merely represents a working table that gives us a first approximation of plankton taxonomy. A 'real' taxonomic database would need complete taxonomic descriptions (with history) for each taxon and a series of images to illustrate them. Cathy Nigrini, Jean-Pierre Caulet, and Dave Lazarus are currently working on a detailed taxonomic database for radiolarians, but it is well beyond the scopes of Neptune to even attempt anything like this for all groups.The taxonomic list also needs continuous update: every time a new hole is added to Neptune, the biostratigraphic range charts carry with them new names, sometimes several ones. These need to be added to the 'Species Names' list and identified as valid or not.

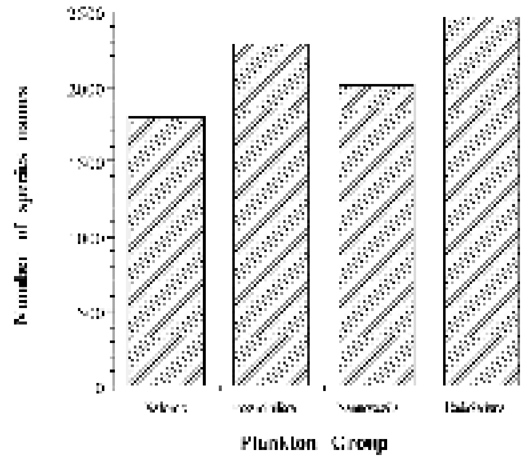


Figure 3.4.

3.4. Biostratigraphy

There is an uneven distribution in the number of reports by plankton group in Neptune. Over 60% of the 225 articles from which data for Neptune have been extracted (Table 2.4) are on calcareous plankton, almost equally distributed between nannofossils and foraminifera. Radiolarians follow with about 21% and diatoms trail with only 16%. At the same time, biostratigraphic work on siliceous plankton is underrepresented in Paleogene sections, and most often limited to the Oligocene and younger sections (Fig. 3.5). This unevenness represents a bias for evolution studies where we would like to compare calcareous and siliceous plankton occurrences. Whether this distribution represents the average abundance of fossil plankton in deep-sea deposits or is instead the reflection of staffing decisions by DSDP and ODP is yet to be determined.

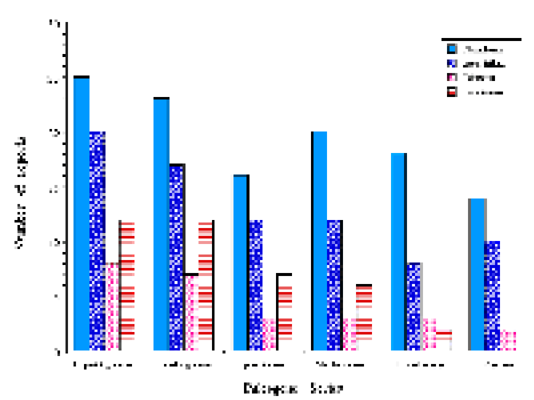


Figure 3.5.

One of the limitations of Neptune as a comprehensive micropaleontological database is given by our decision to include only four plankton groups. The DSDP and ODP

Reports include many articles on benthic foraminifera, silicoflagellates, dinoflagellates as well as palynology. At the moment, there are no plans to include their occurrence data in the database, which in itself would not be a huge task.

Next Section...

Close Window

Figure 3.1. Total core recovery in percentage in the holes included in Neptune.

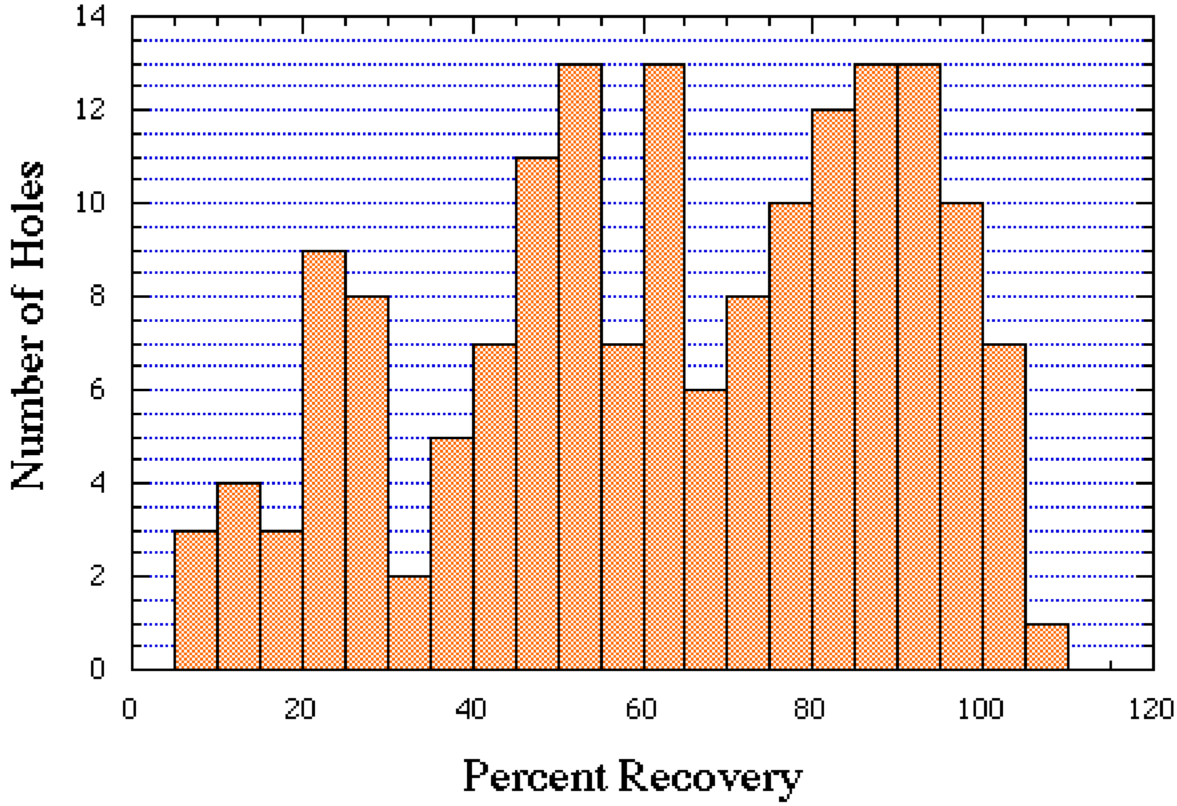


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Figure 3.2. Age distribution of the sections included in Neptune.

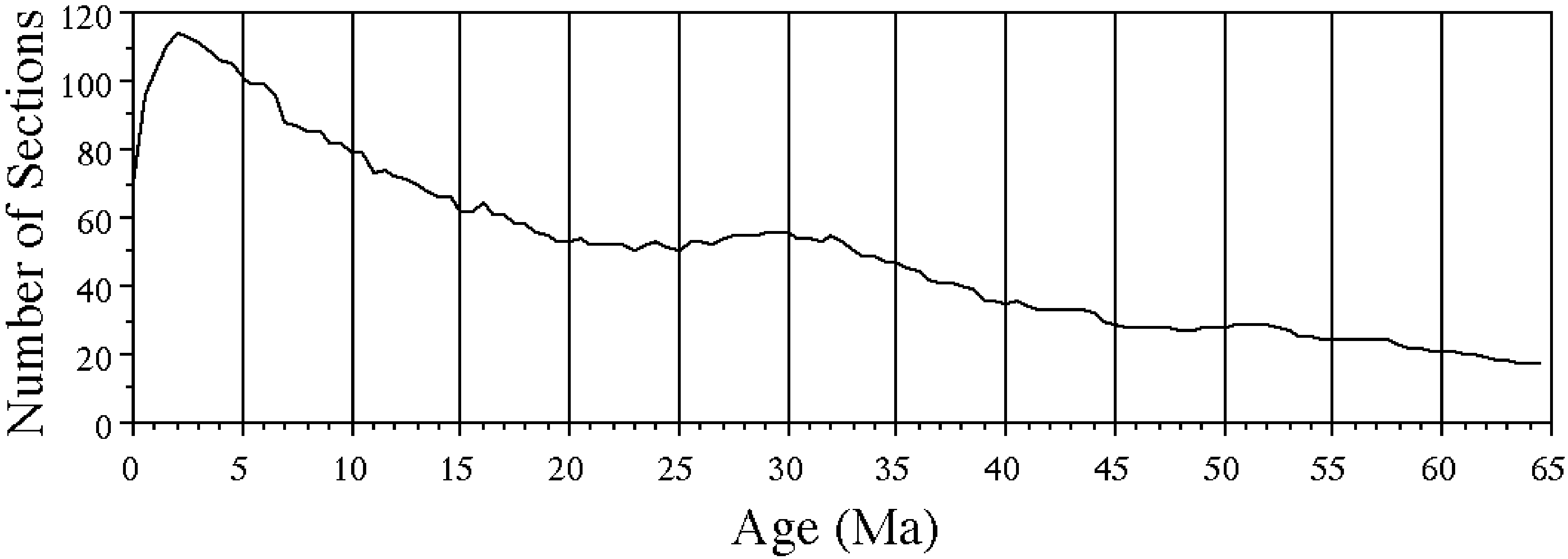

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Figure 3.3. Age distribution of hiati in the sections included in Neptune.

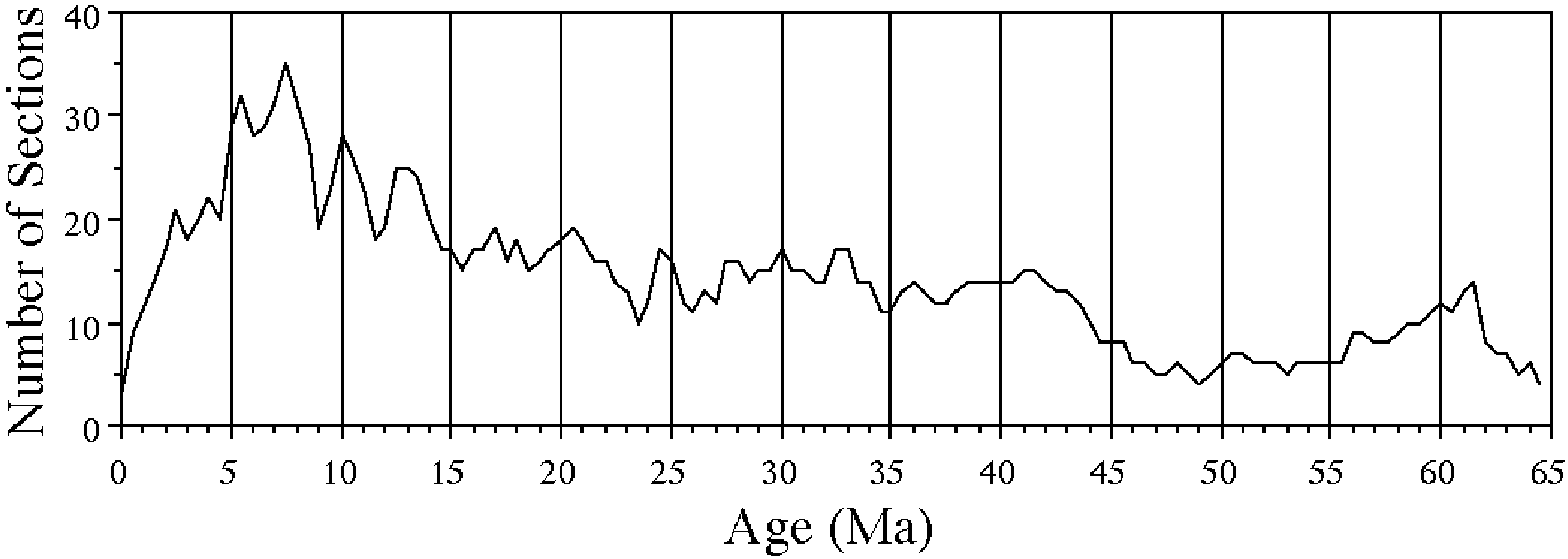

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Figure 3.4. Number of species names in each plankton group included in Neptune.

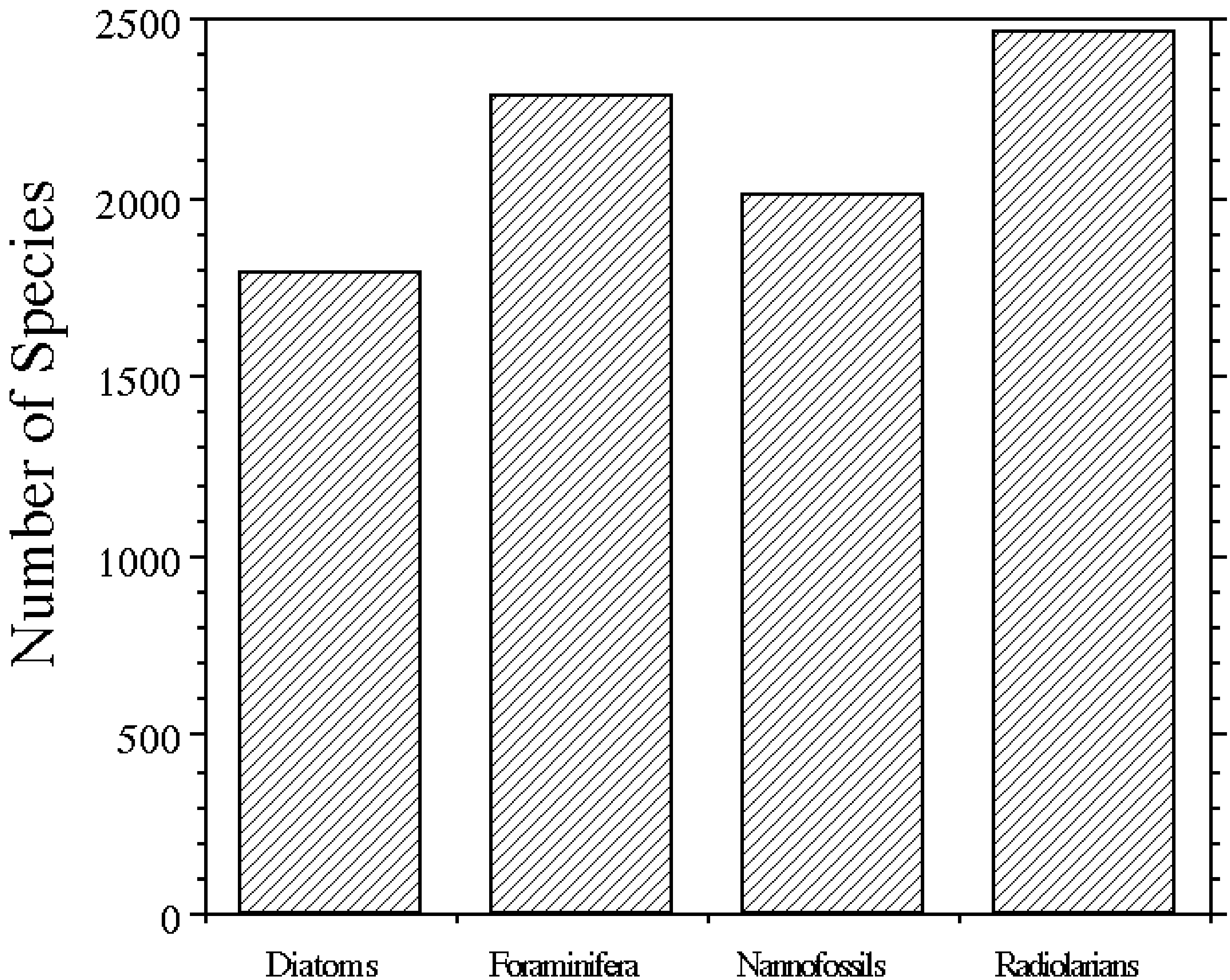

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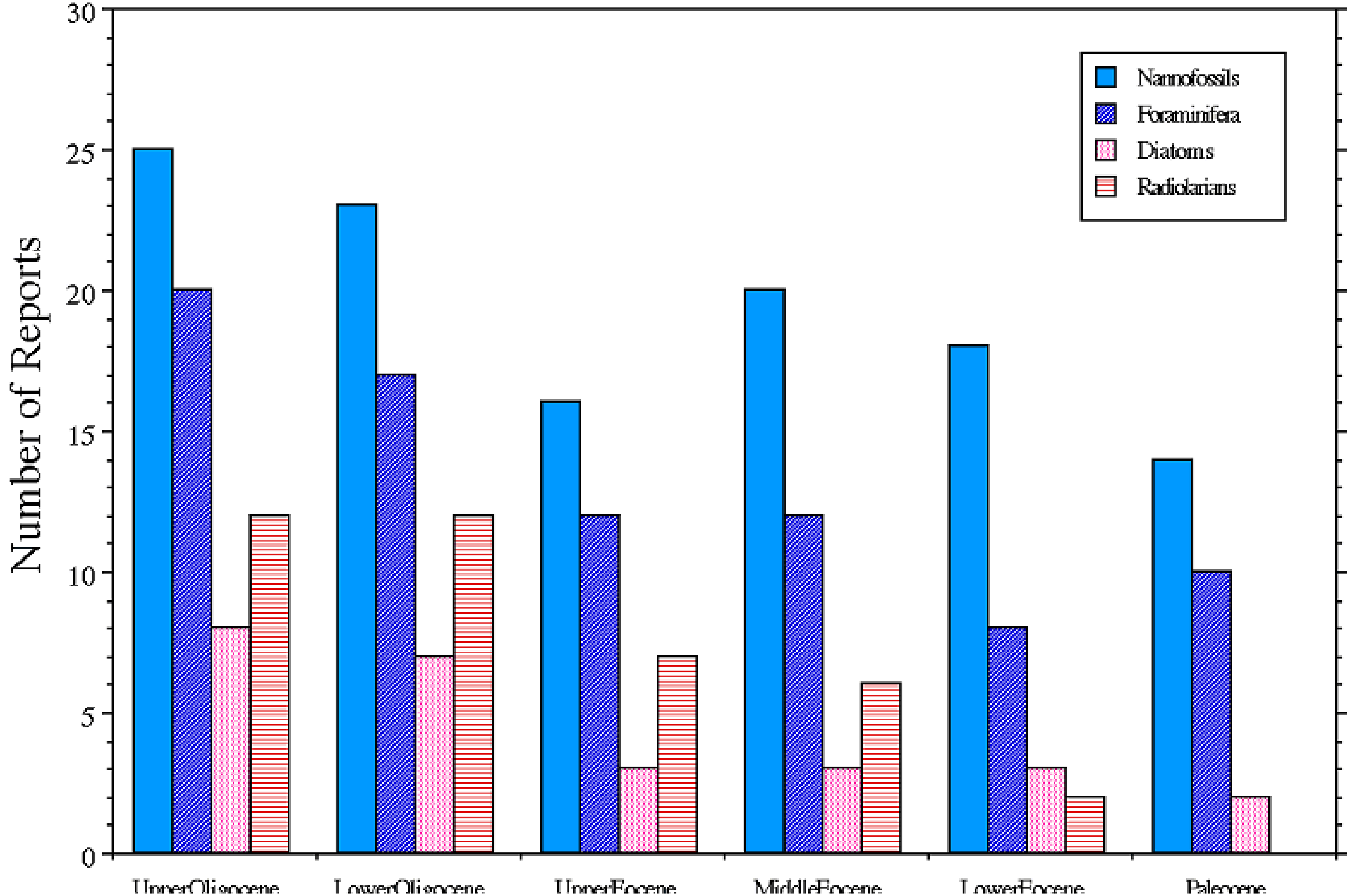
Figure 3.5. Number of reports on Paleogene biostratigraphy in Neptune by plankton group.



4. RESEARCH PROJECTS CARRIED OUT WITH NEPTUNE, WHAT THEY TOLD US, AND RECOMMENDATIONS FOR THE FUTURE

4.1. The database structure and search capabilities: a tool to find out what we do or don't know

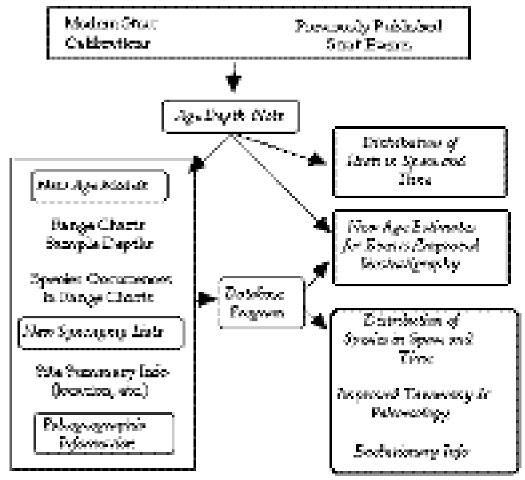
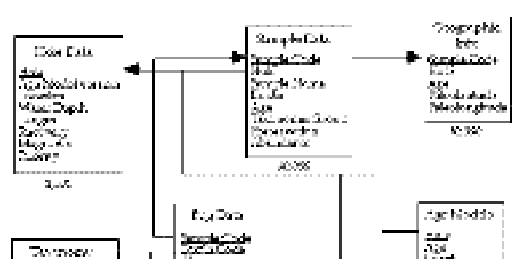


Figure 4.1.

The Neptune database currently provides rapid retrieval of age information on 165 DSDP and ODP holes; taxonomically corrected species lists and other taxonomic information for calcareous nannofossils, planktic foraminifera, diatoms and radiolarians for the entire Cenozoic; paleogeographic location of the 165 holes (paleolatitude and paleolongitude); extensive distributional data for these fossil groups (e.g., biogeographic occurrence information, computerized microfossil range charts) (Fig. 4.1). The design and implementation of the database software have been described in Lazarus (1994) and in an unpublished guide (Lazarus, personal commun., 1996). These will be used for this description, with the updates of the data tables based on the present status of the database (after the most recent upgrade).

4.1.1. Overview of database structure. Neptune is designed as a relational database. Macintosh computers and 4th Dimension™ database software (4D) are used to run the database (Lazarus 1994). The database is implemented as several relational tables that contain (as of February 1998) close to 500,000 records.

Import procedures for range chart data as well as search procedures are available. The search procedures can locate all reported occurrences of any taxon or combination of taxa, automatically identifying occurrences recorded under synonymous names. Searches can also be used to locate other relevant information, such as general hole information, sample age, species occurrences, etc. Commercial mapping software (e.g., Atlas™) is used to plot locations of species occurrences, using a Neptune-generated plotting data file with latitude and longitude. A 'composite age range chart' program can also be used with an appropriately formatted file generated by a Neptune search (Lazarus 1994).



Neptune was created as a relational database where the data are separated into simple tables, with relational links between the tables. The structure of the database is shown in Figure 4.2. Five data tables hold the primary data: stratigraphic occurrence data for taxa ('Bug Data' table);

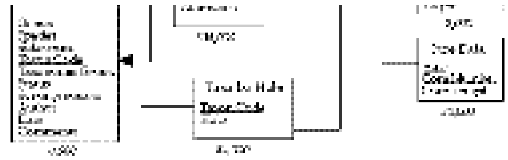


Figure 4.2.

taxonomic data on species' names ('Taxonomy'); biogeographic data on species' occurrences ('Taxa by Hole'); geologic age information ('Age Models'); and paleogeographic information ('Geographic Info'). Paleo-water depths are available for selected samples and have been published (Spencer-Cervato 1998). As this information is not available for all samples, it is not currently included in Neptune.

The database maintains a strict separation between the primary observational data (occurrences of named taxa at specific depths in holes) and the interpreted meaning of the data (i.e., the species to which the name belongs - 'Taxonomy' - or the age of the section at a specific depth - 'Age Models'). These tables can be in fact modified repeatedly, but the observations remain constant (Lazarus 1994).

The stratigraphic occurrence data form the core of the database (over 380,000 records of 'Bug Data'). A typical range chart is decomposed into a minimum of one species occurrence in one sample. Further data separation is achieved by putting all information about samples and species into separate tables ('Sample Data' and 'Taxonomy'). Samples and species are represented in the 'Bug Data' table only by internal codes, linked to the more detailed records in other tables.

4.1.1.1. Species names ('Taxonomy' table). All names in the database are identified by a separate entry in this table. Each occurrence, including misspellings and questionable names (e.g., **A. deflandrei?**), is given as a separate entry. Each is identified by up to three words (genus, species, subspecies or qualifier). The qualifier is generally used to identify questionable entries, marked with the letter 'Q'. Each entry is uniquely identified by a 'Taxon code', a combination of nine characters originally given by DSDP. This code is central to the functioning of the database, as it provides links to the other tables. The first five characters are letters, all upper case. The first letter identifies the fossil group (D for Diatoms, N for Nannofossils, etc.). The next four letters are characteristic of the genus. The last four characters are numbers and give the species number in the genus. DSDP started with 0010 and incremented by units of 10 for each new species name. ODP does not use codes to identify species names. Thus, we created new codes for new species names that occur in ODP range charts. To avoid any overlap, we have used the same 5 letters to identify the group and the genus, but started with 5010 to number the new species (DSDP never had numbers higher than 2500).

Every entry has other information attached to it. The Status (or validity) field is a single uppercase letter which states that the name is V-alid, a S-ynonym to another name (with corresponding taxon code entered in the 'synonymous to' field), I-nvalid, Q-uestionable, or U-nknown. A G is used to indicate a genus-level name. Every name has also an author code (initials of person responsible for the entries in the Status field) and a date (mm/dd/yy). Comments of any length are also entered in the 'Comments' field.

Additional species' records are available in the 'Species by Hole' table which comes directly from the DSDP data set. The current table, reformatted from the original data set to save space, contains simply a Taxon Code and a Hole field.

4.1.1.2. Age Models and Hole summary data ('Age Models' and 'Hole Data' tables). The 'Age Models' table contains the age model developed for each hole with range chart available in the database. The age model was constructed by a broken line composed of straight segments, which can be horizontal in the case of hiati. The extremes of the segments are identified by age and depth and entered in the corresponding field, next to the 'Hole' field. To keep track of which age model is being used in the database, each age model's time of creation date stamp is entered automatically in the 'Hole Data' table ('Age model version'). This latter table contains a variety of information, including latitude and longitude, water depth, ocean basin, hole length and recovery, etc. Holes that have an age model (and therefore range chart data) have an entry in the 'Age Model version' field and a ranking for each fossil group (originally used to select holes).

4.1.1.3. Sample Info ('Sample Data' table). Most of the fields in this table are created directly from computer files or by Neptune. Each sample described in each range chart is identified by a unique digital code and is specific for one fossil group. This means that, if in one sample (identified as depth in a hole (mbsf), but also in three separate fields as core-section-depth interval format - grouped in Figure 4.2 under 'Sample Name') both diatoms and radiolarians ('Taxonomic Group' field) were described, this sample would be described twice in Neptune, each time with a different 'Sample Code'. The age of the sample is derived from the 'Age Model' table through a relational link. If available, information on the preservation and abundance of the specific fossil group in that sample is also given.

4.1.1.4. Paleogeographic data ('Geographic Info' table). With the addition of Paleogene range charts, I considered it necessary to locate species occurrences in their appropriate paleogeographic position. For this purpose, I used a PC-based program kindly provided by Alan Smith (Cambridge University) which uses finite rotations. The program is based on published reconstruction data (Euler rotations and their ages) used to move a given site relative to Africa and then reposition that site in paleomagnetic coordinates (Smith, personal commun., 1997). The input file contained present latitude and longitude: paleolatitudes and paleolongitudes were determined for each hole at 5 m.y. intervals. This approximation was necessary to simplify the entry of these data into Neptune, but I believe that it does not significantly affect the already approximated estimate of paleolatitude and paleolongitude made by the finite rotations program. These paleogeographic data, with hole and age, were imported into a separate table ('Geographic Info') and the Sample Code used to link it to other tables.

4.1.2. Importing data into Neptune (range charts and age models). Data can be imported into Neptune by the 'administrator' (this function is not available in the 'user' mode or with the runtime version of 4D). Most of the DSDP range charts were imported directly from the DSDP CD-ROM data, but ODP data need to be imported as individual spreadsheet format files. Each procedure creates automatically new sample records for each sample in the range chart data ('Sample Data') and new 'Bug Data' records for each non blank cell of occurrence data in the range chart. No ages are assigned in this procedure and all sample ages are set at zero. Only when the age model is imported, a corresponding age is recorded in the age field of the 'Sample Data'.

Each range chart file needs to hold data for one hole and one fossil group only. Each sample must be entered in one row in a 'leg-hole-core-section-first depth-second depth' format (e.g., 113-689-B-2H-1-115-116). These data are automatically entered in the corresponding fields in the 'Sample Data' table. The depth in mbsf is derived from the 'Core Data' table, where the core depth files for each hole are imported as soon as a hole is selected. Species names must be entered as Species Codes (9 characters, e.g., DACTI0020). Every species code present in the spreadsheet must be already available in the 'Taxonomy' table. The 'import from spreadsheet' procedure in Neptune automatically checks each DSDP Code in the spreadsheet and if it encounters a code that is not present in the 'Taxonomy' table, the procedure aborts.

Age information is present in Neptune in two forms. The 'Age Model' table actually holds all the line of correlations (age models) for each hole. Age for samples are calculated from the line of correlations and stored as calculated fields in the 'Sample Data' table. This calculation is done only once, when the age model is read into the database, and is automatic. Only one age model can be imported at a time. To update an existing age model, it is sufficient to read in the new file and the old ages will be automatically replaced by ages based on the new line of correlation.

4.1.3. Report capabilities and external graphics. Data can be extracted from the database in a variety of ways. The results can be then saved as export files, that can eventually be used with other programs. Procedures that search for taxa, in either the 'Bug Data' table of stratigraphic occurrence information, or in the 'Taxa by Hole' table of biogeographic information, create lists of Taxon Codes (from 'Taxonomy') to search for. These lists include the taxonomic name/s requested by the user, but are supplemented by lists of synonyms to these names. Users can edit these lists to fine-tune searches.

In addition to export formats for statistics and spreadsheet packages (usually in ASCII format), the database exports data in formats specific for two types of graphic data display. Data on the location of specific DSDP/ODP sites can be plotted in a map form using Atlas™ (WTC Scientific). The most recent version of this program for Macintosh computers does not run reliably on PowerPCs and the use of the PC IBM-compatible version (which

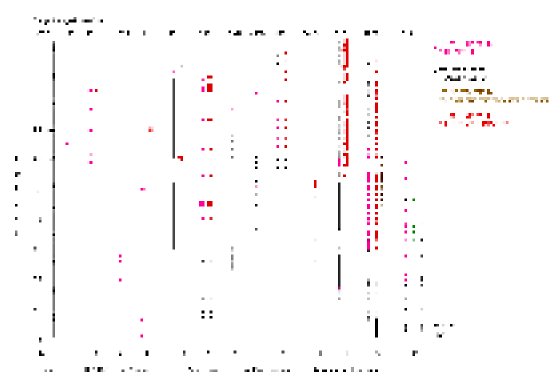


Figure 4.3

Figure 4.3.

can use the same cross-platform file) is recommended. A custom application creates graphic displays of occurrence data for taxa, plotted by age and hole ('Age Range Charts', Lazarus 1994) (Fig. 4.3).

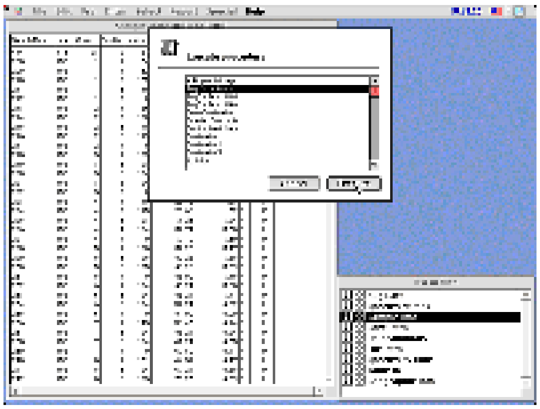


Figure 4.5.

4.1.4. Searching the database. The simplest way to search Neptune is by using the built-in 4D 'Search Editor' (under the 'Select' menu). Any of the tables previously described (Species Names, Hole Info etc.) can be selected from the list in the small window that automatically appears when Neptune is started. This shows a window with all the records in that table. The 'Search Editor' function displays a dialogue window which shows the fields available in the table. Only fields in bold can be selected and additional search criteria (equal to, contains, less than etc.) added. The results of the search are displayed in a few seconds (Fig. 4.4).

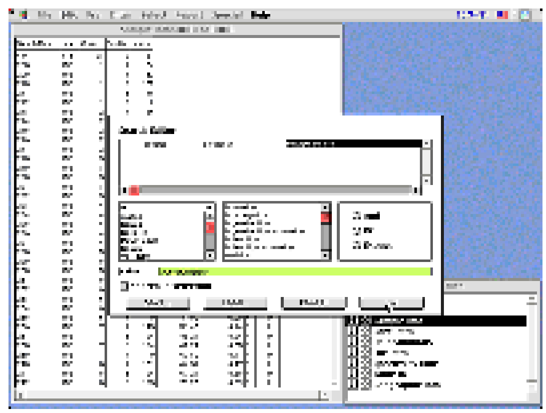


Figure 4.6.

More complex procedures, such as a 'Bug Data' search, allow to locate range chart data about one or more taxa. These predetermined procedures can be selected with the 'Execute Procedure' function under the 'Special' menu (Fig. 4.5). The 'Bug Data Search' procedure first shows a search editor window for 'Species Names' and waits for a taxon entry. This can be formulated as 'Species - is equal to - **name'** or done directly with DSDP codes (Fig. 4.6). This procedure locates all taxa matching the entered criteria, as well as other taxa identified in the database as synonyms for any of these. The user can then select one or all of the identified taxon names and click the 'done' button at the bottom of the window (Fig. 4.7). The procedure then searches the 'Bug Data' table to locate all records for this list of taxa. This search is done using indices, and only takes a few seconds (Fig. 4.8).

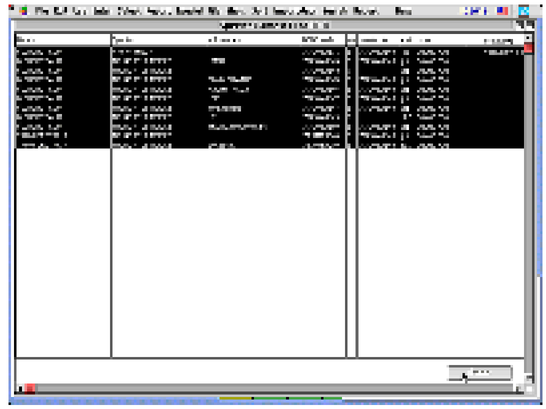


Figure 4.7.

The procedure informs the user via a dialogue box how many records have been found, and then presents the search editor window a second time. At this point the user can enter any other criteria, such as only samples with ages greater than 0 (i.e., holes with age models), or from holes from a specific geographic location (Fig. 4.9). The 'search in selection' box (lower left corner) is automatically marked allowing to search only among the already identified occurrences (and not the whole database!). The user should then click 'ok' to proceed. The procedure will refine the selection according to these secondary criteria, and present the user with a list (Fig. 4.10). This list can also be edited to refine the selection. Lastly, the user clicks 'done' to exit the procedure. The selected records can then be printed, exported to disc, or summarized in a report.

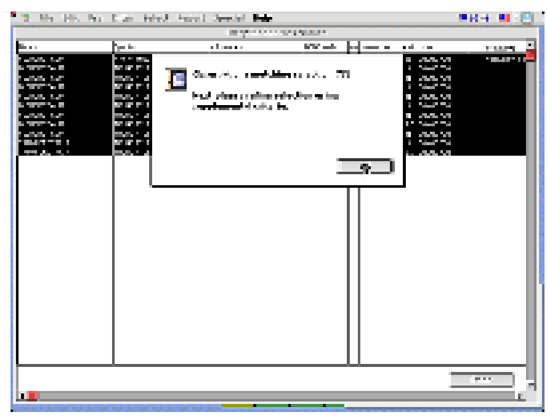
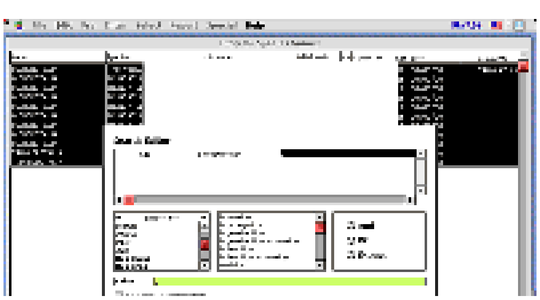


Figure 4.8.

A search procedure is also available to the automatic search for the ages of all samples recording several taxa given in a list (and their synonyms). This ‘Batch Search’ (‘BugDataSearchBat’) allows for the automatic operation of the series of procedures described above (Species name selection, identification of synonyms, bug data search, restriction to holes with age models, sorting of samples by age). It produces one separate output file for each name, as well as a cumulative file. This procedure was used to obtain species longevity data (described below). Alternatively, samples can be sorted by latitude and longitude to obtain ranges of geographic distribution of taxa through time (e.g., to identify cosmopolitan or endemic taxa).

4.2. Paleontological research based on Neptune: plankton evolution



In this and in the next section (4.3), I am presenting a summary of published paleontological and stratigraphic research conducted with Neptune, as well as some unpublished data on macroevolution. Neptune’s potential for paleontological research has been, so far, only marginally exploited. In spite

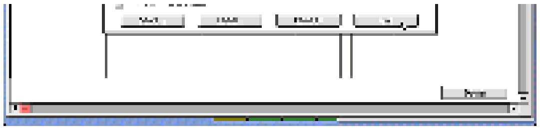


Figure 4.9.

of the limitations outlined in Chapter 3, the database provides the opportunity for large-scale macroevolutionary studies that could go well beyond presently available studies (e.g., Jablonski 1993; Kammer et al. 1997). The age control and time resolution, combined with the taxonomic information at species level on four distinct plankton groups, make Neptune a high quality data set.

Currently, the two studies we published on evolution were focused on the evolution of one foraminifer species and were based on Plio-Pleistocene sediments, which are represented in a large number of holes in Neptune (Lazarus et al. 1995b; Spencer-Cervato and Thierstein 1997). The goal of these studies was to document patterns of evolution of a new species (the planktic foraminifer, **Globorotalia truncatulinoides)** from its ancestors and to identify speciation and migration in distinct biogeographic provinces by using the tests' morphometry. In addition, we attempted to determine the environmental conditions (water depth, thermal structure of water column) at the time of speciation or immigration with stable isotope geochemistry. Whether changes in these environmental conditions were a determinant factor in the speciation or migration, even after these detailed studies, remains still speculative.

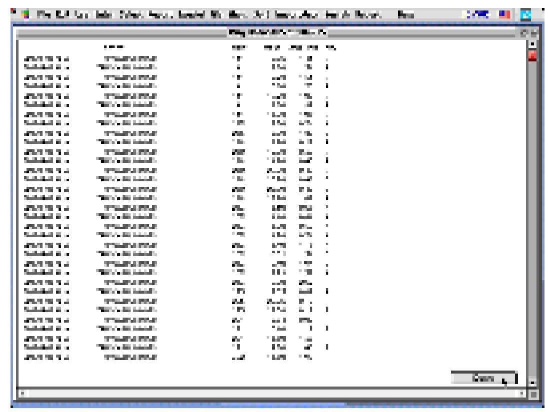


Figure 4.10.

For these studies, Neptune was used in the selection of sites by identifying the occurrences by hole and FADs/LADs (first appearance datum/last appearance datum) of the species and its ancestors. An age range chart was produced from the search for all **G. truncatulinoides** and related species occurrences (Fig. 4.3). This was used to identify the oldest first occurrences and to have an overview of the age distribution, which shows a distinct diachrony (Fig. 4.11). This search lead to the selection of suitable DSDP and ODP sites from which samples were requested. The samples were then analyzed morphometrically and isotopically to determine patterns of evolution (in this case, cladogenesis or phylogenetic branching) and species migration (Lazarus et al. 1995b; Spencer-Cervato and Thierstein 1997).

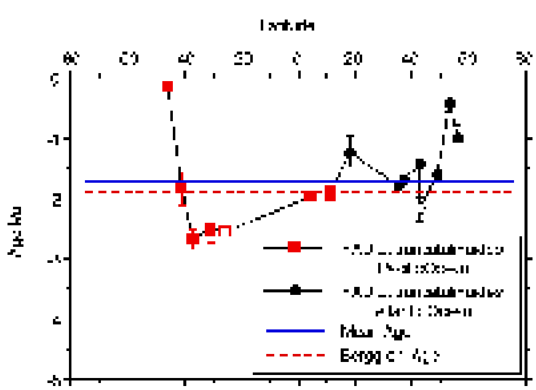


Figure 4.11.

The earliest first occurrences are found in several sites in the southwest Pacific. Gradual cladogenesis was documented in this region during the late Pliocene in sympatric or parapatric populations (Lazarus et al. 1995b). Based on qualitative observations, similar but younger, gradual transitions had been reported from other areas of the world's oceans. Therefore, the hypothesis arose that this gradual evolutionary branching might have occurred in response to changing environments at different times in different ocean areas. To evaluate this hypothesis, we studied the morphological transitions of the three taxa, using image analytical techniques, in several deep-sea sections from various areas, identified with Neptune (Spencer-Cervato and Thierstein 1997). The morphometric analyses showed that **G. truncatulinoides** evolved between 2.8-2.3 Ma sympatrically in large populations from its ancestor **G. crassaformis** in the southwest Pacific. Differentiated morphotypes of **G. truncatulinoides** subsequently immigrated into the Indian and Atlantic Oceans between 2.3 and 1.9 Ma. Our morphometric data show these younger appearances outside the southwest Pacific to be punctuated, and representing migration events (Spencer-Cervato and Thierstein 1997).

One of the most crucial, yet elusive issues in evolution is the role played by the environment in the appearance of a new species or its extinction. Planktic foraminifera are ideally suited for these studies because of the large populations, widespread occurrence of tests in marine sediments, relatively large size that allows for detailed identification with traditional microscopic techniques, abundance of information on living populations and their habitats, conceivably rapid colonization of biogeographic provinces under suitable conditions, and the possibility to reconstruct these conditions (e.g., water depth, temperature, nutrients) with stable isotope geochemistry.

Globorotalia truncatulinoides is an ideal species for the study of the environmental conditions at the time of speciation. We hypothesized that the global cooling of surface waters, coinciding with the northern hemisphere glaciation, led to the formation of oceanographic barriers that could have retarded the expansion of **G. truncatulinoides** up to 2.3 Ma. At this time, a relative warming and subsequent transgression could have spurred the migration from the southwest Pacific into the Indian Ocean, possibly through the Indonesian passage. A direct link between the speciation and surface water changes linked to the northern hemisphere glaciation has not been proven so far and seems unlikely. In fact, stable isotope data in **G. truncatulinoides** and its ancestors indicate that the three species' depth habitat preferences remained unchanged through the speciation and migration of **G. truncatulinoides** and that all three species were dominantly deep-dwellers, in agreement with their present environmental preferences (Spencer-Cervato and Thierstein 1997).

One of the original goals of the Neptune project was to perform macroevolutionary studies. Macroevolution is a major area of paleontology that developed during the 1970s and 1980s, inspired by the apparent success of the taxic approach to evolutionary patterns (Smith 1994). Macroevolution covers various concepts and processes. These studies differ from the previously described, 'microevolutionary' ones - which concentrated on the heritable variations of a population composed of one species and its immediate ancestors - mainly in the scale. Macroevolution studies large-scale patterns of diversification and extinction arising from processes active at or above the species level (Smith 1994 and citations therein). Some workers have instead defined macroevolution as the extrapolation of microevolutionary processes into geological time (e.g., Levinton 1988). Smith (1994, Chapter 4) presents a comprehensive review of macroevolutionary concepts and theories.

Existing studies mainly consider fossil records of marine invertebrates in high hierarchical groupings (orders, families) with low stratigraphic age resolution (e.g., Jablonski 1993) from punctual, geographically restricted sources. Amongst the various causes of artifacts in macroevolutionary patterns, sampling resolution seems to be an important biasing factor (e.g., Alroy 1998). The chronological control of Neptune and its large amount of paleontological data with taxonomic accuracy at species level, combined with its comparably high sampling resolution (on average, 185 k.y. for the Neogene (Spencer-Cervato et al. 1994) and 330 k.y. for the Paleogene) holds promise for potentially significant contributions to this field of paleontology. Because the quality of the results of macroevolutionary studies is strongly dependent on a sound basis of chronology and taxonomy, we have first exploited the stratigraphic data set (see Section 4.3) and revised the taxonomy of the paleontological records (Section 3.3). We have thus left the study of macroevolutionary patterns in marine plankton to the final phase of the project.

I am presenting here some examples of data searches conducted with Neptune to answer some typical paleobiological questions. They cover the overall longevity and speciation/extinction distribution of Cenozoic marine plankton. I am purposely leaving the discussion and interpretation of these data to an absolute minimum. My goal is in fact to show what type of data can be obtained from the database and the potential of Neptune for paleobiological research.

To optimize the diverse paleontological data set in Neptune, the analyses have been conducted separately for the four plankton groups and the results interpreted in terms of similarities or differences among the groups. The data presented here are based on more than 1400 valid species names (Table 4.1), and include the occurrences of their synonyms. The output of every species' search consisted of their oldest first appearance and their youngest last appearance. Every result was checked to eliminate false entries caused by, for example, occurrences near hiati, typos, occurrences reported in one single sample, etc. Species that were reported only in one hole were not considered to eliminate the bias of single geographic data points. Finally, one table was produced for each group including the species name, the number of times it had been reported in a sample, the location (paleolatitude and paleolongitude) and age of its first appearance, and the location and age of its last occurrence. From these ages, the species' longevity was calculated.

- What is the distribution of the longevity of plankton species? Are there substantial differences or similarities among the four plankton groups?

Figure 4.12 shows the species' longevity

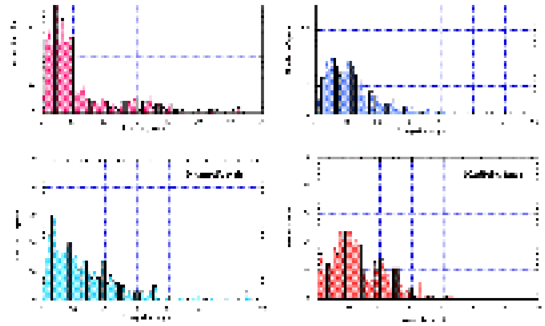


Figure 4.12.

distribution of the four groups with a 1 m.y. resolution. Comparing the four groups, three simple observations can be made: (1) all groups show an asymmetric, unimodal distribution, with a mode around 7 m.y. (diatoms and radiolarians), 14 m.y. (foraminifera) and 19 m.y. (nannofossils), and a tail towards higher longevity values; (2) the median for all distributions is around 10 m.y., except for diatoms, where it is around 7 m.y. - comparing these values with the mode, the peak of the distribution of diatoms is narrower and has a higher symmetry than the other groups; (3) a few phytoplankton species (diatoms and nannofossils) are very longevous (more than 40 m.y.), whilst zooplankton species (foraminifera and radiolarians) live all less than 43 m.y. These observations point to similarities between phyto- or zooplankton in one case, and between siliceous or calcareous plankton in another. However, they also show that diatoms are quite distinct from the other groups.

- What is the average species' longevity? Are there substantial differences between extinct and extant species' longevities?

Table 4.2 shows the average longevity (and standard deviations) of both extant and extinct plankton species. It is noticeable that the longevity of extinct species is consistently shorter than the one of extant species. This could be due to the different sizes of the populations considered (less than 30% of the species are extant), which might also explain the larger standard deviations of extant species' longevity. Alternatively, this could be the effect of differential preservation. Or it could be caused by the artificial boundary set at the beginning of the Cenozoic - the data might include species originated in the Mesozoic, giving them a shorter-than-real longevity. However, only a very small number of species (e.g., the extant nannofossils **Braarudosphera bigelowii** and **Scapholithus fossilis,** the extinct nannofossil **Placozygus sigmoides**; Perch-Nielsen 1985) are reported also from the Mesozoic. Statistically, they should not significantly affect the data set.

For demographic reasons, one would expect a gradually decreasing longevity instead of the asymmetrical peaks shown in Fig. 4.12. Is this lower-than-expected number of short-lived species an artifact of the analysis or a real signal? On the other hand, the differences seen in the longevity data could be real, suggesting for example that species which evolved in the Neogene (the majority of the extant species) are more likely to live longer. One can only speculate on the cause of this, such as larger surface water temperature gradients linked to growth of ice caps in polar regions? However, the Neogene climate mode, characterized by abrupt shifts from glacials to interglacials and vice versa, would seem to provide stressful environmental conditions that intuitively should increase species turnover, i.e., shorter longevities. This question requires further analyses (e.g., longevity plots at selected critical times) before a viable hypothesis can be formulated.

To help answer the various open hypotheses on species' longevities, an important factor that should be considered is the geographic distribution of species throughout their duration. This parameter allows to identify endemic versus cosmopolitan species and is an important factor in ecological studies. By comparing this parameter with species longevity, one would test if a species restricted to a narrow geographic region is more likely to survive longer than a globally widespread species, or vice versa.

- Are there periods in the Cenozoic with a high concentration of species' appearances or extinctions? Are there geographically defined speciation centers or survival refugia?

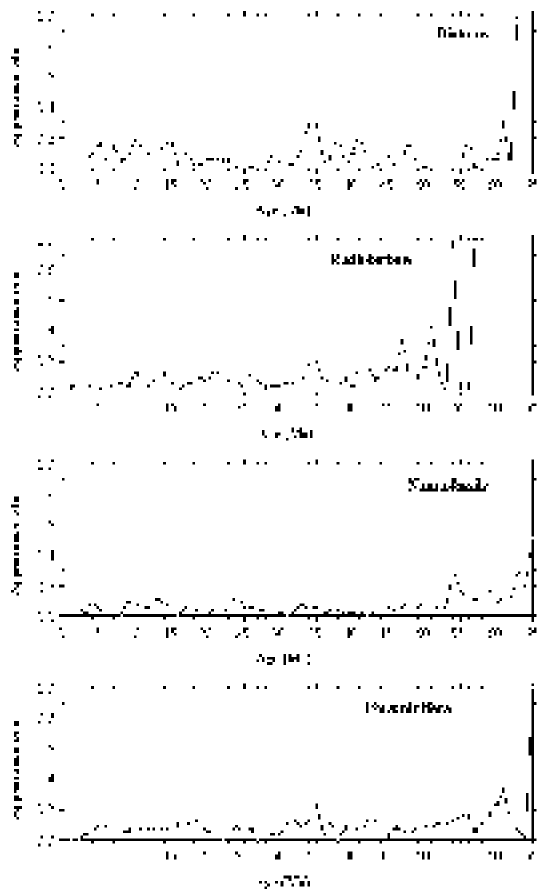


Figure 4.13.

Appearance and extinction rates were calculated for the four groups to eliminate the bias of the sample size (Wei and Kennett 1983). The rates are calculated as the ratio between the number of extinctions or appearances and the total diversity (number of species) in each 1 m.y. time slice. The Cenozoic appearance rates are shown in Fig. 4.13. Appearances are widespread throughout the Cenozoic and no specific time interval is characterized by anomalously high appearance rates, with the exception of the Paleocene. The graphs show that diatom, radiolarian and foraminifer species appeared all during the Cenozoic, with 100% peaks in the Paleocene, while only 50% of the nannofossil species present in the first million year of the Cenozoic appeared then - the remaining 50% existed already in the Mesozoic (see above for some examples). The apparent late appearance of radiolarians in the early Cenozoic is probably an artifact of the data set: no radiolarian reports are available for the Paleocene (Fig. 3.5). Average appearance rates are less than 10% and only rarely reach 30%, and are characterized by short fluctuations with a somewhat random frequency. In some instances (e.g., at 61 Ma, 35 Ma, 10 Ma), peaks of appearances in one group correspond to peaks in other groups, but no consistent pattern is apparent.

Extinction rate values are much lower than appearance rates and show a more random distribution (Fig. 4.14). Diatoms show a distinct peak in extinctions at the Paleocene/Eocene boundary which is not clearly reproduced in the other groups. On the other hand, radiolarians, nannofossils and foraminifera show a minor peak around the Oligocene/Miocene boundary (25-22 Ma), while all groups (with the exception of radiolarians) show exceptionally high extinctions in the past 3 m.y.

It is interesting to notice that these trends do not

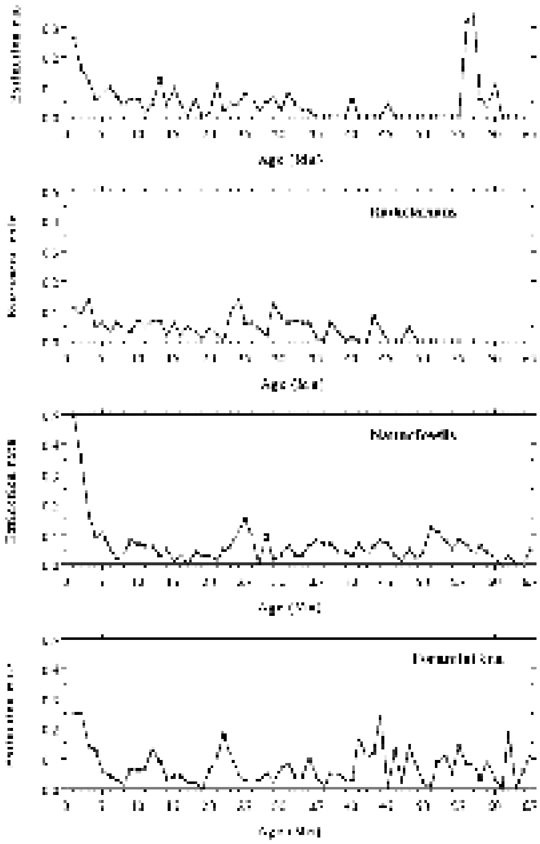


Figure 4.14.

correspond to peaks in appearances (Fig. 4.13), but there seems to be a time lapse of a couple of million years between the peaks in extinctions and appearances as the two curves are mostly out of phase. The increase in extinctions in the last 5-7 Ma might be related to the onset of highly variable environmental conditions, which apparently did not cause a corresponding increase in the rate of species' appearances.

Speciation centers and survival refugia are discrete geographic regions with high concentrations of appearances or extinctions. These are often associated with particularly favorable or stressed environmental conditions and may be limited by biogeographic or oceanographic boundaries (e.g., Jablonski 1993). One simple way to identify these regions is by plotting the latitude of the location of the earliest first appearance or the latest last appearance (Fig. 4.15). The latitudinal distribution of FADs (and of LADs, not shown here, but with an identical pattern to FADs) is clearly different in siliceous and calcareous plankton. Appearances and extinctions of diatom and radiolarian species are concentrated in three belts, around the equator and at mid- to high northern and southern latitudes respectively. These belts are bound by well established nutrient boundaries, like e.g., the polar front. This pattern also reflects the present distribution of siliceous plankton in marine sediments (e.g., Leinen et al. 1986), suggesting that the environmental preferences of these organisms did not change through time. A different scenario is presented by calcareous plankton groups, whose appearances (and extinctions) are more uniformly distributed throughout the latitudinal range.

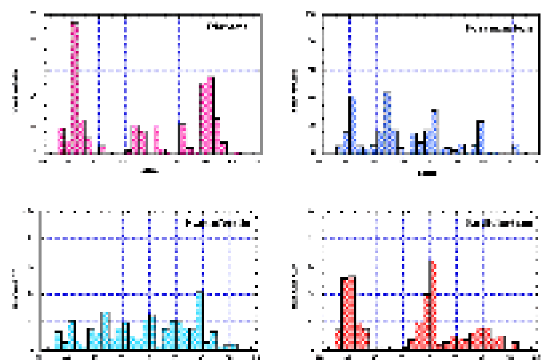


Figure 4.15.

- How did plankton diversity change through time? How do the patterns for the four plankton groups compare?

Even with the limitations summarized in Chapter 3, I attempted to estimate the distribution of plankton species' diversity during the Cenozoic. This 'partial' diversity, limited mainly to occurrences of biostratigraphic markers and biased by the low number of extensive range charts published for DSDP and ODP holes, is still a very comprehensive estimate, even though not a 'real' diversity. I present here some preliminary results based on the data included in Neptune.

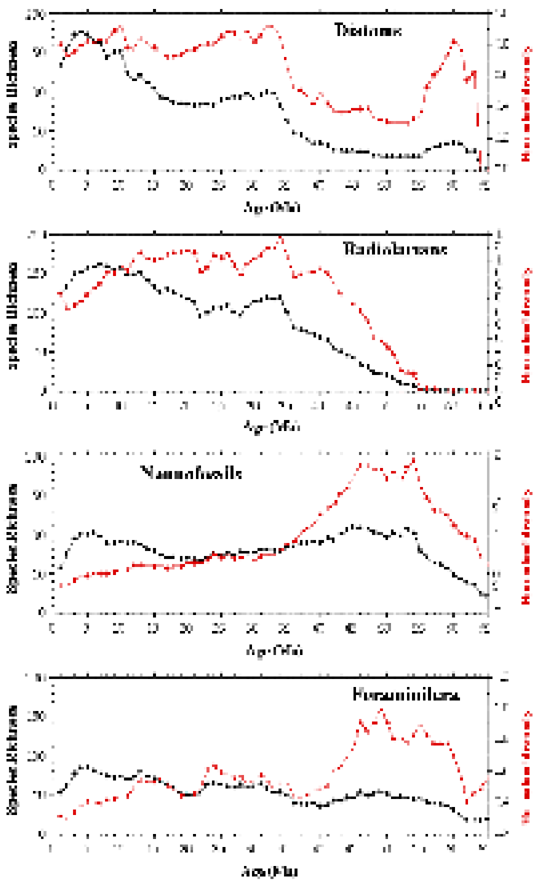


Figure 4.16.

The total species richness for the four plankton groups was calculated at one million-year intervals. To eliminate the bias of the uneven distribution of the number of sections in Neptune (progressively more sections in younger times, Fig. 3.2), I have normalized the diversity by dividing it by the total number of sections in each time interval. The results are shown in Figure 4.16. The normalized diversity patterns shown by siliceous plankton are quite similar and clearly distinct from what is shown by calcareous plankton. The two distinct patterns shown by the siliceous and calcareous plankton groups are exactly out of phase, with diatoms and radiolarians showing maximum diversity in the Oligocene to Recent, when nannofossils and foraminifera show their minimum values. Both diatoms and radiolarians show a gradual increase in diversity peaking around the Eocene/Oligocene boundary, followed by a relatively stable plateau during the Neogene. Diatoms also show a peak of diversity in the late Paleocene, when radiolarians are not reported. Diversity of nannofossils and foraminifera, instead, peaked during the early to middle Eocene, decreased in the late Eocene, and has remained more of less constant since the Oligocene.

While it is possible that much of the general variability is due to taphonomy, several further speculations could be made on these patterns. However, potential biases would have to be examined first. For example, what is the lithology of the sections in Neptune through time? Are siliceous sediments more common in the Neogene, thereby explaining the higher siliceous plankton diversity? And how do the absolute normalized values compare? The highest values are recorded in nannofossils while the lowest ones are given for diatoms. The number of valid species names in the two groups is almost identical (Table 4.1), but nannofossil names (valid and non valid) are overall slightly more abundant than diatom names in Neptune (Fig. 3.4). However,

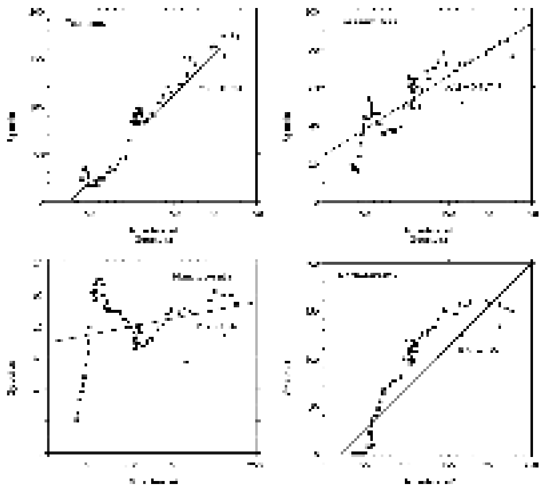


Figure 4.17.

foraminifera and radiolarian names are the most abundant ones of the four groups, while their normalized diversity is intermediate between diatoms' and nannofossils' diversity. Is there a consistent bias in the published range charts, with more reports available on siliceous plankton than on calcareous plankton in the Neogene? The number of reports on Paleogene sections (Fig. 3.5) shows a relatively lower number of reports on siliceous groups than on calcareous groups. The high correlation shown between diatoms' and radiolarians' species richness (and to a lesser extent foraminifera) and the total number of sections available for each time interval (Fig. 4.17) suggests that absolute values of species diversity are strongly biased by the size of the data set (i.e., more species are described when more sections, and therefore reports, are available). On the other hand, the species richness of nannofossils shows a complex polynomial correlation with the number of sections but a completely random linear correlation (R_2 = 0.07). This may be due to the fact that the correlation is made with the total number of sections and not with the number of sections that contain nannofossil stratigraphy. For nannofossils and foraminifera the latter may be the significant parameter which would perhaps show a higher correlation with the species richness, similarly to the one shown for siliceous plankton.

Finally, how strong is the bias caused by the dominant presence of stratigraphic markers in the reports? Siliceous plankton biostratigraphy is better developed for Neogene sediments than it is for the Paleogene, while it is more uniform for calcareous plankton groups. One approach to this question would be to separate the species included in the distribution into stratigraphic markers, other common taxa and rare taxa, and see if the diversity patterns remain the same or change substantially.

These are only some of the factors that one must consider before a feasible interpretation of these trends can be formulated, and some of these require the addition of data to Neptune which are not currently available (e.g., distribution of siliceous versus calcareous sediments). But however preliminary and partial, these results are still quite encouraging and represent a more detailed data set than what is available from the paleobiological literature.

4.2.1. Availability of relational databases for the paleontological community: the ODP database JANUS versus Neptune. At present, the ODP database, JANUS, which is currently available onboard the **JOIDES Resolution** and through the WWW, does not represent a viable substitute for Neptune. I must point out, however, that JANUS is very new and that the import of data has just begun. My experience with JANUS is limited to a superficial browsing through ODP's database WWW site, which provided me with the following information. Site data (water depth, coordinates, length drilled, length recovered, etc.), physical properties (e.g., GRAPE, magnetic susceptibility), and chemical results (e.g., carbonate content) represent the bulk of the database and are available for most ODP Legs. Age model and paleontological information are part of the database structure, but (as of March 1998) are given only for a handful of sites. There is one general grouping ('Paleontology') which is divided into four searchable tables: Age Model, Paleontological Investigation, Range Table, and Species Information. Age Model information is currently (as of March 1998) available only for one hole in Leg 105 and consists of two points, the top of the drilled section and the bottom. ODP is probably planning to progressively add more detailed age model data for all ODP sites.

I used a simple, predetermined query to search the database for paleontological information and I only obtained very preliminary information, such as the name/s of the paleontologist/s who did the shipboard study, the depth in meters below seafloor of the samples analyzed, their relative stratigraphic position (e.g., middle Eocene), and the abundance and preservation of the microfossil group. As this information was available only from Leg 171 onward, legs for which no reports are published as yet, I do not know if it is planned to add more detailed paleontological information (e.g., the range charts that are available in Neptune) from the **Scientific Results,** once they become available.

Very basic taxonomic information is also available. For example, the search for **'Globorotalia truncatulinoides'** resulted in the name of the author who named the species (d'Orbigny), when the species was first described (1839), and the stratigraphic interval it is found in (Neogene).

I finally attempted to develop a customized 'Power Query' to search JANUS but I did not succeed. No instructions were given on how to select the various items present in the relational tables and the query routine was neither user-friendly nor intuitive.

While JANUS is undoubtedly a very valuable resource for site information and shipboard results (mainly physical properties), the preliminary search of the paleontological content of JANUS suggests that Neptune is still clearly a more valuable source of paleontological information. Although I do not see how JANUS and Neptune could be easily integrated, the two databases certainly complement each other. As shown in the studies outlined above (Lazarus et al. 1995b; Spencer-Cervato and Thierstein 1997), Neptune can be extremely helpful to biostratigraphers during ODP cruises, for example for the identification of the taxa previously recorded in a specific region during a certain time interval, thereby restricting the field of species identification to likely occurrences.

4.3. Stratigraphic research with Neptune: diachrony and hiati distribution. The field where Neptune's potential has been already quite thoroughly exploited is stratigraphy. The chronology of Neptune's holes has been revised several times and even if the quality of age models is quite varied (Table 2.1), it still represents the most complete and reliable data set available for stratigraphic studies. Two major groups of information have been derived from this data set, the first directly applicable to biostratigraphy, the second of a stratigraphic and paleoceanographic significance.

The goal for the first group of studies (Spencer-Cervato et al. 1993; 1994) was to determine the reliability of biostratigraphic markers, in terms of their regional versus global significance and of their synchrony or diachrony. As mentioned in Chapter 3, siliceous biostratigraphy is based on several regional calibrations of events, whilst calcareous biostratigraphy relies on a single, mainly low-latitude calibration (Berggren et al. 1995a, b). The use of the latter approach (one calibration for all holes, irrelative of their biogeographic location) implies a global synchrony of biostratigraphic events, that has actually been demonstrated only in very few cases. The first study (Spencer-Cervato et al. 1993) was aimed to calibrate several Neogene radiolarian events in the north Pacific and to study the degree of diachrony within this biogeographic region (Fig. 4.18). The projected ages of radiolarian first and last occurrences derived from the line of correlation of age/depth plots from the North Pacific have been computed from twelve North Pacific sites, and 28 radiolarian events have thereby been newly cross-calibrated to North Pacific diatom and other stratigraphy. Several of the North Pacific radiolarian events are older than in previously published equatorial Pacific calibrations (Johnson and Nigrini 1985) (Fig. 4.18), and some may be diachronous within the North Pacific. We hypothesized that these patterns may be due to complex latitudinal patterns of clinal variation in morphotypes within lineages, or to migration events from the North Pacific towards the Equator.

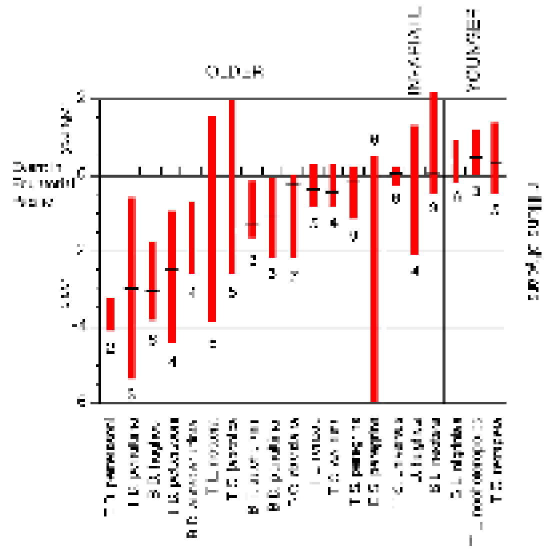


Figure 4.18.

The second, more comprehensive study (Spencer-Cervato et al. 1994) evaluated the synchrony and diachrony of 124 commonly used Neogene biostratigraphic events in 35 globally distributed DSDP and ODP holes. Global mean age estimates based on combined biostratigraphy and magnetostratigraphy were calculated for each event. The ages' standard deviations were used as an estimate of synchrony/diachrony. Average standard deviations for event ages by fossil group are: calcareous nannofossil first appearance datums (FADs): 0.57 m.y. (21 events), calcareous nannofossil last appearance datums (LADs): 0.60 m.y. (25 events), diatom FADs: 0.57 m.y. (7 events), diatom LADs: 0.85 m.y. (14 events), planktic foraminifera FADs: 0.88 m.y. (22 events),

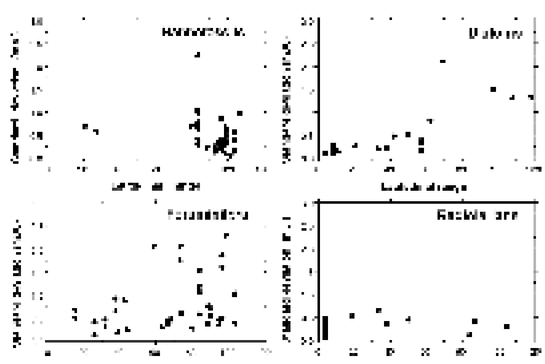


Figure 4.19.

foraminifera LADs: 0.68 m.y. (16 events), radiolarian FADs: 0.30 m.y. (9 events), radiolarian LADs: 0.31 m.y. (10 events). 53 of the 124 events can be considered synchronous, within the resolution of the method (± two average sample spacings, i.e., 360 k.y.). The remaining diachronous events were analyzed for true patterns of diachrony and other biases. Generally, diachrony is more frequent among cosmopolitan than among endemic taxa (Fig. 4.19). Also, the precision of age calibrations decreases with increasing age. Some diachrony patterns may be due to investigator bias (see examples shown in Spencer-Cervato et al. 1994), but in general they appear to be, at least in part, real phenomena. Thus, they could provide opportunities for exploration of paleobiological processes (see for example the study on **G. truncatulinoides** described above, Spencer-Cervato and Thierstein 1997).

A similar study of diachrony was not attempted for Paleogene events and is not recommended either. The age control on the chronology of Paleogene sediments is poorer than what is available for Neogene sediments. Moreover, fewer sections were analyzed for magnetostratigraphy, which provides the independent control on the age models selected for the Neogene study described above. I expect that the patterns of diachrony that could be obtained for Paleogene events would be largely biased by the data set and, therefore, would not provide a scientifically sound basis for further studies.

The chronology of the 165 holes in Neptune was the subject of the third stratigraphic study originated from Neptune. It was mentioned in Chapter 3 that continuous stratigraphic sequences were very rare and that most age models were characterized by hiati. Hiati are commonly recognized in shelf sediments, but regional deep-sea hiati have also been extensively studied (e.g., Keller and Barron 1983). The reason for the interest in the timing and geographic distribution of hiati lies in the processes that cause them. A hiatus is a stratigraphic gap caused by erosion, dissolution, corrosion, nondeposition, rate of sediment supply versus dissolution (corrosion) of sediments (controlled by fluctuations in the calcite compensation depth - CCD), or shallow to deep water sediment fractionation (Berger 1970). Several studies have interpreted the occurrence of deep-water hiati in terms of changes in deep water circulation and corrosiveness (e.g., Keller and Barron 1987). Other studies have focused on the occurrence of hiati in continental shelf sediments and some authors have interpreted them within a framework of sea-level fluctuations (e.g., Vail et al. 1977; Haq et al. 1987).

For this study (Spencer-Cervato 1998) I have identified ‘hiatus events’ during the Cenozoic, based on the occurrence of individual hiati both in shelf and deep-sea sediments. The goal of the study was to test if there is a causal link between sea-level fluctuations (and climate change) and global occurrences of hiati, which are linked to oceanic circulation through a variety of complex processes. I initially attempted to reproduce the ‘global eustatic sea-level curve’ of Haq et al. (1987) with a curve of hiati distribution. This sea-level curve was constructed by the Exxon Exploration Group and is based on proprietary seismic data collected mainly on the eastern Atlantic passive continental margin. This curve has been a source of controversy since its publication, mainly because scientists had failed to reproduce it and because it was difficult to find physical mechanisms that could cause rapid sea-level fluctuations of more than 250 m, such as the ones implied in the curve. Drilling off New Jersey during ODP Leg 150X has recovered stratigraphic sequences which contain gaps that can be correlated to the ones used to construct the sea-level curve. These results (e.g., Miller et al., 1996) seem to have sedated the debates on the reliability of the sea-level curve, but the dispute on the magnitude of the fluctuations is still unresolved.

Compared to previous compilations of hiatus distribution in the DSDP stratigraphic record (e.g., Moore et al., 1978), the curve that I have obtained (Fig. 4.20c) has a better resolution (0.5 m.y.), contains more recent holes with better recovery, and is based on a more reliable and updated biochronology. Other studies (e.g., Keller and Barron 1983; Ramsay et al. 1994) instead focused on specific regions, e.g., the Indian or the Atlantic Ocean, while my study (Spencer-Cervato 1998) is of global extent.

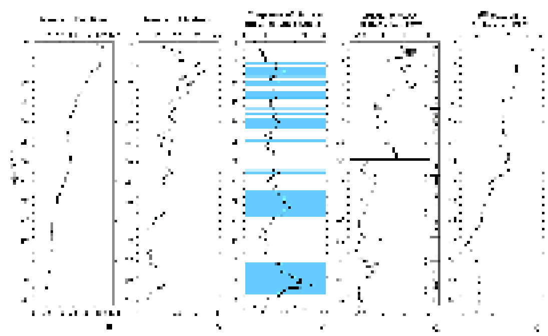


Figure 4.20.

To help in the interpretation of the record of hiati, I have estimated the paleo-water depth at which the hiati occurred and constructed three individual curves for shallow (0-2000 m), intermediate (2000-3000 m) and deep (> 3000 m) water (Fig. 4.21). The curves show that the Paleogene is characterized by few, several million-years long hiati, while the Neogene is punctuated by short, frequent hiati events (Fig. 4.20), occurring nearly synchronously in shallow and deep water sediments. The most significant Cenozoic hiatus event spans most of the Paleocene. Epoch boundaries are characterized by peaks in deepwater hiati possibly caused by an increased circulation of corrosive bottom water and sediment dissolution. The Plio-Pleistocene is characterized by a gradual decrease in the frequency of hiati. This could be caused by several factors, including the better recovery of younger sediments and therefore a lower chance of recording artificial hiati. Alternatively, this can indicate that sediment erosion and corrosion is time dependent and thus that there has been insufficient time to create hiati in the youngest sections. However, this smooth drop can also be an artifact of the time interval chosen for this analysis, which masks the high-frequency cycles of Quaternary glacio-eustatic sea level change possibly characterized by short (<0.5 m.y.) hiati, not recorded in this study.

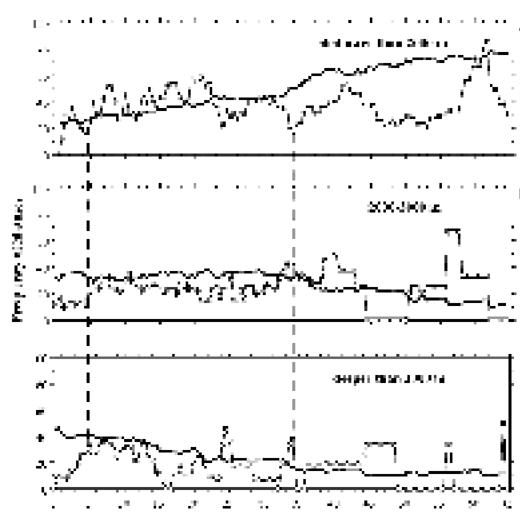


Figure 4.21.

Although some speculations were advanced on the causes of these hiatus events, their regional significance and possible causes will be the topic of future, more detailed studies. Among these, of particular interest would be the geographic distribution of hiati within ocean basins (e.g., latitudinal distribution of hiati versus latitudinal distribution of DSDP and ODP holes in the database and western versus eastern margins to identify the temporal evolution of oceanic gyre circulation) and their comparison to detailed isotopic records of deepwater circulation (e.g., Wright and Miller 1993). The depth distribution of hiati in mid-ocean and aseismic ridge sites versus continental shelf and slope sites must be also analyzed separately. These areas should be affected differently by sea level changes.

In summary, Neptune's data have been used for five published studies of plankton evolution and stratigraphy. While the stratigraphic studies provide a quite complete overview of the potential of Neptune, the study of plankton evolution has so far been limited to biostratigraphic applications. The analysis of plankton longevity and diversity has been shown here as raw data. This is the field where Neptune's data still have much to offer to the paleontological community. In the following section, I will explore the possibility of expanding Neptune beyond the paleontological field and will suggest possible future avenues of research based on this database.

4.4. Potential additional data for Neptune for sedimentological and paleoceanographic research

In my opinion, the potential of Neptune for future research extends considerably beyond analyses of micropaleontological data. Neptune's chronology and relatively large number of holes are its greatest assets and they should be properly exploited. A significant step forward would be represented by the addition of sedimentological data, which would open up a whole new range of research possibilities. The expansion of Neptune would benefit the research community by providing interdisciplinary links and correlations that are at present rarely possible to scientists working on ODP material. Time pressure and poor funding force ODP-participating scientists to limit their post-cruise research to very limited, mainly isolated goals (James D. Wright, personal commun., 1998). Once their duty as sedimentologists or micropaleontologists is fulfilled and their report is submitted, scientists move quickly to the next 'hot' research topic, and the potential for correlations between data sets and large-scale research studies is left largely untouched. In this scenario, the opportunities provided by Neptune's chronology and paleontological data would be greatly enhanced by other data that would allow to make large-scale, interdisciplinary (e.g., modeling) studies, or at least would provide an easily accessible source of a large amount of quality data from which to start such studies. Only very few of these studies based on deep-sea sediments are available at present (e.g., Delaney and Boyle 1988).

Among the data that should be included in Neptune, and that are consistently available at least for the more recent ODP holes, are: lithology (percentage carbonate, percentage silica); organic carbon content; physical properties (e.g., bulk density, grain density, porosity); and grain-size distribution. The field of paleoceanography would be the primary beneficiary of the combination of the existing paleontological and chronological data in Neptune with sedimentological information and physical properties data. I will mention here only a couple of the several, current research questions that are debated in the paleoceanographic community and that could be addressed with these additional data.

During the middle Miocene, important changes occurred in the climate of the Earth, an important step toward the establishment of cold polar climates and the modern climate mode characterized by glacial and interglacial cycles. These changes are documented in the oxygen isotope records (e.g., Miller et al. 1987; Fig. 4.20e), and indicate the onset of a progressive global cooling. It is not yet known what causes the abrupt shifts in climate mode that the Earth has experienced in the last million years, even though some recent evidence (Zachos et al. 1997) suggest that these shifts might have characterized the earth's climate already since the Oligocene. It is, therefore, obvious why so many studies have focused on middle Miocene sediments and have led to the formulation of various hypotheses. Several hypotheses have linked climate changes to large-scale deepwater circulation (e.g., Shackleton et al. 1983), but the causal relationship between middle Miocene changes in deepwater circulation and the establishment of a permanent ice sheet in eastern Antarctica, is still uncertain (e.g., Kennett and Barker 1990).

Keller and Barron (1983) proposed that a "silica switch" occurred between the Atlantic and Pacific Ocean in the middle Miocene, around 15 Ma and contemporary to the $\delta^{18}O$ increase. Based on the relative abundance of siliceous sediments in nine tropical Atlantic sites, they suggested that prior to 15 Ma, Atlantic sediments were silica-rich, but that after that time, silica sedimentation switched to the Pacific Ocean. Predominantly carbonatic sediments have apparently been accumulating in the Atlantic since then. This switch would have been caused by the initiation of the Northern Component Water (NCW) circulation in the north Atlantic. However, Wright et al. (1992) have raised some concerns on the selection of data on which Keller and Barron (1983) based their hypothesis, and argue that NCW's production began earlier (around 19 Ma) and had actually shut down during the 15 Ma $\delta^{18}O$ event. Wright et al. (1992) propose that the middle Miocene $\delta^{18}O$ increase does not correlate with deepwater circulation changes and does not represent the transition from an ice-free to an ice-house world, but is part of two or three glacial/interglacial cycles.

How could Neptune help solve this controversy? The cause of disagreement in the interpretations is the data on which Keller and Barron (1983) based their hypothesis. The possibility of modeling the results of a larger number of chronologically well constrained holes in the Atlantic and Pacific Oceans would give the 'middle Miocene controversy' a strong, potentially unbiased basis of data. The data that would be needed are the concentrations of carbonate and opal. These data have not been incorporated in Neptune yet, because data from different holes are potentially incompatible, due to the different methods used in their collection.

Since the beginning of the DSDP project, carbonate concentration has been a routine analysis performed on the sediments. Biogenic opal data are also available for DSDP holes, but only in the more recent ODP holes has it been estimated analytically. It would be conceptually simple to add a new table to Neptune, which would include the sample number, percentage carbonate and percentage opal. This table would be linked to the Sample Data table, which would provide an age estimate for each sample. In reality, this task is far from being trivial. The main reason for this is due to the analytical methodology used to determine the concentration of carbonate and opal. During DSDP, several different methods were used, giving results that are not comparable to each other. Routinely, percentage carbonate and opal have been estimated from smear slides, a method that has a maximum accuracy of ±10% (Hsü, Montadert et al. 1978). These data are highly subjective and not useful for rigorous quantitative studies. Keller and Barron (1983) used these counts for their "silica switch" hypothesis, on sites where the biosiliceous component was actually minimal and easily affected by dissolution of diatoms, the primary components of siliceous productivity (Wright et al. 1992). Quantitative analytical measurements of carbonate and opal would be required to map the distribution of these carbonatic and siliceous sediments in the entire ocean basins and to test the "silica switch" hypothesis.

The shipboard-based ‘carbonate bomb’ method (Müller and Gastner 1971) has been used relatively early in the DSDP on a few selected samples to provide a control on the smear slide estimates. The accuracy of this method, the most common analytical method used during DSDP cruises, is between 1 and 5%, lower for carbonate-rich sediments. In some instances, other shorebase methods (e.g., the LECO method; Hsü, Montadert et al. 1978) were compared to the results of the ‘carbonate bomb’ method and systematic differences observed. In more recent ODP Legs, a shipboard Coulometer is used to determine percent carbonate (and percent organic carbon)(e.g., Leg 121), with a precision of approx. 1%. I am not aware of a study that compares this method to the previous methods. The silica content has been quantitatively analyzed only for some ODP holes, using X-Rayx-ray fluorescence and the normative equation of Leinen (1977) (e.g., Littke et al. 1991) or, more recently, a single-step alkaline extraction method (Mortlock and Froelich 1989). The precision of the latter method is ±4%. The carbonate bomb, LECO and Coulometer estimates for carbonate and the X-ray fluorescence and alkaline extraction estimates of opal content from holes where sampling frequency is sufficient (e.g., one sample every 0.5 m.y.), could be selectively incorporated into Neptune. Some of these data are available for ODP holes from the JANUS database, but they would probably need to be added manually for the DSDP holes.

These same lithological data, combined with the paleo-water depth estimates of Spencer-Cervato (1998) (not yet included in Neptune but available at the NOAA-WDCA for Paleoclimatology Data Contr. Series #97-030: ftp://ftp.ngdc.noaa.gov/paleo/paleocean/by_contributor/spencer-cervato1998/) could be used to reconstruct the depth fluctuations of the Calcite Compensation Depth (CCD) during the Cenozoic, for which the curve by van Andel (1975) is still being used. The very smooth fluctuations of the CCD curve of van Andel (1975) do not agree with the abrupt changes that have been recently shown to characterize the earth's climate and ocean systems in the Cenozoic. This is probably caused by the low resolution of stratigraphic studies in the 1970s. The better resolution (around 0.5 m.y. or better) of the Neptune data would allow us to refine the curve and to make it more compatible with, for example, the isotopic data currently being produced.

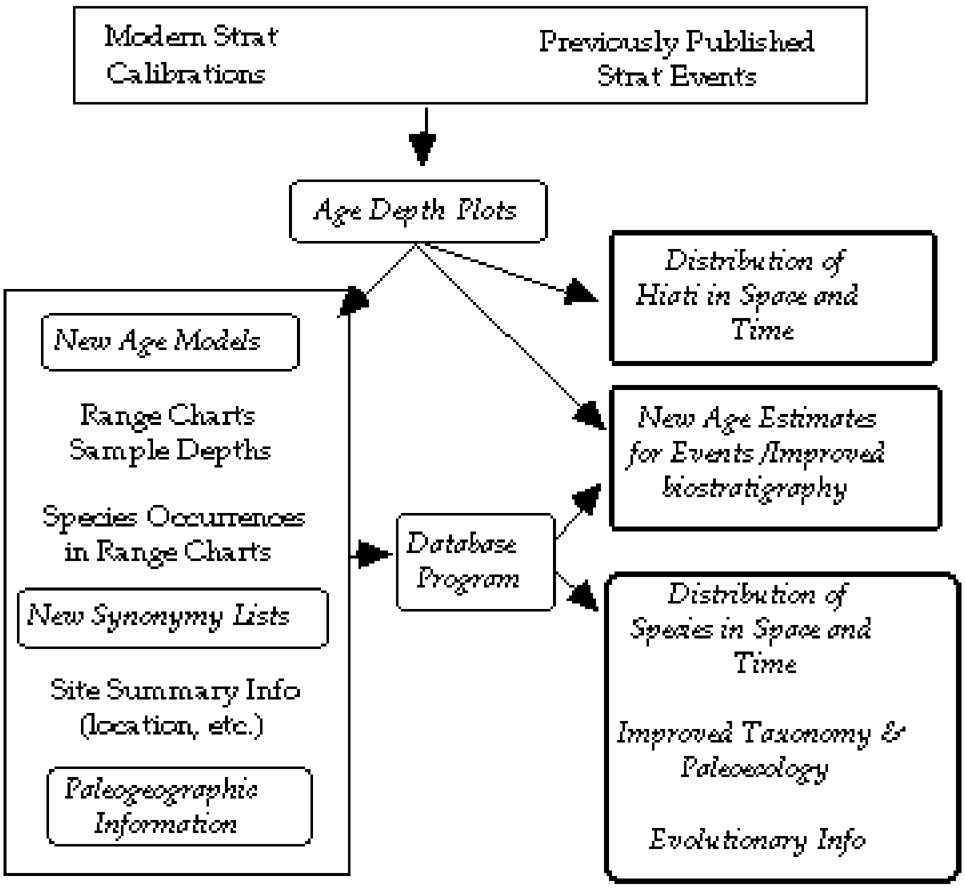
I briefly mentioned earlier the importance of deepwater circulation reconstruction for the understanding of the climate/ocean systems. Sediment accumulation rates and dissolution profiles can be reconstructed from physical property data and grain-size distributions, all data that are routinely produced onboard ship and that could be quite easily added to Neptune. Recent studies (Zachos et al. 1997) use a record of percent coarse fraction to demonstrate that glacial/interglacial cycles existed as far back as the late Oligocene. This parameter, combined with a high resolution $\delta^{18}O$ record from ODP Leg 154 (Ceara Rise - south Atlantic), shows a 40-k.y. periodicity, indicating a high-latitude orbital control on ice volume and temperature. This isotopic record suggests that there is an orbital control on deepwater circulation, which had not yet been shown so early probably because of the low resolution of previous studies and the paucity of deep-sea sections with high sedimentation rates and a long stratigraphic record, like the ones recovered by Leg 154 on the Ceara Rise.

The trend for future paleoceanographic studies is toward high (tens of thousands of years) resolution studies. Is Neptune ready for these studies? The answer is: not yet. The chronology of Neptune, its biggest strength and the most updated record available, is based on biostratigraphy and magnetostratigraphy, which provide an accuracy on the order of hundreds of thousands of years, at best. Oxygen isotope stratigraphy is currently the only means to obtain a better age resolution than this for Neogene sediments. Results from ODP Leg 154 provide the longest and most complete isotopic record for the whole Neogene which extends into the Oligocene (Weedon et al. 1997). A calibration of the sporadic isotopic records available for DSDP holes and the more common records from ODP holes to this recent isotopic calibration would allow us to refine the (mainly) late Neogene chronological resolution for some of the sites in Neptune. My biggest concern about this calibration is that correlations with standard isotopic records are still done by 'wiggle matching'. Because the absolute isotopic values vary depending on the foraminifer species or sediment fraction used to obtain the record, the shape of the curve (which remains substantially the same) is used for the correlation. I am not aware of any comprehensive study that has carefully pinpointed and tabulated some of the ages of the 200+ (the total number is actually unknown: some 140 are recognized only in the Plio-Pleistocene) isotopic stages to magnetostratigraphy beyond the late Miocene (Hodell et al. 1994). This would provide fixed reference points for stratigraphic interpretations. 'Eye-balled' graphic correlation is, in my opinion, too inaccurate for the type of studies that it is used for (unless one can actually count back all stages starting from the Holocene) and greatly reduces the potential resolution of isotope stratigraphy.

Next Section...

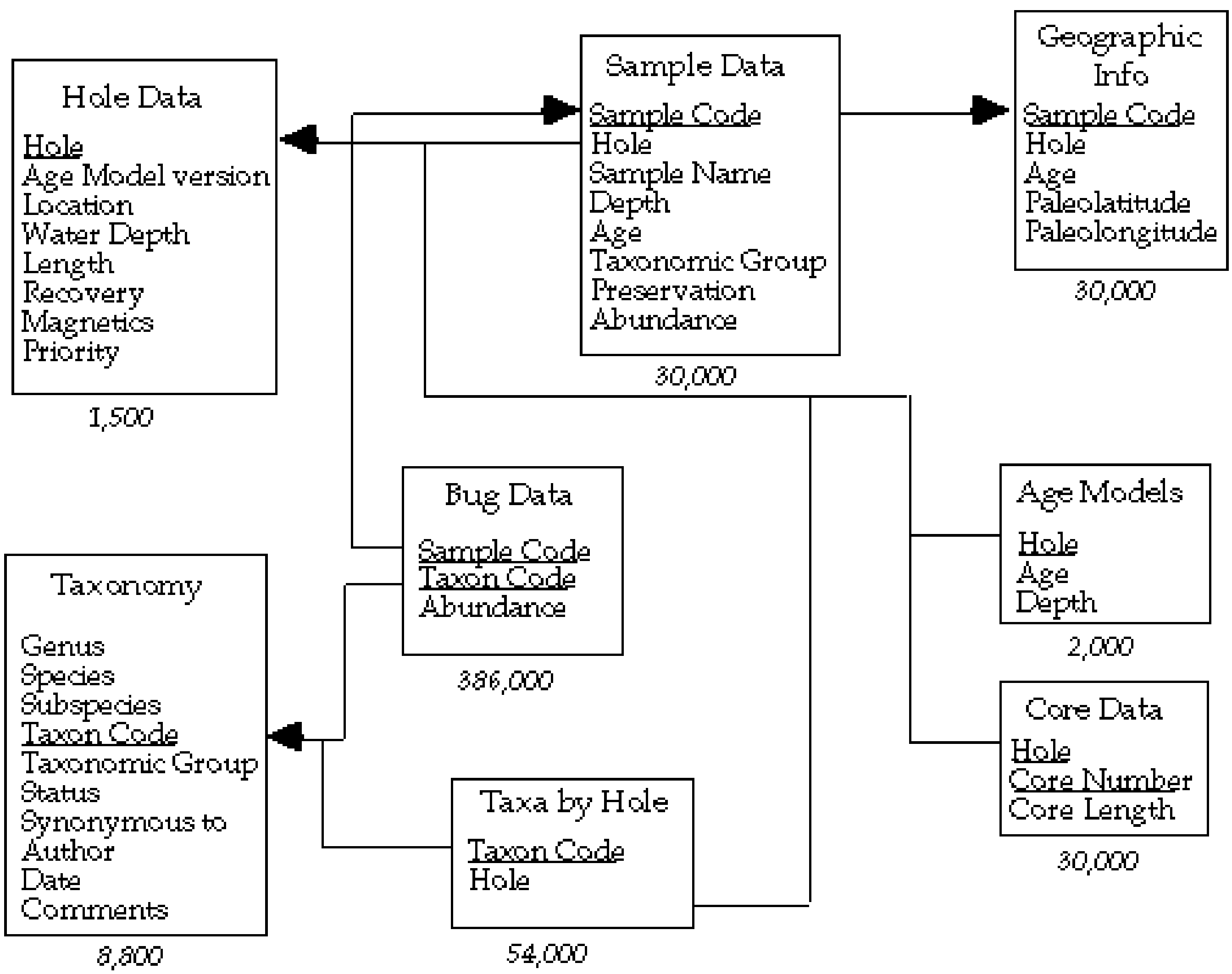
Close Window

Figure 4.1. Overview of database project (modified after Lazarus, 1994). Combining existing data (boxes with thin outlines) with new information generated by project members (rounded boxes with italic text), we have produced new information (bold outline boxes).



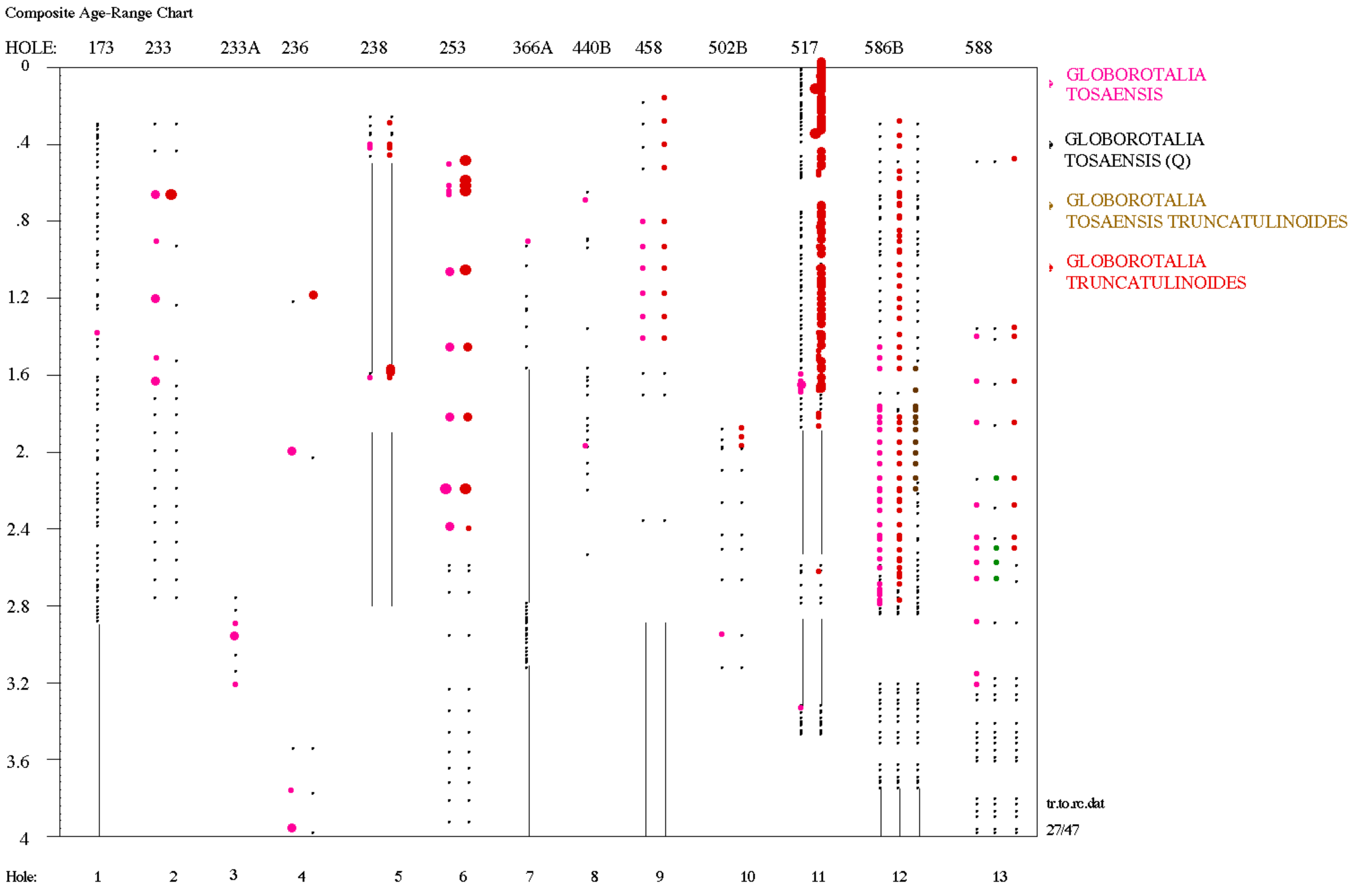
Close Window

Figure 4.2. Simplified sketch of the database structure (modified after Lazarus 1994). Each box represents one relational table, with field names listed in the box. Relational links between tables are shown by thin lines. Arrows point from a table with many records with the same value for the relating field, to a table with unique values for each record in this field. The primary key for each table (the combination of one or more fields which makes each record in the table unique) is underlined. The approximate number of records (as of February, 1998) is shown below each box. The records in the 'Taxa by Hole' table were extracted from the DSDP CD-ROM. The other tables were created by Neptune.



Close Window

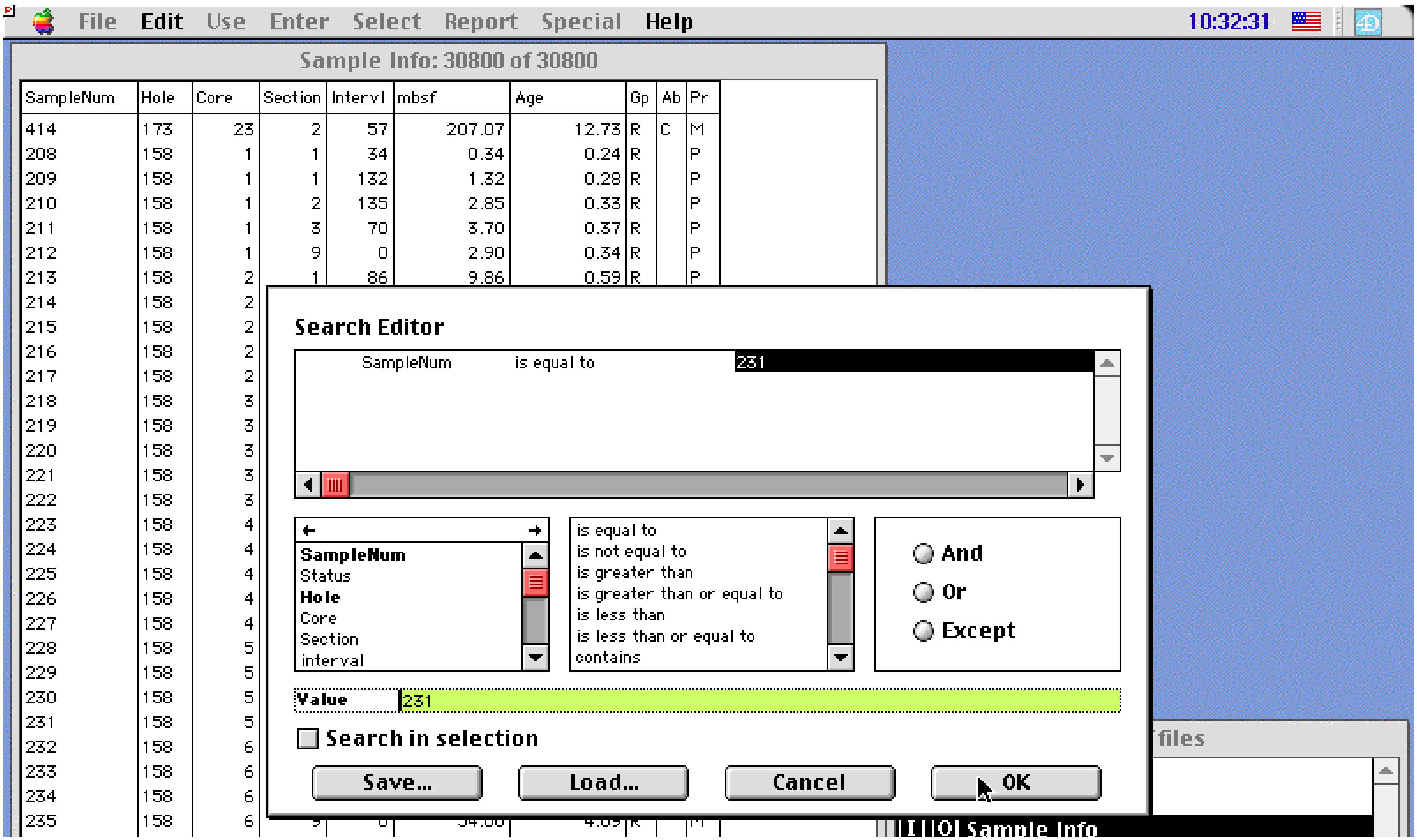
Figure 4.3. Age Range Chart produced from Neptune for the occurrences of **Globorotalia truncatulinoides** and **Globorotalia tosaensis**. The plot shown here represents only a subset of the data obtained from Neptune for this search. The symbols are explained in the caption at the bottom of the figure. The charts are produced in colour, with the colour of the bullets corresponding to the species name on the right. Small black dots represent samples that were examined but where none of the selected species was found. This figure is an unmodified reproduction of the format produced by the Age Range Chart program ([Lazarus, 1994](#)). The large number of data in the figure and its format make difficult to understand it when it is reduced to a one-page size and does not clearly show the differences between the different species' occurrences.

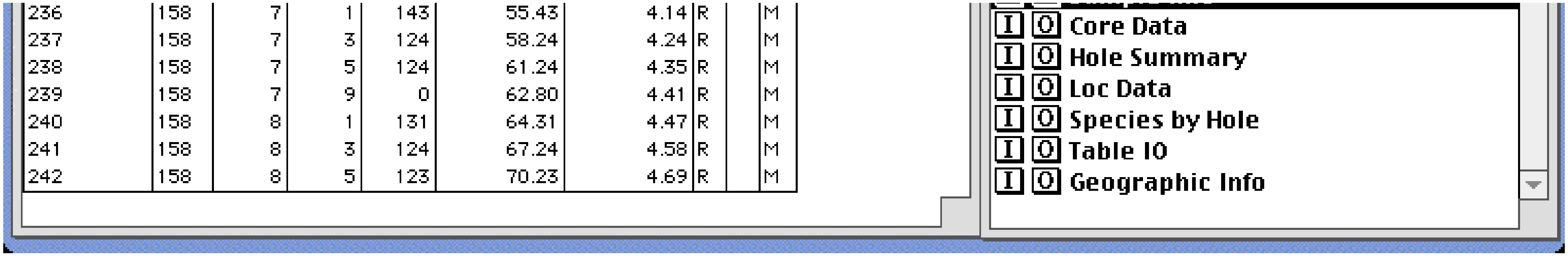


KEY: | HIATUS • Absent • Trace-Rare ● Few-Common ⬤ Abundant-Dominant

Close Window

Figure 4.4. Screen snapshot of a simple query in Neptune. The table in the lower right corner is the list of tables in Neptune that are directly searchable with a 'Search Editor' window (under the 'Select' menu). Selecting one of the tables shows the records included in it and their number (in the heading). The larger table in the background is the 'Sample Info' table, which contains 30800 records.

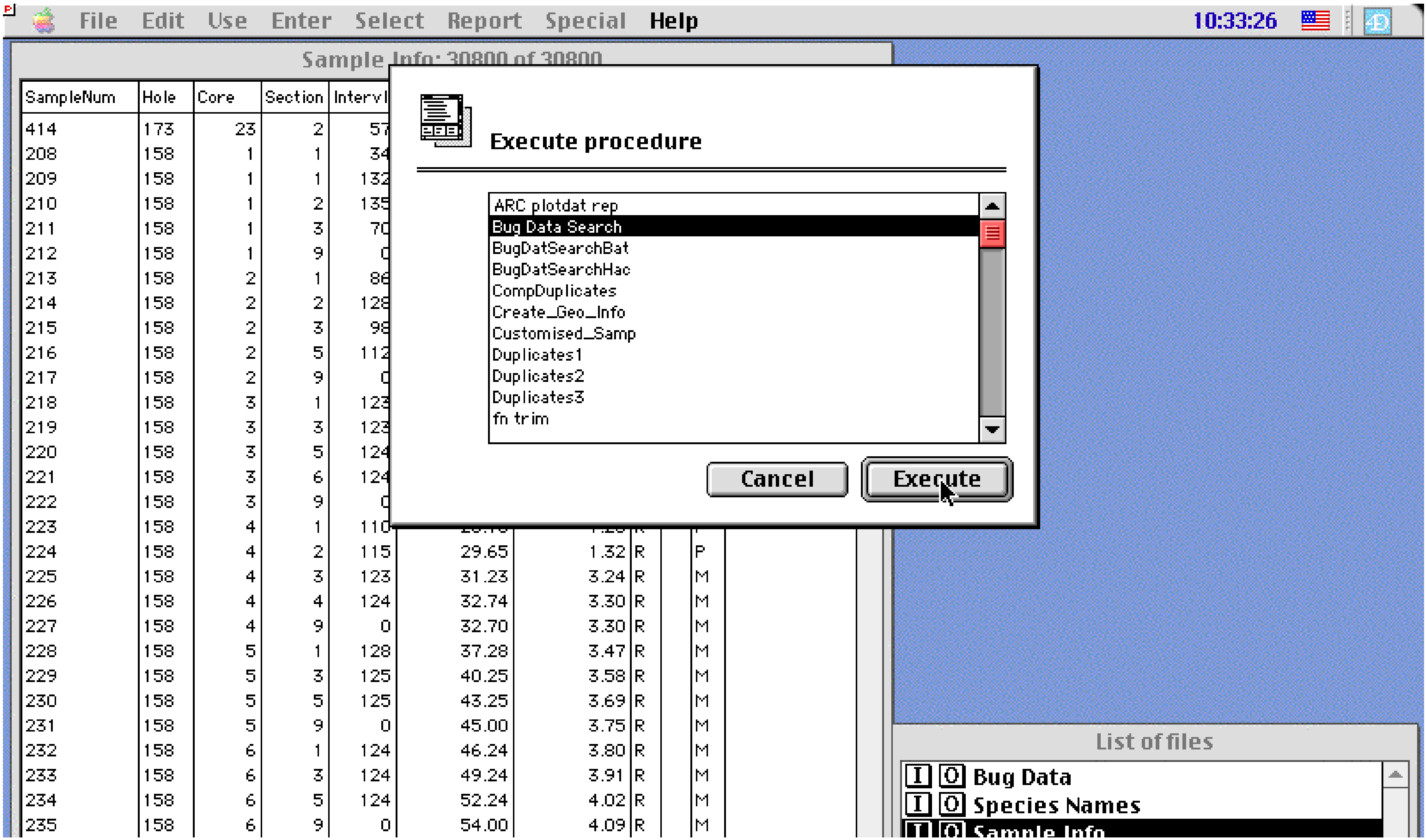




236	158	7	1	143	55.43	4.14	R		M
237	158	7	3	124	58.24	4.24	R		M
238	158	7	5	124	61.24	4.35	R		M
239	158	7	9	0	62.80	4.41	R		M
240	158	8	1	131	64.31	4.47	R		M
241	158	8	3	124	67.24	4.58	R		M
242	158	8	5	123	70.23	4.69	R		M

Close Window

Figure 4.5. Screen snapshot of the 'Execute Procedure' window (under the 'Special' menu). This allows to search a combination of tables using one of the predefined procedures. The following figures show the progression of a 'Bug Data Search' procedure for the occurrence of the planktic foraminifer **Globorotalia truncatulinoides** in the Neptune holes. A 'Bug Data Search Batch' (described in Section 4.1.4) is one of the other procedures shown on the list.

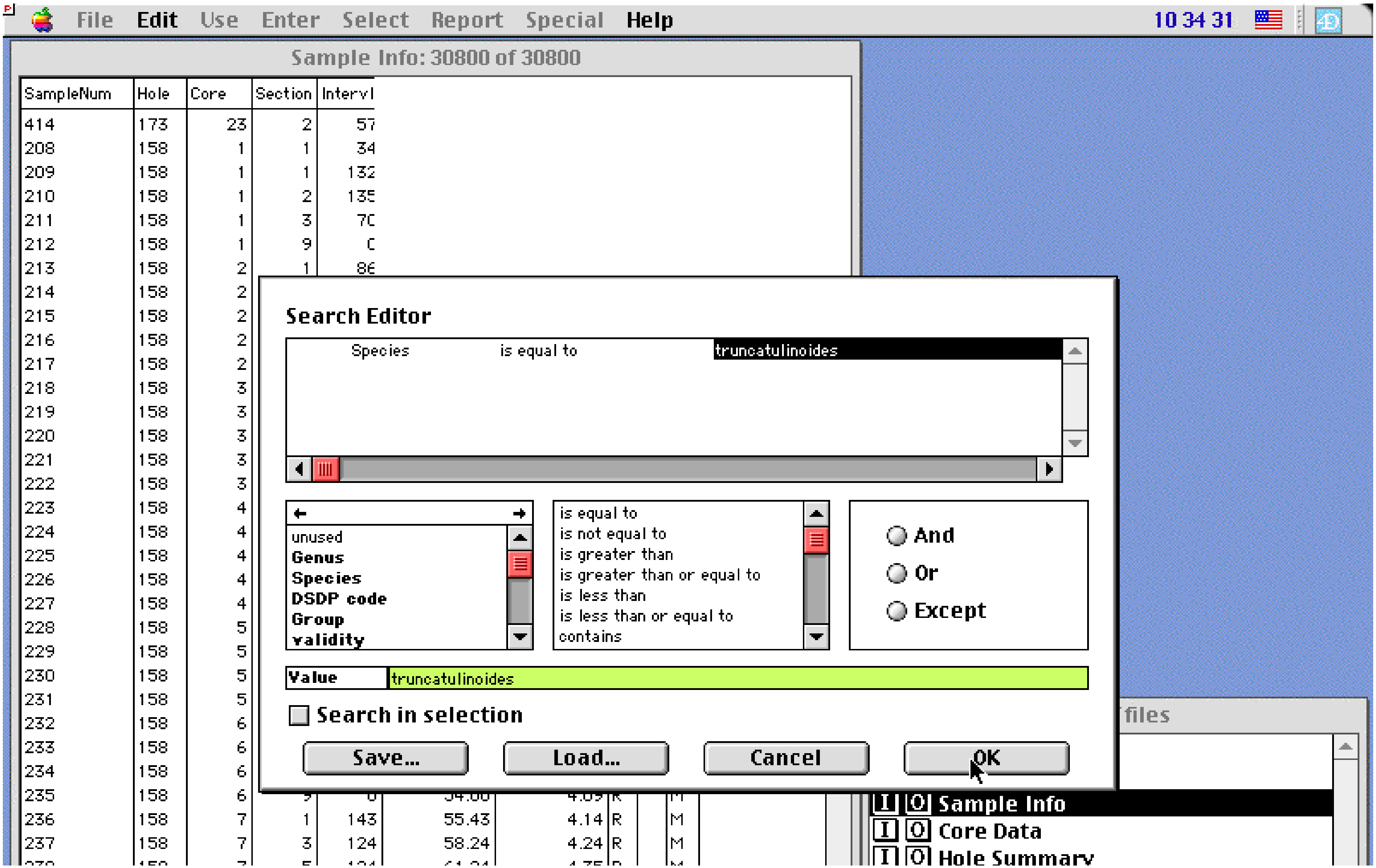


236	158	7	1	143	55.43	4.14	R		M
237	158	7	3	124	58.24	4.24	R		M
238	158	7	5	124	61.24	4.35	R		M
239	158	7	9	0	62.80	4.41	R		M
240	158	8	1	131	64.31	4.47	R		M
241	158	8	3	124	67.24	4.58	R		M
242	158	8	5	123	70.23	4.69	R		M

I O Core Data
I O Hole Summary
I O Loc Data
I O Species by Hole
I O Table IO
I O Geographic Info

Close Window

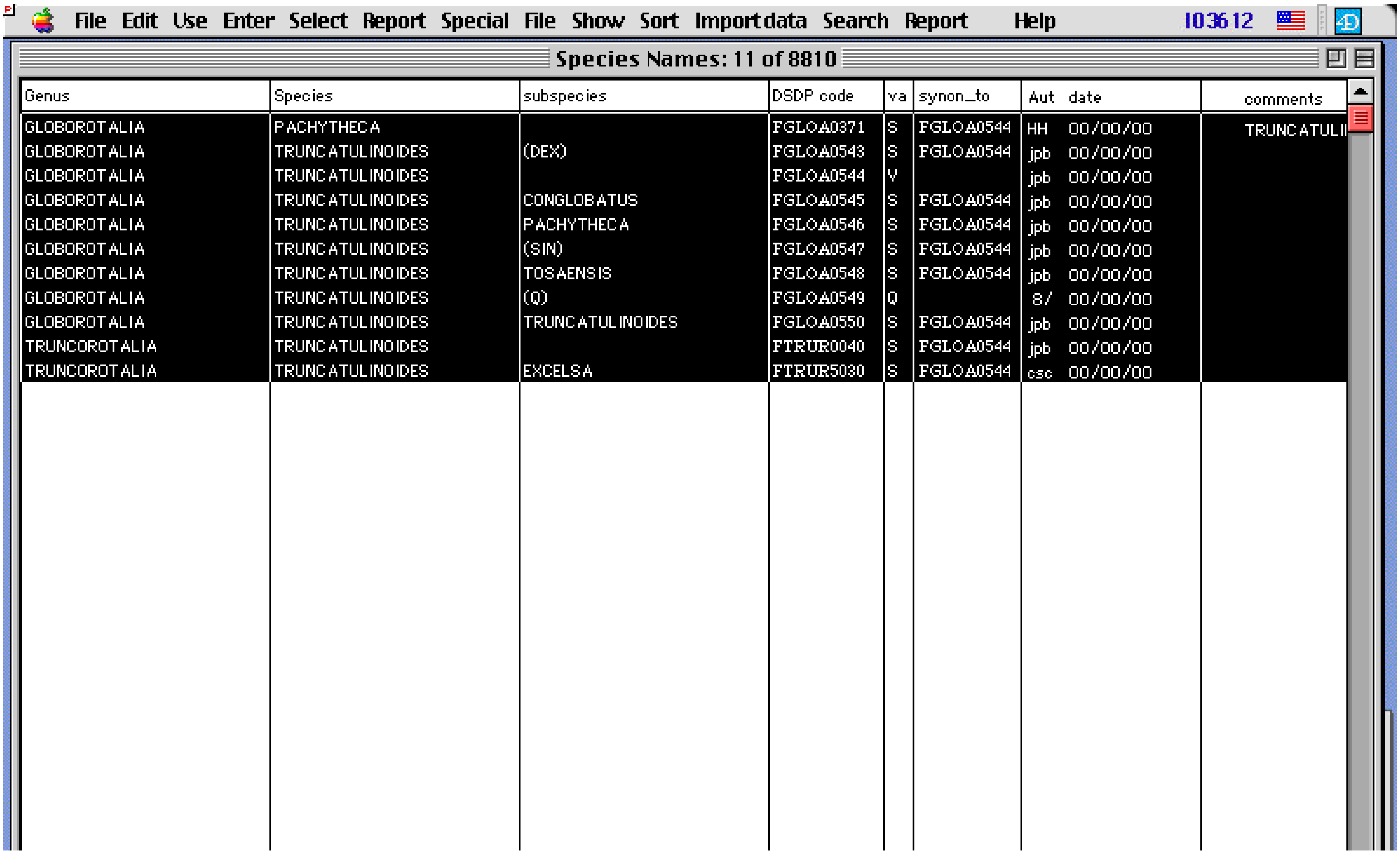
Figure 4.6. Once the type of procedure is chosen, a ‘Search Editor’ window is shown. In this example, a search is made for the species’ name - ‘Species’ ‘is equal to’ ‘**truncatulinoides**’.



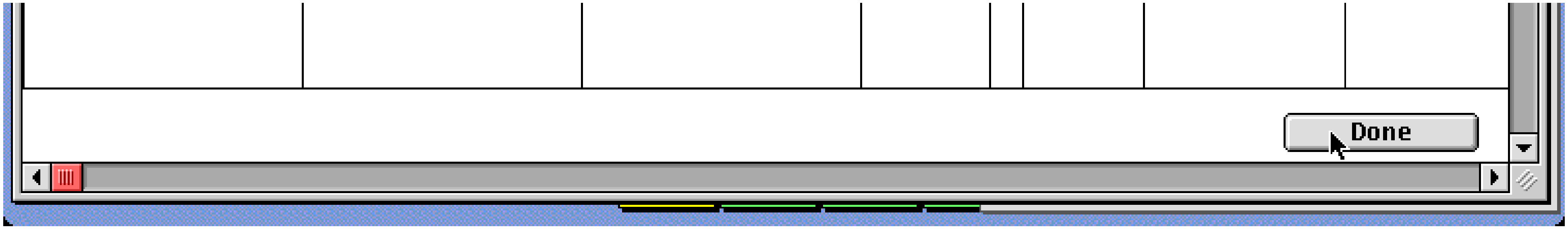

239 158 7 9 0 62.80 4.41 R M
240 158 8 1 131 64.31 4.47 R M
241 158 8 3 124 67.24 4.58 R M
242 158 8 5 123 70.23 4.69 R M
Loc Data
Species by Hole
Table IO
Geographic Info

Close Window

Figure 4.7. The selected species' name is found in the 'Species Names' table together with linked synonyms. After one has highlighted the names that should be used, one can proceed with the Search. Note the format of the data in the 'Species Names' table, described in Section 3.3 and characteristic of Neptune.

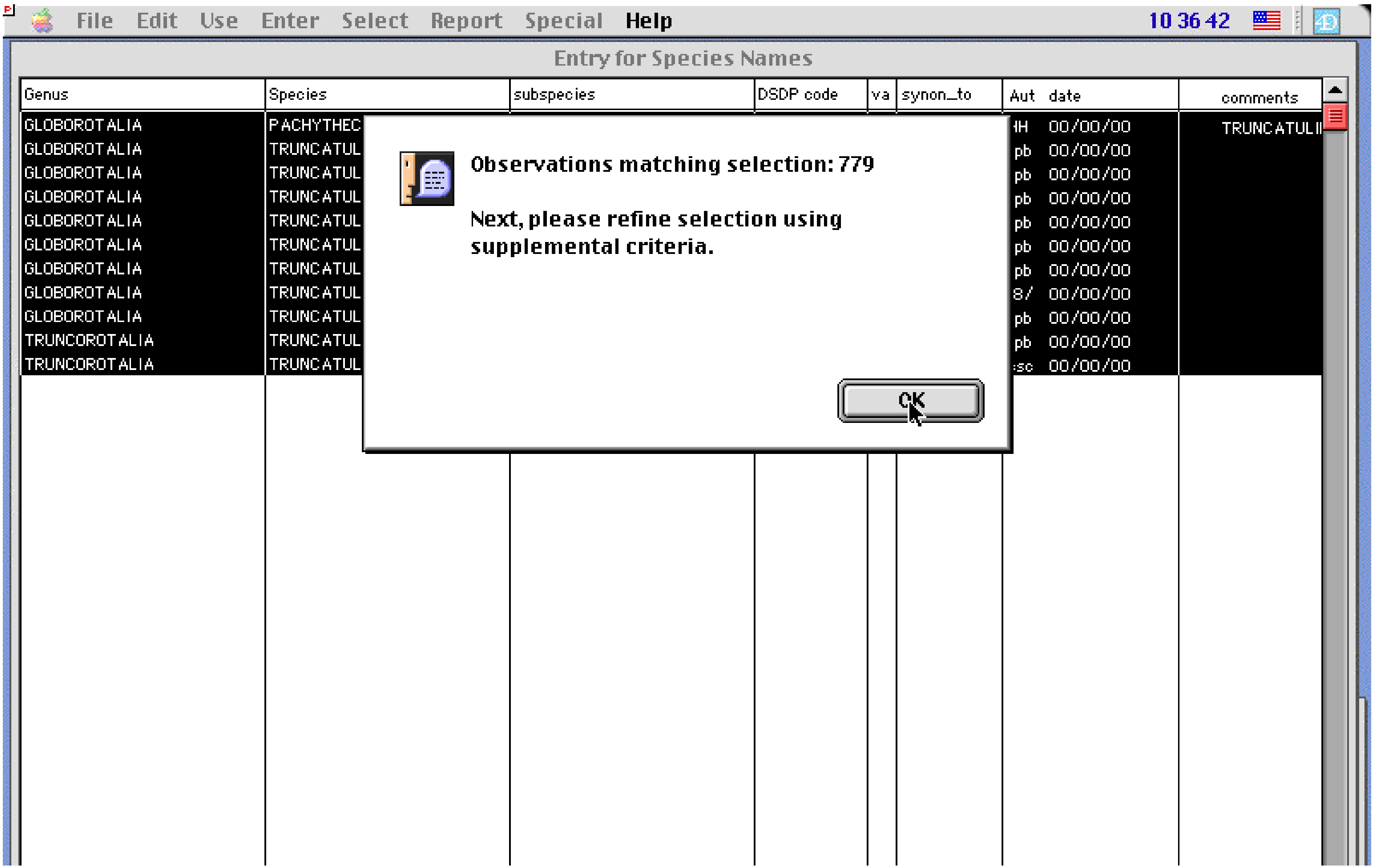


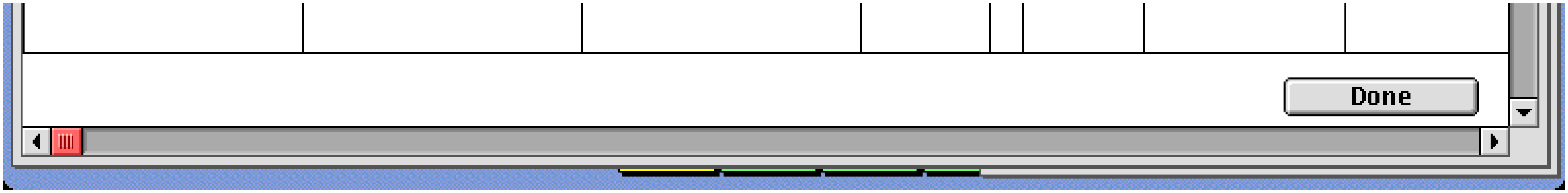
Genus	Species	subspecies	DSDP code	va	synon_to	Aut	date	comments
GLOBOROTALIA	PACHYTHECA		FGLOA0371	S	FGLOA0544	HH	00/00/00	TRUNCATULI
GLOBOROTALIA	TRUNCATULINOIDES	(DEX)	FGLOA0543	S	FGLOA0544	jpb	00/00/00	
GLOBOROTALIA	TRUNCATULINOIDES		FGLOA0544	V		jpb	00/00/00	
GLOBOROTALIA	TRUNCATULINOIDES	CONGLOBATUS	FGLOA0545	S	FGLOA0544	jpb	00/00/00	
GLOBOROTALIA	TRUNCATULINOIDES	PACHYTHECA	FGLOA0546	S	FGLOA0544	jpb	00/00/00	
GLOBOROTALIA	TRUNCATULINOIDES	(SIN)	FGLOA0547	S	FGLOA0544	jpb	00/00/00	
GLOBOROTALIA	TRUNCATULINOIDES	TOSAENSIS	FGLOA0548	S	FGLOA0544	jpb	00/00/00	
GLOBOROTALIA	TRUNCATULINOIDES	(Q)	FGLOA0549	Q		8/	00/00/00	
GLOBOROTALIA	TRUNCATULINOIDES	TRUNCATULINOIDES	FGLOA0550	S	FGLOA0544	jpb	00/00/00	
TRUNCOROTALIA	TRUNCATULINOIDES		FTRUR0040	S	FGLOA0544	jpb	00/00/00	
TRUNCOROTALIA	TRUNCATULINOIDES	EXCELSA	FTRUR5030	S	FGLOA0544	csc	00/00/00	


Done

Close Window

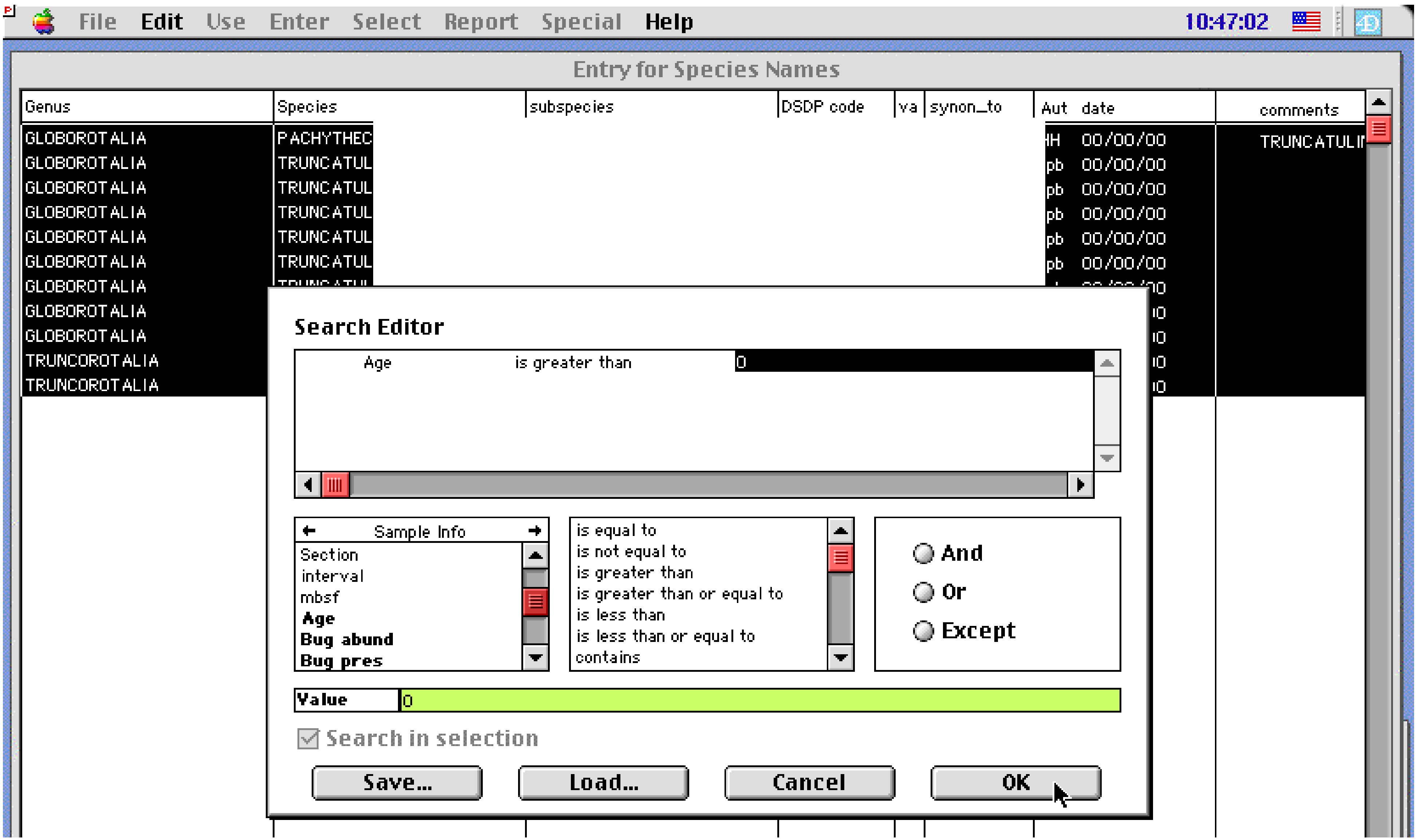
Figure 4.8. The result of the search is shown in a window that gives the number of occurrences in all the holes present in Neptune (779 in this example). The next step allows to refine the selection with additional criteria.

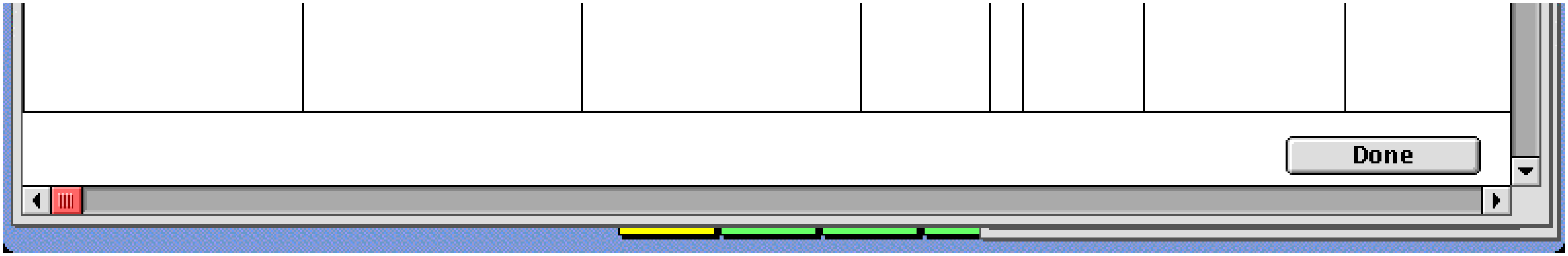



Done

Close Window

Figure 4.9. In this example I have chosen to refine the search to obtain only data from holes for which we have age models. To do this, I have selected ‘Age’ in the ‘Sample Info’ table (left) and specified that it has to be greater than 0 (all samples from holes without age models have ages set to 0). The ‘Search in selection’ box, which allows to search only in the selection found through the previous queries, is automatically marked.




Done

Close Window

Figure 4.10. The results of this procedure are shown in a table containing 485 records (of the 779 found earlier in the search). This table and related data can be sorted, printed out, exported, or saved in various formats.

File Edit Use Enter Select Report Special File Show Sort Importdata Search Report Help 104506

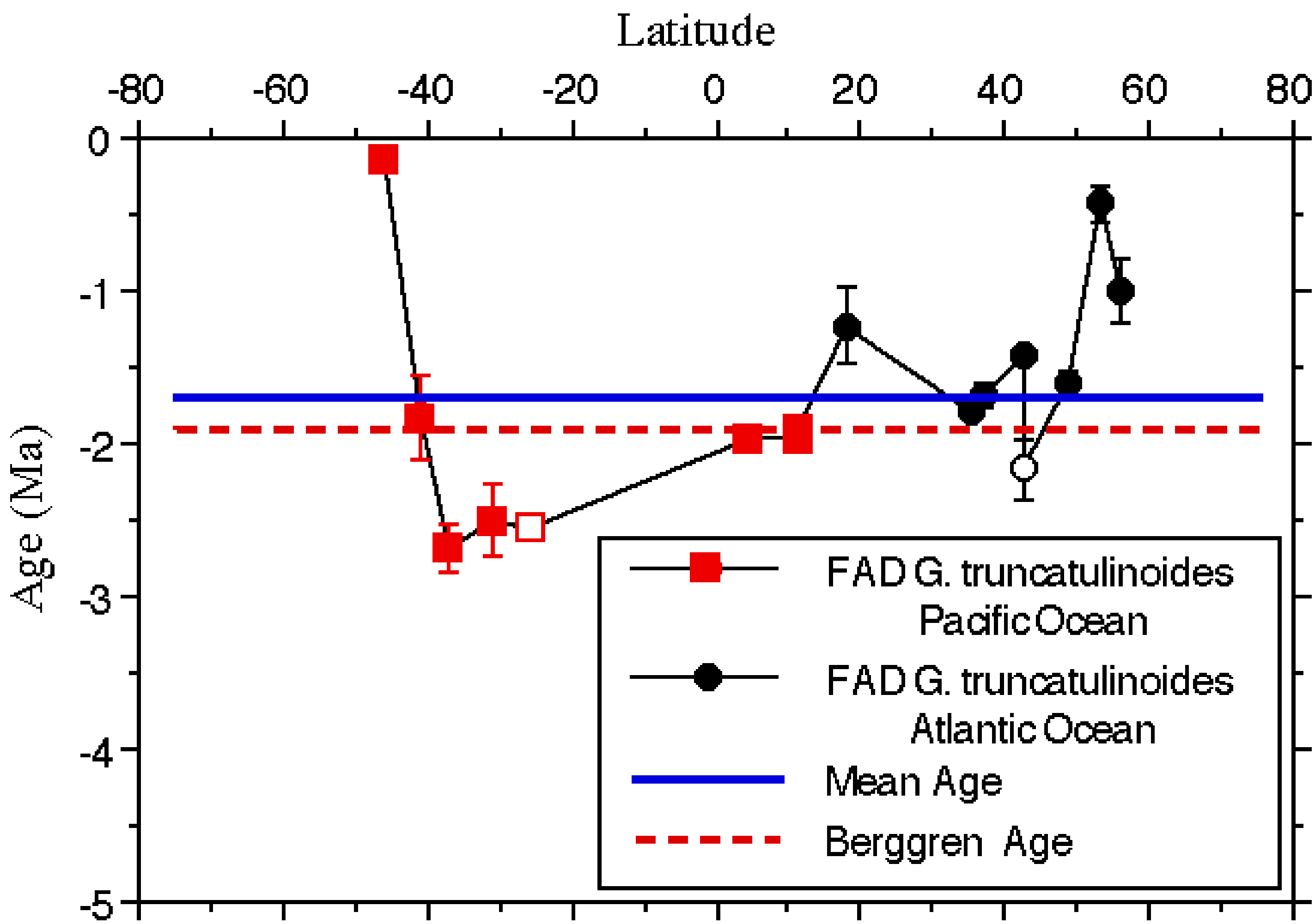
Bug Data: 485 of 384915

	Taxon	Hole	mbsf	Age, Ma	Ab.
GLOBOROTALIA	TRUNCATULINOIDES	141	6.05	1.41	R
GLOBOROTALIA	TRUNCATULINOIDES	141	7.70	1.51	R
GLOBOROTALIA	TRUNCATULINOIDES	141	9.20	1.61	R
GLOBOROTALIA	TRUNCATULINOIDES	141	10.70	1.70	R
GLOBOROTALIA	TRUNCATULINOIDES	141	12.20	1.80	R
GLOBOROTALIA	TRUNCATULINOIDES	141	13.70	1.89	R
GLOBOROTALIA	TRUNCATULINOIDES	141	13.00	1.85	R
GLOBOROTALIA	TRUNCATULINOIDES	233	17.20	0.74	A
GLOBOROTALIA	TRUNCATULINOIDES	236	7.88	1.28	C
GLOBOROTALIA	TRUNCATULINOIDES	238	13.30	0.28	R
GLOBOROTALIA	TRUNCATULINOIDES	238	19.80	0.38	R
GLOBOROTALIA	TRUNCATULINOIDES	238	21.30	0.40	R
GLOBOROTALIA	TRUNCATULINOIDES	238	22.80	0.43	R
GLOBOROTALIA	TRUNCATULINOIDES	238	25.80	0.47	C
GLOBOROTALIA	TRUNCATULINOIDES	238	27.30	0.49	C
GLOBOROTALIA	TRUNCATULINOIDES	238	29.30	1.68	R
GLOBOROTALIA	TRUNCATULINOIDES	253	1.18	0.55	A
GLOBOROTALIA	TRUNCATULINOIDES	253	1.60	0.66	A
GLOBOROTALIA	TRUNCATULINOIDES	253	1.70	0.69	A
GLOBOROTALIA	TRUNCATULINOIDES	253	1.80	0.71	A
GLOBOROTALIA	TRUNCATULINOIDES	253	3.48	1.15	A
GLOBOROTALIA	TRUNCATULINOIDES	253	5.02	1.56	C
GLOBOROTALIA	TRUNCATULINOIDES	253	6.48	1.94	C
GLOBOROTALIA	TRUNCATULINOIDES	253	7.98	2.33	A
GLOBOROTALIA	TRUNCATULINOIDES	253	8.70	2.52	P
GLOBOROTALIA	TRUNCATULINOIDES	265	8.55	0.09	R
GLOBOROTALIA	TRUNCATULINOIDES	265	26.95	0.18	F
GLOBOROTALIA	TRUNCATULINOIDES	265	27.00	0.18	P
GLOBOROTALIA	TRUNCATULINOIDES	281	7.64	0.89	P
GLOBOROTALIA	TRUNCATULINOIDES	281	10.10	1.19	P
GLOBOROTALIA	TRUNCATULINOIDES	281	11.50	1.36	P

GLOBOROTALIA	TRUNCATULINOIDES	281	12.20	1.45	P
GLOBOROTALIA	TRUNCATULINOIDES	362	45.50	1.90	P

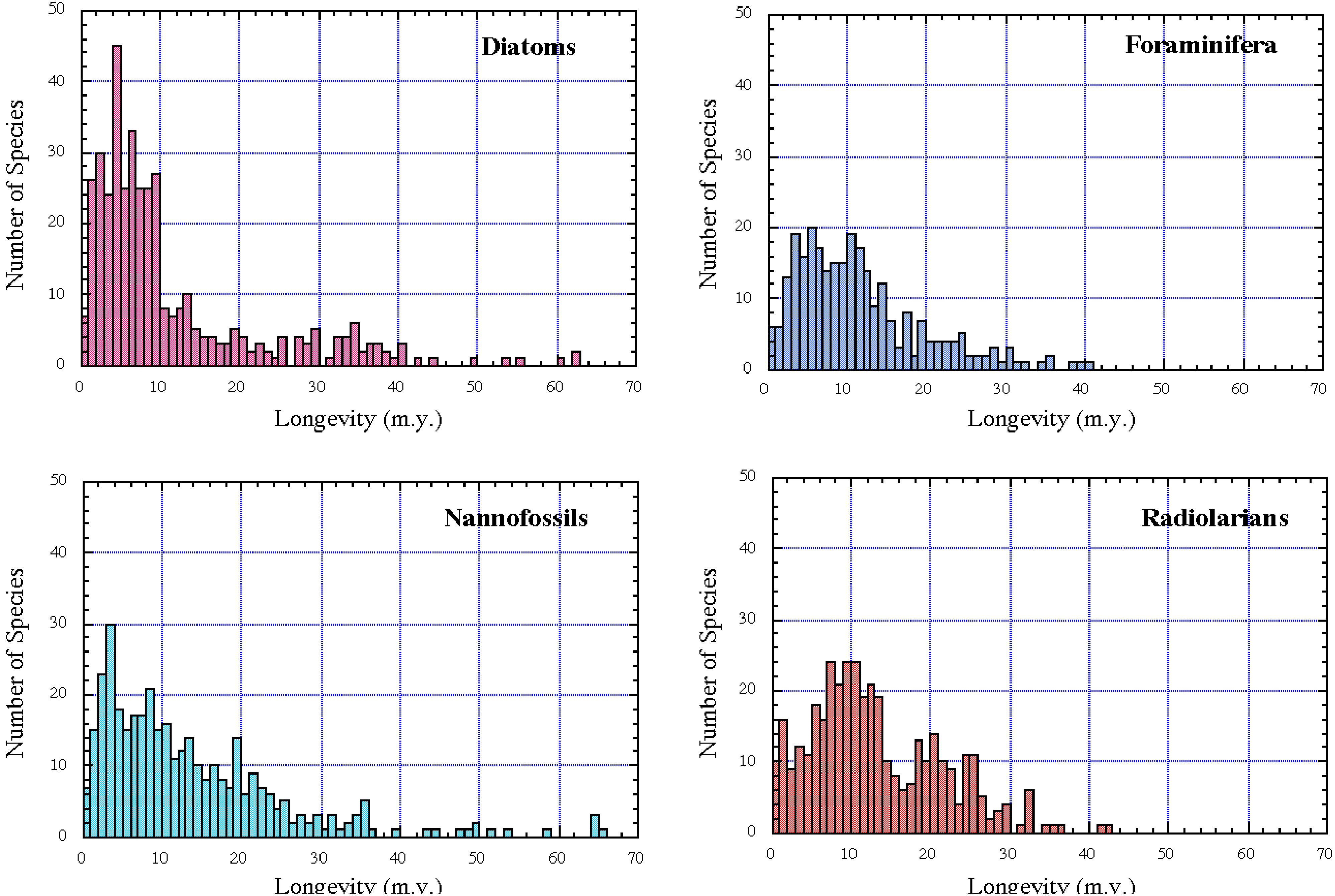
Close Window

Figure 4.11. Age versus latitude plot of the first occurrences of **G. truncatulinoides** in selected Neptune sites (from Spencer-Cervato and Thierstein 1997).



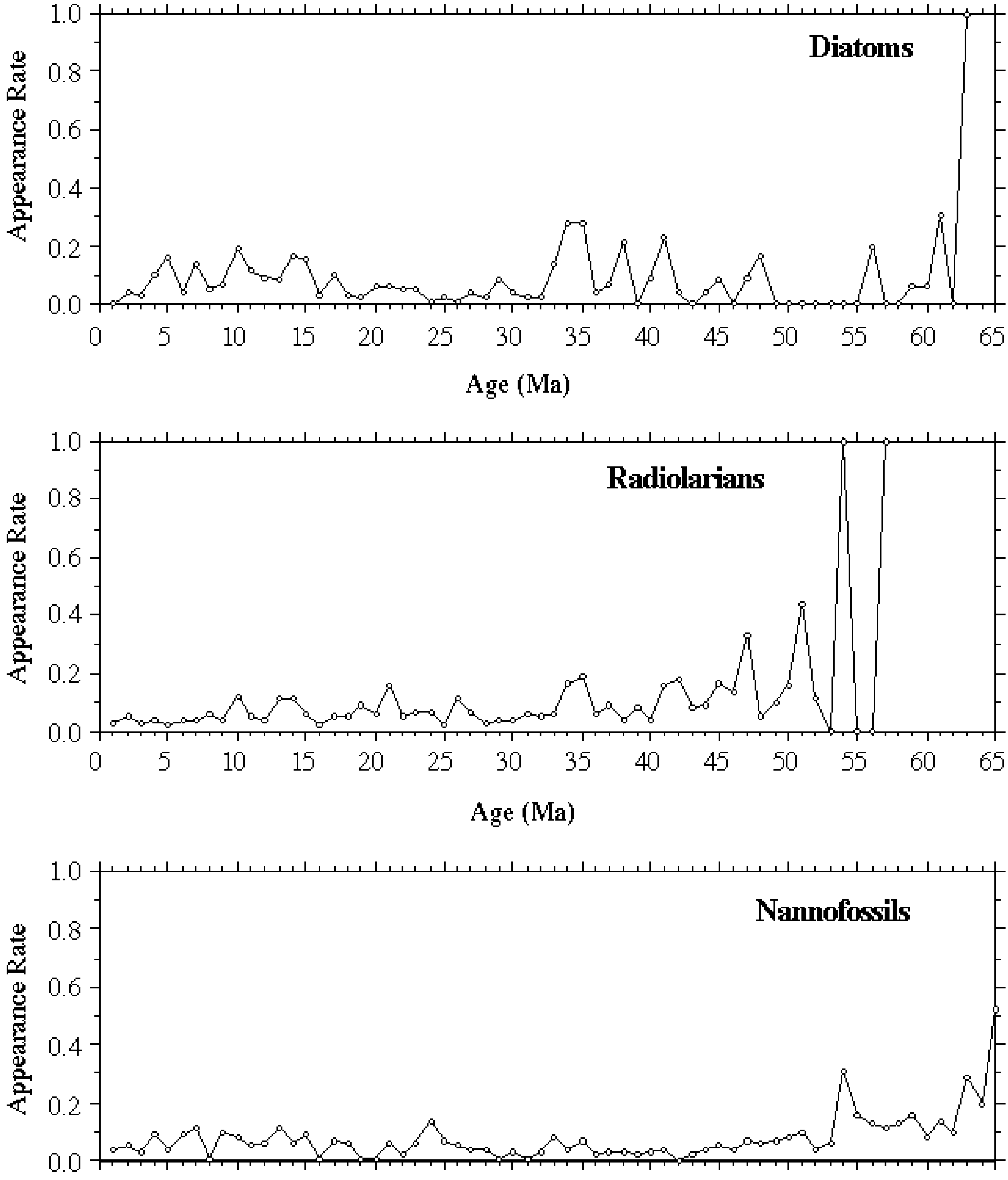
Close Window

Figure 4.12. Distribution of diatom, foraminifera, nannofossil and radiolarian longevity by species (in m.y.), including both extant and extinct species. Note that, while most phytoplankton species are less longevous than zooplankton species, extreme longevity values are exclusively found in phytoplankton species.



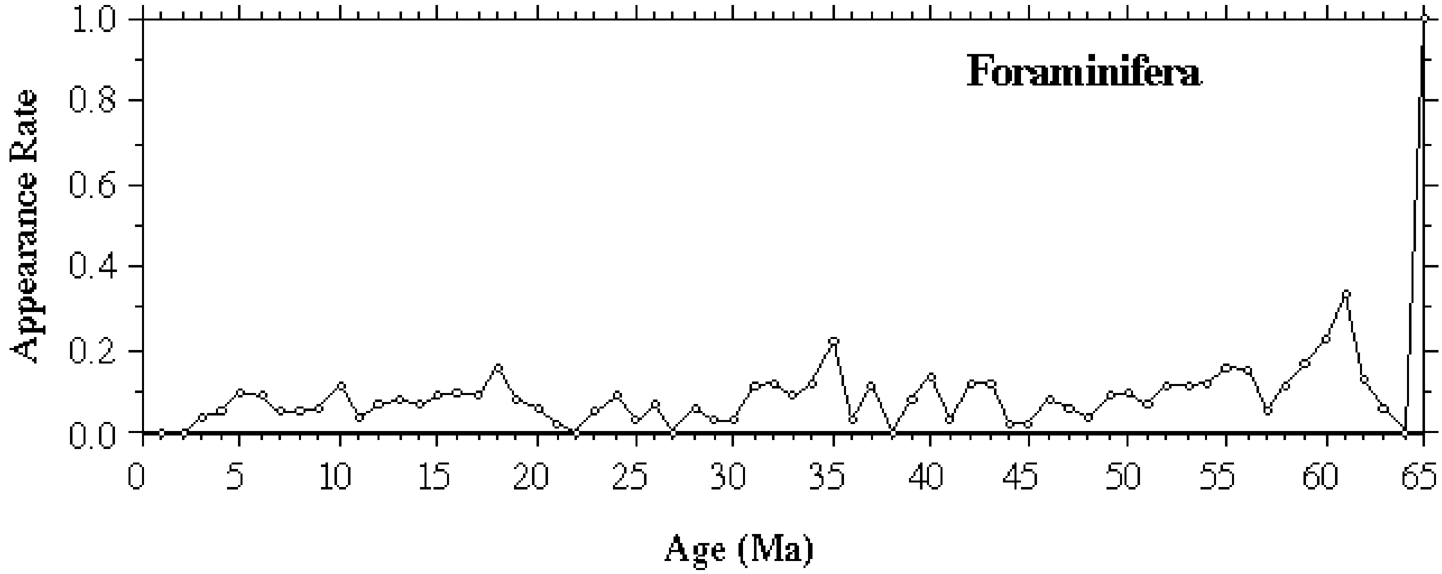
Close Window

Figure 4.13. Appearance rates (calculated as the ratio between number of FADs versus number of species) of the four groups during the Cenozoic Note that the rates are biased by species richness in low diversity intervals (see Fig. 4.9).



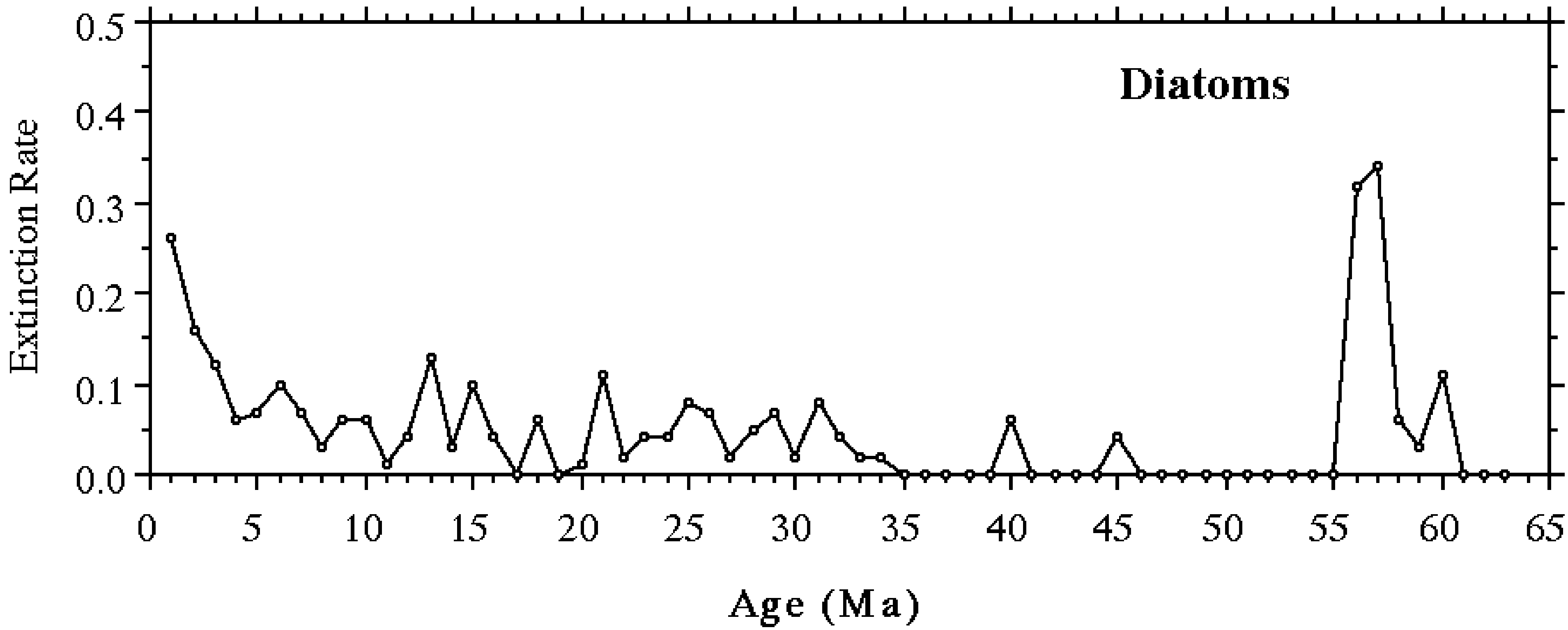
0 5 10 15 20 25 30 35 40 45 50 55 60 65

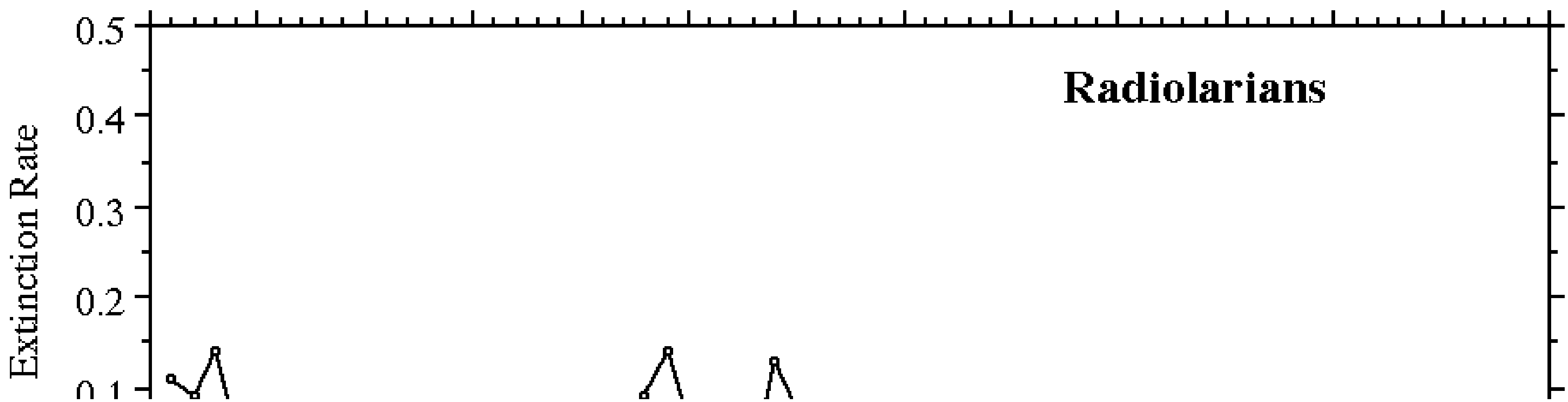
Age (Ma)

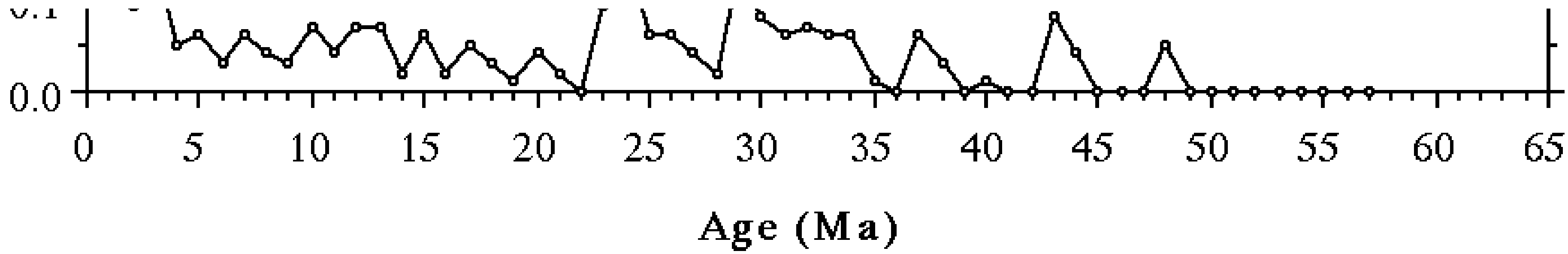


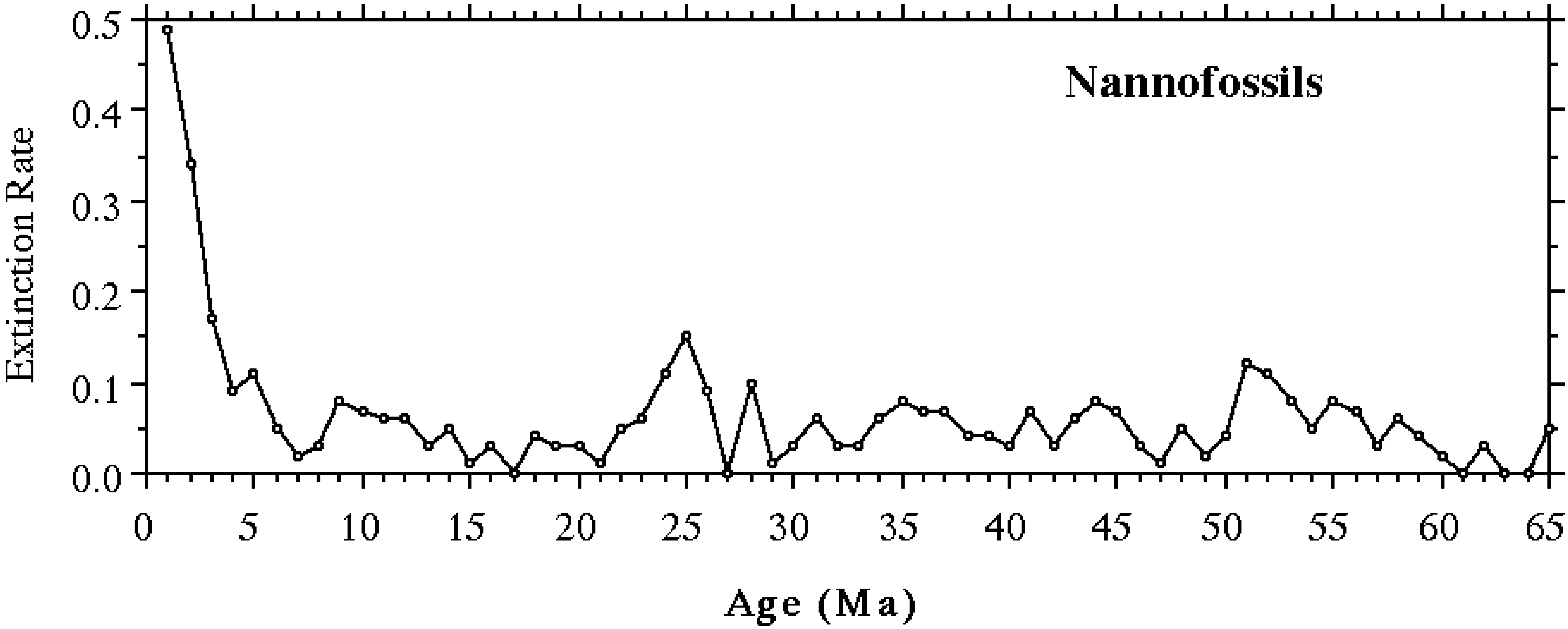
Close Window

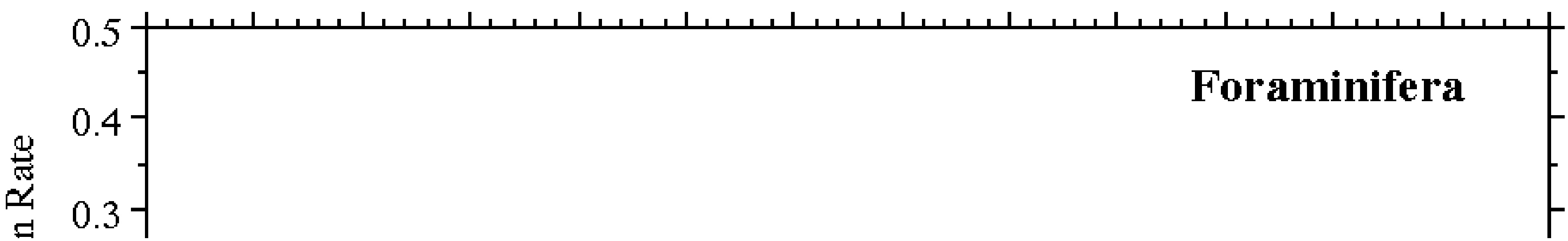
Figure 4.14. Extinction rates (calculated as the ratio between number of LADs versus number of species) of the four groups during the Cenozoic.

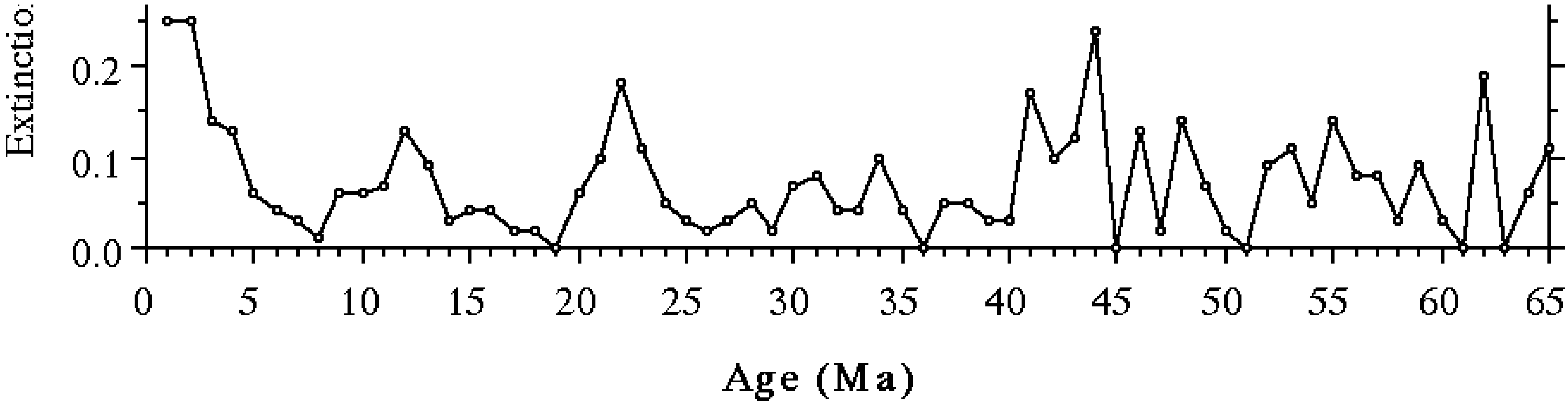





0.1
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Age (Ma)

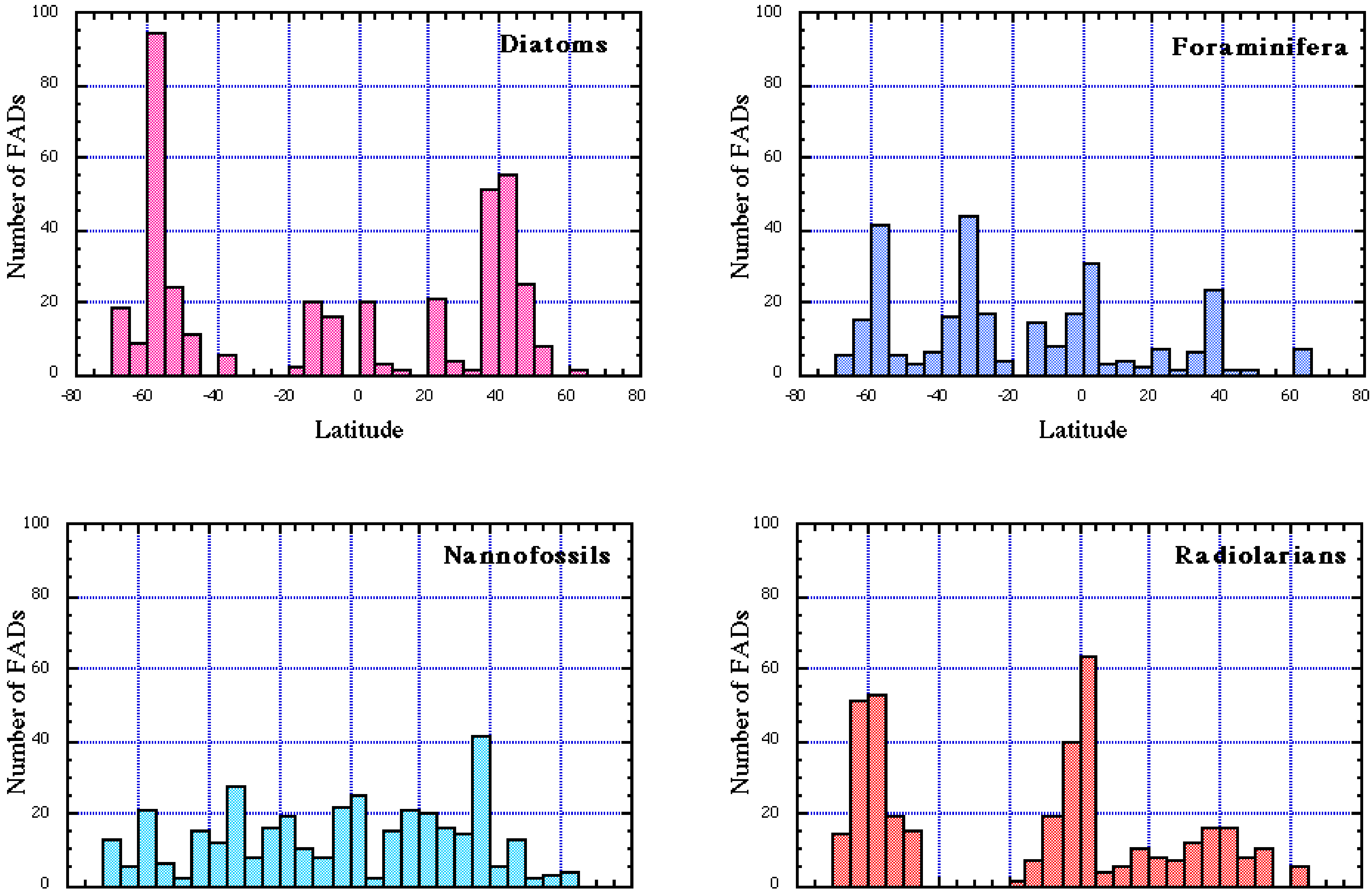

Extinction Rate
0.5
0.4
0.3
0.2
0.1
0.0
Nannofossils
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Age (Ma)


n Rate
0.5
0.4
0.3
Foraminifera


Extinctio
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Age (Ma)

Close Window

Figure 4.15. Geographic distribution of species FADs for the four groups. Southern latitudes are given as negative numbers. The latitude given for each FAD is a calculated paleolatitude at the time of the appearance (see 4.1.1.4 for details on the method).



-80 -60 -40 -20 0 20 40 60 80

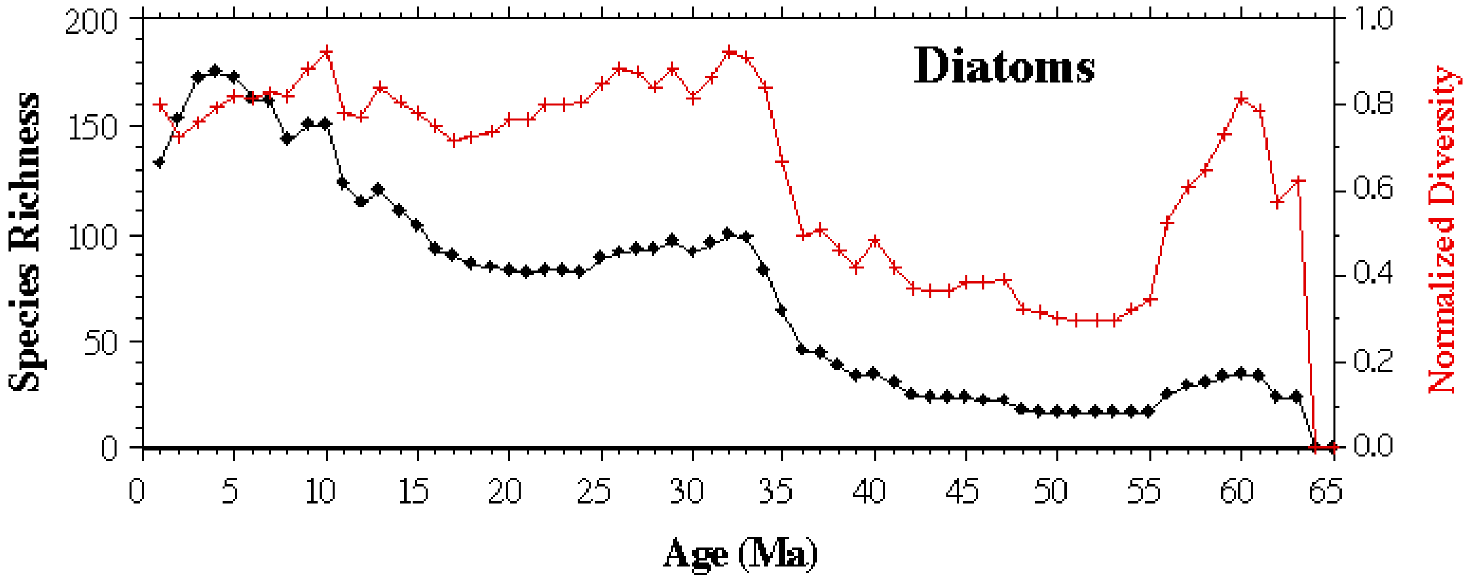
Latitude

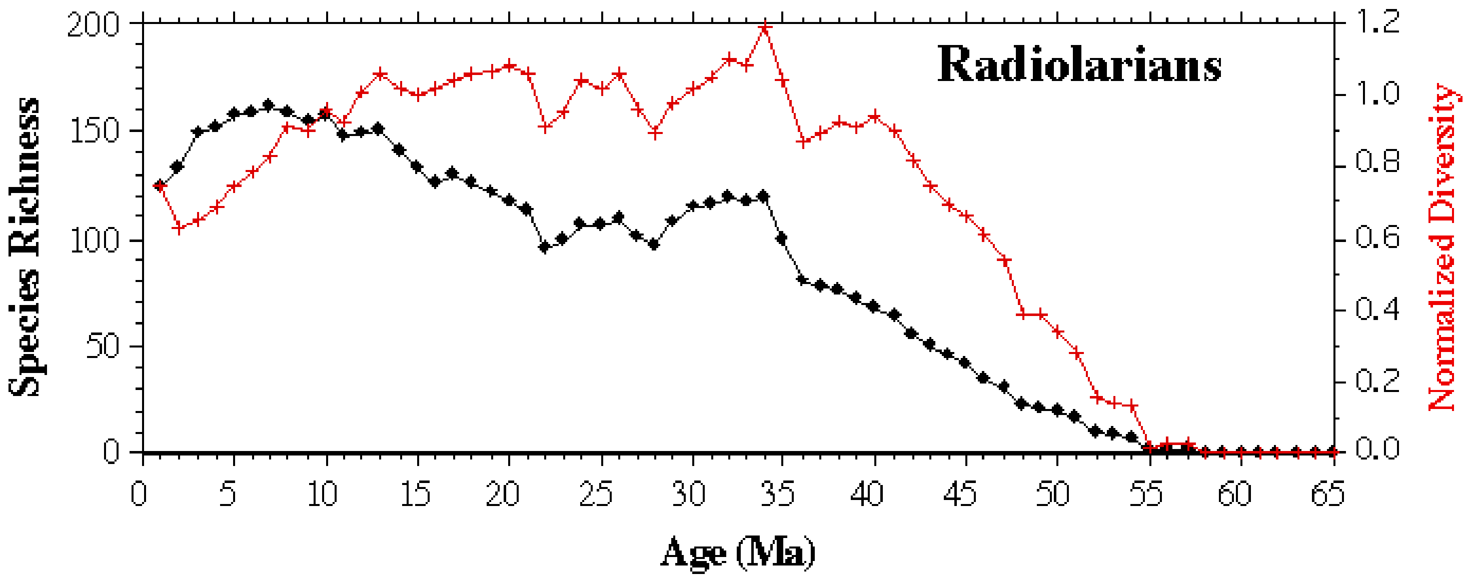
-80 -60 -40 -20 0 20 40 60 80

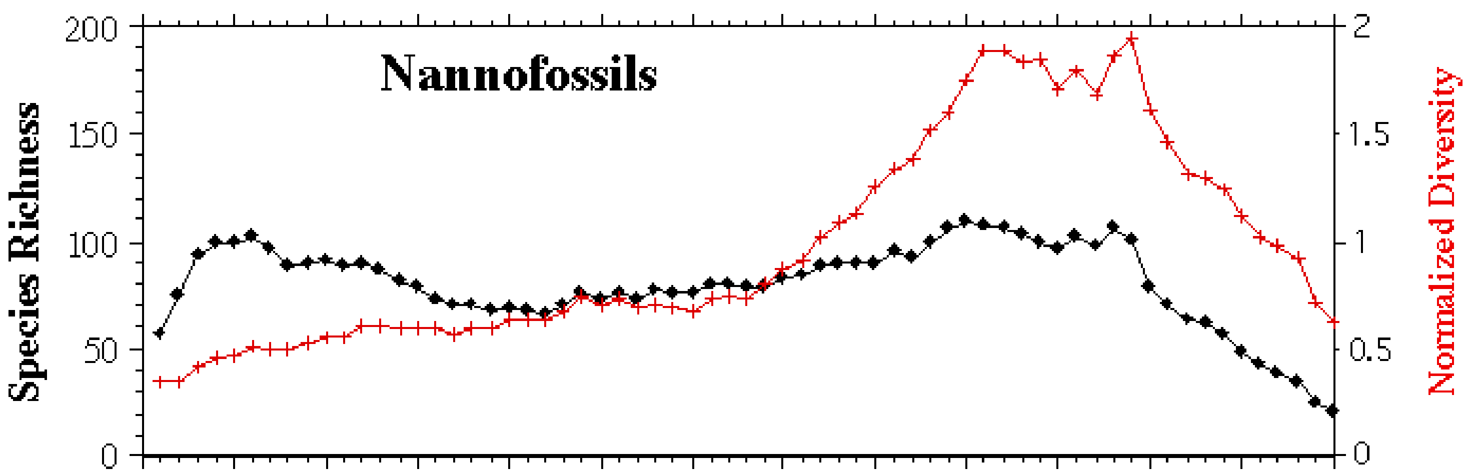
Latitude

Close Window

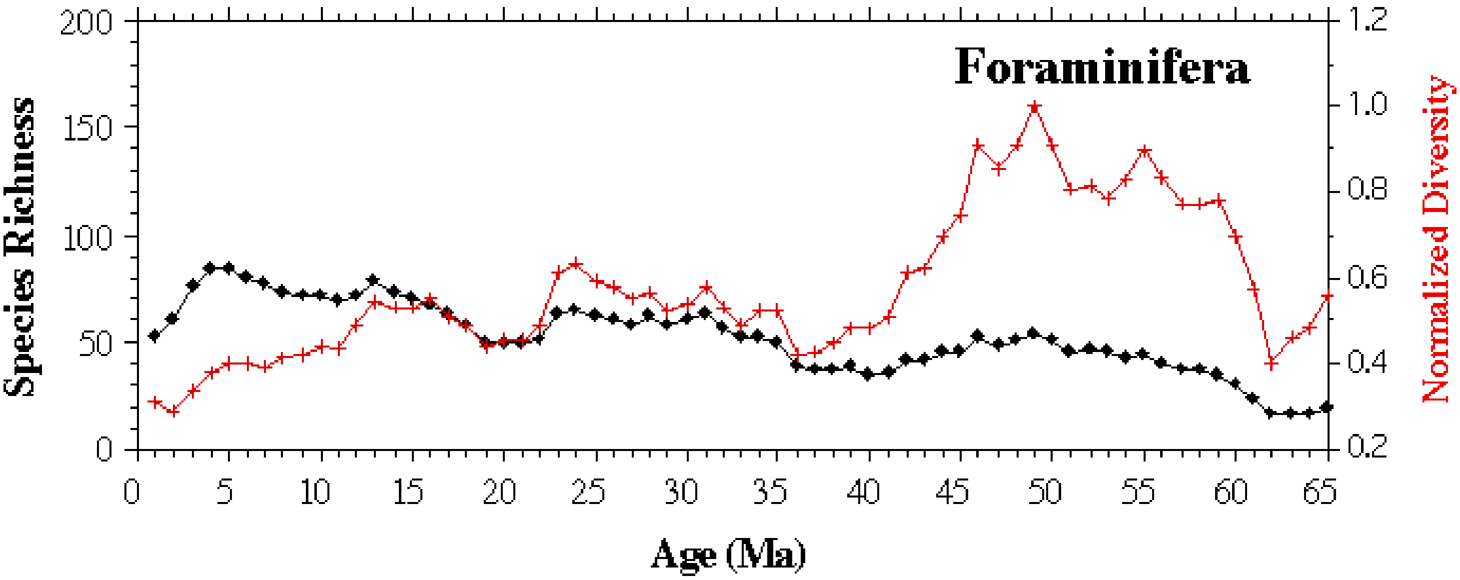
Figure 4.16. Species richness (total number of species - diamond symbols and black line) and diversity normalised on the number of sections in Neptune (ratios between diversity and number of sections - crosses and grey line) for the four plankton groups during the Cenozoic. Species richness is calculated at 1 m.y. intervals. Note that the scale of the normalised diversity is different in the four graphs.





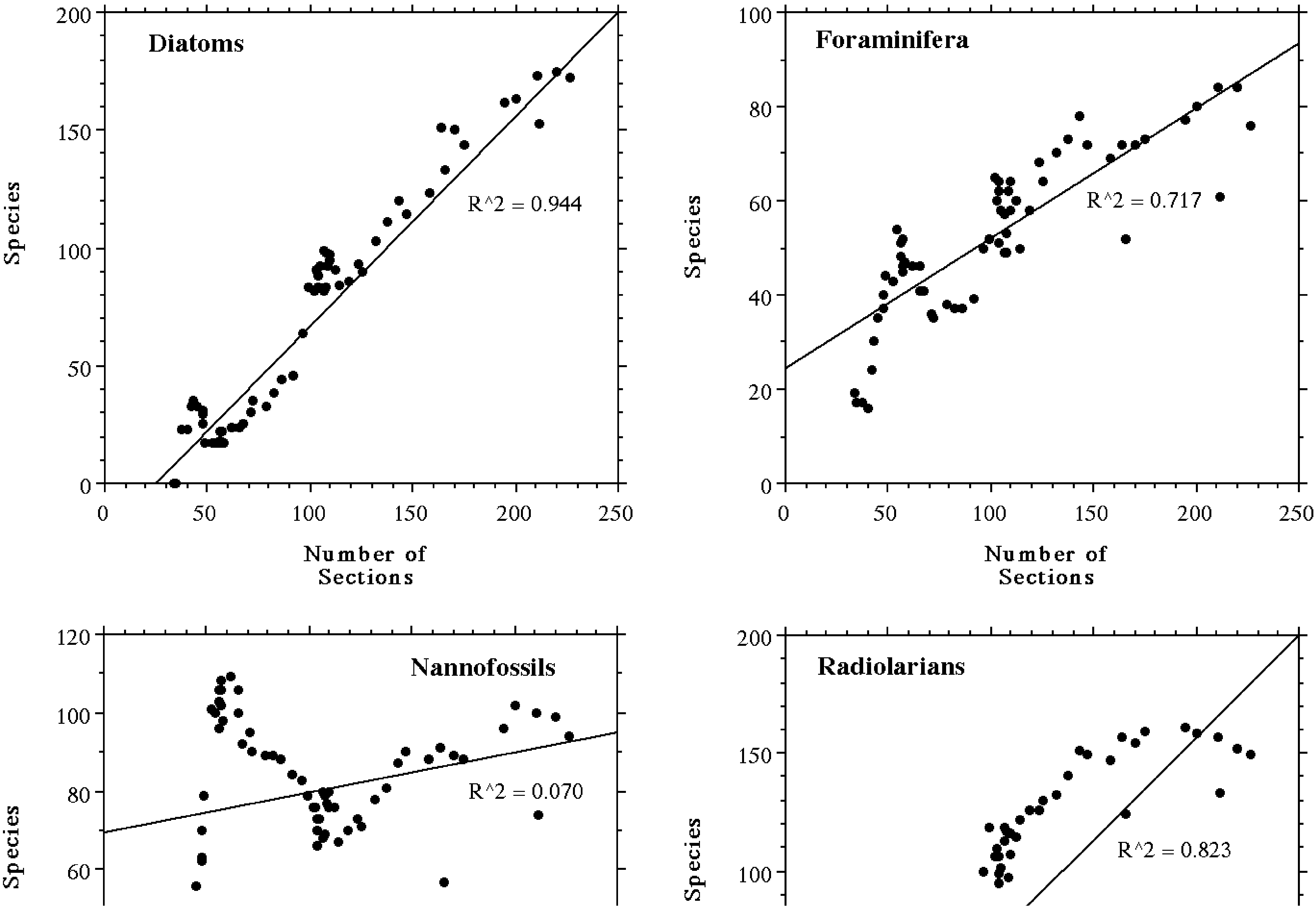


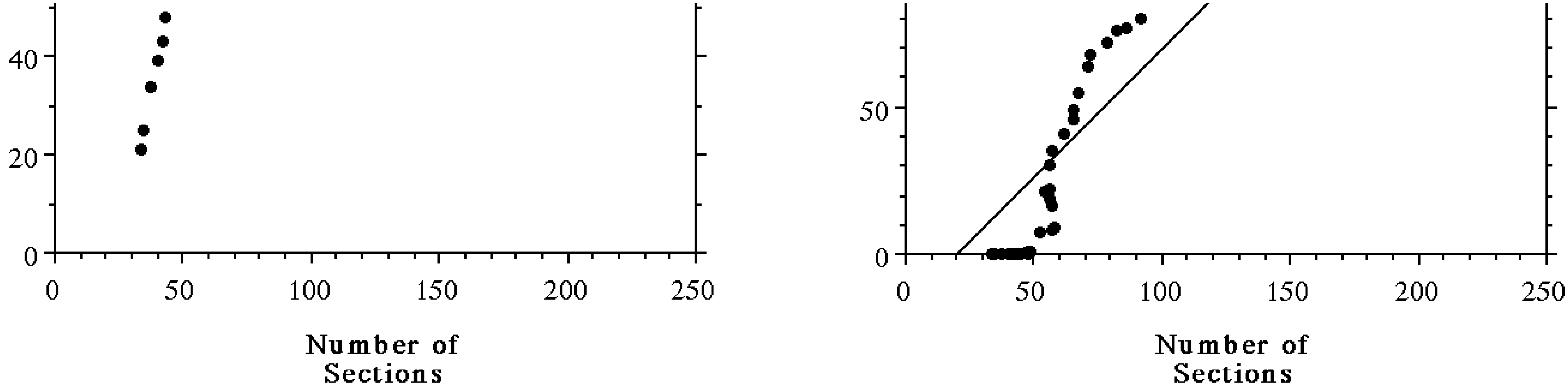

0 5 10 15 20 25 30 35 40 45 50 55 60 65
Age (Ma)


Foraminifera
Species Richness
200
150
100
50
0
Normalized Diversity
1.2
1.0
0.8
0.6
0.4
0.2
0 5 10 15 20 25 30 35 40 45 50 55 60 65
Age (Ma)

Close Window

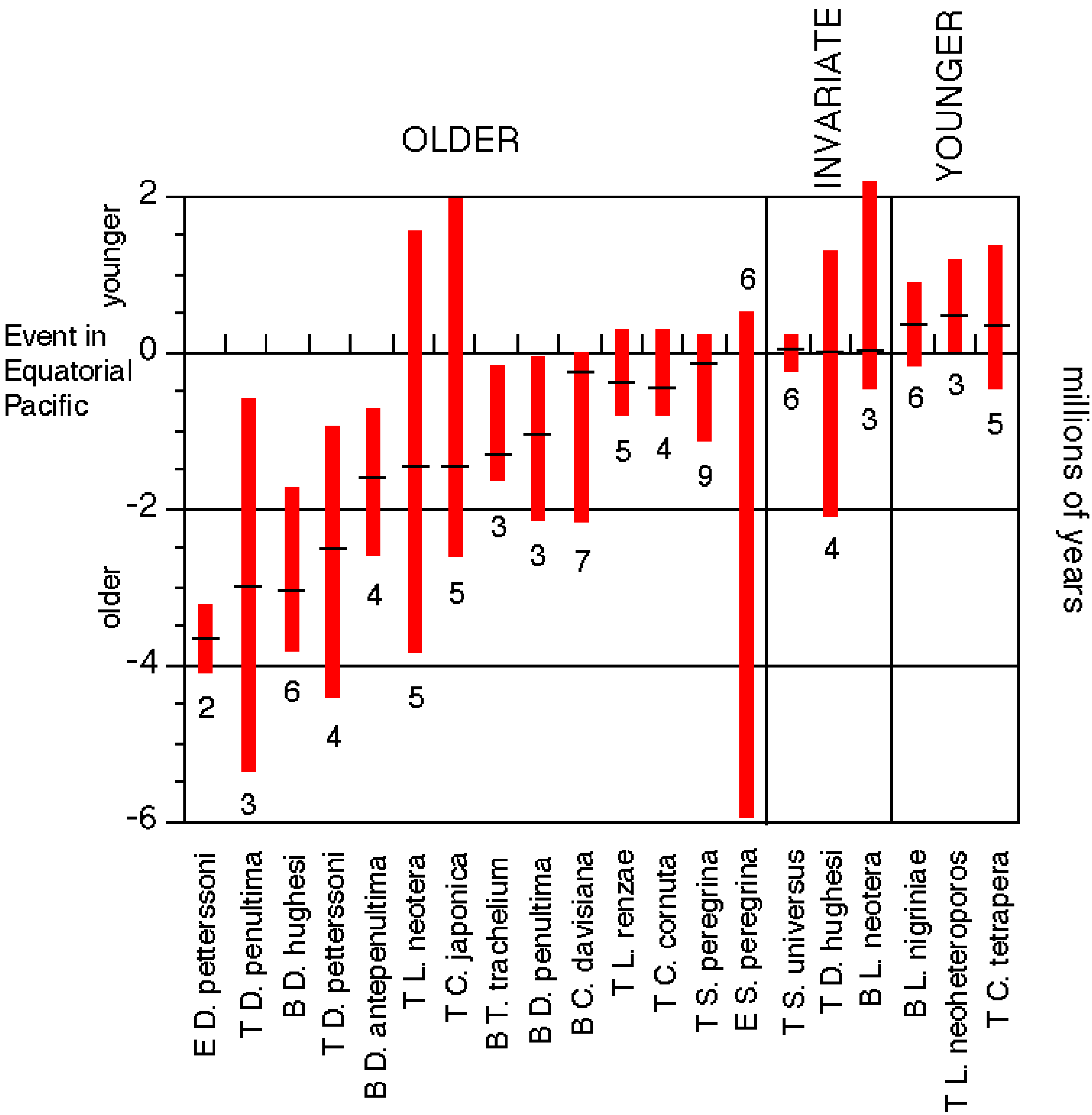
Figure 4.17. Species richness versus the total number of sections in Neptune. The R2 refers to the simple linear correlation shown in the graphs.




40
20
0
0
50
100
150
200
250
Number of Sections
50
0
0
50
100
150
200
250
Number of Sections

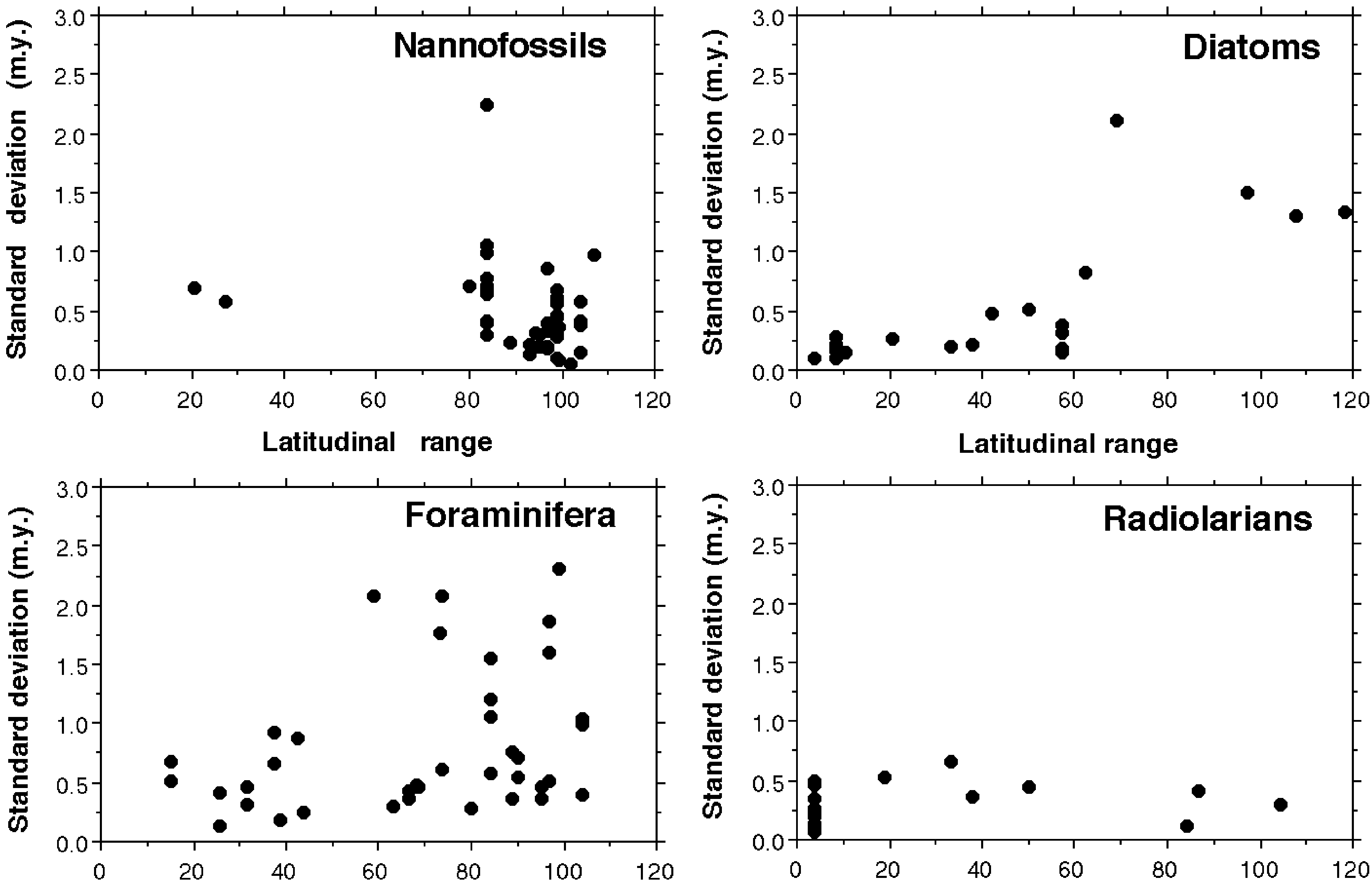
Close Window

Figure 4.18. Age differences between equatorial Pacific calibration (defined as 0) and North Pacific age ranges. The horizontal bar represents the suggested calibration for the single events. The events are divided into three groups, from left to right: the first, largest group includes events that are older in the North Pacific than they are in the Equatorial Pacific, the second group of events is synchronous in the equatorial and North Pacific, the third group includes events that are younger in the North Pacific. The number of sites included in the age range is written below the bar (from Spencer-Cervato et al. 1993).



Close Window

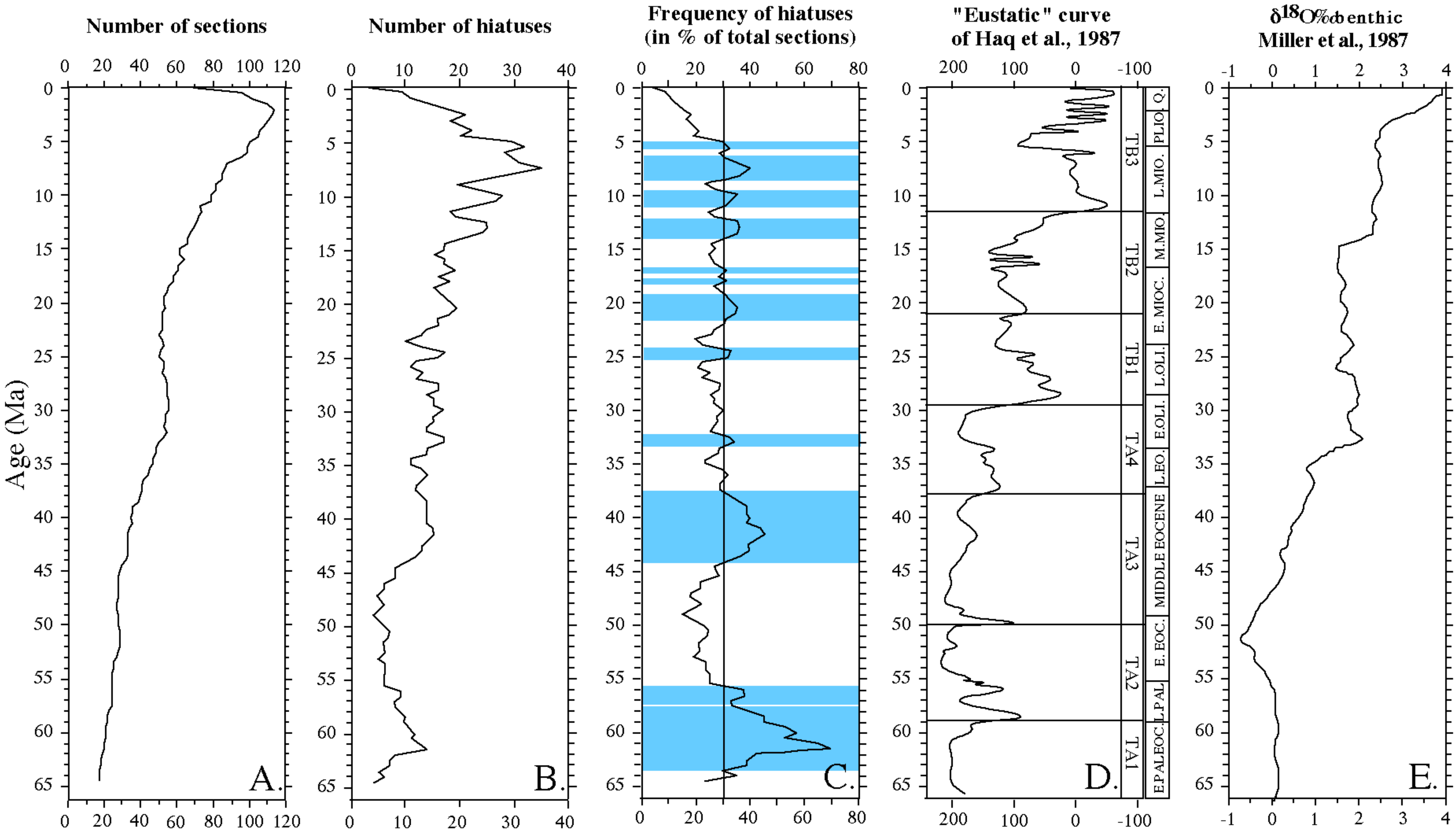
Figure 4.19. Latitudinal range versus standard deviation (in m.y.) for four plankton groups (from Spencer-Cervato et al. 1994). Note the higher standard deviations (interpreted as higher diachrony) for events with broader latitudinal ranges (i.e., cosmopolitan events). Also, note the relatively low standard deviation values for calcareous nannofossils, which are largely cosmopolitan. This suggest that they are particularly well suited for biostratigraphic correlations.



Latitudinal range

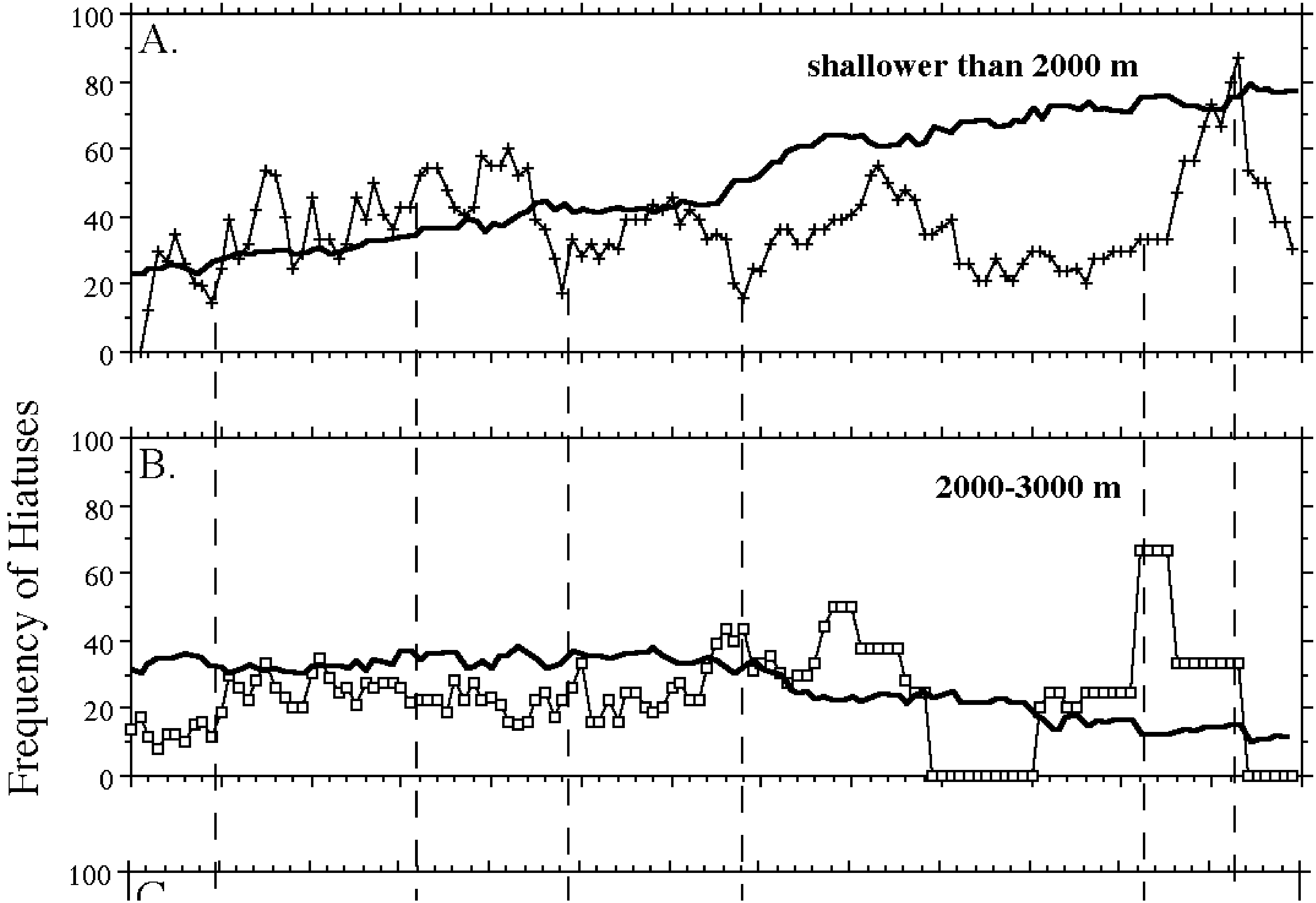
Latitudinal range

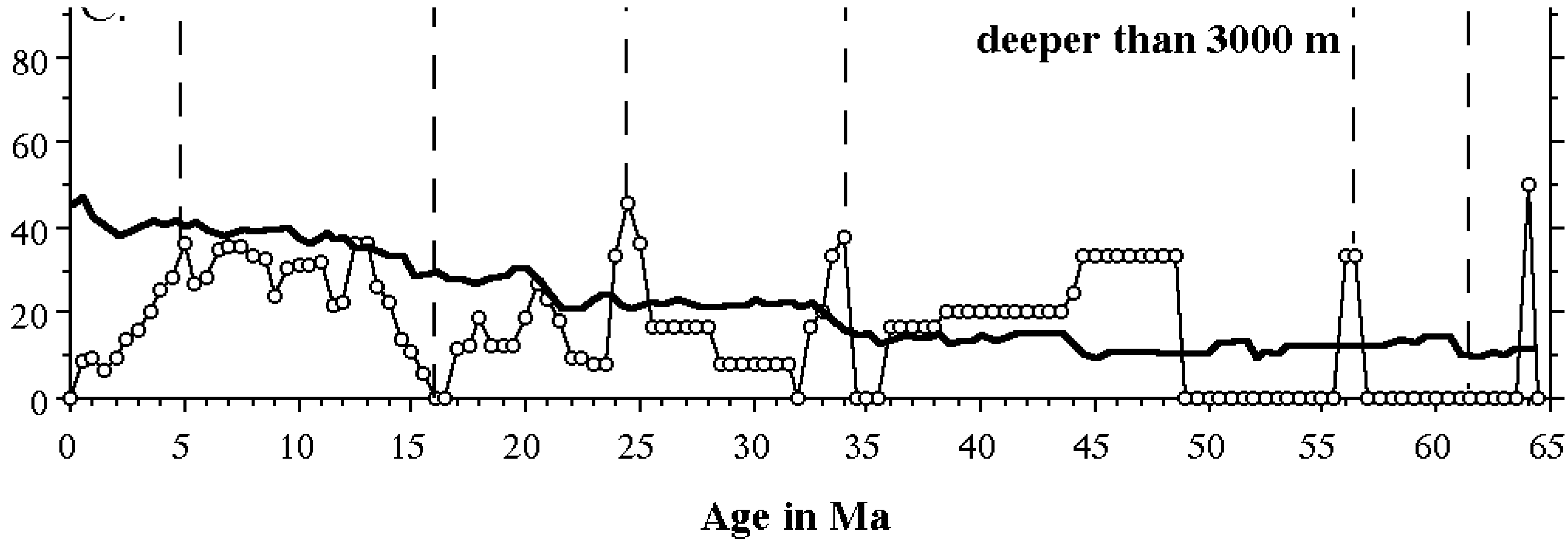
Figure 4.20. (a) Number of Cenozoic DSDP and ODP sections per 0.5 m.y. in the Neptune database. (b) Number of hiati recorded in the Neptune database during the last 65 m.y. (c) Curve of the frequency of hiati. The vertical line represents the average frequency (30%). Shaded intervals mark periods characterised by a higher than average frequency of hiati (hiatus events). (d) "Eustatic" sea level curve of Haq et al. (1987). (e) Benthic foraminifera oxygen isotope curve (Miller et al. 1987). All curves are calibrated to Berggren et al.'s (1995b) biochronology (from Spencer-Cervato 1998).



Close Window

Figure 4.21. The lines with symbols represent the frequency of hiati recorded at various paleodepth intervals: (a) shallower than 2000 m, (b) between 2000 and 3000 m, and (c) deeper than 3000 m. The continuous lines represent the percentage of sections in the Neptune database in that interval of paleo-water depth (from Spencer-Cervato 1998).




deeper than 3000 m
0
20
40
60
80
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Age in Ma

Close Window

Table 4.1. Names of 1418 species included in the macroevolution analyses.

Diatoms

ABAS WITTII

ACHTINOPTYCHUS BIPUNCTATUS

ACHTINOPTYCHUS SENARIUS

ACHTINOPTYCHUS SPLENDENS

ACTINOCYCLUS CURVATULUS

ACTINOCYCLUS ELLIPTICUS

ACTINOCYCLUS ELONGATUS

ACTINOCYCLUS INGENS

ACTINOCYCLUS LANCEOLATUS

ACTINOCYCLUS MORONENSIS

ACTINOCYCLUS OCHOTENSIS

ACTINOCYCLUS OCTONARIUS

ACTINOCYCLUS OCULATUS

ACTINOCYCLUS TSUGARUENSIS

ACTINOCYCLUS ACTINOCHILUS

ACTINOCYCLUS FASCICULATUS

ACTINOCYCLUS FRYXELLAE

ACTINOCYCLUS KARSTENII

ANNELLUS CALIFORNICUS

ASTEROLAMPRA ACUTILOBA

ASTEROLAMPRA AFFINIS

ASTEROLAMPRA GREVILLEI

ASTEROLAMPRA INSIGNIS

ASTEROLAMPRA MARYLANDICA

ASTEROLAMPRA PUNCTIFERA

ASTEROLAMPRA VULGARIS

ASTEROLAMPRA SCHMIDTII

ASTEROMPHALUS ARACHNE

ASTEROMPHALUS DARWINII

ASTEROMPHALUS FLABELLATUS

ASTEROMPHALUS HEPTACTIS

ASTEROMPHALUS HOOKERI

ASTEROMPHALUS IMBRICATUS

ASTEROMPHALUS OLIGOCENICUS

ASTEROMPHALUS PARVULUS

ASTEROMPHALUS PETERSONII

ASTEROMPHALUS ROBUSTUS

ASTEROMPHALUS SYMMETRICUS

ASTEROMPHALUS KENNETTII

AZPEITIA NODULIFER

AZPEITIA ENDOI

AZPEITIA TABULARIS

AZPEITIA GOMBOSI

AZPEITIA OLIGOCENICA

AZPEITIA PRAENODULIFER

AZPEITIA VETUSTISSIMA

BACTERIOSIRA FRAGILIS

BACTERIASTRUM HYALINUM

BAXTERIA BRUNII

BOGOROVIA VENIAMINI

BOGOROVIA PALEACEA

BOGOROVIA PRAEPALEACEA

CESTODISCUS CONVEXUS

CESTODISCUS MUKHINAE

CESTODISCUS PEPLUM

CESTODISCUS PULCHELLUS

CESTODISCUS RETICULATUS

CESTODISCUS ROBUSTUS

CESTODISCUS STOKESIASUS

CESTODISCUS TROCHUS

CESTODISCUS ANTARCTICUS

CESTODISCUS DEMERGITUS

CESTODISCUS PARMULA

CHAETOCEROS FURCELLATUS

CHAETOCEROS ASYMMETRICUS

CHAETOCEROS BULBOSUM

CLADOGRAMMA DUBIUM

COCCONEIS CALIFORNICA

COCCONEIS COSTATA

COCCONEIS PSEUDOMARGINATA

COCCONEIS SCUTELLUM

CORETHRON CRIOPHILUM

COSCINODISCUS AFRICANUS

COSCINODISCUS APICULATUS

COSCINODISCUS ASTEROMPHALUS

COSCINODISCUS BLYSMOS

COSCINODISCUS CENTRALIS

COSCINODISCUS CRENULATUS

COSCINODISCUS DEFORMANS

COSCINODISCUS ELEGANS

COSCINODISCUS EXCAVATUS

COSCINODISCUS FLEXUOSUS

COSCINODISCUS GIGAS

COSCINODISCUS KOLBEI

COSCINODISCUS LEWISIANUS

COSCINODISCUS MARGINATUS

COSCINODISCUS NODULIFER

COSCINODISCUS OCCULUS-IRIDIS

COSCINODISCUS PLICATUS

COSCINODISCUS PRAEYABEI

COSCINODISCUS PUSTULATUS

COSCINODISCUS RADIATUS

COSCINODISCUS RHOMBICUS

COSCINODISCUS STELLARIS

COSCINODISCUS SUPERBUS

COSCINODISCUS TEMPEREI

COSCINODISCUS TUBERCULATUS

COSCINODISCUS YABEI

COSCINODISCUS CRUXII

COSCINODISCUS HAJOSIAE

COSCINODISCUS VULNIFICUS

COSMIODISCUS INSIGNIS

CRASPEDODISCUS COSCINODISCUS

CRASPEDODISCUS UMBONATUS

CRUCIDENTICULA NICOBARICA

CRUCIDENTICULA PUNCTATA

CRUCIDENTICULA KANAYAE

CUSSIA LANCETTULA

CYCLOTELLA STRIATA

CYMATOGONIA AMBLYOCERAS

CYMATOSIRA COMPACTA

CYMATOSIRA DEBYI

CYMATOTHECA WEISSFLOGII

DACTYLIOSOLEN ANTARCTICUS

DELPHINEIS SURIRELLA

DELPHINEIS ISCHABOENSIS

DENTICULOPSIS DIMORPHA

DENTICULOPSIS HUSTEDTII

DENTICULOPSIS HYALINA

DENTICULOPSIS LAUTA

DENTICULOPSIS MACCOLLUMII

DENTICULOPSIS MIOCENICA

DENTICULOPSIS NORWEGICA

DENTICULOPSIS PRAEDIMORPHA

DENTICULOPSIS PUNCTATA

DENTICULOPSIS SEMINAE

DENTICULOPSIS KATAYAMAE

DENTICULOPSIS MERIDIONALIS

DIMEROGRAMMA FOSSILE

DIPLONEIS BOMBUS

DIPLONEIS COFFAEIFORMIS

DIPLONEIS SMITHII

DIPLONEIS WEISSFLOGII

ETHMODISCUS REX

EUCAMPIA ANTARCTICA

GONIOTHECIUM DECORATUM

GONIOTHECIUM ODONTELLA

GRUNOWIELLA GEMMATA

GRUNOWIELLA PALAEOCAENICA

HEMIDISCUS CUNEIFORMIS

HEMIDISCUS KARSTENII

HEMIDISCUS OVALIS

HEMIDISCUS SIMPLICISSIMUS

HEMIDISCUS TRIANGULARUS

HEMIAULUS ALTAR

HEMIAULUS BARBADENSIS

HEMIAULUS CARACTERISTICUS

HEMIAULUS EXIGUUS

HEMIAULUS INCISUS

HEMIAULUS POLYMORPHUS

HEMIAULUS PUNGENS

HEMIAULUS SUBACUTUS

HEMIAULUS TAURUS

HEMIAULUS FRAGILIS

HEMIAULUS GRACILIS

HEMIAULUS KRISTOFFERSENII

HEMIAULUS NOCCHIAE

HEMIAULUS PERIPTERUS

HEMIAULUS POLYCYSTINORUM

HEMIAULUS RECTUS

HEMIAULUS ROSSICUS

HYALODISCUS OBSOLETUS

HYALODISCUS AMBIGUUS

IKEBEA TENUIS

KATATHIRAIA ASPERA

KISSELEVIELLA CARINA

KOZLOVIELLA MINOR

LISITZINIA ORNATA

LITHODESMIUM CORNIGERUM

LITHODESMIUM MINUSCULUM

LITHODESMIUM REYNOLDSII

LITHODESMIUM UNDULATUM

MACRORA STELLA

MEDIARIA SPLENDIDA

MELOSIRA ALBICANS

MELOSIRA SOL

NAVICULA LYRA

NAVICULA UDENTSEVII

NAVICULA WISEI

NEOBRUNIA MIRABILIS

NEODENTICULA KAMTSCHATICA

NEODENTICULA KOIZUMII

NITZSCHIA AEQUATORIALIS

NITZSCHIA ANGULATA

NITZSCHIA BICAPITATA

NITZSCHIA BRAARUDII

NITZSCHIA CHALLENGERI

NITZSCHIA CLAVICEPS

NITZSCHIA CURTA

NITZSCHIA CYLINDRICA

NITZSCHIA GRANULATA

NITZSCHIA GROSSEPUNCTATA

NITZSCHIA GRUNOWII

NITZSCHIA INFLATULA

NITZSCHIA INTERFRIGIDARIA

NITZSCHIA INTERRUPTESTRIATA

NITZSCHIA JANUARIA

NITZSCHIA JOUSEAE

NITZSCHIA KERGUELENSIS

NITZSCHIA KOLACZECKII

NITZSCHIA MARINA

NITZSCHIA MIOCENICA

NITZSCHIA PANDURIFORMIS

NITZSCHIA PORTERI

NITZSCHIA PRAEINTERFRIGIDARIA

NITZSCHIA PRAEREINHOLDII

NITZSCHIA PSEUDOKERGUELENSIS

NITZSCHIA PUNCTATA

NITZSCHIA PUSILLA

NITZSCHIA REINHOLDII

NITZSCHIA RITSCHERII

NITZSCHIA ROLANDII

NITZSCHIA SEPARANDA

NITZSCHIA SERIATA

NITZSCHIA SICULA

NITZSCHIA SUIKOENSIS

NITZSCHIA UMAOIENSIS

NITZSCHIA WEAVERI

NITZSCHIA CYLINDRUS

NITZSCHIA DENTICULOIDES

NITZSCHIA DIETRICHII

NITZSCHIA DONAHUENSIS

NITZSCHIA EFFERANS

NITZSCHIA EVENESCENS

NITZSCHIA EXTINCTA

NITZSCHIA FOSSILIS

NITZSCHIA MALEINTERPRETARIA

ODONTELLA AURITA

ODONTELLA TUOMEYI

PARALIA SULCATA

PARALIA ARCHITECTURALIS

PARALIA CLAVIGERA

PLAGIOGRAMMA STAUROPHORUM

PLANKTIONELLA SOL

POROSIRA GLACIALIS

PSEUDOEUNOTIA DOLIOLUS

PSEUDOPODOSIRA ELEGANS

PSEUDOPODOSIRA SIMPLEX

PSEUDOPYXILLA AMERICANA

PSEUDOPYXILLA RUSSICA

PSEUDOTRICERATIUM CHENEVIERI

PSEUDOTRICERATIUM RADIOSORETICULATUM

PTEROTHECA ACULEIFERA

PTEROTHECA CLAVATA

PTEROTHECA EVERMANNI

PTEROTHECA KITTONIANA

PYXILLA RETICULATA

RHABDONEMA ARCUATUM

RHABDONEMA JAPONICUM

RHAPHIDODISCUS MARYLANDICUS

RHAPHONEIS AMPHICEROS

RHAPHONEIS ANGUSTATA

RHAPHONEIS MARGARITALIMBATA

RHIZOSOLENIA ALATA

RHIZOSOLENIA BERGONII

RHIZOSOLENIA CRETACEA

RHIZOSOLENIA CURVIROSTRIS

RHIZOSOLENIA HEBETATA

RHIZOSOLENIA INTERPOSITA

RHIZOSOLENIA MATUYAMAI

RHIZOSOLENIA MIOCENICA

RHIZOSOLENIA PRAEBERGONII

RHIZOSOLENIA STYLIFORMIS

RHIZOSOLENIA ANTARCTICA

RHIZOSOLENIA OLIGOCENICA

RHIZOSOLENIA SETIGERA

RIEDELIA CLAVIGER

ROCELLA GELIDA

ROCELLA VIGILANS

ROCELLA PRAENITIDA

ROPERIA PRAETESSELATA

ROPERIA TESSELATA

ROSSIELLA PALEACEA

ROSSIELLA PRAEPALEACEA

ROSSIELLA TATSUNOKUCHIENSIS

ROSSIELLA SYMMETRICA

ROUXIA CALIFORNICA

ROUXIA GRANDA

ROUXIA HETEROPOLARA

ROUXIA ISOPOLICA

ROUXIA NAVICULOIDES

ROUXIA OBESA

ROUXIA PERAGALLI

ROUXIA YABEI

SCEPTRONEIS GRUNOWII

SCEPTRONEIS HUMUNCIA

SCEPTRONEIS PESPLANUS

SCEPTRONEIS TENUE

SCEPTRONEIS LINGULATUS

SIMONSENIELLA BARBOI

SIMONSENIELLA PRAEBARBOI

SKELETONEMA BARBADENSE

SPHYNCTOLETHUS HEMIAULOIDES

STEPHANOPYXIS DIMORPHA

STEPHANOPYXIS GRUNOWII

STEPHANOPYXIS HORRIDUS

STEPHANOPYXIS MARGINATA

STEPHANOPYXIS SPINOSISSIMA

STEPHANOPYXIS TURRIS

STEPHANOPYXIS ORNATA

STEPHANOGONIA HANZAWAE

STELLARIMA MICROTRIAS

STELLARIMA PRIMALABIATA

SYNEDRA INDICA

SYNEDRA JOUSEANA

SYNEDRA MIOCENICA

THALASSIOSIRA ANTARCTICA

THALASSIOSIRA ANTIQUA

THALASSIOSIRA BURCKLIANA

THALASSIOSIRA CONVEXA

THALASSIOSIRA DECIPIENS

THALASSIOSIRA DELICATULA

THALASSIOSIRA ECCENTRICA

THALASSIOSIRA FRAGA

THALASSIOSIRA GRACILIS

THALASSIOSIRA GRAVIDA

THALASSIOSIRA HYALINA

THALASSIOSIRA JACKSONII

THALASSIOSIRA KRYOPHILA

THALASSIOSIRA LACUSTRIS

THALASSIOSIRA LEPTOPUS

THALASSIOSIRA LINEATA

THALASSIOSIRA NIDULUS

THALASSIOSIRA NODULOLINEATA

THALASSIOSIRA NORDENSKIOELDII

THALASSIOSIRA OESTRUPII

THALASSIOSIRA OPPOSITA

THALASSIOSIRA PACIFICA

THALASSIOSIRA PLICATA

THALASSIOSIRA PRAECONVEXA

THALASSIOSIRA PUNCTATA

THALASSIOSIRA SINGULARIS

THALASSIOSIRA SPINOSA

THALASSIOSIRA SPUMELLAROIDES

THALASSIOSIRA SYMBOLOPHORA

THALASSIOSIRA SYMMETRICA

THALASSIOSIRA TEMPEREI

THALASSIOSIRA TAPPANES

THALASSIOSIRA TRIFULTA

THALASSIOSIRA TUMIDA

THALASSIOSIRA USATSCHEVII

THALASSIOSIRA YABEI

THALASSIOSIRA ZABELINAE

THALASSIOSIRA BUKRYI

THALASSIOSIRA ELLIPTIPORA

THALASSIOSIRA GERSONDEI

THALASSIOSIRA LENTIGINOSA

THALASSIOSIRA MANIFESTA

THALASSIOSIRA MARUJAMICA

THALASSIOSIRA MIOCENICA

THALASSIOSIRA NATIVA

THALASSIOSIRA OLIVERANA

THALASSIOSIRA STRIATA

THALASSIOSIRA WEBBI

THALASSIONEMA BACILLARIS

THALASSIONEMA HIROSAKIENSIS

THALASSIONEMA NITZSCHIOIDES

THALASSIONEMA ROBUSTA

THALASSIONEMA SCHRADERI

THALASSIOTHRIX FRAUENFELDII

THALASSIOTHRIX LONGISSIMA

THALASSIOTHRIX MIOCENICA

TRACHYNEIS ASPERA

TRICERATIUM ACUTANGULUM

TRICERATIUM BARBADENSE

TRICERATIUM CINNAMOMEUM

TRICERATIUM CONDECORUM

TRICERATIUM GRONINGENSIS

TRICERATIUM SCHULZII

TRICERATIUM CELLULOSUM

TRICERATIUM GOMBOSII

TRICERATIUM MIRABILE

TRICERATIUM UNGUICULATUM

TRINACRIA EXCAVATA

TRINACRIA PILEOLUS

TRINACRIA REGINA

TRINACRIA SIMULACRUM

TRINACRIA SUBCAPITATA

TRINACRIA CONIFERA

TRINACRIA DECIUSII

TRINACRIA SENTA

TRINACRIA SIMULACROIDES

TROCHOSIRA CONCAVA

TROCHOSIRA SPINOSA

TROCHOSIRA GRACILLIMA

TROCHOSIRA MARGINATA

TROCHOSIRA RADIATA

XANTHIOPYXIS OBLONGA

XANTHIOPYXIS ACROLOPHA

Foraminifera

ACARININA ASPENSIS

ACARININA BROEDERMANNI

ACARININA BULLBROOKI

ACARININA CONVEXA

ACARININA DECEPTA

ACARININA ESNAENSIS

ACARININA INTERMEDIA

ACARININA MATHEWSAE

ACARININA MCKANNAI

ACARININA PENTACAMERATA

ACARININA PRIMITIVA

ACARININA ROTUNDIMARGINATA

ACARININA RUGOSOACULEATA

ACARININA SOLDADOENSIS

ACARININA SPINULOINFLATA

ACARININA SPIRALIS

ACARININA TRIPLEX

ACARININA WILCOXENSIS

ACARININA APPRESSOCAMERATA

ACARININA CUNEICAMERATA

ACARININA ECHINATA

ACARININA PRAEPENTACAMERATA

ACARININA PRAETOPILENSIS

BEELLA DIGITATA

CANDEINA NITIDA

CASSIGERINELLOITA AMEKIENSIS

CASSIGERINELLA CHIPOLENSIS

CATAPSYDRAX DISSIMILIS

CATAPSYDRAX PARVULUS

CATAPSYDRAX STAINFORTHI

CHILOGUEMBELINA CUBENSIS

CHILOGUEMBELINA MIDWAYENSIS

CHILOGUEMBELINA WILCOXENSIS

CHILOGUEMBELINA CRINITA

CRIBROHANTKENINA INFLATA

DENTOGLOBIGERINA GALAVISI

EOGLOBIGERINA EOBULLOIDES

EOGLOBIGERINA TAURICA

EOGLOBIGERINA FRINGA

GLOBOROTALIA AEMILIANA

GLOBOROTALIA ACROSTOMA

GLOBOROTALIA ANFRACTA

GLOBOROTALIA ARCHAEOMENARDII

GLOBOROTALIA BIRNAGAE

GLOBOROTALIA BONONIENSIS

GLOBOROTALIA CIBAOENSIS

GLOBOROTALIA COLLACTEA

GLOBOROTALIA CONICA

GLOBOROTALIA CONOIDEA

GLOBOROTALIA CONOMIOZEA

GLOBOROTALIA CONTINUOSA

GLOBOROTALIA CRASSAFORMIS

GLOBOROTALIA CRASSATA

GLOBOROTALIA EXILIS

GLOBOROTALIA FOHSI

GLOBOROTALIA GEMMA

GLOBOROTALIA HIRSUTA

GLOBOROTALIA INCONSTANS

GLOBOROTALIA INCREBESCENS

GLOBOROTALIA INFLATA

GLOBOROTALIA INSOLITA

GLOBOROTALIA JUANAI

GLOBOROTALIA KUGLERI

GLOBOROTALIA ICHINOSEKIENSIS

GLOBOROTALIA LENGUAENSIS

GLOBOROTALIA MARGARITAE

GLOBOROTALIA MARGINODENTATA

GLOBOROTALIA MAYERI

GLOBOROTALIA MENARDII

GLOBOROTALIA MENDACIS

GLOBOROTALIA MEROTUMIDA

GLOBOROTALIA MINIMA

GLOBOROTALIA MINUTISSIMA

GLOBOROTALIA MIOCENICA

GLOBOROTALIA MIOTUMIDA

GLOBOROTALIA MIOZEA

GLOBOROTALIA MULTICAMERATA

GLOBOROTALIA NANA

GLOBOROTALIA OBESA

GLOBOROTALIA OPIMA

GLOBOROTALIA NYMPHA

GLOBOROTALIA PANDA

GLOBOROTALIA PERIPHEROACUTA

GLOBOROTALIA PERIPHERORONDA

GLOBOROTALIA PERMICRA

GLOBOROTALIA PERTENUIS

GLOBOROTALIA PLESIOTUMIDA

GLOBOROTALIA PLIOZEA

GLOBOROTALIA POSTCRETACEA

GLOBOROTALIA PRAEMENARDII

GLOBOROTALIA PSEUDOMENARDII

GLOBOROTALIA PSEUDOMIOCENICA

GLOBOROTALIA PSEUDOPUMILIO

GLOBOROTALIA PUNCTICULATA

GLOBOROTALIA QUADRATA

GLOBOROTALIA QUETRA

GLOBOROTALIA REISSI

GLOBOROTALIA SCITULA

GLOBOROTALIA SEMIVERA

GLOBOROTALIA SIAKENSIS

GLOBOROTALIA SUTERAE

GLOBOROTALIA TADJIKITANENSIS

GLOBOROTALIA THEYERI

GLOBOROTALIA TOSAENSIS

GLOBOROTALIA TRINIDADENSIS

GLOBOROTALIA TRUNCATULINOIDES

GLOBOROTALIA TUMIDA

GLOBOROTALIA UNCINATA

GLOBOROTALIA UNGULATA

GLOBOROTALIA WHITEI

GLOBOROTALIA ZEALANDICA

GLOBOROTALIA SHERICOMIOZEA

GLOBOCONUSA DAUBJERGENSIS

GLOBIGERINOIDES ALTIAPERTURUS

GLOBIGERINOIDES BISPHERICUS

GLOBIGERINOIDES BOLLII

GLOBIGERINOIDES CONGLOBATUS

GLOBIGERINOIDES DIMINUTUS

GLOBIGERINOIDES FISTULOSUS

GLOBIGERINOIDES HIGGINSI

GLOBIGERINOIDES MITRA

GLOBIGERINOIDES PRIMORDIUS

GLOBIGERINOIDES RUBER

GLOBIGERINOIDES SACCULIFER

GLOBIGERINOIDES SICANUS

GLOBIGERINOIDES SUBQUADRATUS

GLOBIGERINOIDES TYRRHENICUS

GLOBIGERINOIDES OBLIQUUS

GLOBIGERINATELLA INSUETA

GLOBIGERINA AMPLIAPERTURA

GLOBIGERINA ANGULIOFFICINALIS

GLOBIGERINA ANGULISUTURALIS

GLOBIGERINA APERTURA

GLOBIGERINA ATLANTICA

GLOBIGERINA BINAIENSIS

GLOBIGERINA BRAZIERI

GLOBIGERINA BREVIS

GLOBIGERINA BULBOSA

GLOBIGERINA BULLOIDES

GLOBIGERINA CARIACOENSIS

GLOBIGERINA CIPEROENSIS

GLOBIGERINA CORPULENTA

GLOBIGERINA CRYPTOMPHA

GLOBIGERINA DRURYI

GLOBIGERINA EAMESI

GLOBIGERINA EUAPERTA

GLOBIGERINA FALCONENSIS

GLOBIGERINA FOLIATA

GLOBIGERINA GLOBULARIS

GLOBIGERINA GORTANII

GLOBIGERINA HAGNI

GLOBIGERINA INAEQUISPIRA

GLOBIGERINA JUVENILIS

GLOBIGERINA LABIACRASSATA

GLOBIGERINA LINAPERTA

GLOBIGERINA MEGASTOMA

GLOBIGERINA MUNDA

GLOBIGERINA NEPENTHES

GLOBIGERINA OFFICINALIS

GLOBIGERINA OUACHITAENSIS

GLOBIGERINA PATAGONICA

GLOBIGERINA PRAEBULLOIDES

GLOBIGERINA PRAEDIGITATA

GLOBIGERINA PRAETURRITILINA

GLOBIGERINA PRASAEPIS

GLOBIGERINA PSEUDOAMPLIAPERTURA

GLOBIGERINA PSEUDOCIPEROENSIS

GLOBIGERINA PSEUDOBULLOIDES

GLOBIGERINA PSEUDOVENEZUELANA

GLOBIGERINA RUBESCENS

GLOBIGERINA SELLII

GLOBIGERINA SENNI

GLOBIGERINA TAPURIENSIS

GLOBIGERINA TENELLA

GLOBIGERINA TRILOCULINOIDES

GLOBIGERINA TRIPARTITA

GLOBIGERINA TRIVIALIS

GLOBIGERINA UTILISINDEX

GLOBIGERINA VARIANTA

GLOBIGERINA WINKLERI

GLOBIGERINA WOODI

GLOBIGERINA YEGUAENSIS

GLOBIGERINELLOIDES SUBCARINATUS

GLOBIGERINELLOIDES MULTISPINATUS

GLOBIGERINELLA CALIDA

GLOBIGERINELLA SIPHONIFERA

GLOBOQUADRINA ALTISPIRA

GLOBOQUADRINA BAROEMOENENSIS

GLOBOQUADRINA CONGLOMERATA

GLOBOQUADRINA DEHISCENS

GLOBOQUADRINA LARMEUI

GLOBOQUADRINA PSEUDOFOLIATA

GLOBOQUADRINA VENEZUELANA

GLOBIGERINATHEKA BARRI

GLOBIGERINATHEKA INDEX

GLOBIGERINATHEKA MEXICANA

GLOBIGERINATHEKA SEMIINVOLUTA

GLOBIGERINATHEKA SUBCONGLOBATA

GLOBOROTALOIDES SUTERI

GLOBOROTALOIDES TESTARUGOSUS

GLOBOROTALOIDES TREMA

GLOBOROTALOIDES VARIABILIS

GLOBOROTALOIDES HEXAGONA

GLOBOROTALOIDES OREGONENSIS

GLOBIGERINITA GLUTINATA

GLOBIGERINITA HOWEI

GLOBIGERINITA PERA

GLOBIGERINITA UVULA

HANTKENINA ALABAMENSIS

HANTKENINA PRIMITIVA

HASTIGERINA PELAGICA

IGORINA PUSILLA

MOROZOVELLA ACUTA

MOROZOVELLA ACUTISPIRA

MOROZOVELLA AEQUA

MOROZOVELLA ANGULATA

MOROZOVELLA ARAGONENSIS

MOROZOVELLA CONICOTRUNCATA

MOROZOVELLA FORMOSA

MOROZOVELLA LEHNERI

MOROZOVELLA LENSIFORMIS

MOROZOVELLA OCCLUSA

MOROZOVELLA SPINULOSA

MOROZOVELLA SUBBOTINAE

MOROZOVELLA VELASCOENSIS

MOROZOVELLA CRATER

MOROZOVELLA EDITA

MOROZOVELLA NICOLI

MOROZOVELLA PRAECURSORIA

MURICOGLOBIGERINA AQUIENSIS

MURICOGLOBIGERINA CHASCANONA

NEOGLOBOQUADRINA ACOSTAENSIS

NEOGLOBOQUADRINA ASANOI

NEOGLOBOQUADRINA DUTERTREI

NEOGLOBOQUADRINA HUMEROSA

NEOGLOBOQUADRINA PACHYDERMA

NEOGLOBOQUADRINA PSEUDOPIMA

ORBULINA SUTURALIS

ORBULINA UNIVERSA

PLANOROTALITES AUSTRALIFORMIS

PLANOROTALITES CHAPMANI

PRAEORBULINA GLOMEROSA

PRAEORBULINA TRANSITORIA

PROTENTELLA CLAVATICAMERATA

PROTENTELLA NAVAZUELENSIS

PSEUDOHASTIGERINA BARBADOENSIS

PSEUDOHASTIGERINA MICRA

PSEUDOHASTIGERINA NAGUEWICHIENSIS

PSEUDOHASTIGERINA WILCOXENSIS

PSEUDOHASTIGERINA DANVILLENSIS

PULLENIATINA OBLIQUILOCULATA

PULLENIATINA PRAECURSOR

PULLENIATINA PRIMALIS

PULLENIATINA SPECTABILIS

SPHAEROIDINELLA DEHISCENS

SPHAEROIDINELLOPSIS DISJUNCTA

SPHAEROIDINELLOPSIS SEMINULINA

SPHAEROIDINELLOPSIS MULTILOBA

STREPTOCHILUS GLOBIGERUM

SUBBOTINA ANGIPOROIDES

SUBBOTINA EOCAENA

SUBBOTINA EOCAENICA

SUBBOTINA TRIANGULARIS

SUBBOTINA TRILOCULARIS

SUBBOTINA TURGIDA

SUBBOTINA BAKERI

SUBBOTINA CROCIAPERTURA

SUBBOTINA EUAPERTURA

SUBBOTINA PSEUDOEOCAENA

TENUITELLINATA IOTA

TENUITELLA ANGUSTIUMBILICATA

TRUNCOROTALOIDES PSEUDOTOPILENSIS

TRUNCOROTALOIDES ROHRI

TRUNCOROTALOIDES TOPILENSIS

TURBOROTALIA CERROAZULENSIS

TURBOROTALIA COMPRESSA

TURBOROTALITA HUMILIS

TURBOROTALITA QUINQUELOBA

ZEAGLOBIGERINA INCISA

ZEAGLOBIGERINA MICROSTOMA

EOGLOBIGERINA EOBULLOIDES

Nannofossils

AMAUROLITHUS AMPLIFICUS

AMAUROLITHUS BIZZARUS

AMAUROLITHUS DELICATUS

AMAUROLITHUS PRIMUS

AMAUROLITHUS TRICORNICULATUS

AMAUROLITHUS SIGMUNDII

ANGULOLITHINA ARCA

BIANTHOLITHUS SPARSUS

BICOLUMNUS OVATUS

BIRKELUNDIA STAURION

BRAARUDOSPHAERA BIGELOWII

BRAARUDOSPHAERA DISCULA

BRAMLETTEIUS SERRACULOIDES

CALCIDISCUS LEPTOPORUS

CALCIDISCUS MACINTYREI

CALCIDISCUS PREMACINTYREI

CALCIDISCUS PROTOANNULUS

CAMPYLOSPHAERA DELA

CAMPYLOSPHAERA EODELA

CATINASTER CALYCULUS

CATINASTER COALITUS

CERATOLITHUS ACUTUS

CERATOLITHUS ARMATUS

CERATOLITHUS CRISTATUS

CERATOLITHUS RUGOSUS

CERATOLITHUS TELESMUS

CHIASMOLITHUS ALTUS

CHIASMOLITHUS BIDENS

CHIASMOLITHUS CALIFORNICUS

CHIASMOLITHUS CONSUETUS

CHIASMOLITHUS DANICUS

CHIASMOLITHUS EOGRANDIS

CHIASMOLITHUS EXPANSUS

CHIASMOLITHUS FREQUENS

CHIASMOLITHUS GIGAS

CHIASMOLITHUS GRANDIS

CHIASMOLITHUS OAMARUENSIS

CHIASMOLITHUS SOLITUS

CHIASMOLITHUS TITUS

CHIPHRAGMALITHUS ACANTHODES

CHIPHRAGMALITHUS AUSTRIACUS

CHIPHRAGMALITHUS CALATHUS

CLAUSICOCCUS CRIBELLUM

CLAUSICOCCUS FENESTRATUS

COCCOLITHUS EOPELAGICUS

COCCOLITHUS MIOPELAGICUS

COCCOLITHUS PELAGICUS

COCCOLITHUS TENUISTRIATUS

COCCOLITHUS CRASSIPONS

COCCOLITHUS FUSCUS

CORANNULUS GERMANICUS

CORONOCYCLAS PRIONION

CORONOCYCLUS NITESCENS

CORONOCYCLUS SERRATUS

CRASSIDISCUS BACKMANII

CRASPEDOLITHUS DECLIVUS

CRENALITHUS PRODUCTELLUS

CRIBROCENTRUM RETICULATUM

CRUCIPLACOLITHUS EDWARDSII

CRUCIPLACOLITHUS PRIMUS

CRUCIPLACOLITHUS SUBROTUNDUS

CRUCIPLACOLITHUS TENUIS

CRUCIPLACOLITHUS NOTUS

CRUCIPLACOLITHUS CRIBELLUM

CRUCIPLACOLITHUS CRUCIFORMIS

CRUCIPLACOLITHUS LATIPONS

CRUCIPLACOLITHUS TARQUINIUS

CRUCIPLACOLITHUS VANHECKAE

CYCLICARGOLITHUS ABISECTUS

CYCLICARGOLITHUS FLORIDANUS

CYCLICARGOLITHUS PSEUDOGAMMATON

CYCLICARGOLITHUS LUMINIS

CYCLOCOCCOLITHINA KINGII

DICTYOCOCCITES ANTARCTICUS

DICTYOCOCCITES BISECTUS

DICTYOCOCCITES CALLIDUS

DICTYOCOCCITES HESSLANDII

DICTYOCOCCITES ONUSTUS

DICTYOCOCCITES PRODUCTUS

DICTYOCOCCITES SCRIPPSAE

DICTYOCOCCITES DAVIESII

DISCOASTER ADAMANTEUS

DISCOASTER ASYMMETRICUS

DISCOASTER AULAKOS

DISCOASTER BARBADIENSIS

DISCOASTER BELLUS

DISCOASTER BERGGRENII

DISCOASTER BIFAX

DISCOASTER BINODOSUS

DISCOASTER BLACKSTOCKAE

DISCOASTER BOLLII

DISCOASTER BRAARUDII

DISCOASTER BRAMLETTEI

DISCOASTER BROUWERI

DISCOASTER CALCARIS

DISCOASTER CRUCIFORMIS

DISCOASTER DECORUS

DISCOASTER DEFLANDREI

DISCOASTER DELICATUS

DISCOASTER DIASTYPUS

DISCOASTER DISTINCTUS

DISCOASTER DIVARICATUS

DISCOASTER DRUGGII

DISCOASTER ELEGANS

DISCOASTER EXILIS

DISCOASTER EXTENSUS

DISCOASTER FALCATUS

DISCOASTER FORMOSUS

DISCOASTER GEMMIFER

DISCOASTER GERMANICUS

DISCOASTER HAMATUS

DISCOASTER INTERCALARIS

DISCOASTER KUEPPERI

DISCOASTER KUGLERI

DISCOASTER LENTICULARIS

DISCOASTER LIDZII

DISCOASTER LODOENSIS

DISCOASTER LOEBLICHII

DISCOASTER MEDIOSUS

DISCOASTER MIRUS

DISCOASTER MISCONCEPTUS

DISCOASTER MOHLERI

DISCOASTER MOOREI

DISCOASTER MULTIRADIATUS

DISCOASTER NEOHAMATUS

DISCOASTER NEORECTUS

DISCOASTER NEPHADOS

DISCOASTER NOBILIS

DISCOASTER NODIFER

DISCOASTER NONARADIATUS

DISCOASTER PANSUS

DISCOASTER PENTARADIATUS

DISCOASTER PREPENTARADIATUS

DISCOASTER PSEUDOVARIABILIS

DISCOASTER QUADRAMUS

DISCOASTER QUINQUERAMUS

DISCOASTER ROBUSTUS

DISCOASTER SAIPANENSIS

DISCOASTER SALISBURGENSIS

DISCOASTER SANMIGUELENSIS

DISCOASTER SAUNDERSI

DISCOASTER SEPTEMRADIATUS

DISCOASTER SIGNUS

DISCOASTER STELLULUS

DISCOASTER STRICTUS

DISCOASTER SUBLODOENSIS

DISCOASTER SUBSURCULUS

DISCOASTER SURCULUS

DISCOASTER TAMALIS

DISCOASTER TANII

DISCOASTER TRIDENUS

DISCOASTER TRINIDADENSIS

DISCOASTER TRIRADIATUS

DISCOASTER TRISTELLIFER

DISCOASTER VARIABILIS

DISCOASTER WEMMELENSIS

DISCOASTER CHALLENGERI

DISCOASTEROIDES MEGASTYPUS

DISCOSPHAERA TUBIFERA

ELLIPSOLITHUS DISTICHUS

ELLIPSOLITHUS LAJOLLAENSIS

ELLIPSOLITHUS MACELLUS

EMILIANIA ANNULA

EMILIANIA HUXLEYI

ERICSONIA CAVA

ERICSONIA FORMOSA

ERICSONIA OBRUTA

ERICSONIA OVALIS

ERICSONIA ROBUSTA

ERICSONIA SUBDISTICHA

ERICSONIA SUBPERTUSA

FASCICULITHUS BILLII

FASCICULITHUS INVOLUTUS

FASCICULITHUS MITREUS

FASCICULITHUS PILEATUS

FASCICULITHUS SCHAUBII

FASCICULITHUS TYMPANIFORMIS

FASCICULITHUS ULII

GEMINILITHELLA ROTULA

GEPHYROCAPSA APERTA

GEPHYROCAPSA CARIBBEANICA

GEPHYROCAPSA ERICSONIA

GEPHYROCAPSA OCEANICA

GEPHYROCAPSA PROTOHUXLEYI

GEPHYROCAPSA SINUOSA

HAYASTER PERPLEXUS

HAYELLA SITULIFORMIS

HELICOSPHAERA AMPLIAPERTA

HELICOSPHAERA BRAMLETTEI

HELICOSPHAERA CARTERI

HELICOSPHAERA COMPACTA

HELICOSPHAERA DINESENII

HELICOSPHAERA EUPHRATIS

HELICOSPHAERA GRANULATA

HELICOSPHAERA HEEZENI

HELICOSPHAERA INTERMEDIA

HELICOSPHAERA INVERSA

HELICOSPHAERA KAMPTNERI

HELICOSPHAERA LOPHOTA

HELICOSPHAERA NEOGRANULATA

HELICOSPHAERA OBLIQUA

HELICOSPHAERA RECTA

HELICOSPHAERA RETICULATA

HELICOSPHAERA SELLII

HELICOSPHAERA SEMINULUM

HELICOSPHAERA OMANICA

HELICOSPHAERA PERCH-NIELSENIAE

HELICOSPHAERA WILCOXONII

HELIOLITHUS CANTABRIAE

HELIOLITHUS CONICUS

HELIOLITHUS KLEINPELLII

HELIOLITHUS RIEDELII

HOLODISCOLITHUS MACROPORUS

HORNIBROOKINA AUSTRALIS

HORNIBROOKINA TEURIENSIS

ILSELITHINA FUSA

ISTHMOLITHUS RECURVUS

LANTERNITHUS MINUTUS

LITHOSTROMATION PERDURUM

LOPHODOLITHUS ACUTUS

LOPHODOLITHUS NASCENS

LOPHODOLITHUS MOCHLOPORUS

MARKALIUS INVERSUS

MICRANTHOLITHUS FLOS

MICRANTHOLITHUS ALTUS

MINYLITHA CONVALLIS

NANNOTETRINA ALATA

NANNOTETRINA CRISTATA

NANNOTETRINA FULGENS

NANNOTETRINA QUADRATA

NEOCHIASTOZYGUS CEARAE

NEOCHIASTOZYGUS CONCINNUS

NEOCHIASTOZYGUS CHIASTUS

NEOCHIASTOZYGUS DISTENTUS

NEOCHIASTOZYGUS JUNCTUS

NEOCHIASTOZYGUS MODESTUS

NEOCHIASTOZYGUS PERFECTUS

NEOCOCCOLITHES DUBIUS

NEOCOCCOLITHES PROTENUS

OOLITHOTUS FRAGILIS

ORTHORHABDUS SERRATUS

ORTHOZYGUS AUREUS

PEDINOCYCLUS LARVALIS

PERITRACHELINA JOIDESA

PLACOZYGUS SIGMOIDES

PONTOSPHAERA ANISOTREMA

PONTOSPHAERA DISCOPORA

PONTOSPHAERA DISTINCTA

PONTOSPHAERA JAPONICA

PONTOSPHAERA JONESII

PONTOSPHAERA MULTIPORA

PONTOSPHAERA OVATA

PONTOSPHAERA PECTINATA

PONTOSPHAERA PACIFICA

PONTOSPHAERA PLANA

PONTOSPHAERA RIMOSA

PONTOSPHAERA SCUTELLUM

PONTOSPHAERA SEGMENTA

PONTOSPHAERA FORMOSA

PONTOSPHAERA SCISSURA

PRINSIUS BISULCUS

PRINSIUS DIMORPHOSUS

PRINSIUS MARTINII

PSEUDOEMILIANIA LACUNOSA

PSEUDOTRIQUETRORHABDULUS INVERSUS

PYROCYCLUS INVERSUS

PYROCYCLUS ORANGENSIS

RETICULOFENESTRA DICTYODA

RETICULOFENESTRA HAMPDENENSIS

RETICULOFENESTRA HAQII

RETICULOFENESTRA HILLAE

RETICULOFENESTRA INSIGNATA

RETICULOFENESTRA LOCKERI

RETICULOFENESTRA MINUTA

RETICULOFENESTRA MINUTULUS

RETICULOFENESTRA OAMARUENSIS

RETICULOFENESTRA PSEUDOUMBILICA

RETICULOFENESTRA SAMODUROVII

RETICULOFENESTRA UMBILICA

RETICULOFENESTRA AMPLA

RETICULOFENESTRA ASANOI

RETICULOFENESTRA GELIDA

RETICULOFENESTRA LONGISTYLIS

RHABDOLITHUS STYLIFER

RHABDOLITHUS TENUIS

RHADBOSPHAERA CLAVIGERA

RHADBOSPHAERA INFLATA

RHADBOSPHAERA PROCERA

RHADBOSPHAERA VITREA

RHOMBOASTER CUSPIS

SCAPHOLITHUS FOSSILIS

SCAPHOLITHUS RHOMBIFORMIS

SCYPHOSPHAERA AMPHORA

SCYPHOSPHAERA APSTEINII

SCYPHOSPHAERA CAMPANULA

SCYPHOSPHAERA CANTHARELLA

SCYPHOSPHAERA CONICA

SCYPHOSPHAERA CYLINDRICA

SCYPHOSPHAERA EXPANSA

SCYPHOSPHAERA GLADSTONENSIS

SCYPHOSPHAERA GLOBULATA

SCYPHOSPHAERA INTERMEDIA

SCYPHOSPHAERA MAGNA

SCYPHOSPHAERA PROCERA

SCYPHOSPHAERA PULCHERRIMA

SCYPHOSPHAERA RECTA

SCYPHOSPHAERA RECURVATA

SEMIHOLOLITHUS KERABYI

SPHENOLITHUS ABIES

SPHENOLITHUS ANARRHOPUS

SPHENOLITHUS BELEMNOS

SPHENOLITHUS CIPEROENSIS

SPHENOLITHUS CONICUS

SPHENOLITHUS DELPHIX

SPHENOLITHUS DISSIMILIS

SPHENOLITHUS DISTENTUS

SPHENOLITHUS EDITUS

SPHENOLITHUS FURCATOLITHOIDES

SPHENOLITHUS HETEROMORPHUS

SPHENOLITHUS INTERCALARIS

SPHENOLITHUS MORIFORMIS

SPHENOLITHUS NEOABIES

SPHENOLITHUS OBTUSUS

SPHENOLITHUS ORPHANKNOLLI

SPHENOLITHUS PREDISTENTUS

SPHENOLITHUS PRIMUS

SPHENOLITHUS PSEUDORADIANS

SPHENOLITHUS RADIANS

SPHENOLITHUS SPINIGER

SPHENOLITHUS CAPRICORNUTUS

STRIATOCOCCOLITHIS PACIFICANUS

SYRACOSPHAERA HISTRICA

SYRACOSPHAERA PULCHRA

THORACOSPHAERA ALBATROSSIANA

THORACOSPHAERA DEFLANDREI

THORACOSPHAERA HEIMII

THORACOSPHAERA OPERCULATA

THORACOSPHAERA SAXEA

TOWEIUS CALLOSUS

TOWEIUS CRATICULUS

TOWEIUS EMINENS

TOWEIUS MAGNICRASSUS

TOWEIUS GAMMATION

TOWEIUS TOVAE

TOWEIUS OCCULTATUS

TOWEIUS PERTUSUS

TOWEIUS CRASSUS

TRANSVERSOPONTIS FIMBRIATUS

TRANSVERSOPONTIS OBLIQUIPONS

TRANSVERSOPONTIS PULCHER

TRIBRACHIATUS CONTORTUS

TRIBRACHIATUS NUNNII

TRIBRACHIATUS ORTHOSTYLUS

TRIQUETRORHABDULUS CARINATUS

TRIQUETRORHABDULUS MILOWII

TRIQUETRORHABDULUS RUGOSUS

UMBELLOSPHAERA IRREGULARIS

UMBILICOSPHAERA JAFARII

UMBILICOSPHAERA MIRABILIS

UMBILICOSPHAERA SIBOGAE

ZYGODISCUS ADAMAS

ZYGODISCUS PLACTOPONS

ZYGODISCUS SPIRALIS

ZYGODISCUS HERLYNII

ZYGRHABLITHUS BIJUGATUS

Radiolarians

ACROCUBUS OCTOPYLUS

ACROBOTRYS TRITUBUS

ACROSPHAERA MURRAYANA

ACROSPHAERA SPINOSA

ACROSPHAERA AUSTRALIS

ACROSPHAERA LABRATA

ACROSPHAERA MERCURIUS

ACTINOMMA BEROES

ACTINOMMA GOLOWNINI

ACTINOMMA HOLTEDAHLI

ACTINOMMA MEDIANUM

ACTINOMMA MEDUSA

ACTINOMMA DELICATULUM

ACTINOMMA KERGUELENSIS

ACTINOMMA LEPTODERMUM

ACTINOMMA POPOFSKII

ACTINOMMA MAGNIFENESTRA

AMPHYMENIUM CHALLENGERAE

AMPHYMENIUM SPLENDIARMATUM

AMPHICRASPEDUM PROLIXUM

AMPHISTYLUS ANGELINUS

AMPHIRHOPALUM YPSILON

AMPHIRHOPALUM VIRCHOWII

AMPHISPYRIS ROGGENTHENI

ANDROSPYRIS ANTHROPISCUS

ANOMALACANTHA DENTATA

ANTARCTISSA CYLINDRICA

ANTARCTISSA DENTICULATA

ANTARCTISSA LONGA

ANTARCTISSA ROBUSTA

ANTARCTISSA STRELKOVI

ANTARCTISSA DEFLANDREI

ANTHOCYRTELLA CALLOPISMA

ANTHOCYRTIDIUM EURYCLATHRUM

ANTHOCYRTIDIUM JENGHISI

ANTHOCYRTIDIUM PLIOCENICA

ANTHOCYRTIDIUM ANGULARE

ANTHOCYRTIDIUM EHRENBERGII

ANTHOCYRTIDIUM OPHIRENSE

ANTHOCYRTIDIUM MICHELINAE

ANTHOCYRTIDIUM NOSICAAE

ARTOPHORMIS BARBADENSIS

ARTOPHORMIS GRACILIS

ARTOSTROBUS ANNULATUS

AXOPRUNUM ANGELINUM

AXOPRUNUM PIERINAE

BATHROPYRAMIS WOODRINGI

BEKOMIFORMA MYNX

BOTRYOPYLE DICTYOCEPHALUS

BOTRYOPYLE DIONISI

BOTRYOPERA TRILOBA

BOTRYOSTROBUS AQUILONARIS

BOTRYOSTROBUS AURITUS-AUSTRALIS

BOTRYOSTROBUS MIRALESTENSIS

BOTRYOSTROBUS TUMIDULUS

BOTRYOSTROBUS BRAMLETTEI

BOTRYOSTROBUS KERGUELENSIS

BOTRYOSTROBUS REDNOSUS

BUCCINOSPHAERA INVAGINATA

BURYELLA CLINATA

CALOCYCLETTA ACANTHOCEPHALA

CALOCYCLETTA CAEPA

CALOCYCLETTA COSTATA

CALOCYCLETTA ROBUSTA

CALOCYCLETTA SERRATA

CALOCYCLETTA VIRGINIS

CALOCYCLAS ASPERUM

CALOCYCLAS DISPARIDENS

CALOCYCLAS HISPIDA

CALOCYCLAS TURRIS

CALOCYCLAS BANDYCA

CALOCYCLOMA AMPULLA

CARPOCANOPSIS BRAMLETTEI

CARPOCANOPSIS CINGULATA

CARPOCANOPSIS FAVOSA

CARPOCANOPSIS CRISTATA

CENOSPHAERA CRISTATA

CENOSPHAERA OCEANICA

CENTROBOTRYS GRAVIDA

CENTROBOTRYS PETRUSHEVSKAYAE

CENTROBOTRYS THERMOPHILA

CERATOCYRTIS AMPLUS

CERATOCYRTIS MASHAE

CERATOCYRTIS HISTRICOSA

CERATOCYRTIS STIGI

CERATOSPYRIS PENTAGONA

CIRCODISCUS ELLIPTICUS

CLATHROCANIUM SPHAEROCEPHALUM

CLATHROCYCLAS BICORNIS

CLATHROCYCLAS UNIVERSA

COLLOSPHAERA ORTHOCONUS

COLLOSPHAERA TUBEROSA

CORYTHOSPYRIS FISCELLA

CORYTHOMELISSA HORRIDA

CORNUTELLA PROFUNDA

CRYPTOCARPIUM AZYX

CRYPTOCARPIUM ORNATUM

CYCLADOPHORA GOLLI

CYCLADOPHORA DAVISIANA

CYCLADOPHORA HUMERUS

CYCLADOPHORA SPONGOTHORAX

CYCLADOPHORA PLIOCENICA

CYCLADOPHORA BICORNIS

CYCLADOPHORA ANTIQUA

CYCLADOPHORA CABRILLOENSIS

CYCLADOPHORA CONICA

CYMAETRON SINOLAMPAS

CYRTOCAPSELLA CORNUTA

CYRTOCAPSELLA ELDHOLMI

CYRTOCAPSELLA ELONGATA

CYRTOCAPSELLA JAPONICA

CYRTOCAPSELLA TETRAPERA

CYRTOCAPSELLA ROBUSTA

CYRTOCAPSELLA LONGITHORAX

CYRTOLAGENA LAGUNCULA

DENDROSPYRIS BURSA

DENDROSPYRIS DAMAECORNIS

DENDROSPYRIS MEGALOCEPHALIS

DENDROSPYRIS STABILIS

DENDROSPYRIS RHODOSPYROIDES

DESMOSPYRIS SPONGIOSA

DIARTUS HUGHESI

DIARTUS PETTERSSONI

DICTYOPRORA AMPHORA

DICTYOPRORA ARMADILLO

DICTYOPRORA MONGOLFIERI

DICTYOPRORA OVATA

DICTYOPRORA PIRUM

DICTYOPRORA URCEOLUS

DICTYOPRORA PHYSOTHORAX

DICTYOPHIMUS CALLOSUS

DICTYOPHIMUS INFABRICATUS

DICTYOPHIMUS ARCHIPILIUM

DICTYOPHIMUS CRATICULA

DICTYOPHIMUS CRISIAE

DICTYOPHIMUS HIRUNDO

DICTYOPHIMUS POCILLUM

DICTYOPHIMUS SPLENDENS

DICTYOCORYNE ONTONGENSIS

DIDYMOCYRTIS ANTEPENULTIMA

DIDYMOCYRTIS AVITA

DIDYMOCYRTIS DIDYMUS

DIDYMOCYRTIS LATICONUS

DIDYMOCYRTIS MAMMIFERA

DIDYMOCYRTIS PENULTIMA

DIDYMOCYRTIS PRISMATICA

DIDYMOCYRTIS TETRATHALAMUS

DIDYMOCYRTIS TUBARIA

DIDYMOCYRTIS VIOLINA

DIDYMOCYRTIS BASSANII

DORCADOSPYRIS ALATA

DORCADOSPYRIS ARGISCA

DORCADOSPYRIS ATEUCHUS

DORCADOSPYRIS CIRCULUS

DORCADOSPYRIS CONFLUENS

DORCADOSPYRIS DENTATA

DORCADOSPYRIS FORCIPATA

DORCADOSPYRIS PAPILIO

DORCADOSPYRIS PENTAGONA

DORCADOSPYRIS PLATYACANTHA

DORCADOSPYRIS QUADRIPES

DORCADOSPYRIS RIEDILI

DORCADOSPYRIS SIMPLEX

DORCADOSPYRIS SPINOSA

DORCADOSPYRIS TRICEROS

DRUPPATRACTUS HASTATUS

EUCECRYPHALUS CRASPEDOTA

EUCHITONIA FURCATA

EUCYRTIDIUM ACUMINATUM

EUCYRTIDIUM ANOMALUM

EUCYRTIDIUM CALVERTENSE

EUCYRTIDIUM CIENKOWSKII

EUCYRTIDIUM DIAPHANES

EUCYRTIDIUM HEXAGONATUM

EUCYRTIDIUM INFLATUM

EUCYRTIDIUM MATUYAMAI

EUCYRTIDIUM PSEUDOINFLATUM

EUCYRTIDIUM BICONICUM

EUCYRTIDIUM ANTIQUUM

EUCYRTIDIUM CHENI

EUCYRTIDIUM INFUNDIBULUM

EUCYRTIDIUM MARIAE

EUCYRTIDIUM TEUSCHERI

EUSYRINGIUM FISTULIGERUM

EUSYRINGIUM LAGENA

GONDWANARIA DEFLANDREI

GONDWANARIA DOGELI

GONDWANARIA HISTER

GONDWANARIA JAPONICA

HAECKELIELLA INCONSTANS

HALIOMMETTA MIOCENICA

HELODISCUS ASTERISCUS

HELOTHOLUS PRAEVEMA

HISTIASTRUM MARTINIANUM

LAMPROMITRA CORONATA

LAMPROCYCLAS AEGLES

LAMPROCYCLAS HANNAI

LAMPROCYCLAS JUNONIS

LAMPROCYCLAS MARGATENSIS

LAMPROCYCLAS MARITALIS

LAMPROCYRTIS DANIELLAE

LAMPROCYRTIS HETEROPOROS

LAMPROCYRTIS NEOHETEROPOROS

LAMPROCYRTIS NIGRINIAE

LARCOSPIRA QUADRANGULA

LARCOPYLE BUTSCHLII

LIPMANELLA DICTYOCERAS

LIRIOSPYRIS ELEVATA

LIRIOSPYRIS GENICULOSA

LIRIOSPYRIS MUTUARIA

LIRIOSPYRIS OVALIS

LIRIOSPYRIS PARKERAE

LIRIOSPYRIS STAUROPORA

LITHELIUS MINOR

LITHELIUS NAUTILOIDES

LITHATRACTUS TIMMSI

LITHOCIRCUS TOXARIA

LITHOMITRELLA MINUTA

LITHOCYCLIA ANGUSTA

LITHOCYCLIA ARISTOTELIS

LITHOCYCLIA CRUX

LITHOCYCLIA OCELLUS

LITHOCARPIUM FRAGILIS

LITHOMELISSA CHALLENGERAE

LITHOMELISSA EHRENBERGII

LITHOMELISSA ROBUSTA

LITHOMELISSA SPHAEROCEPHALIS

LITHOMELISSA TRICORNIS

LITHOMELISSA CHENI

LITHOMELISSA DUPLIPHYSA

LITHOPERA BACCA

LITHOPERA BAUERI

LITHOPERA NEOTERA

LITHOPERA RENZAE

LITHOPERA THORNBURGI

LITHOCHYTRIS VESPERTILIO

LOPHOCYRTIS BIAURITA

LOPHOCYRTIS JACCHIA

LOPHOCYRTIS BRACHYTORAX

LOPHOCYRTIS LEPTETRUM

LOPHOCYRTIS LONGIVENTER

LOPHOCYRTIS MILOWI

LOPHOCYRTIS NEATUM

LOPHOCYRTIS PEGETRUM

LOPHOCYRTIS TANYTHORAX

LYCHNOCANOMA AMPHITRITE

LYCHNOCANOMA BELLUM

LYCHNOCANOMA ELONGATA

LYCHNOCANOMA GRANDE

LYCHNOCANOMA TRIFOLIUM

LYCHNOCANOMA CONICA

MITROCALPIS ARANEAFERA

OTOSPHAERA AURICULATA

PENTAPYLONIUM IMPLICATUM

PERIPHAENA DECORA

PERIPHAENA HELIASTERISCUS

PERIPHAENA TRIPYRAMIS

PERIPHAENA CIRCUMTEXTA

PHORMOCYRTIS EMBOLUM

PHORMOCYRTIS STRIATA

PHORMOSTICHOARTUS CORBULA

PHORMOSTICHOARTUS DOLIOLUM

PHORMOSTICHOARTUS MULTISERIATUS

PHORMOSTICHOARTUS FISTULA

PHORMOSTICHOARTUS FURCASPICULATA

PHORMOSTICHOARTUS MARYLANDICUS

PHORMOSTICHOARTUS PLATYCEPHALA

PHORMOSTICHOARTUS PITOMORPHUS

PHORMOSTICHOARTUS CRUSTULA

PHORTICIUM CLEVEI

PHORTICIUM PYLONIUM

PODOCYRTIS AMPLA

PODOCYRTIS CHALARA

PODOCYRTIS DIAMESA

PODOCYRTIS DORUS

PODOCYRTIS FASCIOLATA

PODOCYRTIS GOETHEANA

PODOCYRTIS MITRA

PODOCYRTIS PAPALIS

PODOCYRTIS SINUOSA

PODOCYRTIS TRACHODES

PRUNOPYLE ANTARCTICA

PRUNOPYLE FRAKESI

PRUNOPYLE HAYESI

PRUNOPYLE TETRAPILA

PRUNOPYLE TYTAN

PRUNOPYLE MONIKAE

PRUNOPYLE POLYACANTHA

PRUNOPYLE TRYPOPYRENA

PERICHLAMYDIUM PRAETEXTUM

PSEUDOCUBUS VEMA

PSEUDODICTYOPHIMUS GRACILIPES

PSEUDODICTYOPHIMUS GALEATUS

PTEROCORYS CAMPANULA

PTEROCORYS CLAUSUS

PTEROCORYS HERTWIGII

PTEROCORYS ZANCLEUS

PTEROCANIUM CHARYBDEUM

PTEROCANIUM KOROTNEVI

PTEROCANIUM PRAETEXTUM

PTEROCANIUM PRISMATIUM

PTEROCANIUM AUDAX

RHABDOLITHIS PIPA

RHIZOSPHAERA ANTARCTICA

RHOPALOCANIUM ORNATUM

SACCOSPYRIS ANTARCTICA

SACCOSPYRIS CONITHORAX

SACCOSPYRIS PREANTARCTICA

SATURNALIS CIRCULARIS

SETHOCHYTRIS BABYLONIS

SETHOCHYTRIS TRICONISCUS

SIPHOCAMPE ACEPHALA

SIPHOCAMPE ARACHNEA

SIPHOCAMPE LINEATA

SIPHOCAMPE NODOSARIA

SIPHOCAMPE IMBRICATA

SIPHOCAMPE PACHYDERMA

SIPHONOSPHAERA VESUVIUS

SIPHONOSPHAERA MAGNISPHAERA

SIPHOSTICHARTUS CORONA

SOLENOSPHAERA OMNITUBUS

SPHAEROPYLE LANGII

SPHAEROPYLE ROBUSTA

SPIROCYRTIS GYROSCALARIS

SPIROCYRTIS SCALARIS

SPIROCYRTIS SUBSCALARIS

SPIROCYRTIS SUBTILIS

SPONGODISCUS AMBUS

SPONGODISCUS CRATICULATUS

SPONGODISCUS OSCULOSUS

SPONGODISCUS KLINGI

SPONGOMELISSA DILLI

SPONGASTER BERMINGHAMI

SPONGASTER PENTAS

SPONGASTER TETRAS

SPONGOCORE PUELLA

SPONGOTROCHUS GLACIALIS

SPONGOTROCHUS VENUSTUM

SPONGURUS PYLOMATICUS

STAUROXIPHOS COMMUNIS

STICHOCORYS ARMATA

STICHOCORYS DELMONTENSIS

STICHOCORYS PEREGRINA

STICHOCORYS JOHNSONI

STICHOCORYS WOLFII

STYLATRACTUS CORONATUS

STYLATRACTUS NEPTUNUS

STYLATRACTUS SANTANNAE

STYLATRACTUS UNIVERSUS

STYLODICTYA TARGAEFORMIS

STYLODICTYA VALIDISPINA

STYLODICTYA HASTATA

STYLODICTYA OCELLATA

STYLOSPHAERA ANGELINA

STYLOSPHAERA HISPIDA

STYLOSPHAERA RADIOSA

STYLACONTARIUM ACQUILONIUM

STYLACONTARIUM BISPICULUM

THEOCOTYLISSA FICUS

THEOCYRTIS ANNOSA

THEOCYRTIS DIABLOENSIS

THEOCYRTIS TUBEROSA

THEOCYRTIS ROBUSTA

THEOCORYS REDONDENSIS

THEOCORYS SPONGOCONUS

THEOCOTYLE CONICA

THEOCOTYLE CRYPTOCEPHALA

THEOCORYTHIUM TRACHELIUM

THEOCORYTHIUM VETULUM

THOLOSPYRIS RHOMBUS

THYRSOCYRTIS BROMIA

THYRSOCYRTIS CLAUSA

THYRSOCYRTIS RHIZODON

THYRSOCYRTIS TENSA

THYRSOCYRTIS TETRACANTHA

THYRSOCYRTIS TRICANTHA

TRICERASPYRIS ANTARCTICA

TRICERASPYRIS CORONATA

TRICOLOCAPSA PAPILLOSA

TRIPILIDIUM CLAVIPES

TRISTYLOSPYRIS TRICEROS

VELICUCULLUS ALTUS

ZYGOCIRCUS BUTSCHLII

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Table 4.2: Average species longevities for 1418 Cenozoic marine plankton species contained in Neptune. Longevities and standard deviations are in million years.

Plankton Group	Number of species	Extant species (in %)	Mean Longevity of Extant Species	Standard Deviation	Mean Longevity of Extinct Species	Standard Deviation
Diatoms	389	26.5	14.4	13.7	10.2	10.3
Foraminifera	281	13.9	13.9	9.2	11.1	7.8
Radiolarians	383	29.8	13.4	9.2	12.9	7.8
Nannofossils	365	8.5	17.8	19.8	13.1	10.6
All groups	1418	20.2	14.3	12.4	11.9	9.4

5. A MORE REALISTIC ASSESSMENT: NEPTUNE AS A TOOL IN SUPPORT OF DATA IMPROVEMENT

Eight years after the first planning meetings at the ETH, I have finally achieved a balance between the initial expectations/dreams and the realization of what Neptune really is and its limitations. I have described the scopes, accomplishments, and drawbacks of this project in the previous chapters and now it is time to answer the question: what next? What is the future of Neptune? In the previous chapters, I tried to convey that Neptune is not a sufficient data set to base several (biostratigraphic) publications on, but mainly a tool to make collecting new data more focused and more efficient. And this is the legacy of this project to the research community.

The chronology of the Neogene sediments of some 100 DSDP holes was published as an Ocean Drilling Program Technical Note (Lazarus et al. 1995a) and is currently available through the WWW site of the NOAA- National Geographic Data Center (NGDC) (http://www.ngdc.noaa.gov/mgg/geology/ lazarus.html). The age models for these sites were based on Berggren et al. (1985). The updated models (to Berggren et al. 1995a, b) extended to the whole Cenozoic, as well as additional ODP holes, are published here in graphic form and as text files in the Appendix A. At the same time, a link to them will be deposited at the widely used archival site of the NGDC.

At present, the database is accessible through the author, at the ETH Zürich, and at the Natural History Museum in Basel, Switzerland. It is still unclear how the whole database with its search options will be made accessible to the community. Among the options discussed are a CD-ROM (which would, however, require the relatively expensive 4th Dimension® program to run) and a server at the Micropaleontological Reference Center (MRC) in Basel. The optimal solution for this second option would be an interactive WWW site that could be remotely accessible world-wide. Recently, the program NetLink/4D™ has been made available on the market. This program apparently makes databases searchable through the Internet (Lazarus, personal commun., 1998). However, I have not seen nor tried the program yet and do not know how user-friendly it is. However, I suspect that the large size of Neptune would make even the simplest searches very slow and time consuming through the Internet. A more modest, but immediately feasible alternative, would be to have one person at the MRC in charge of the use of Neptune. Requests for searches could be e-mailed to

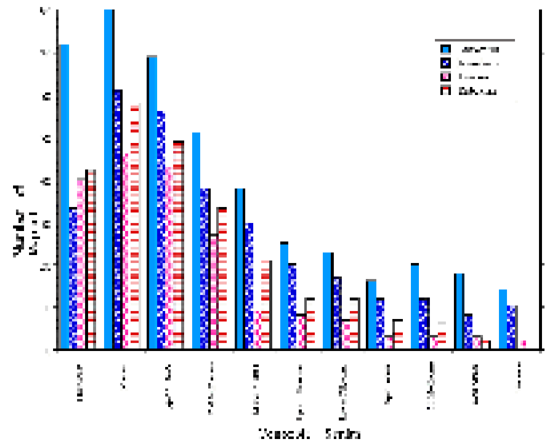

Figure 5.1.

the MRC and the results (in print or as computer files) mailed to the requester. Among the various possibilities, searches for presence/absence and location or number of occurrence of single or multiple taxa would require only a few minutes. This search would also provide information on the taxonomic validity of the taxa and the lists of synonyms. A more extensive search would distinguish between stratigraphically and thematically well and poorly covered intervals. The identification of significant gaps in the biostratigraphic record (e.g., Paleogene biochronology of siliceous microfossils and revisitation of suitable Paleogene sediments for detailed biostratigraphy) (Fig. 5.1) would be the basis for the logical, objective planning of future research. It could spur clearly aimed detailed micropaleontological studies, instead of random studies that generate a lot of repetition and overlap (e.g., Moore 1972).

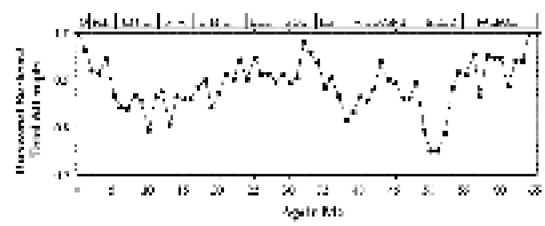

Figure 5.2.

Considering that Neptune contains selected, good quality holes, it is still notable how small the number of useful holes (well cored, well analyzed and well documented with modern biochronological methods and modern taxonomy) has remained. An enormous amount of re-analysis of older sections could be quite profitable. Fig. 5.1 indicates that a lot can still be done on sections older than the late Miocene, especially on siliceous plankton groups. New coring needed to fill the existing coverage gaps could be identified with three dimensional (latitude vs. longitude vs. time) maps of the oceans produced with Neptune. Another way to identify stratigraphic coverage gaps is given by the rate of success in recovering drilled sections (Fig. 5.2). This curve indicates that the early and middle Eocene, as well as large parts of the Miocene, have been less well recovered than e.g., the Plio-Pleistocene or the Eocene/Oligocene boundary. This might be one of the causes of the poor Eocene biochronology for certain plankton groups. Recent ODP Legs (e.g., 171B) have recovered long Eocene sections: these should be studied in detail to cover this recovery gap.

These are just a couple of examples of the utility of Neptune in designing goal-oriented studies aimed to obtain a complete picture of the oceans' history during the Cenozoic, necessary for a better understanding of the complex processes that control the Earth systems. This approach would, however, require the change in nature of the DSDP and ODP projects from 'leg oriented' to 'overview oriented', which in my opinion is a more effective investment of resources. This step would certainly represent the most valuable contribution of Neptune to the geological community.

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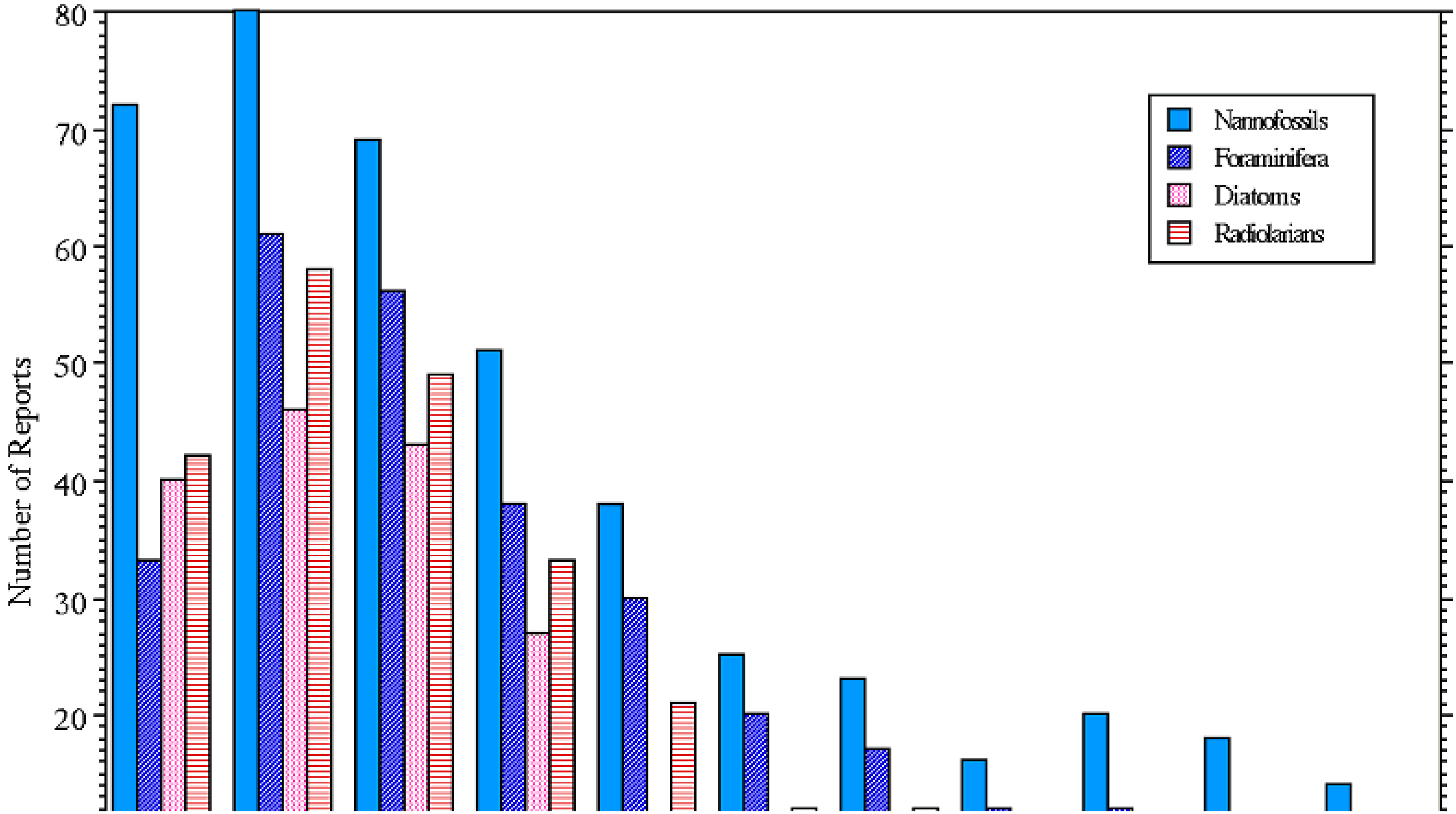
Figure 5.1. Number of reports on Cenozoic biostratigraphy in Neptune by plankton group. Reports that cover the whole or only a part of the series are included. No selection based on the detail or the quality of the reports was made. Note the overall better availability of nannofossil biostratigraphy in comparison with the other plankton groups. The anomalously low number of reports for foraminifera, diatoms and radiolarians may be in part due to the lower number of Pleistocene sections available in Neptune (Fig. 3.2). However, it likely represents also an artifact of the analysis caused by the scarcity of biostratigraphic events of these three groups calibrated for the Pleistocene.



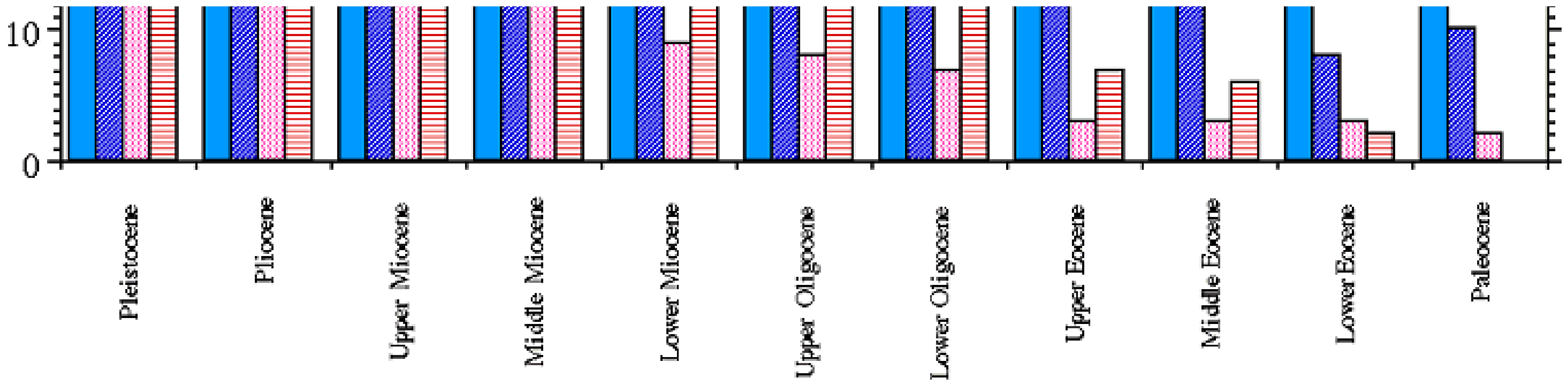
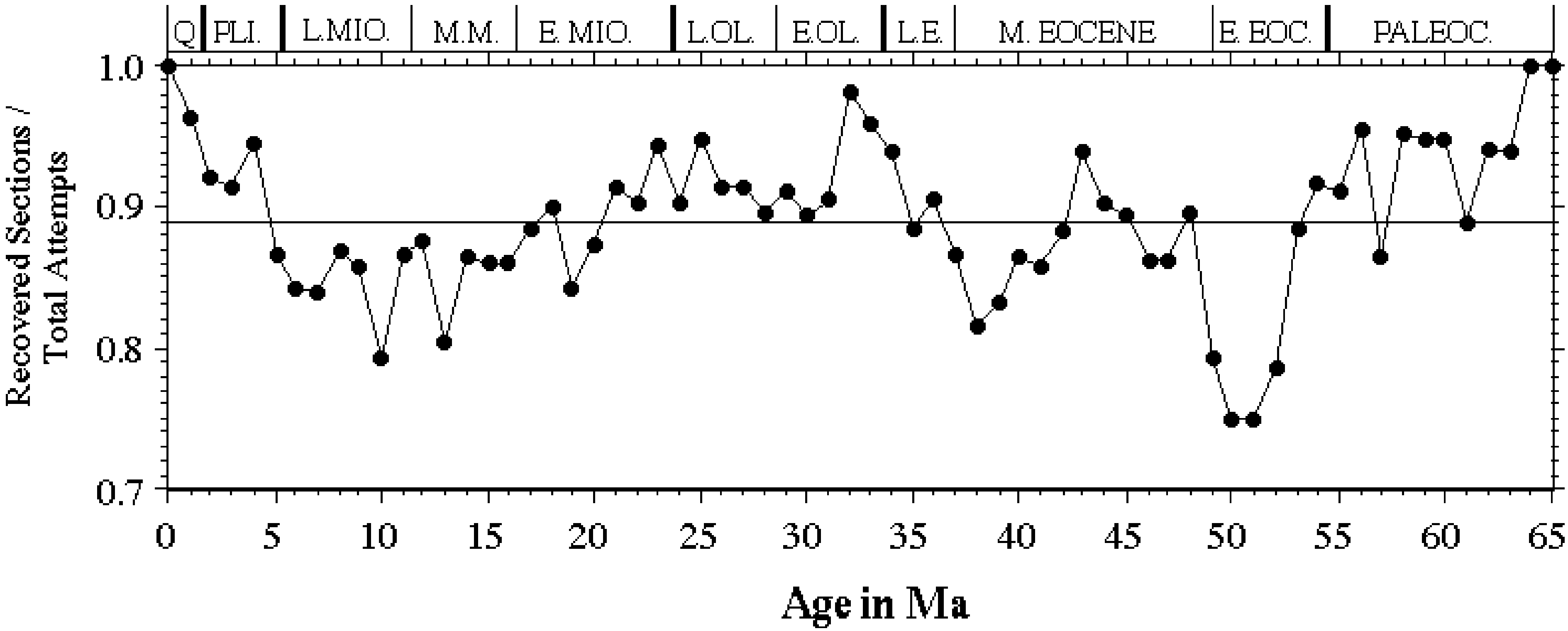

10
0
Pleistocene
Pliocene
Upper Miocene
Middle Miocene
Lower Miocene
Upper Oligocene
Lower Oligocene
Upper Eocene
Middle Eocene
Lower Eocene
Paleocene

Figure 5.2. Ratio between the number of recovered sections and the total number of times recovery was attempted at 1-m.y. resolution. Sections that recovered sediments containing at least 5% of the one m.y. interval are included. The horizontal line represents the average recovery ratio for all the sections analysed (0.89). The data are limited to the sections included in Neptune and for which we have age control. This means that in some instances, deeper sediments were also recovered, but no biostratigraphic study done on them to provide us with an age model. This graph does not reflect the 'true' availability of sediments but only the time interval that was recovered in each section - it includes also intervals that are represented by hiati (see Fig. 3.3), which are e.g., quite frequent in Miocene sediments. Note that Paleocene sediments are overall quite well recovered even though scarce (Fig. 3.2), an improvement from the early study by Moore (1972) which identified this interval as the least well represented in the Cenozoic sediments recovered by the early DSDP legs.



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Appendix A. Age/Depth Plots and Age Model files

One or two plots are given for each hole analysed. Where two plots are available, they cover the Neogene (N in the file name) and the Paleogene (P in the file name) sections, respectively.

All plots were created with the ADP program described in Lazarus (1992), which gives additional details on plotting procedures, conventions, and usage. The x-axis represents the age in million years. There is also a reproduction at the bottom of the plot of the Berggren et al. (1995b) magnetostratigraphic scale. On the left y-axis is the depth in meters below sea floor, on the right a representation of the cores (numbered boxes, with heights proportional to actual recovery) and (short lines on right side of boxes) 1.5 m section breaks. The symbols corresponding to the microfossil groups are on the top of the plot: D=diatoms, F=foraminifera, M=magnetostratigraphy, N=nannofossils, R=radiolarians. Each event is labelled only with a short plotcode to reduce visual clutter in the figure. Translations for the plotcodes are given in Table 2.2. Error bars for the depth level of each event are represented as vertical lines crossing the symbols, but sometimes the error bars are not visible because they are smaller than the symbol itself.

ASCII files of the age models are also given. Only one file is given for each hole. The files consist of two columns. The first row shows the hole name (e.g. 62A) on the left and the date the age model was created on the right (in the format YYMMDD, e.g., 19950725). The second row gives the headings of the data columns, age to the left and depth to the right. The third row gives the number of points in the age model. The coordinates of the age model points follow from the fourth row. The files are exactly in the format generated by Lazarus's (1994) ADP program. This format is required by the ADP program and can, therefore, be used directly to create an age/depth plot with this software. Alternatively, the age and depth coordinates can be used to construct a simple xy line graph. The files can be opened with any word processing or spreadsheet program.

To download full-size diagrams, open the following directory and choose the file (named by hole number). File naming convention is 62A_PICT.GIF (62A = hole number).
DIRECTORY: adps_app

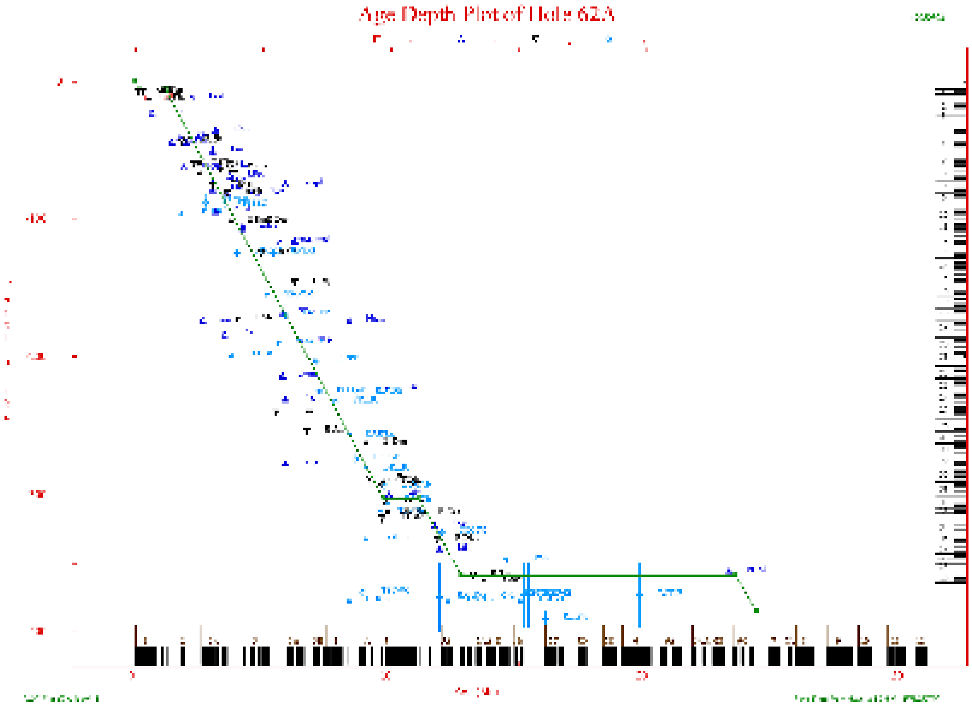
Next Section...

Holes 62A-192

To download full-size diagrams, open the following directory and choose the file (named by hole number). File naming convention is 62A_PICT.GIF (62A = hole number).
DIRECTORY: adps_app

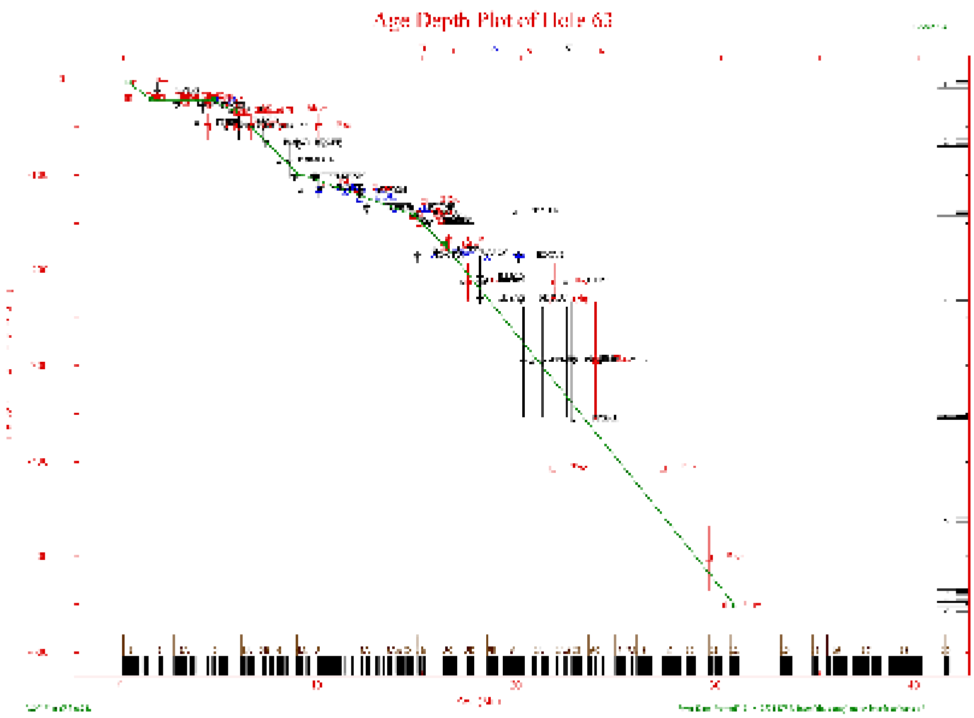
62A 19950725

AGE	DEPTH
8	
2.8417e-6	9.4095e-8
.141939	4.90046
1.12778	4.90046
9.68036	303.216
11.0689	303.216
12.7206	358.864
23.4701	358.864
24.2407	384.073



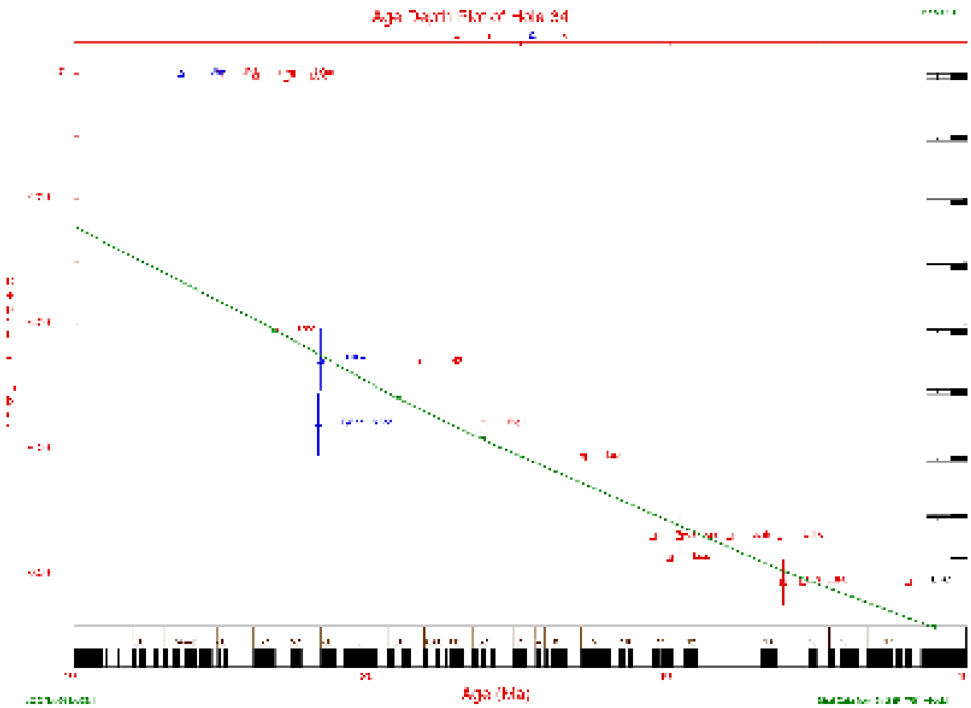
63 19950725

AGE	DEPTH
8	
.235068	2.25
1.41768	21.7458
4.52453	21.7458
5.58455	33.5375
8.79522	98.3155
14.5641	141.439
16.1099	172.741
30.7299	551



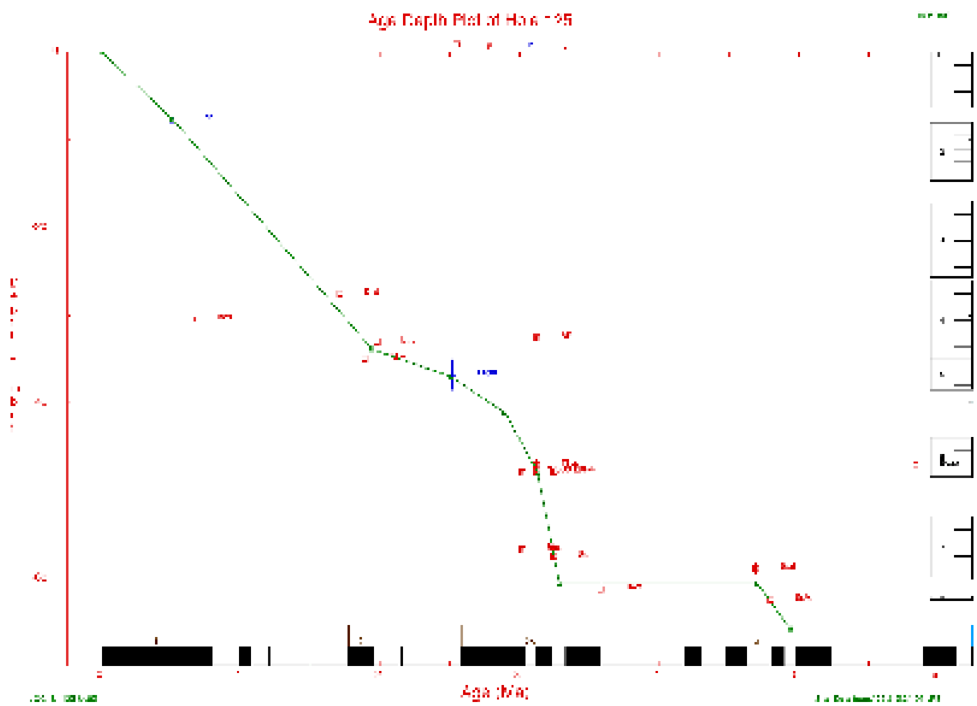
64 19950725

AGE	DEPTH
6	
0	0
16.7269	409.091
20.8714	519.697
23.7088	584.848
33.8393	795.
38.8655	885.



125 19952507

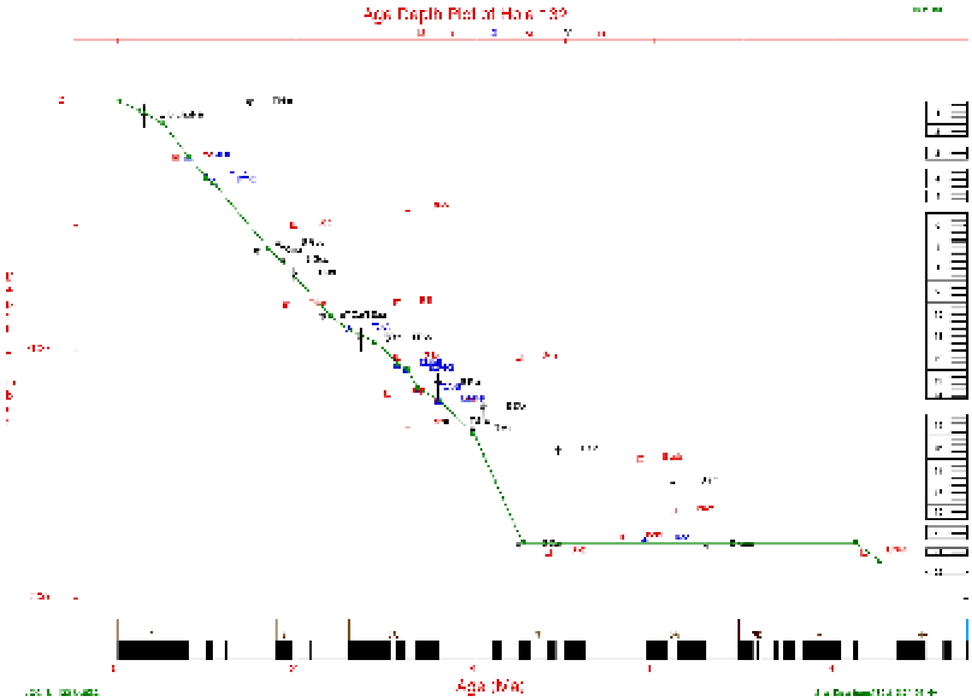
AGE	DEPTH
9	
0	0
0.50725644	7.68817
1.93985455	33.9247
2.50595378	36.9355
2.8905904	41.0215
3.12222222	47.9032
3.281479	60.5914
4.70278875	60.5914
4.932678	65.7527



132 19952507

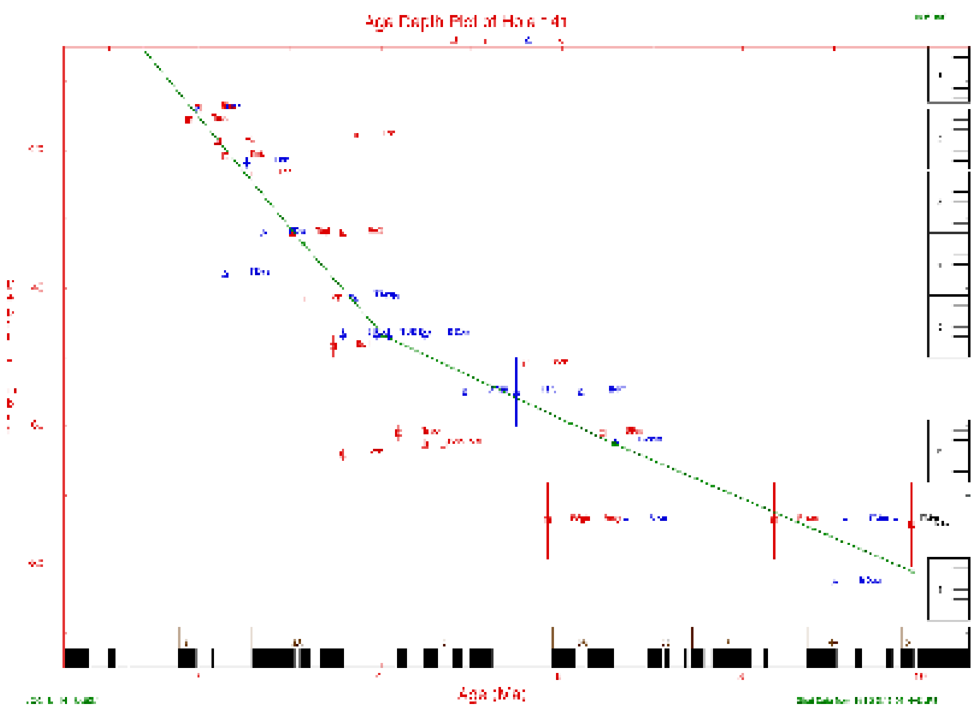
AGE	DEPTH
15	
0	0
0.26997723	3.89784
0.50953233	9.27418

0.78361317	22.043
0.98912967	30.7796
1.06235543	32.7957
1.68955147	59.0054
2.36759366	85.8871
2.589823	91.9355
2.8675078	96.6398
3.13092444	105.376
3.227909	108.064
3.35192045	115.457
3.5893375	120.161
6.33929962	187.366



141 19950803

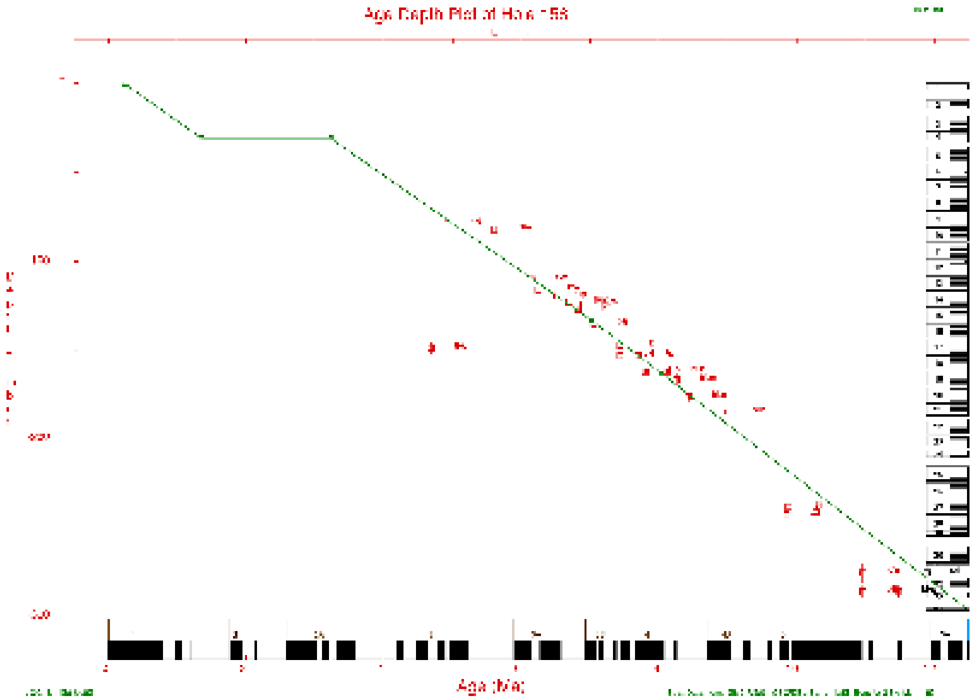
AGE	DEPTH
5	
1.16054	1.98925
3.13713	33.4408
4.02025	46.7273
6.56438	62.4091
9.86958	81.0215



158 19952507

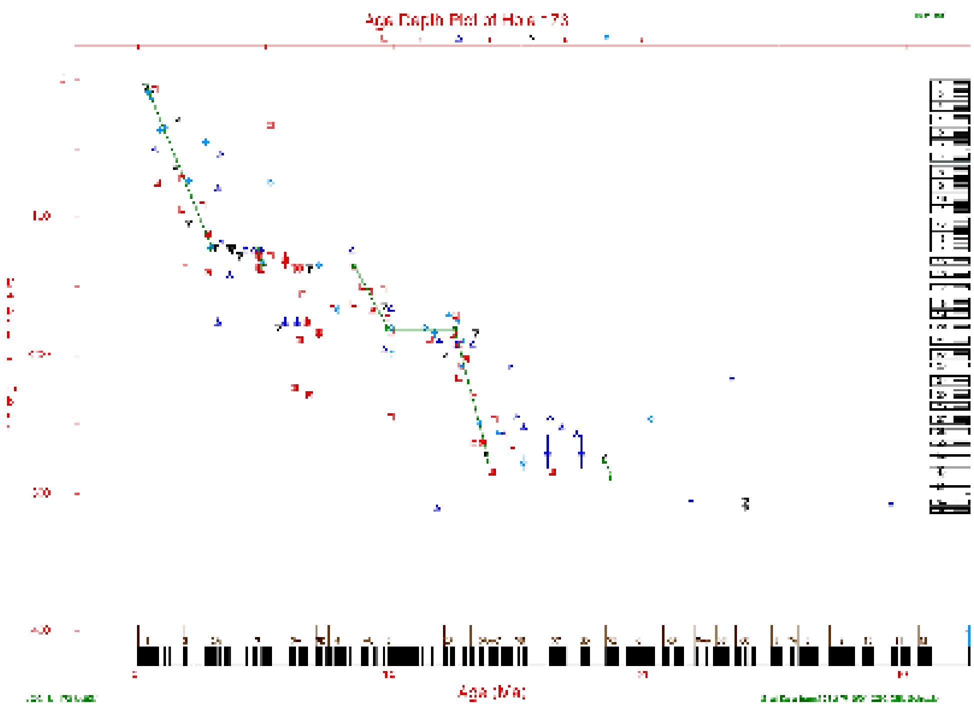
AGE	DEPTH
6	
0.23538477	1.55E-07

1.35996471	30.6483
3.224521	30.6483
7.014726	132.809
8.02257693	162.672
12.797	306.005



173 19950726

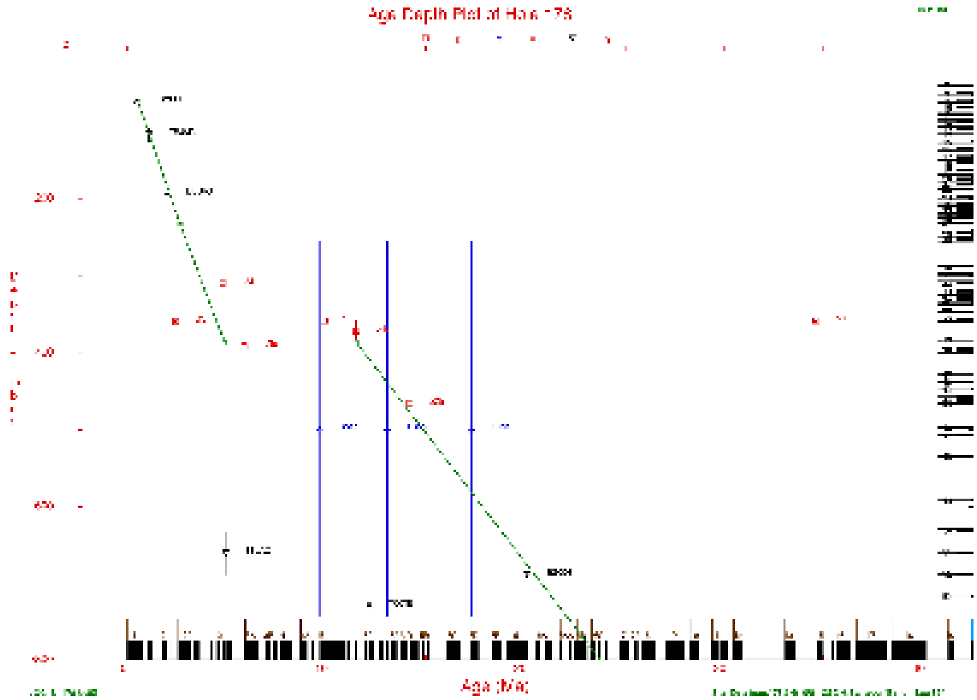
AGE	DEPTH
10	
.32811	4.71513
2.9078	122.888
4.63826	122.888
4.89237	135.077
8.44733	135.077
9.78273	180.814
12.3588	180.814
13.7132	276.364
18.2511	276.364
18.5347	288.636



178 19952507

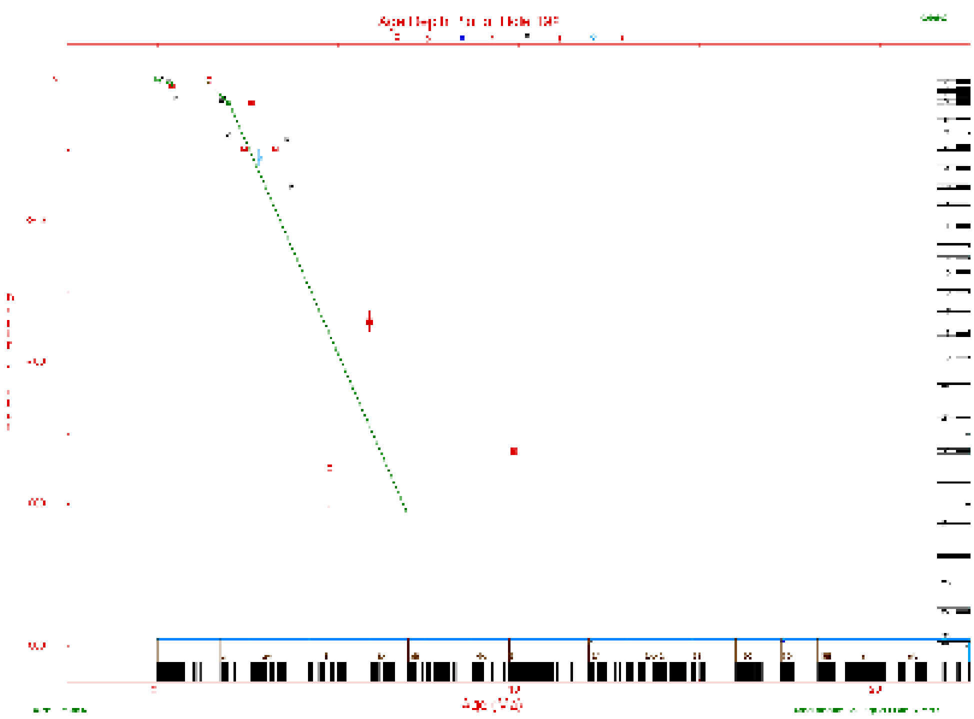
AGE	DEPTH
5	

0.53424658	71.91
2.6569798	233.064
4.88511429	385.484
11.4852402	385.484
23.8425064	801.613



192 19960802

AGE	DEPTH
5	
0	0
.369157	6.23359
1.4214	6.23359
1.97961	33.4449
6.86463	606.483



Next Section...

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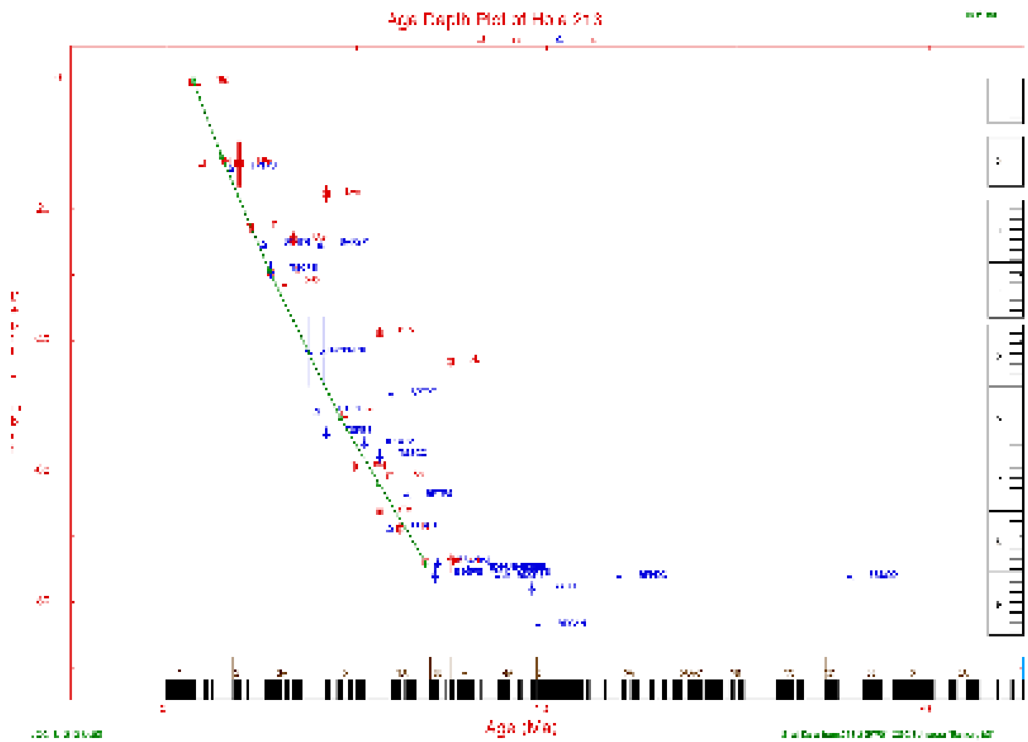
DIRECTORY: adps_app

Holes 213-289

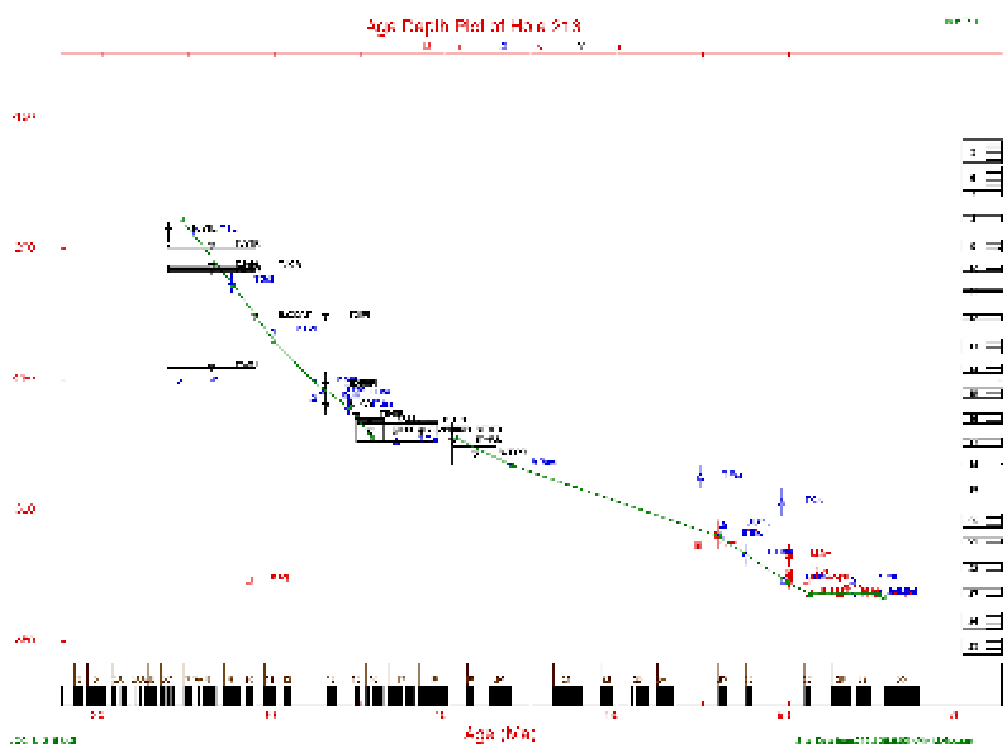
213 19952507

AGE	DEPTH
6	
0.70346063	0.161289
1.47158382	12.0968
2.7295732	29.5161
4.5526	51.7742
5.56461021	61.7742
6.85088167	74.3548



216 19950711

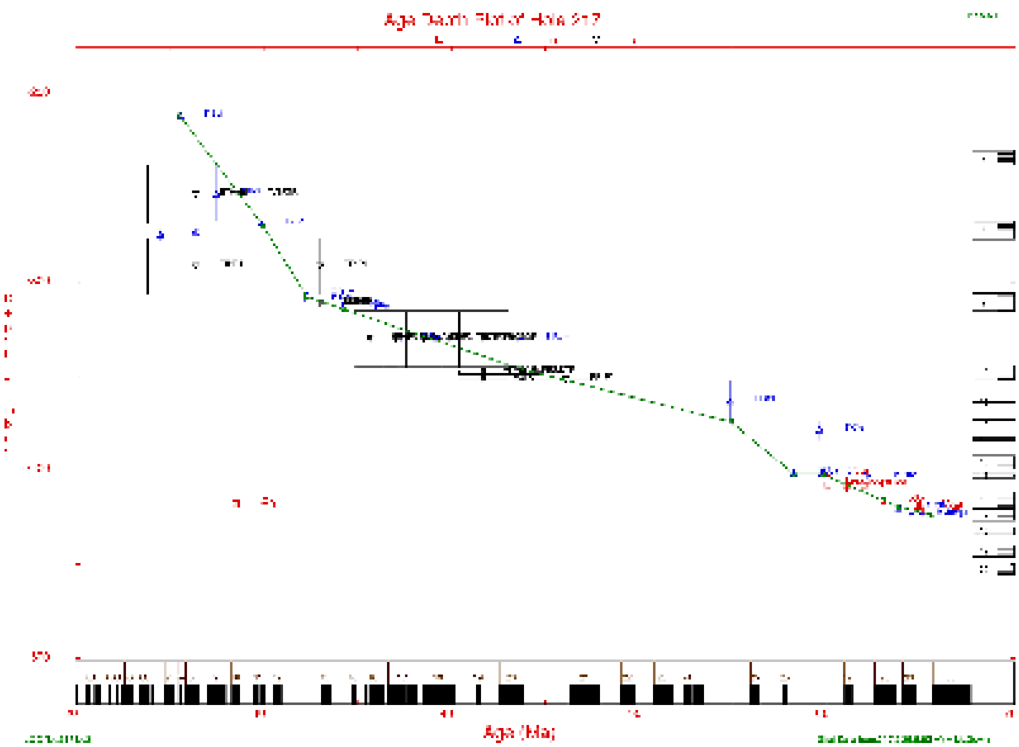
AGE	DEPTH
13	
24.5483	188.636
27.5525	213.553
29.9212	234.848
32.2847	250.909
34.333	260.242
35.6408	271.97
40.5515	271.97
43.7868	282.466
55.9191	310.031



60.021	327.642
61.292	331.853
65.2206	331.853
65.5095	333.002

217 19950711

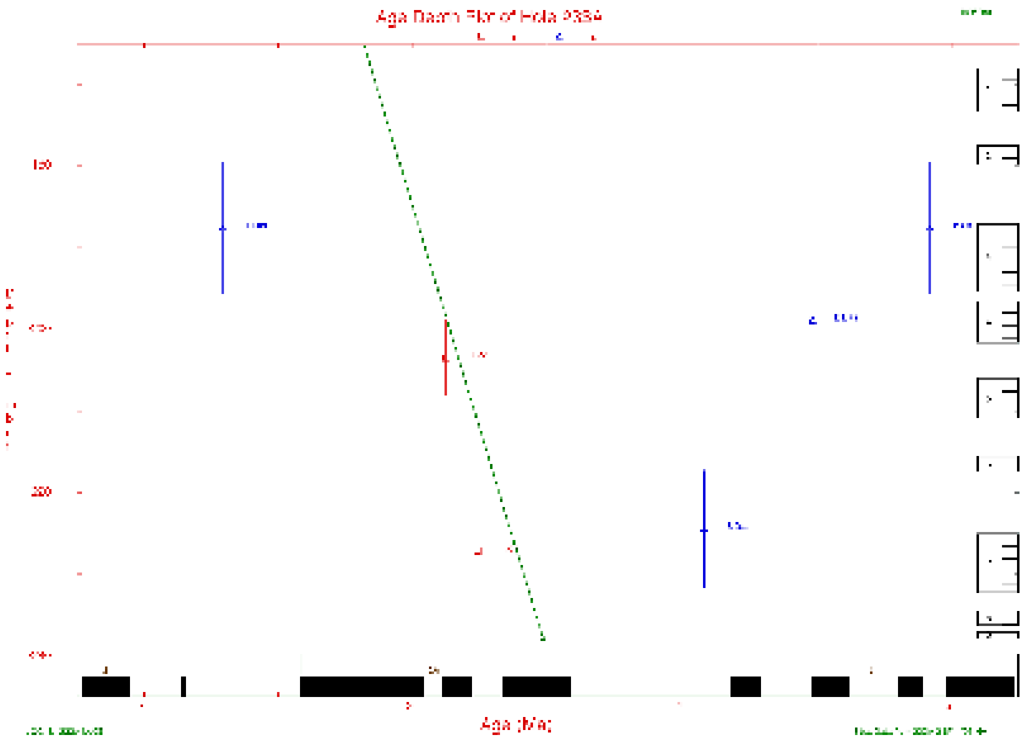
AGE	DEPTH
11	
25.526	211.591
29.9362	269.924
32.2742	307.576
34.2402	314.47
43.6982	346.288
54.8565	374.394
58.188	402.
59.7059	402.
62.9674	416.167
63.8078	419.667
65.5672	423.833



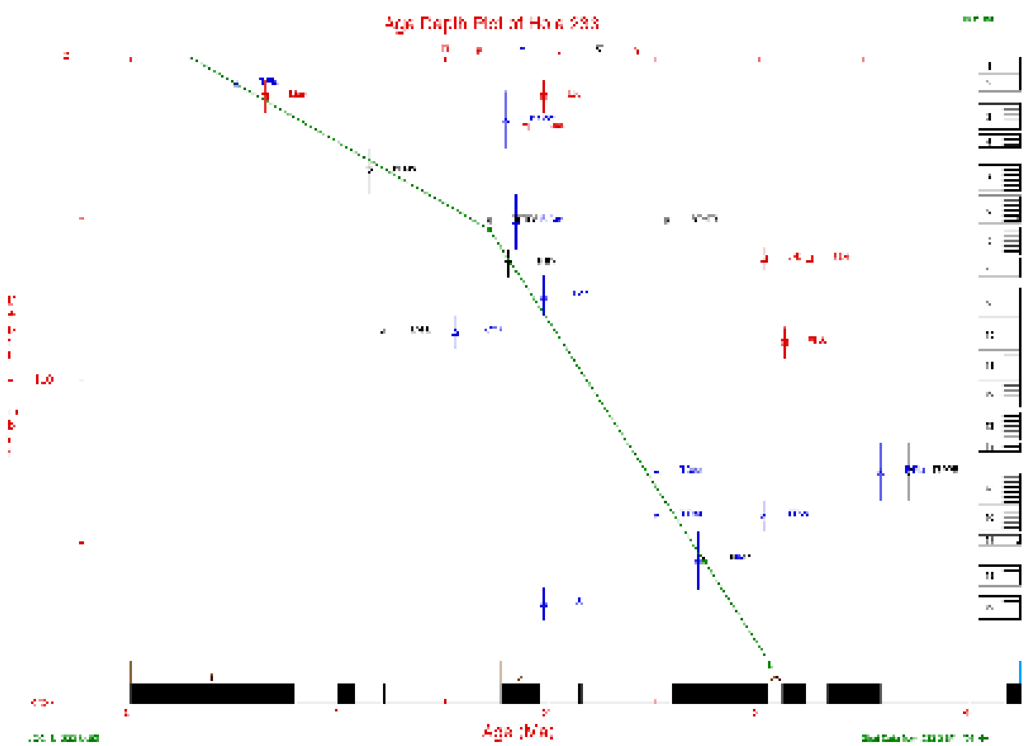
233A 19952507

AGE	DEPTH
3	
0	0
2.7295732	155.484

3.48132955 237.742



233 19952507

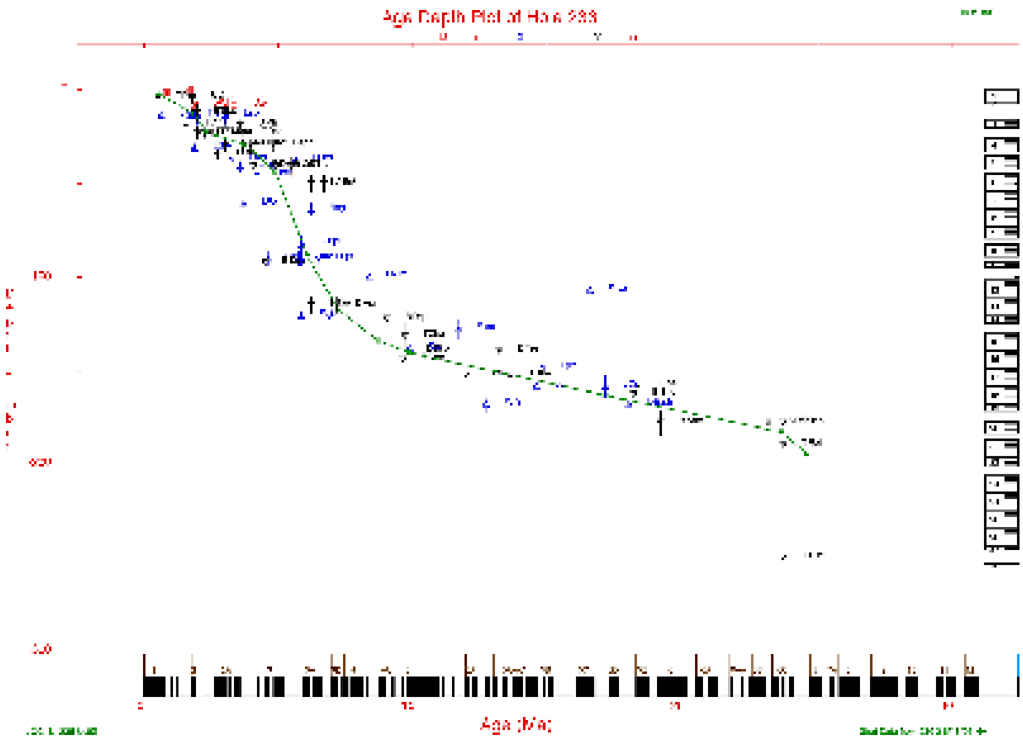


AGE	DEPTH
4	
0.28043244	0.134415
1.70786471	52.957
2.7386512	155.78
3.05683	188.038

236 19952407

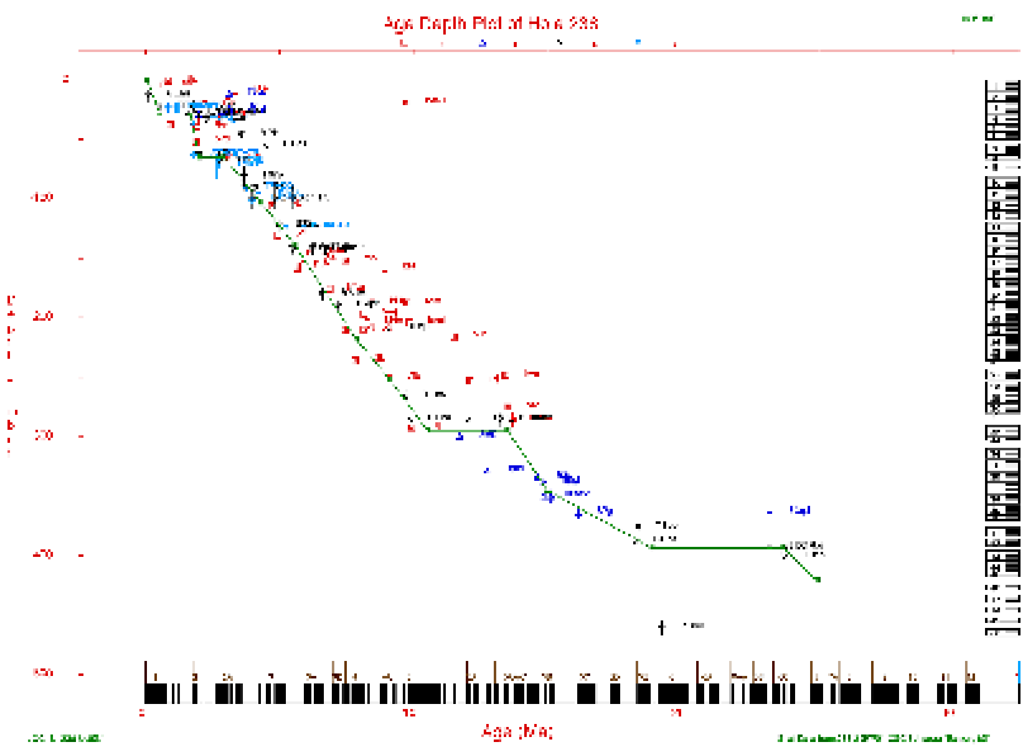
AGE	DEPTH
12	
0.50646575	1.75
1.88222182	12.6344

2.32763746	22.9839
3.7561625	28.629
4.894581	43.6828
6.058079	88.8441
7.2096275	117.07
8.70997	134.005
9.85409067	140.591
17.1451336	163.172
23.6537636	182.93
24.6236353	194.22



238 19950725

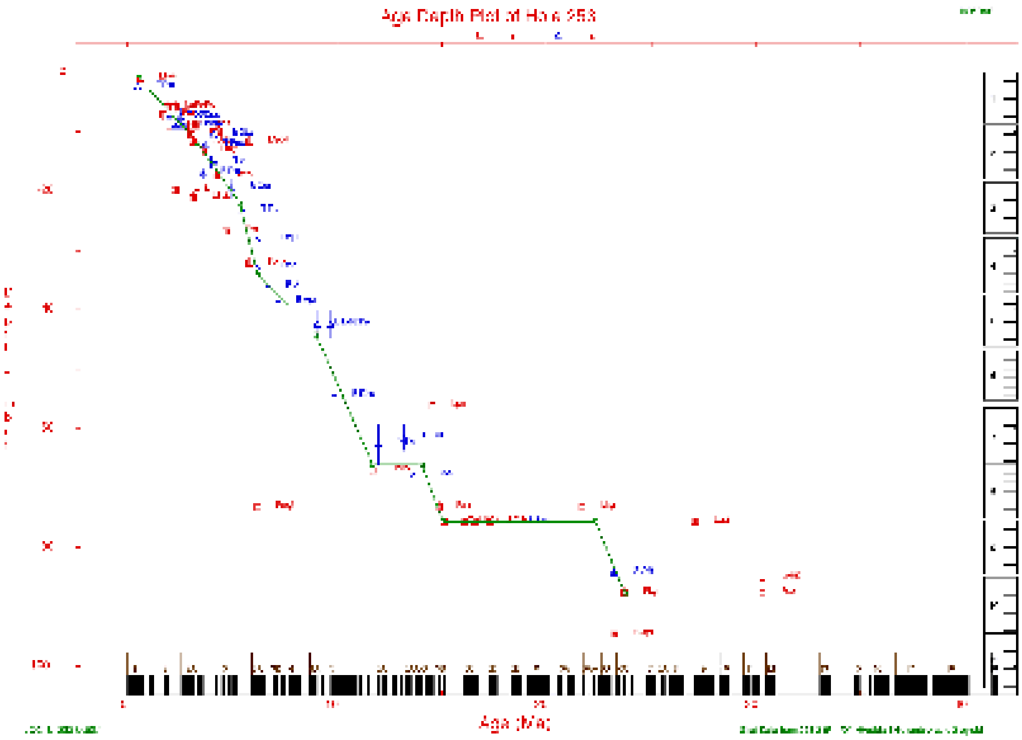
AGE	DEPTH
15	
9.08219e-2	.6
.503739	27.5581
1.6675	27.5581
1.9704	64.7674
2.92014	64.7674
4.30004	103.629
5.53405	139.113
7.83913	217.976
9.03281	250.982
10.4839	294.99
13.4466	294.99
14.9224	344.624
18.8235	393.333
23.7132	393.333



24.9632	420.833

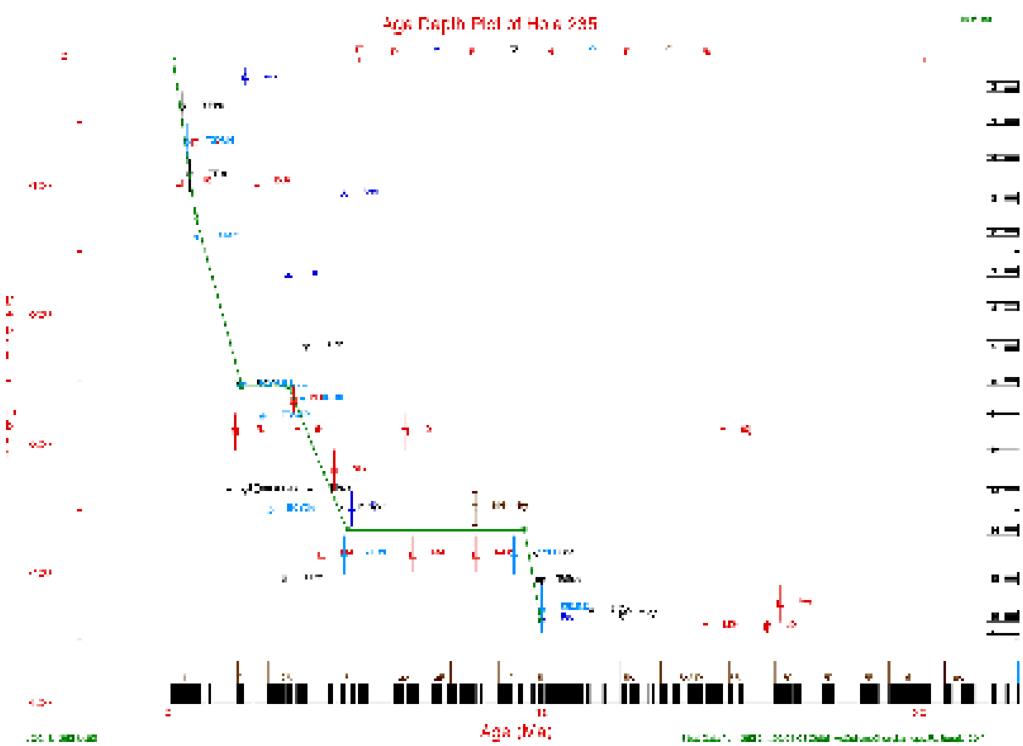
253 19950725

AGE	DEPTH
10	
.506466	1
3.33575	11.7742
5.33283	22.0039
6.20518	34.1847
8.98635	44.1667
11.7006	66.0118
14.0429	66.0118
15.0198	75.6385
22.303	75.6385
23.7325	87.6228



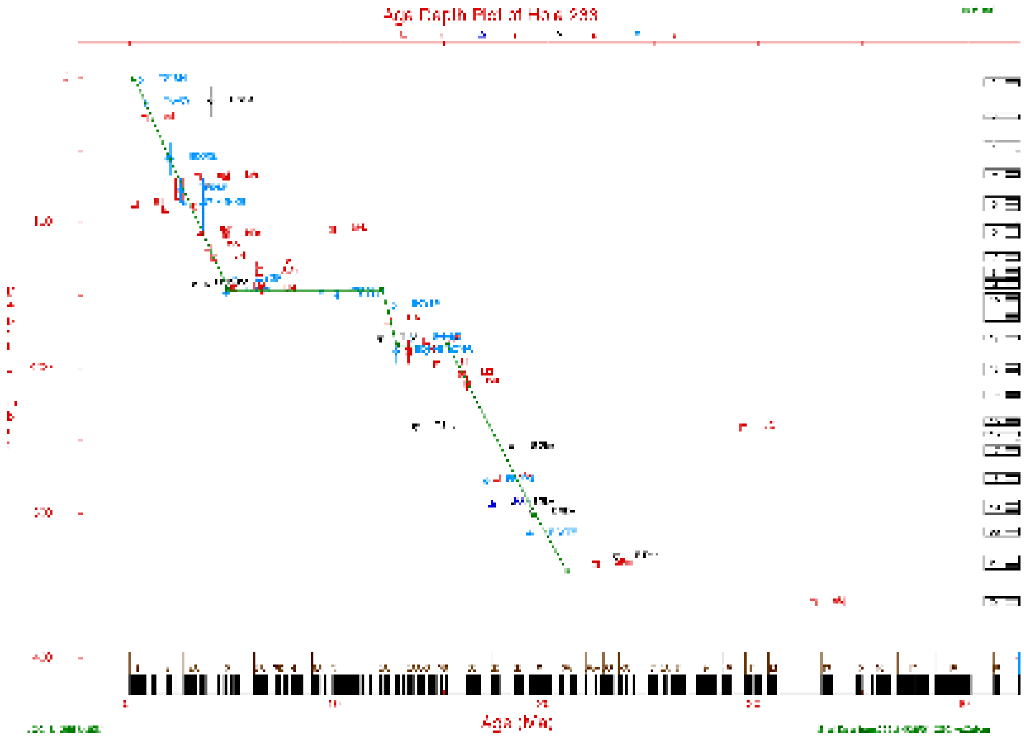
265 19952507

AGE	DEPTH
7	
0.05706523	0.982318
0.65622041	122.79
1.89744	254.42
3.11080667	254.42
4.65641625	365.422
9.36688152	365.422
9.82722467	435.616



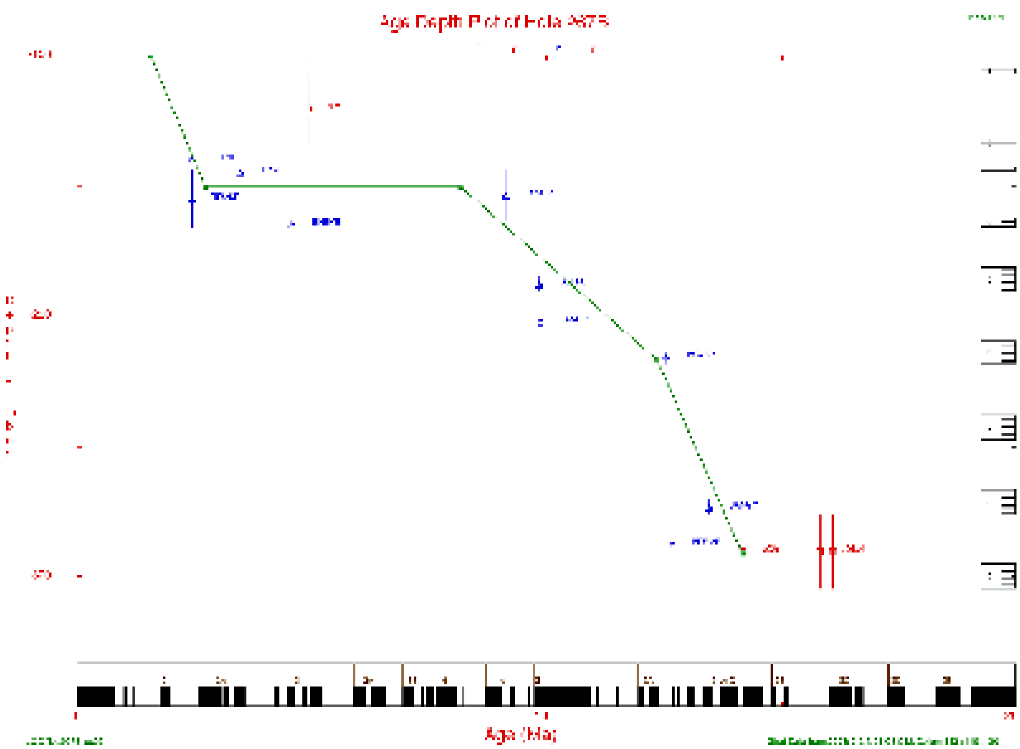
266 19952407

AGE	DEPTH
7	
0.17119184	1.55E-07
4.671435	146.169
12.0819954	146.169
12.7419467	184.274
15.182488	184.274
17.4549109	290.766
20.6570596	368.566



267B 19952507

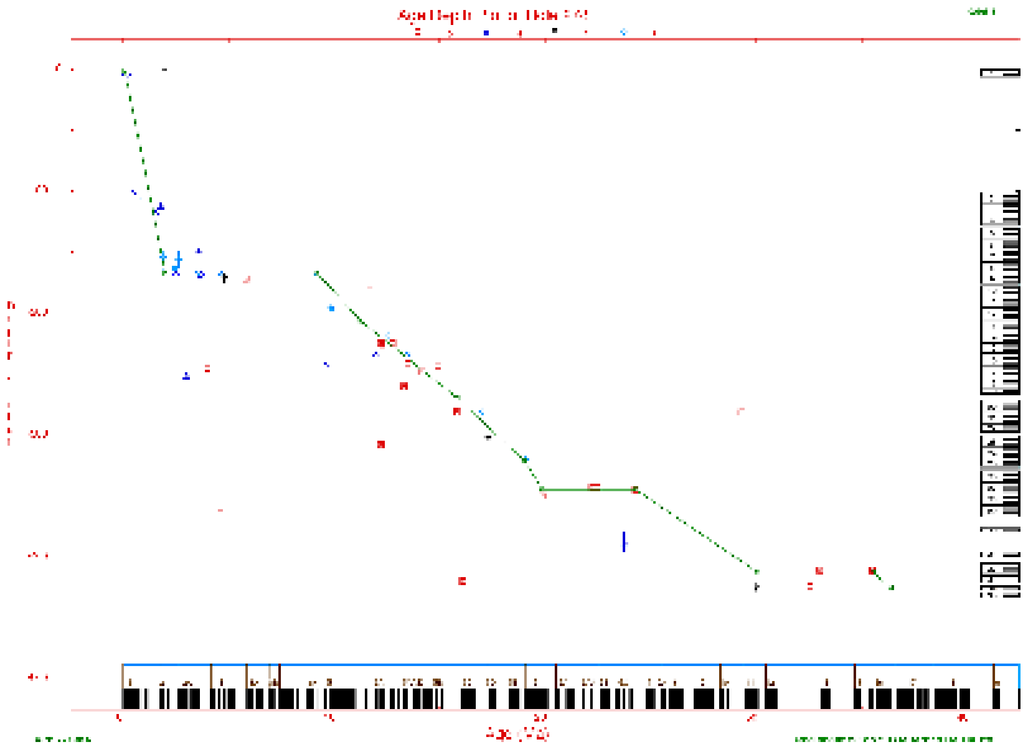
AGE	DEPTH
5	
1.57300147	100
2.7307564	150.098
8.15160371	150.098
12.3394888	216.935
14.160065	290.963



278 19960813

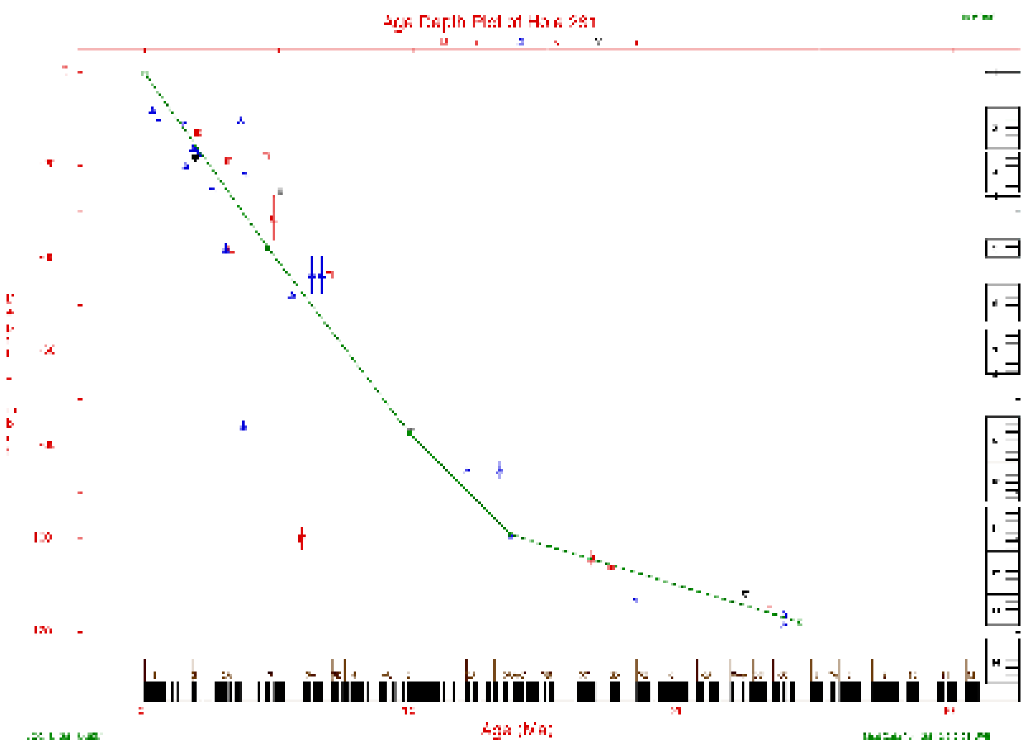
AGE	DEPTH
11	
9.08219e-2	.755

1.99553	167.976
9.20918	167.976
11.2385	205.645
15.8344	269.155
19.0417	321.457
19.875	344.554
24.2917	344.554
30.0833	412.402
35.5417	412.402
36.375	424.672



281 19950725

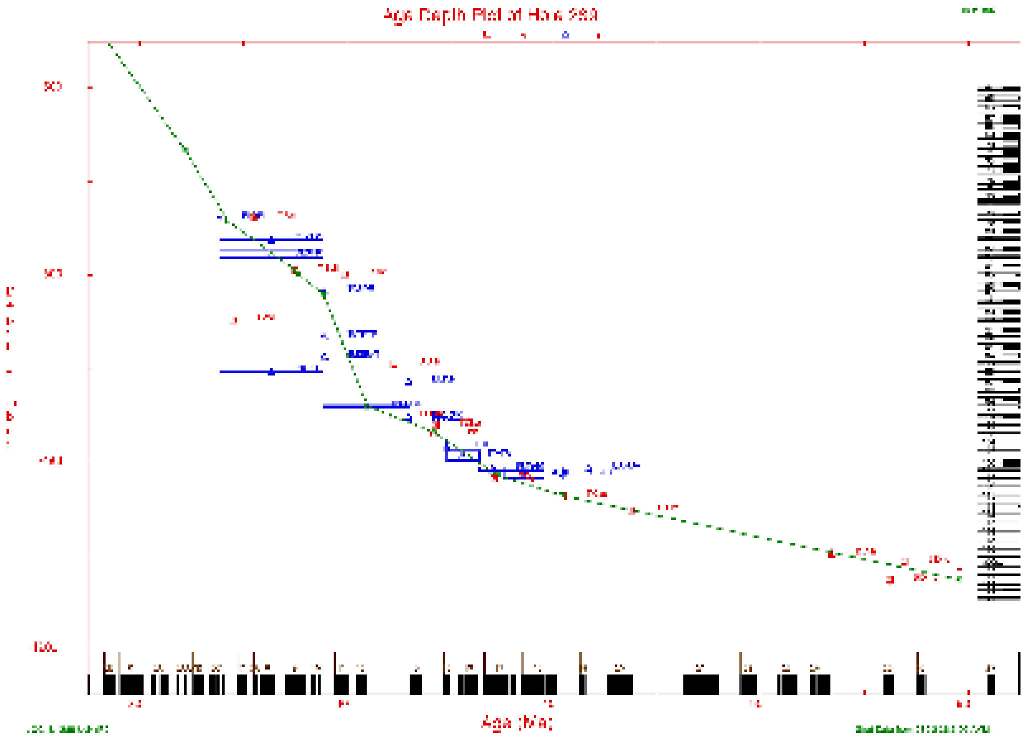
AGE	DEPTH
5	
-.008891	.268816
4.60598	37.9032
9.86571	77.4193
13.6397	99.1515
24.3376	117.878



289 19950725

AGE	DEPTH
22	
.98226	1.51514

5.17537	138.507
7.09866	221.212
8.32915	275.049
9.42646	305.501
9.7598	335.953
9.87195	335.953
11.8377	362.475
12.3424	401.515
13.855	401.515
14.9395	476.621
18.2511	545.454
22.1728	666.208
24.2542	742.424
27.5425	795
27.5806	798.333
28.839	819.167
31.0016	940.
34.1936	968.333
37.314	1014.17
40.3587	1035.83
59.6	1126.3



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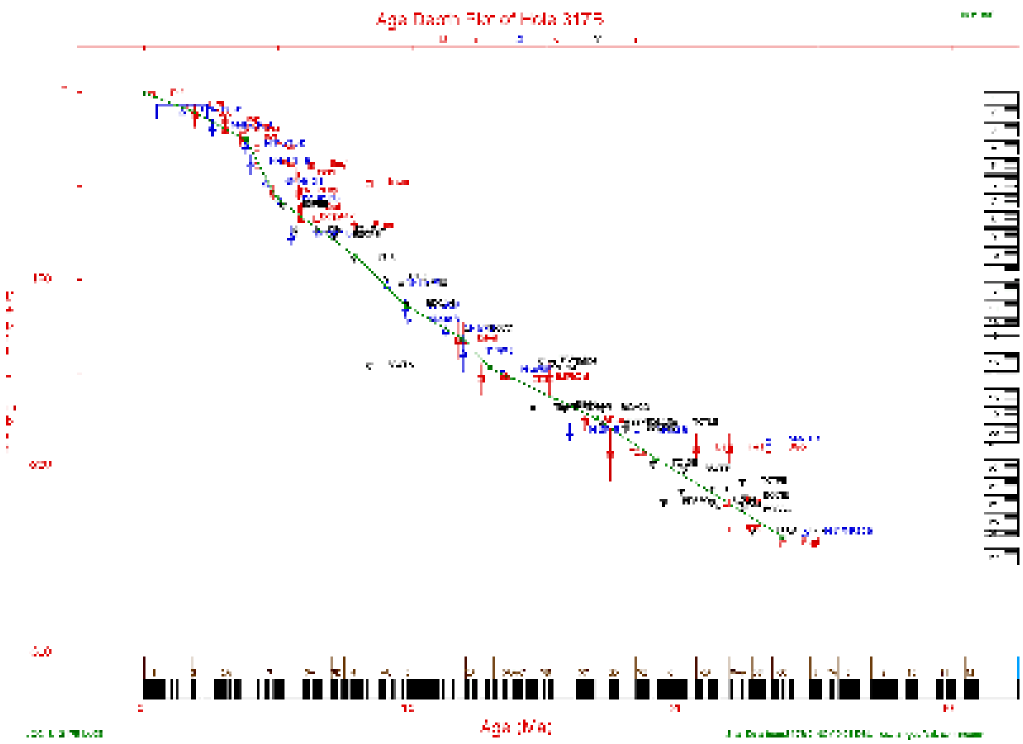
DIRECTORY: adps_app

Holes 317-398D

317B 19952407

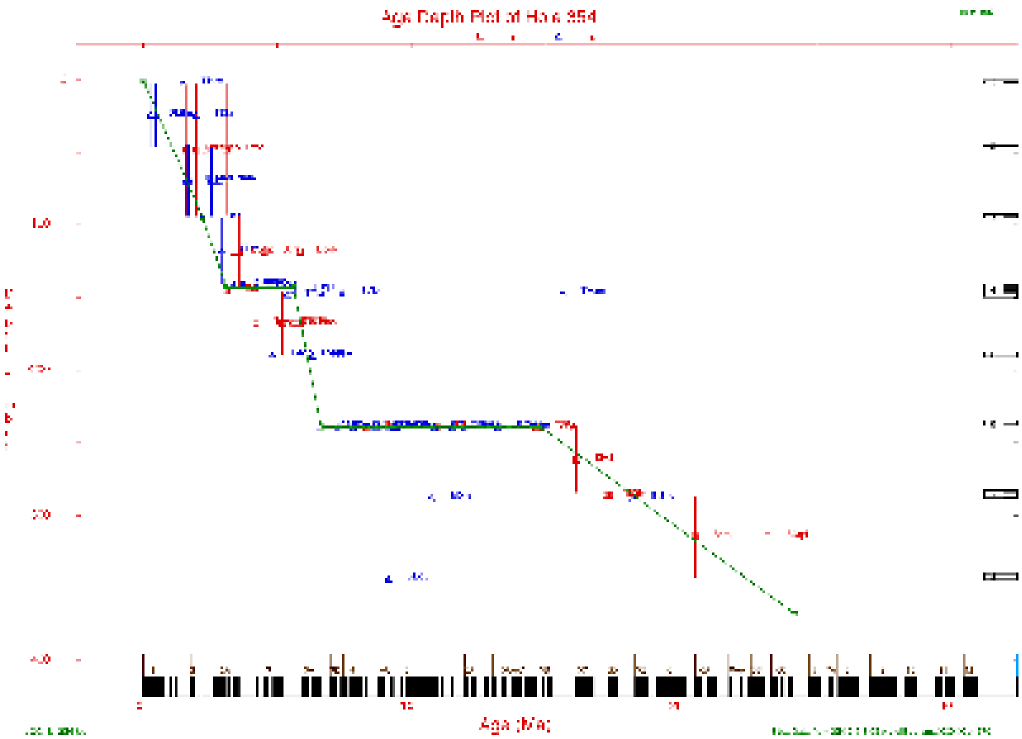


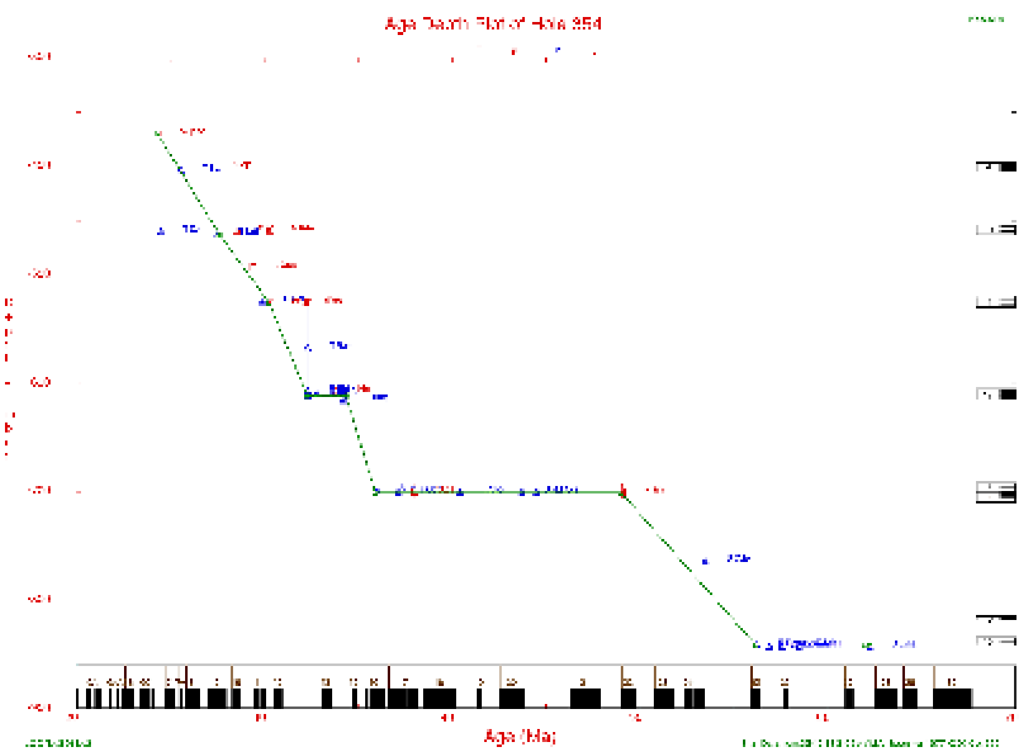
AGE	DEPTH
11	
0.08559784	0.589391
1.82097273	10.0196
3.78595	25.3438
4.940436	56.5815
7.88500493	87.2298
9.74485053	113.752
11.8377352	131.434
12.8819848	147.348
16.7658775	173.87
19.0025073	195.678
23.72128	237.397

354 19950709

AGE	DEPTH
16	
-7.35239e-3	.378792
2.20589	94.3182
3.08351	142.424
5.59244	142.424
6.60294	239.

14.7962	239.
24.2279	367.727
27.5983	462.634
30.2551	526.034
32.2847	611.364
34.3464	611.364
35.8874	700.612
48.9586	700.612
56.1318	841.194
61.9235	841.194
62.2	842.375





356 19950807

AGE	DEPTH
13	
7.79154e-3	.159091
4.84164	17.9848
23.6765	39.9697

25.7563 115.833

44.5798 115.833

47.577 205.207

48.9586 236.6

50.4995 286.371

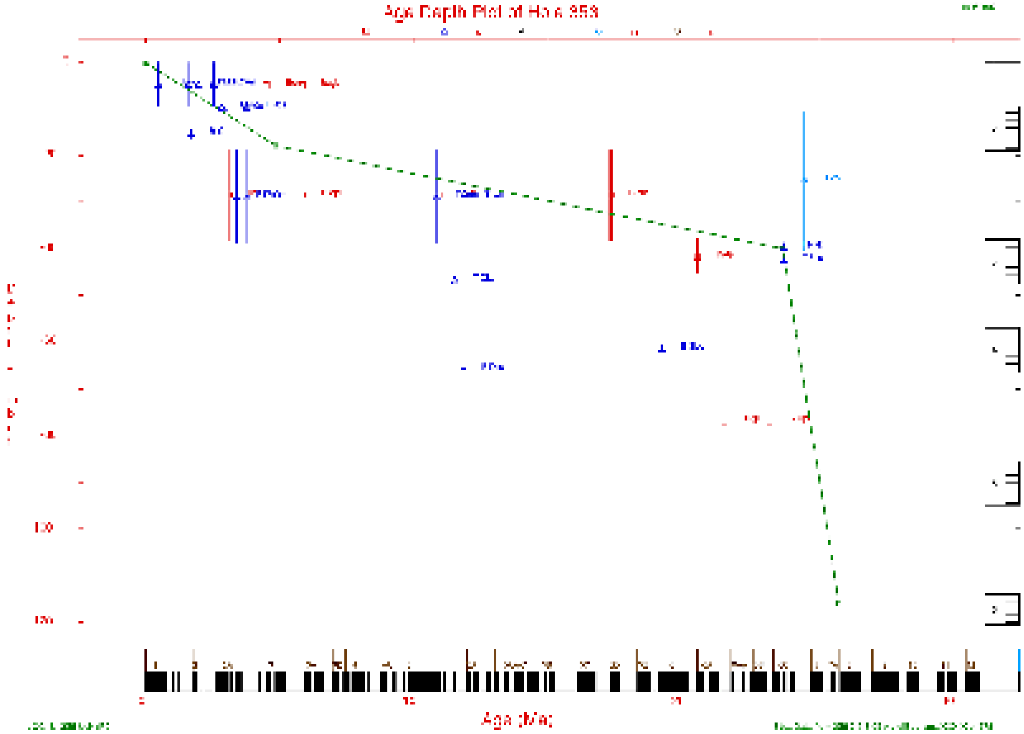
57.779 286.371

59.7981 358.346

61.8172 394.334

63.6238 404.288

64.9034 411.667



362 19950725

AGE DEPTH

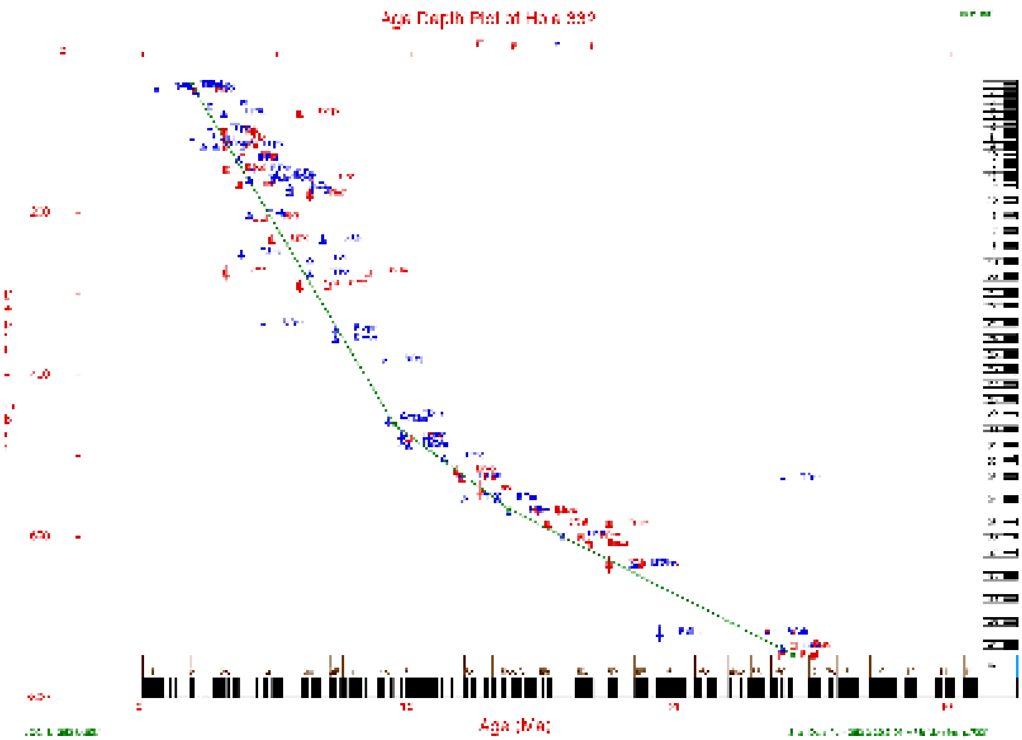
4

1.83992 41.9355

9.33797 460.484

13.6397 566.003

24.1176 744.87



363 19950710

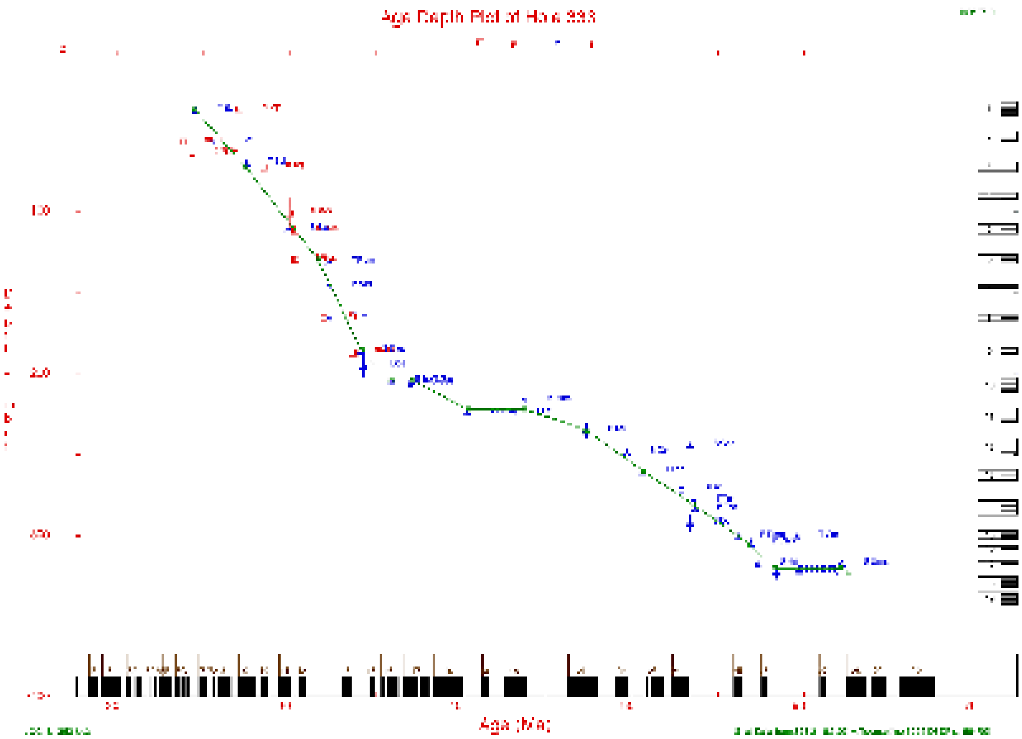
AGE DEPTH

15

24.5165 36.7534

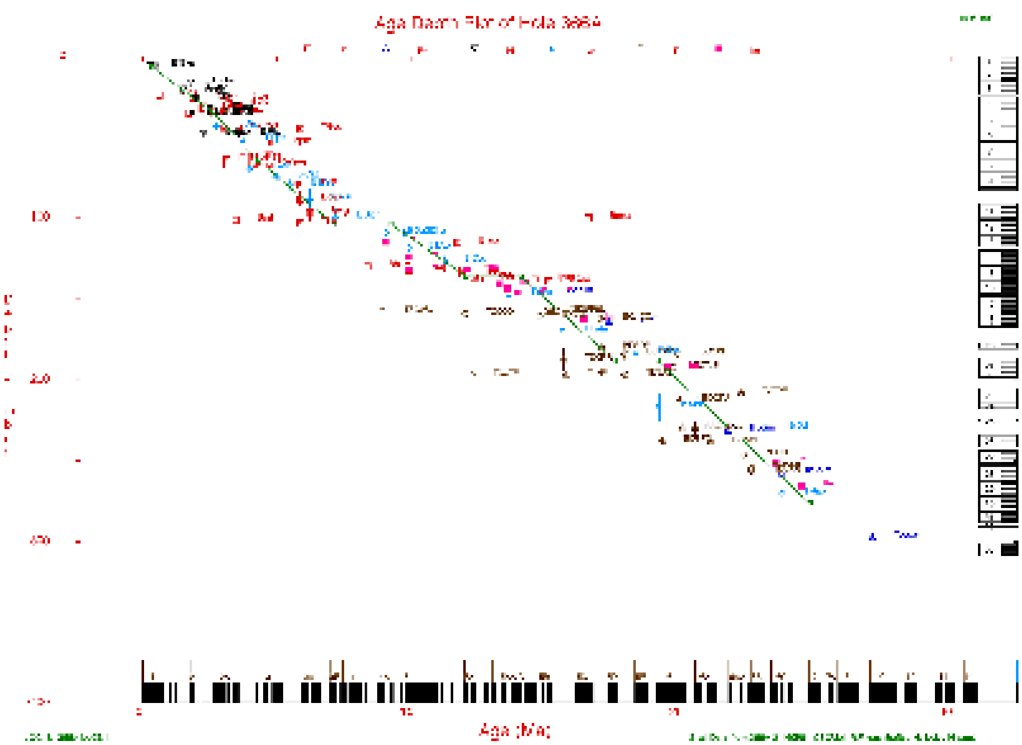
27.4389 72.2818

31.6544	129.25
34.187	185.605
35.9405	203.982
37.2157	203.982
40.3507	221.746
43.6982	221.746
47.3109	234.609
50.6057	259.724
53.5504	280.551
56.9288	305.666
58.3634	320.367
62.1892	320.367
62.6142	322.818

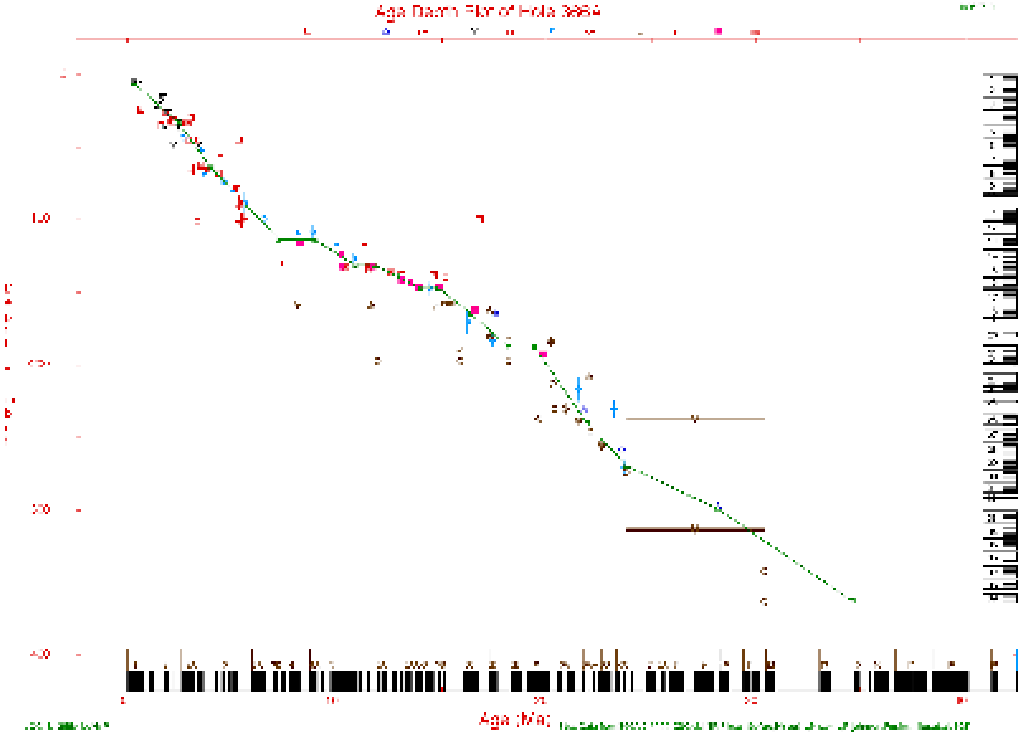


366A 19950710

AGE	DEPTH
17	
.275	5.465
2.40321	33.0059
3.96529	64.2436
7.16956	113.163
8.93191	113.163
10.8545	131.434
11.7757	131.434
12.8571	138.507
13.9386	146.758

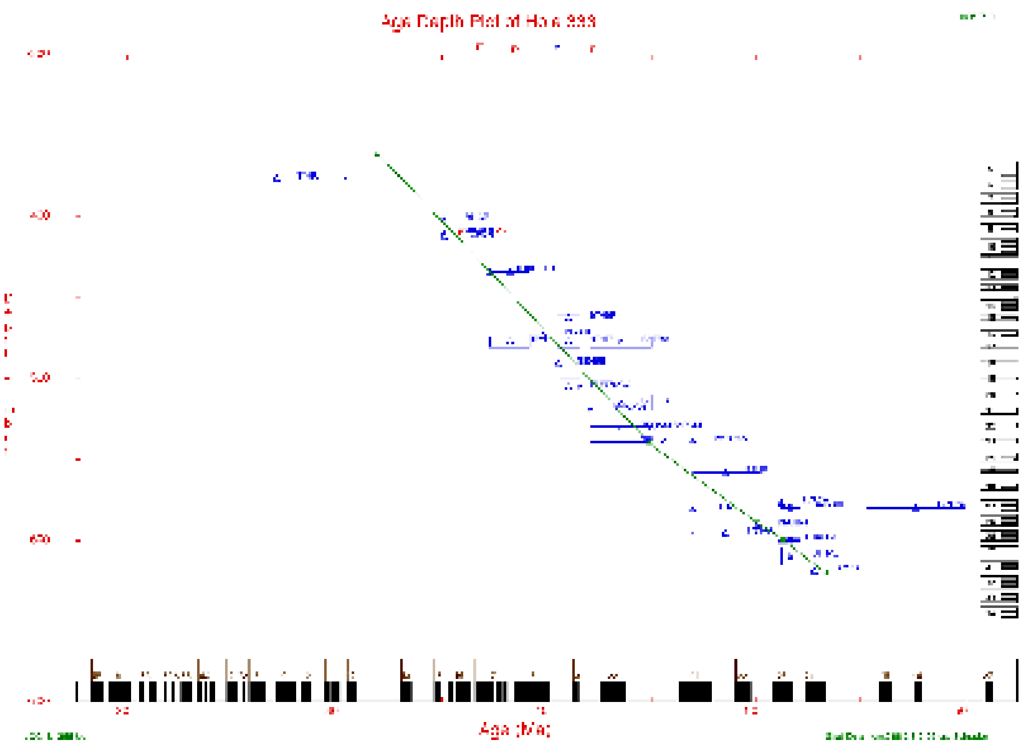


14.8598	146.758
16.4219	164.44
18.2243	188.016
19.4259	188.016
21.9493	240.471
23.7815	268.864
28.1775	298.864
34.6061	362.273



366 19950710

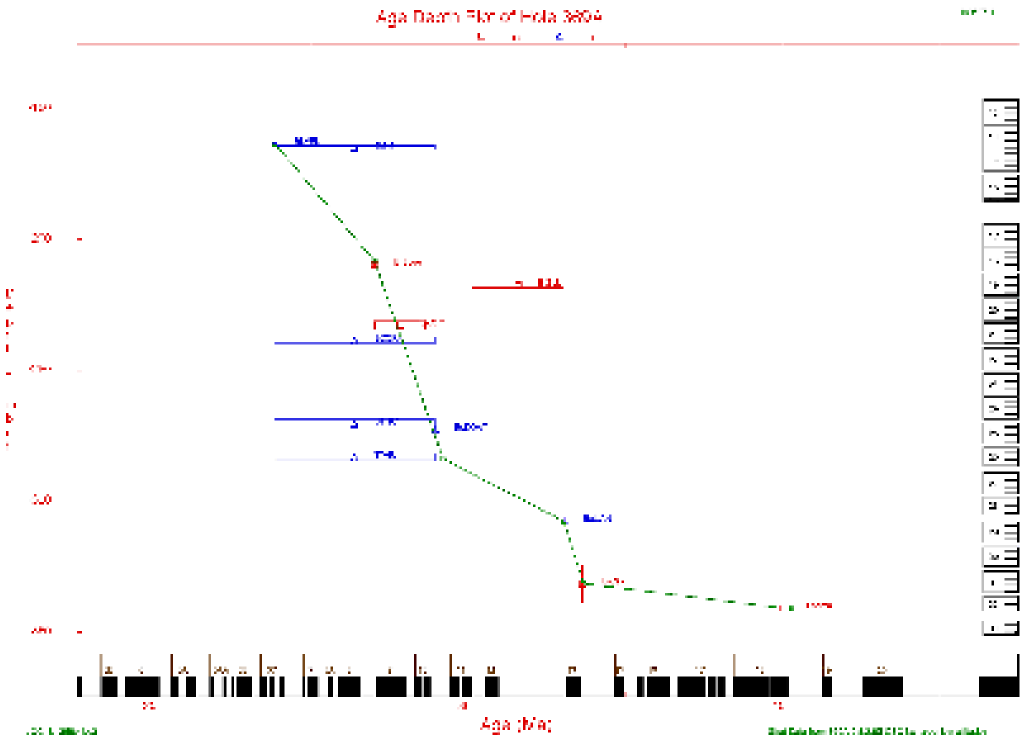
AGE	DEPTH
6	
31.917	360.643
37.3529	434.763
44.916	540.122
50.0683	589.127
51.25	598.928
53.2826	619.755



369A 19952407

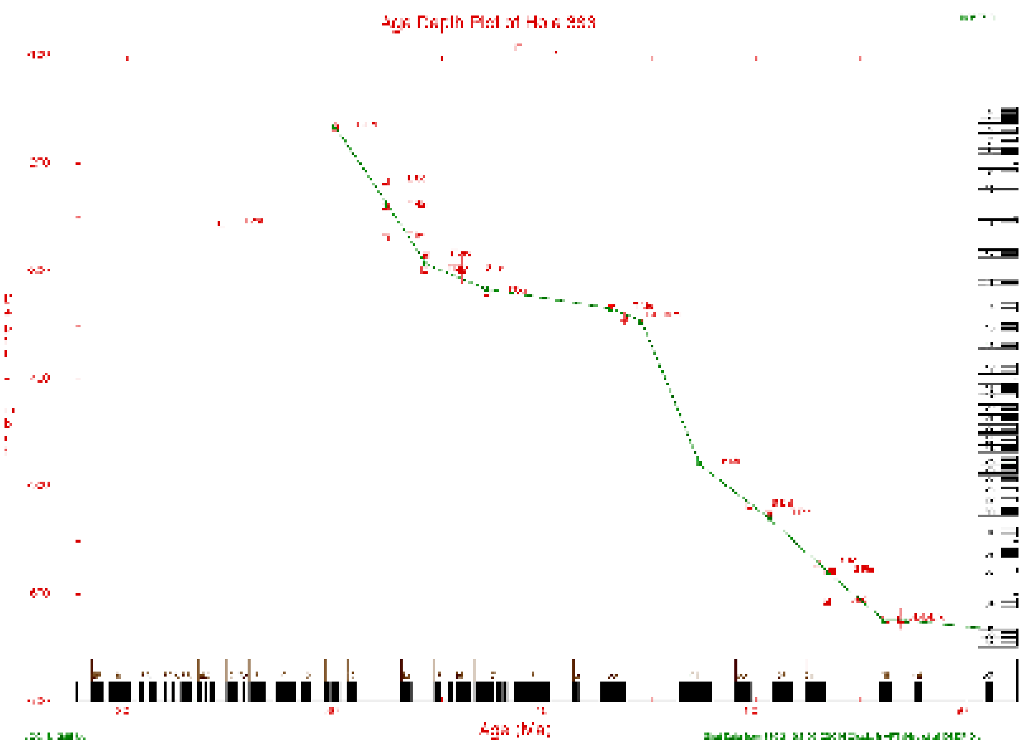
AGE	DEPTH
12	
14.3911317	53.0452
14.7848705	104.126

15.6713946	133.595
16.3542753	143.811
19.1687053	143.811
21.0895673	158.35
23.8	163.43
26.9853	208.333
29.1597	283.712
33.0042	307.576
33.6345	331.439
40.2206	341.288



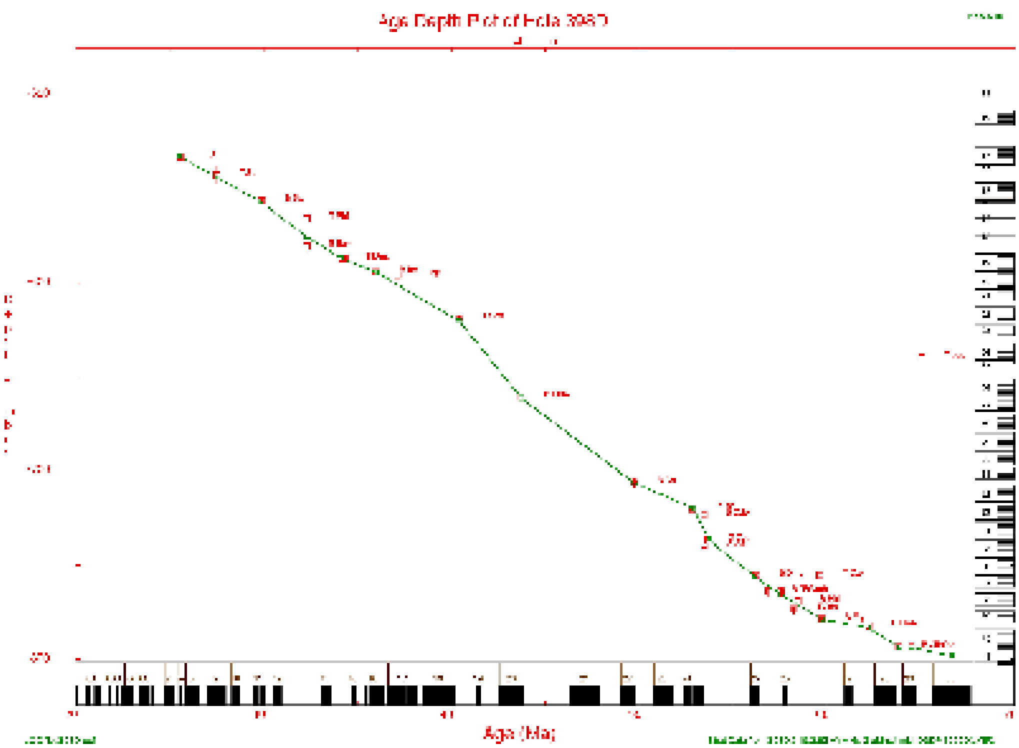
386 19950710

AGE	DEPTH
12	
29.8831	165.237
32.4336	238.744
34.2402	292.956
37.0563	315.926
43.0606	334.303
44.5484	346.248
47.3114	479.479
50.6589	529.096
53.475	579.632
56.1318	623.737
57.1945	623.737
61.2327	632.006



398D 19950710

AGE	DEPTH
17	
25.5	532.74
29.83	556.667
32.2742	575.227
34.1339	586.894
35.9936	594.318
40.4038	620.303
43.6982	661.136
49.7024	706.212
52.8834	720.
53.645	736.667
56.1318	756.061
57.5053	765.667
59.6918	778.864
62.1534	783.
63.8363	793.712
64.4643	793.712
66.5994	798.485



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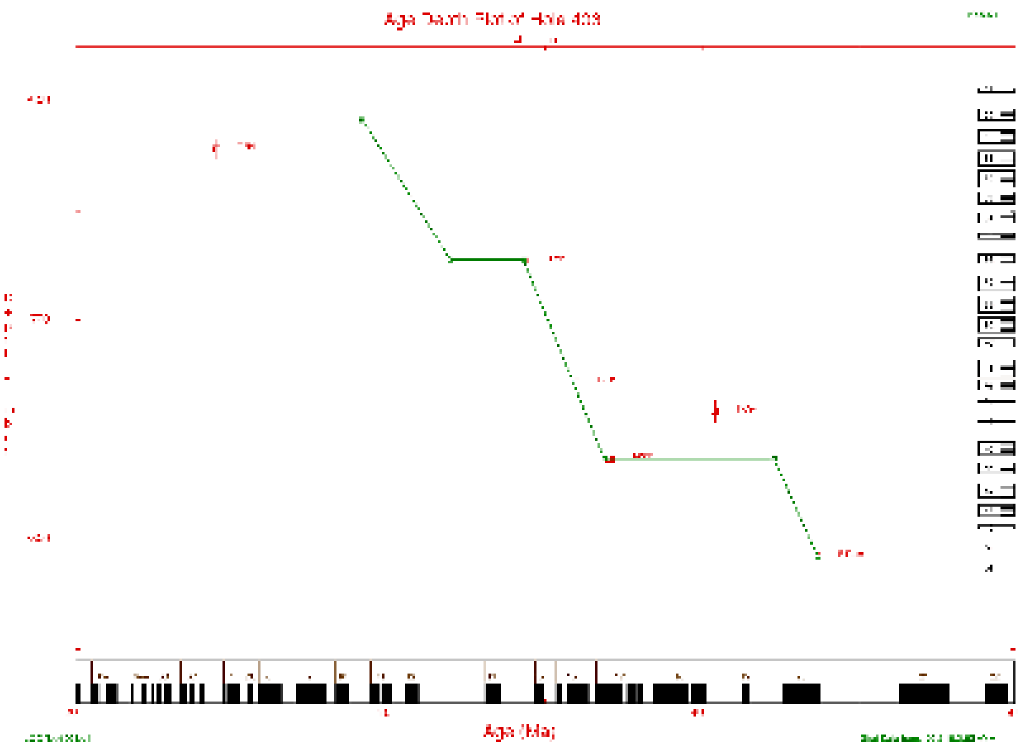
DIRECTORY: adps_app

Holes 406-499

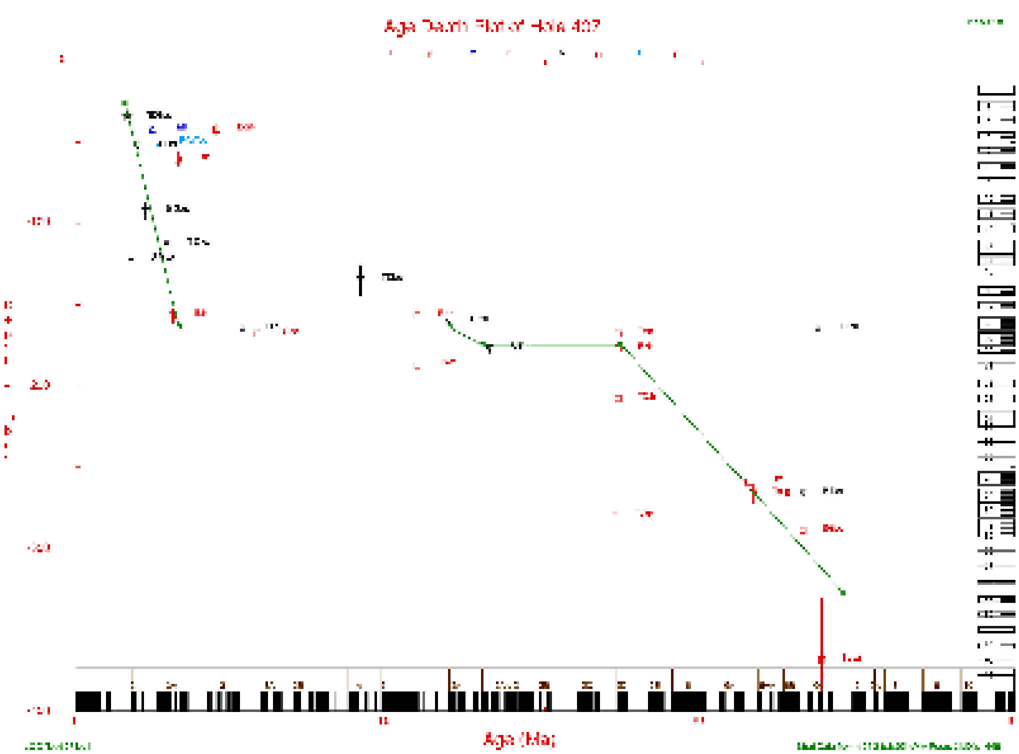
406 19950711

AGE	DEPTH
6	
29.1498	608.636
31.9554	672.273
34.2827	672.273
36.865	763.182
42.2848	763.182
43.7	807.855



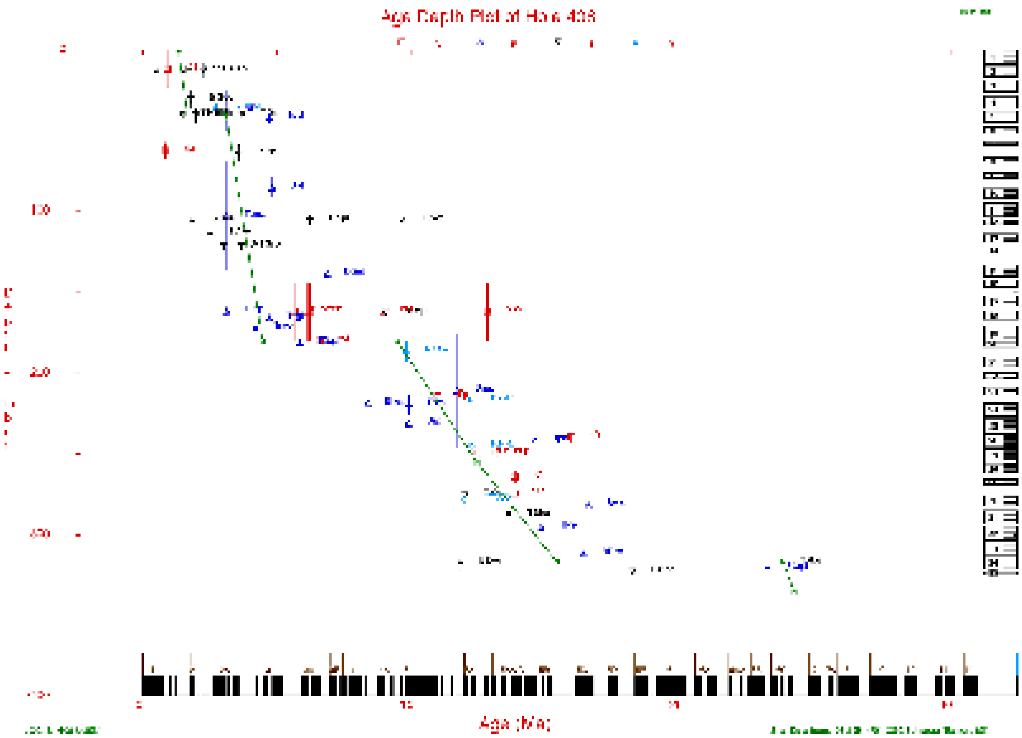
407 19950808

AGE	DEPTH
6	
1.57353	25.6667
3.28374	163.553
11.9235	163.553
12.9674	174.5
17.407	174.5
24.4846	326.493



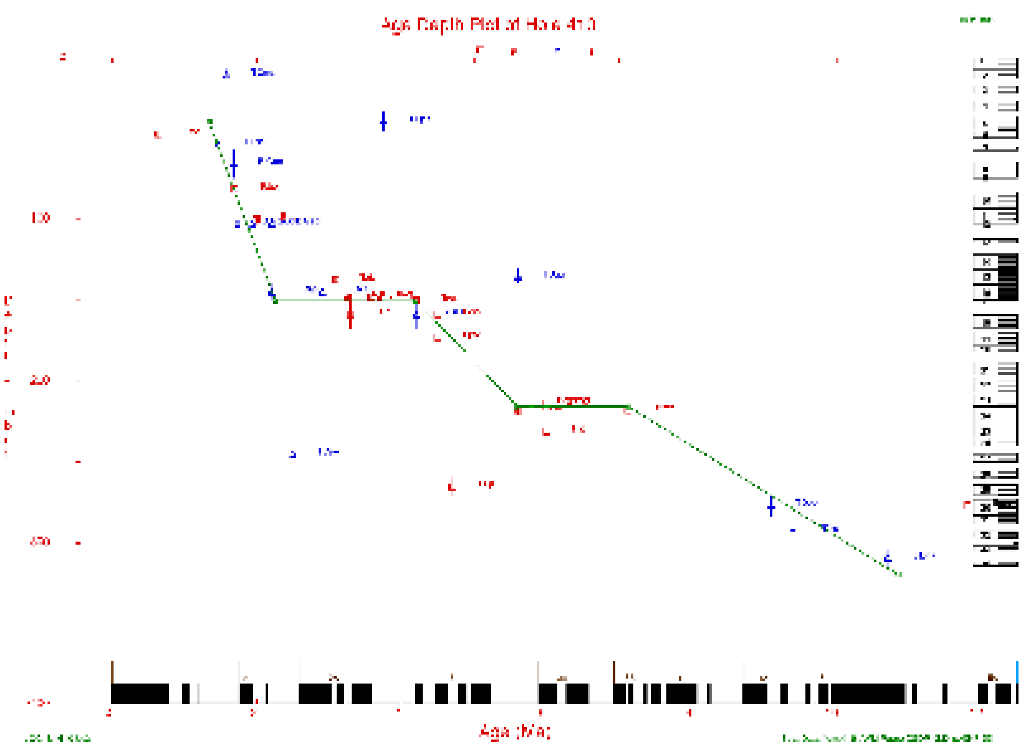
408 19950725

AGE	DEPTH
9	
1.33936	.785855
1.66921	39.2927
3.08396	39.2927
4.45873	179.961
9.45239	179.961
12.4265	255.436
15.3676	316.692
23.8014	316.692
24.2046	335.56



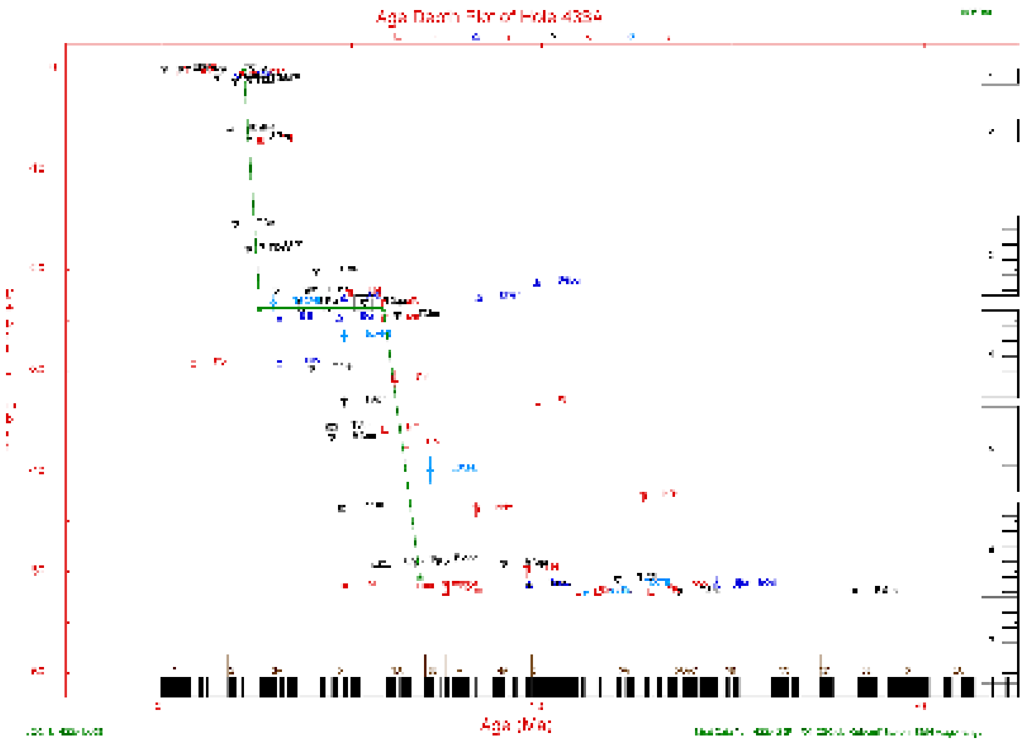
410 19950808

AGE	DEPTH
6	
1.34926	40.1225
2.2563	150.
4.19748	150.
5.58403	215.667
7.1334	215.667
10.8477	319.755



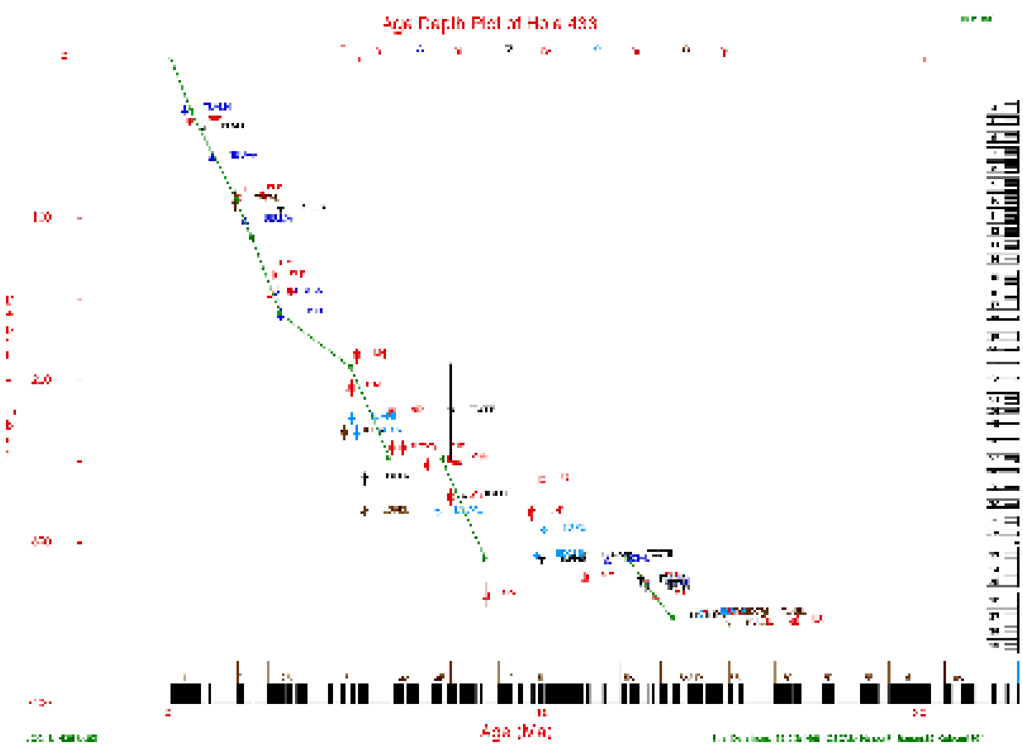
433A 19952507

AGE	DEPTH



4	
2.16277534	0.235756
2.5981768	23.8114
5.83976952	23.8114
6.79059083	50.6876

436 19952507

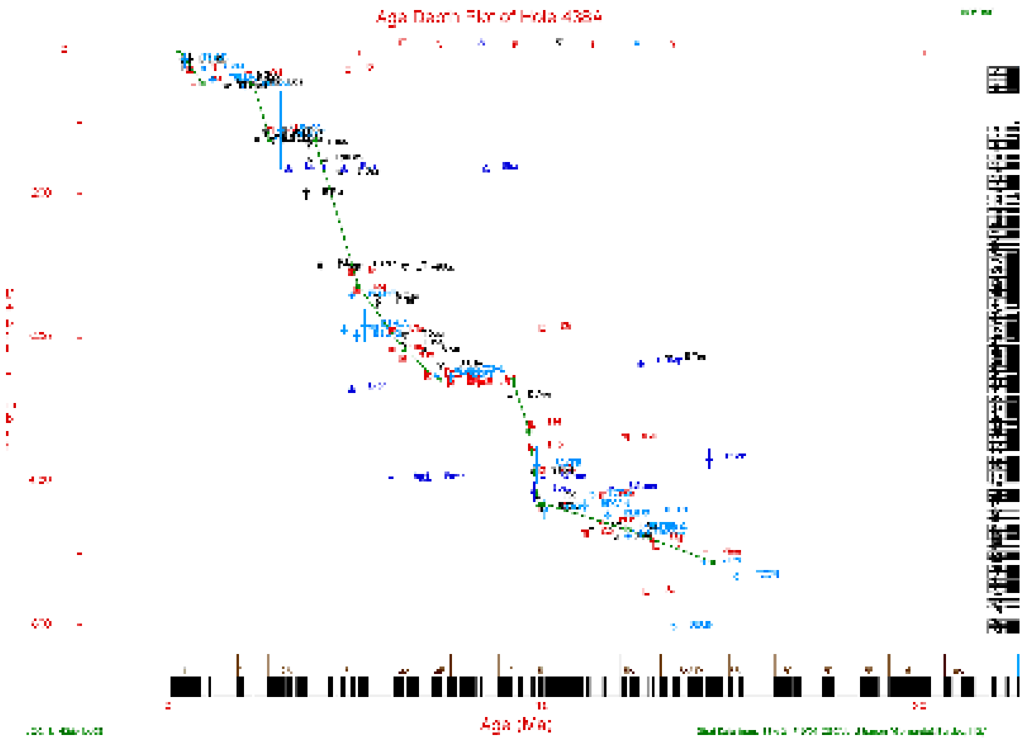


AGE	DEPTH
11	
2.86E-06	0.785854
0.51356375	33.0059
1.73792353	88.0157
2.11830588	110.685
2.9214148	158.743
4.77656625	191.748
5.79136621	247.544
7.15975577	247.544
8.34119649	310.413
12.1370338	310.413
13.2941932	346.562

438A 19952507

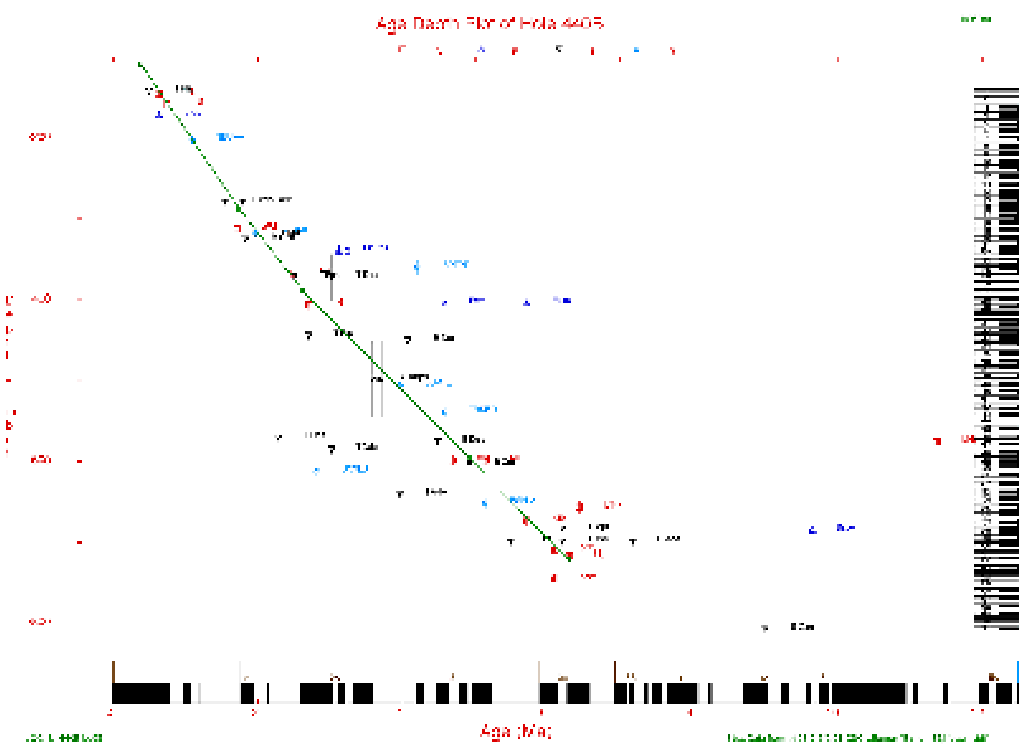
AGE	DEPTH
14	

0.21284811	0.392927
0.84245517	45.9725
2.18343792	45.9725
2.6149864	122.2
3.8026375	122.2
4.9945875	329.273
6.1684512	414.535
7.10732183	459.108
9.06326325	459.108
9.50044648	527.823
9.74402827	630.329
9.8856	630.329
12.1370338	666.601
14.3703752	710.752



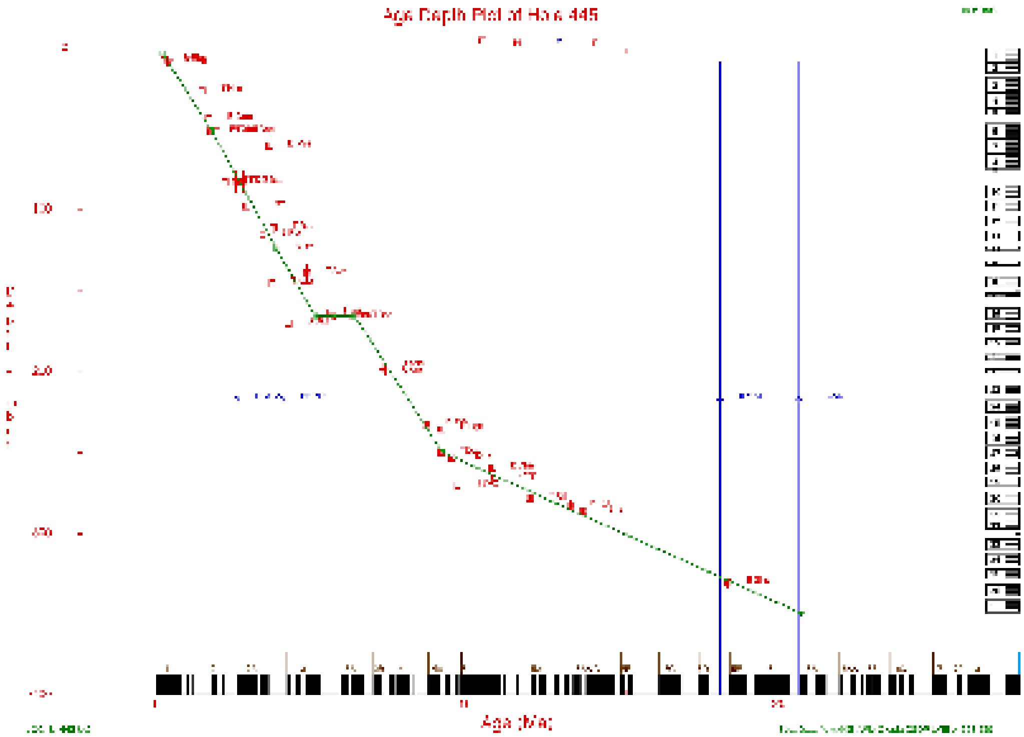
440B 19952507

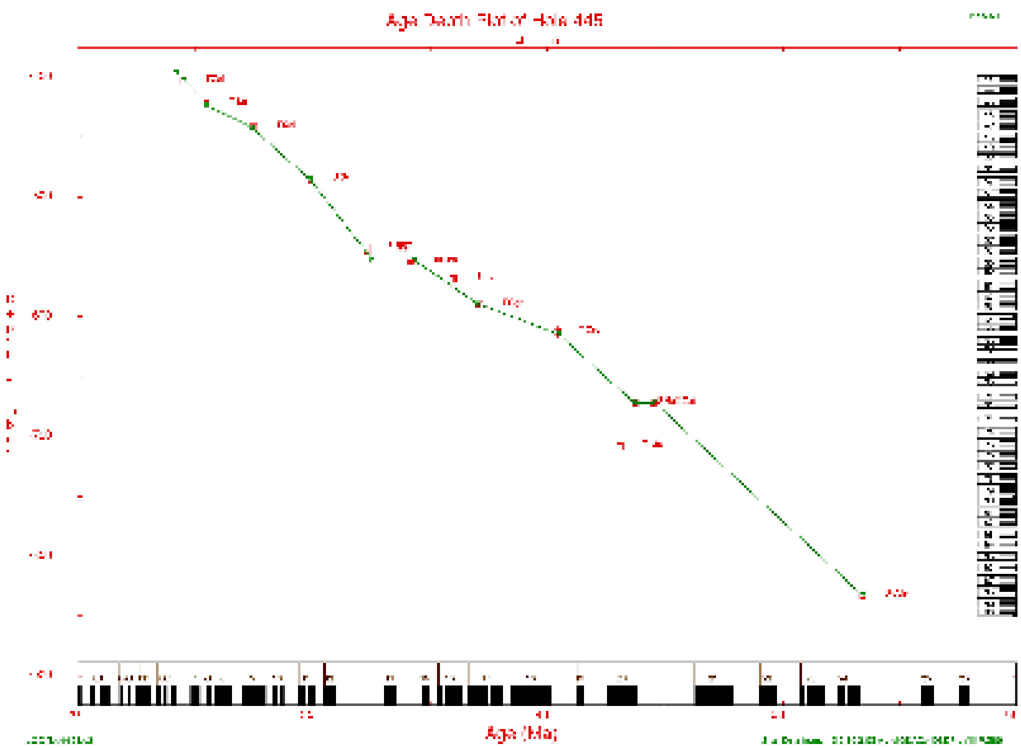
AGE	DEPTH
5	
0.38517255	108.721
1.75166618	288.372
2.6218102	389.535
4.904382	595.349
6.27975638	720.93



445 19950808

AGE	DEPTH
19	
.218488	3.0303
1.74055	50.3788
3.83404	123.737
5.07353	165.182
6.32353	165.182
9.10032	249.364
20.5987	349.77
24.1658	395.833
24.5058	402.91
25.526	423.333
27.3964	441.667
29.8619	484.686
32.5399	552.5
34.3252	552.5
37.0457	589.433
40.4463	614.242
43.6769	671.667
44.5696	671.667
53.4	832.42

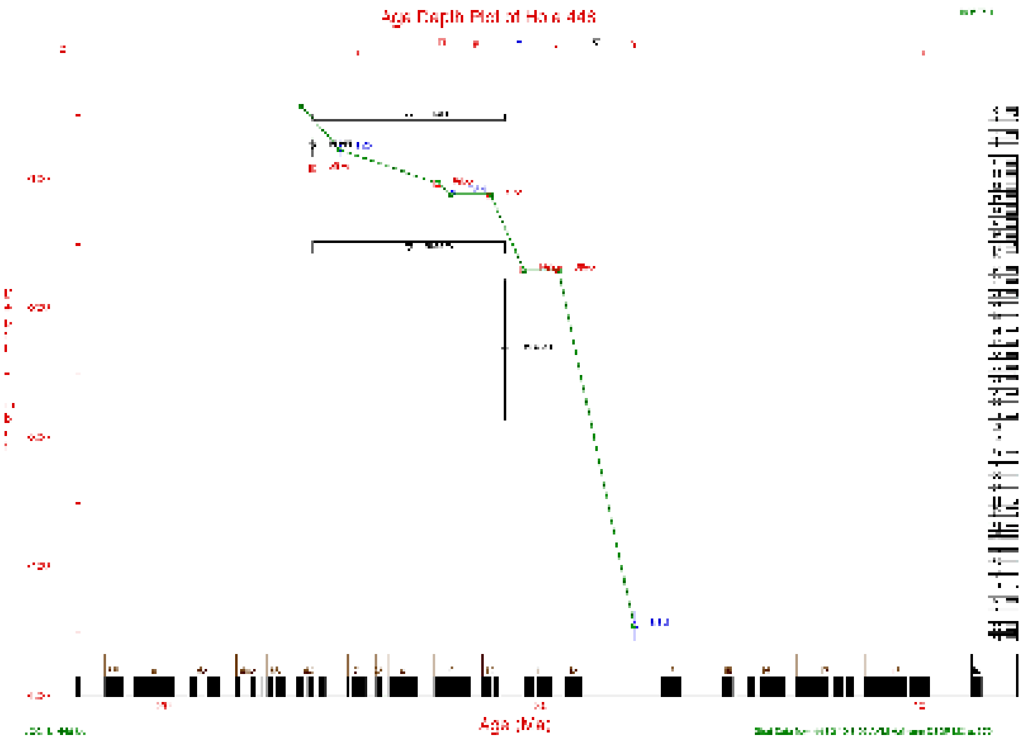




448 19950711

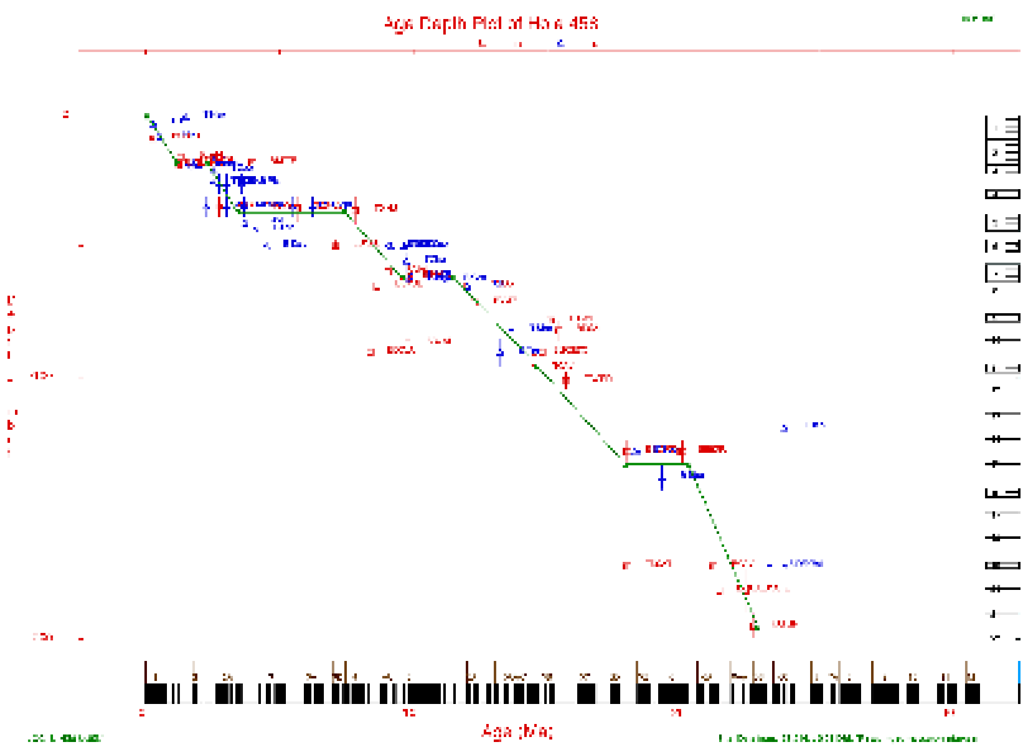
AGE	DEPTH
8	
23.5137	43.6447
24.5116	76.5697

27.1113	102.603
27.479	111.026
28.5032	111.026
29.396	169.985
30.3151	169.985
32.3	444.35



458 19950725

AGE	DEPTH
11	
8.39136e-2	.235756
1.21993	18.389
2.31911	18.389
3.4031	36.9352
7.41749	36.9352
9.53173	62.0498
11.4675	62.0498
14.5588	95.9091
17.8309	133.182
20.1842	133.182
22.7474	195.568

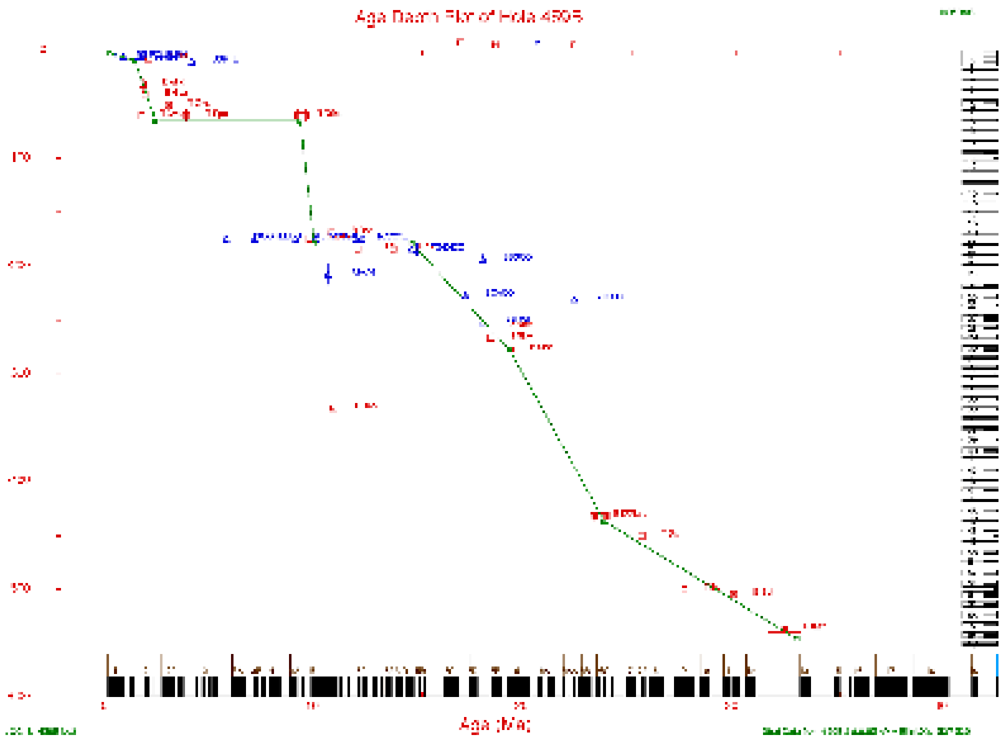


459B 19950808

AGE	DEPTH

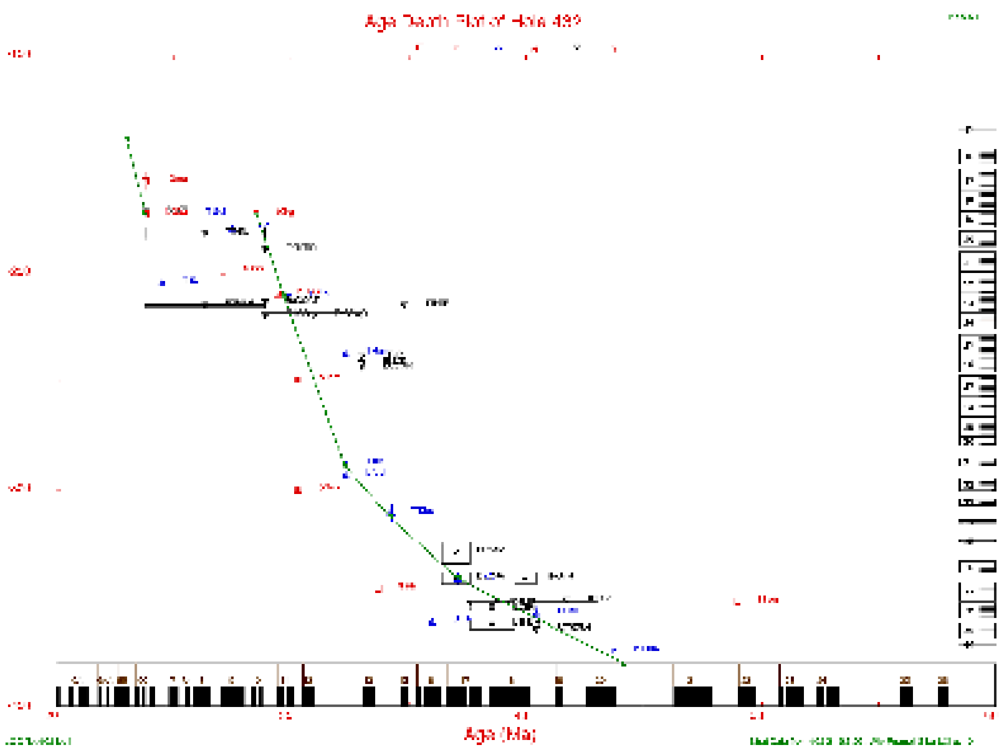
9

.100841	2.33333
1.27941	9.16666
2.28466	64.8333
9.18593	64.8333
9.81618	178.867
14.5168	178.867
19.2143	278.182
23.687	436.447
32.9044	545.789



462 19950711

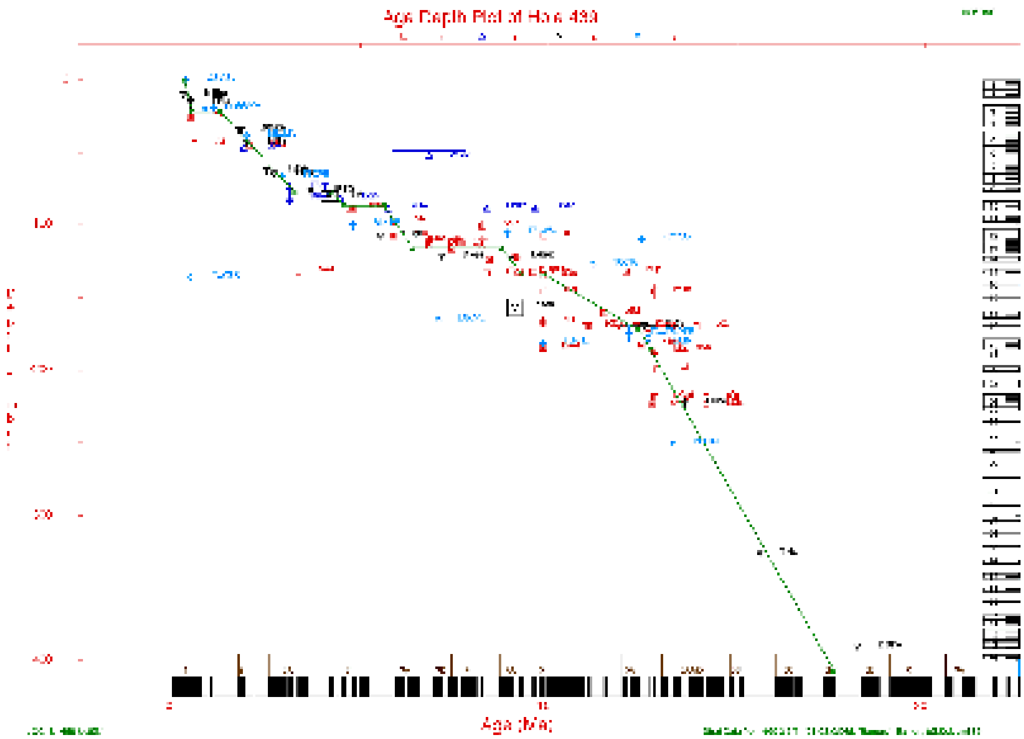
AGE	DEPTH
8	
22.9832	138.636
23.7868	172.045
28.5	172.045
29.6481	210.227
32.2952	289.242
34.1859	312.576
37.0693	340.682
44.1597	379.924



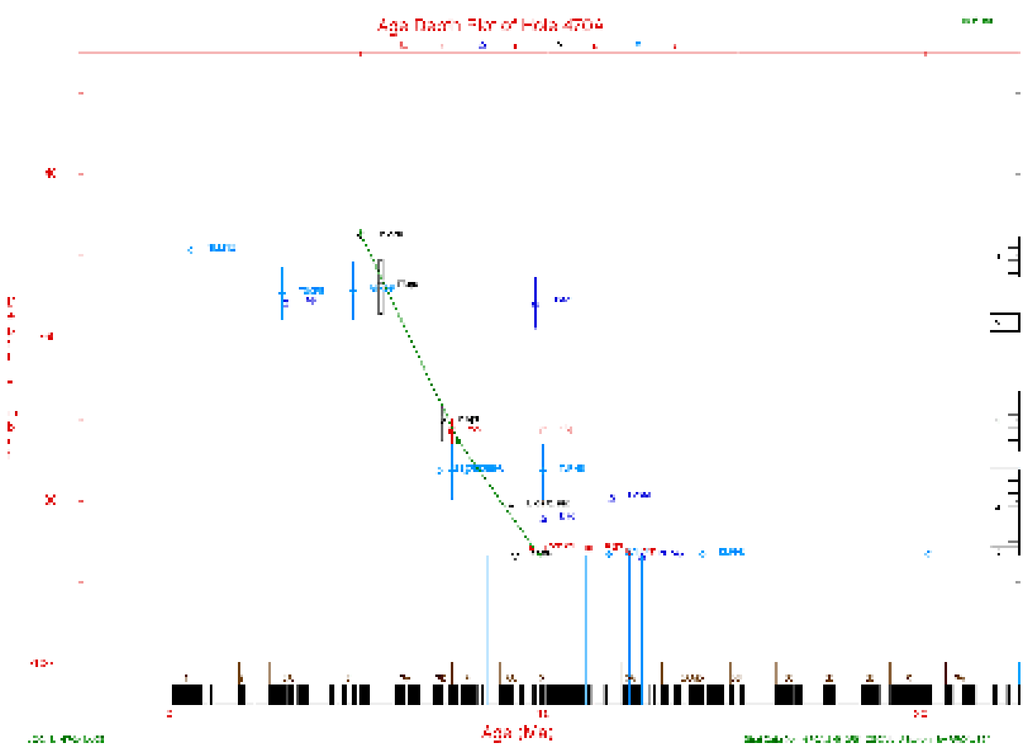
469 19950725

AGE	DEPTH
14.342376	.589391
.534961	21.8075

1.27751	21.8075
3.24655	77.2102
4.18633	77.2102
4.58561	86.6405
5.61559	86.6405
6.36501	115.521
8.71009	115.521
9.26577	133.202
9.84911	133.202
12.3978	172.102
12.7088	186.693
17.563	406.667



470A 19952507

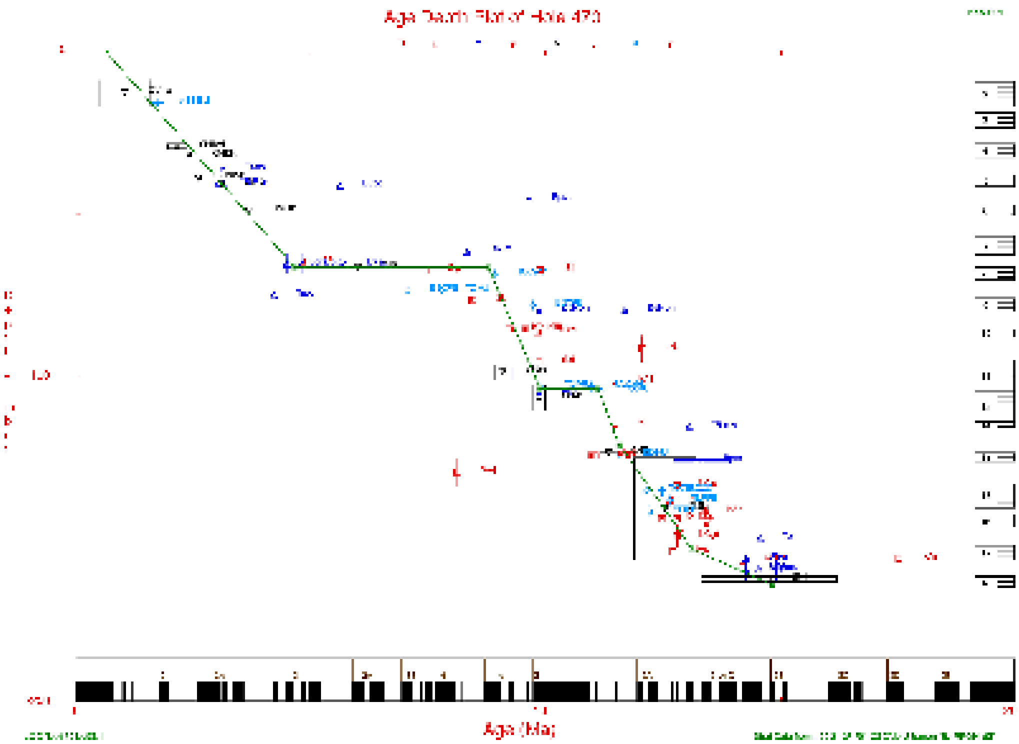


AGE	DEPTH
3	
4.958454	46.9548
7.59855771	72.7701
9.75045707	86.6798

470 19950804

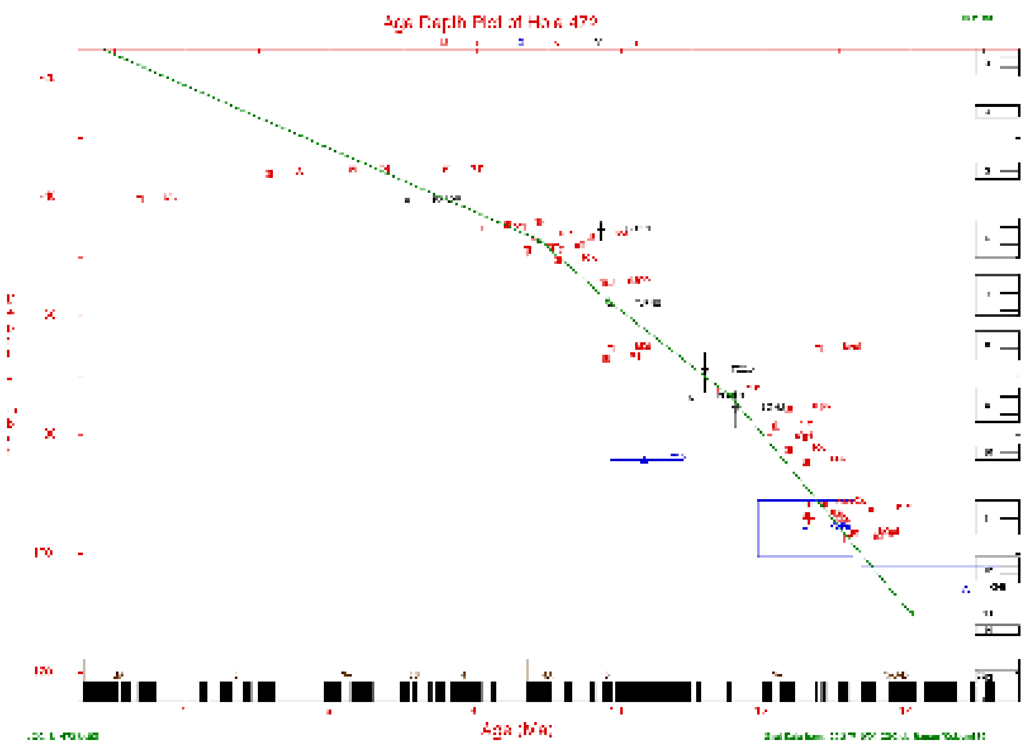
AGE	DEPTH
9	

.608399	.134415
4.65642	66.4047
8.7779	66.4047
9.8831	103.828
11.1158	103.828
11.5635	121.022
12.4903	139.882
13.0902	152.849
14.8227	163.844



472 19952507

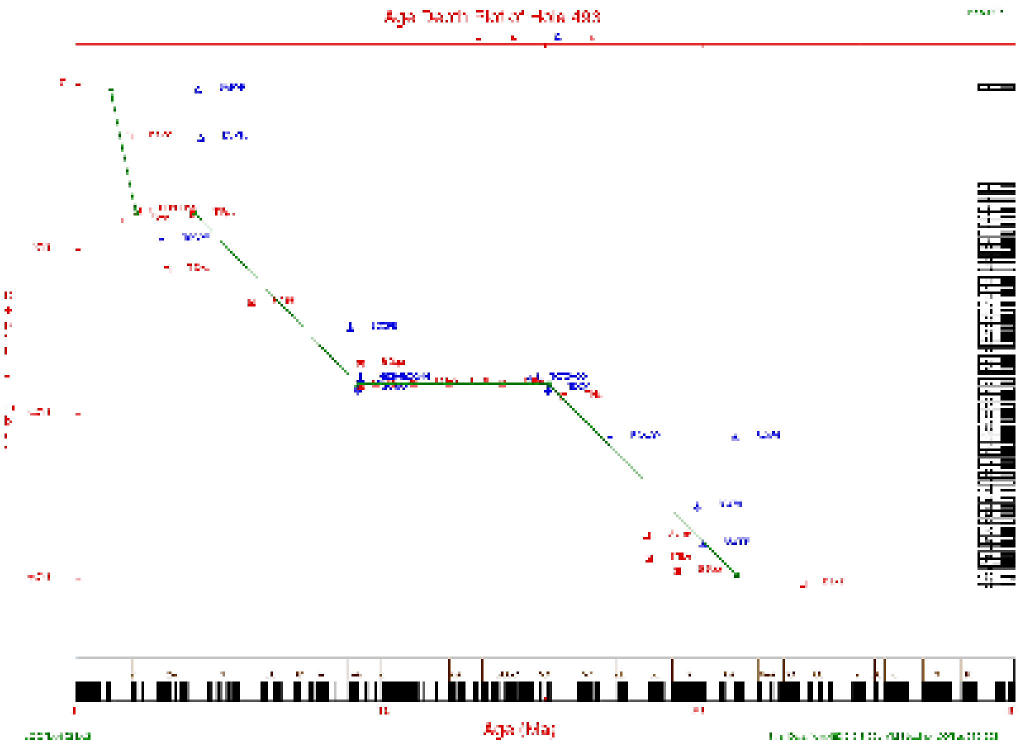
AGE	DEPTH
5	
0.028534	4.65E-08
8.87155916	47.1513
9.81463213	57.2888
11.508555	73.556
13.9918359	110.098



493 19950807

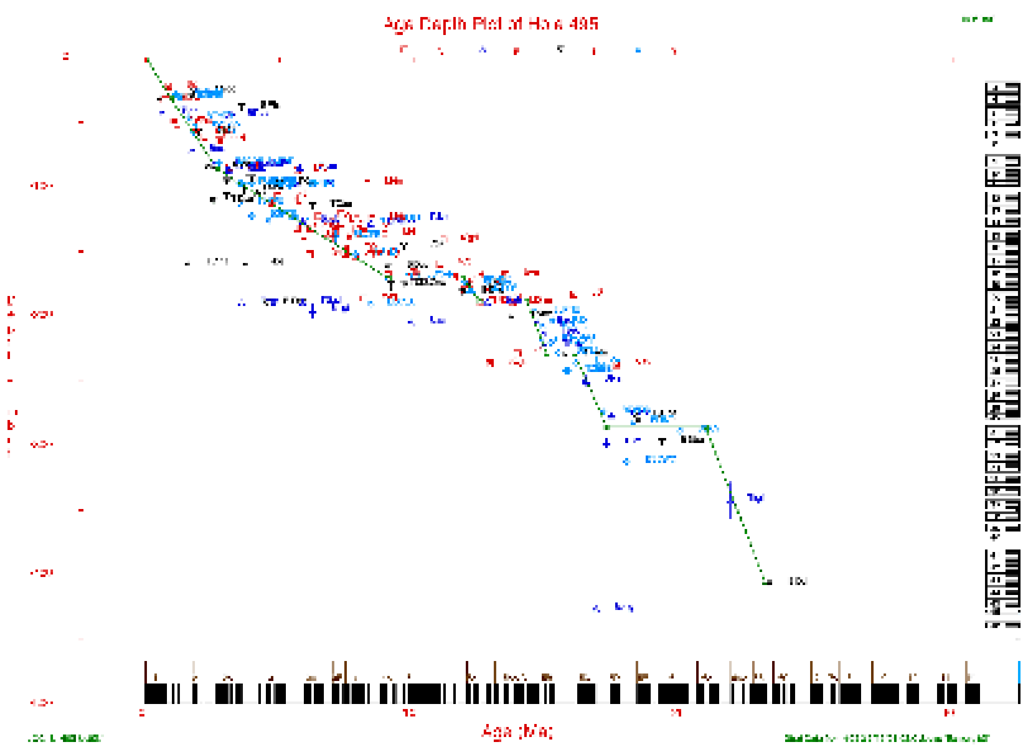
AGE	DEPTH
6	

1.11584	8.5758
1.89706	154.242
3.76103	154.242
8.95324	363.936
15.0744	363.936
21.0893	594.87



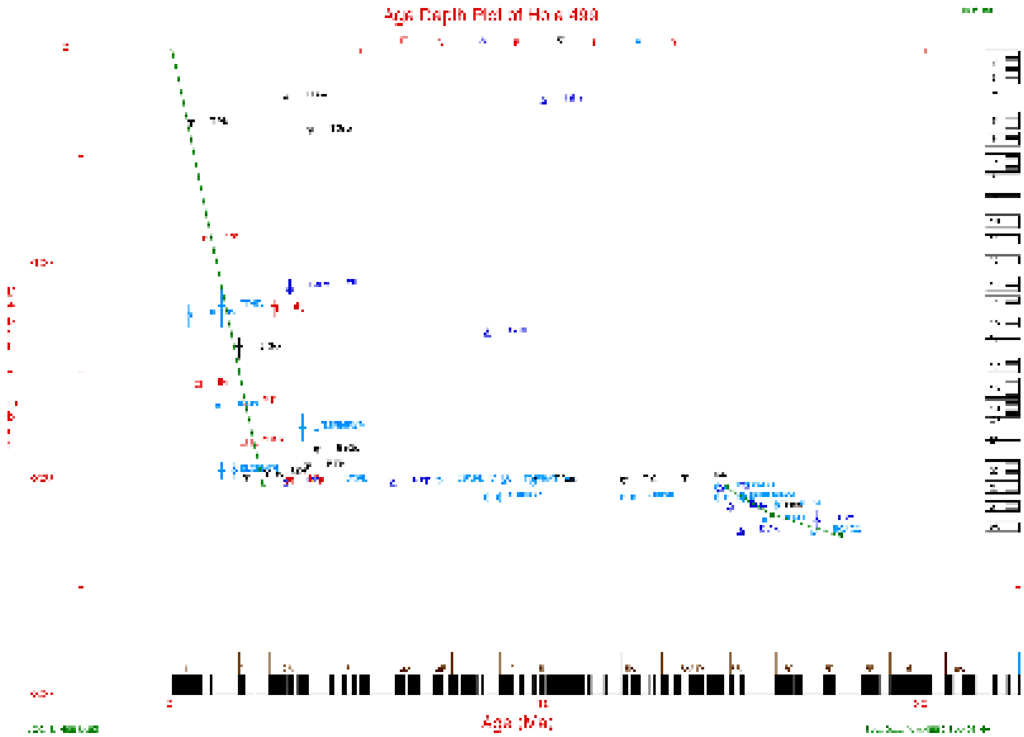
495 19950725

AGE	DEPTH
12	
4.28011e-2	.982318
.956376	32.4165
2.65698	85.8871
9.03966	170.923
11.7965	170.923
12.425	188.409
14.1597	188.409
14.937	228.636
15.943	228.636
17.1399	285.855
20.8085	285.855
23.0035	405.242



499 19952507

AGE	DEPTH
5	
0	0
2.40375317	203.629
14.7013448	203.629
15.9003407	215.86
17.7230736	226.21



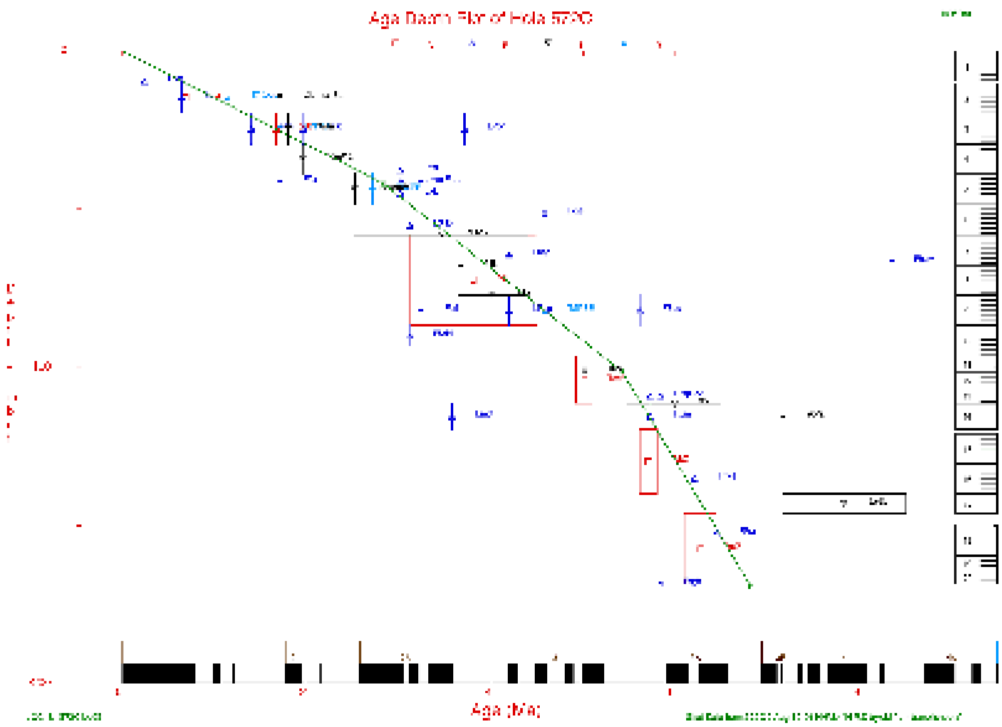
Next Section...

To download full-size diagrams, open the following directory and choose the file (named by hole number). File naming convention is 62A_PICT.GIF (62A = hole number).
DIRECTORY: adps_app

Holes 572C-594

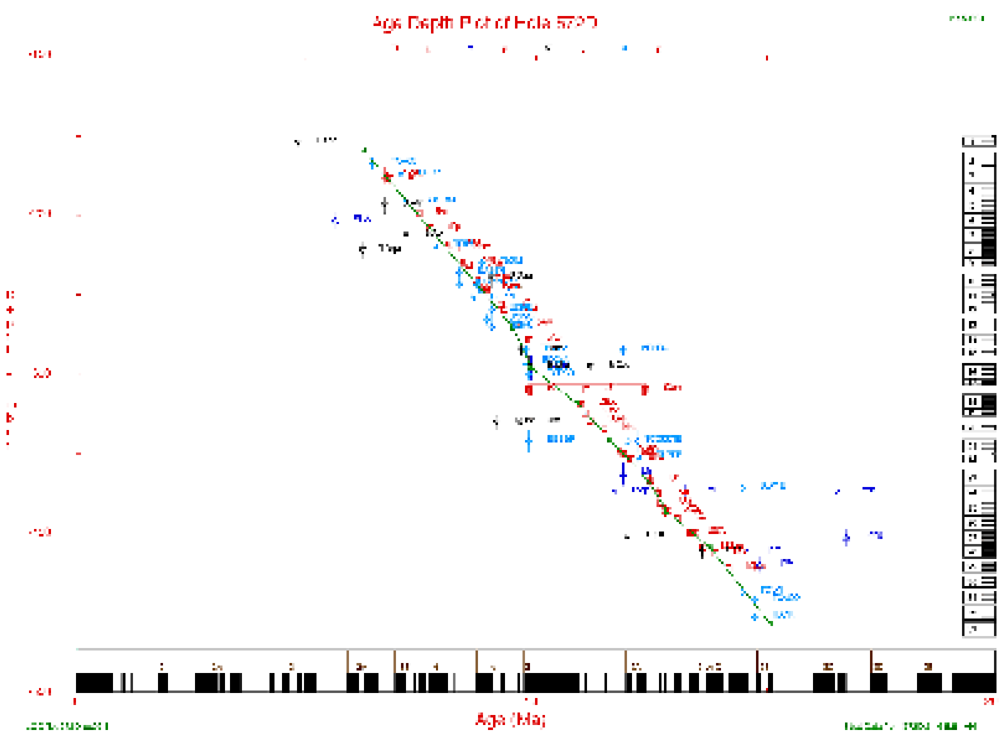
572C 19952507

AGE	DEPTH
4	
0	0
2.8357858	42.0432
5.41273738	100.982
6.82603167	169.352



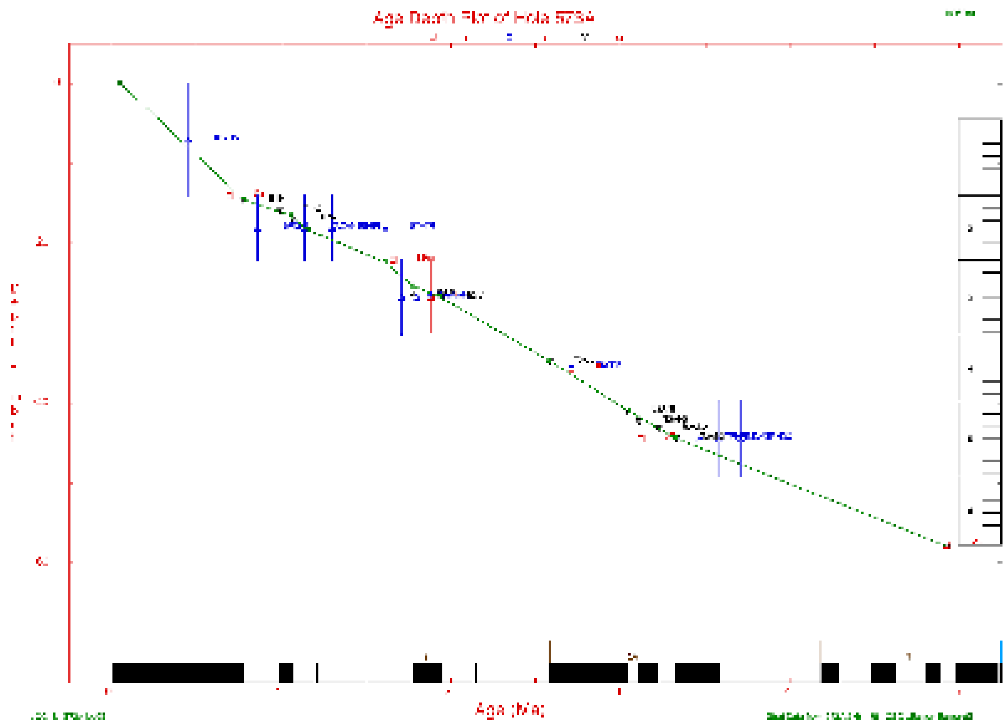
572D 19950803

AGE	DEPTH
9	
6.22868	158.939
9.50053	270.903
9.8831	295.406
10.882	318.07
11.6033	341.257
12.4513	367.397
12.8473	386.027
13.7633	408.841
15.0659	456.778



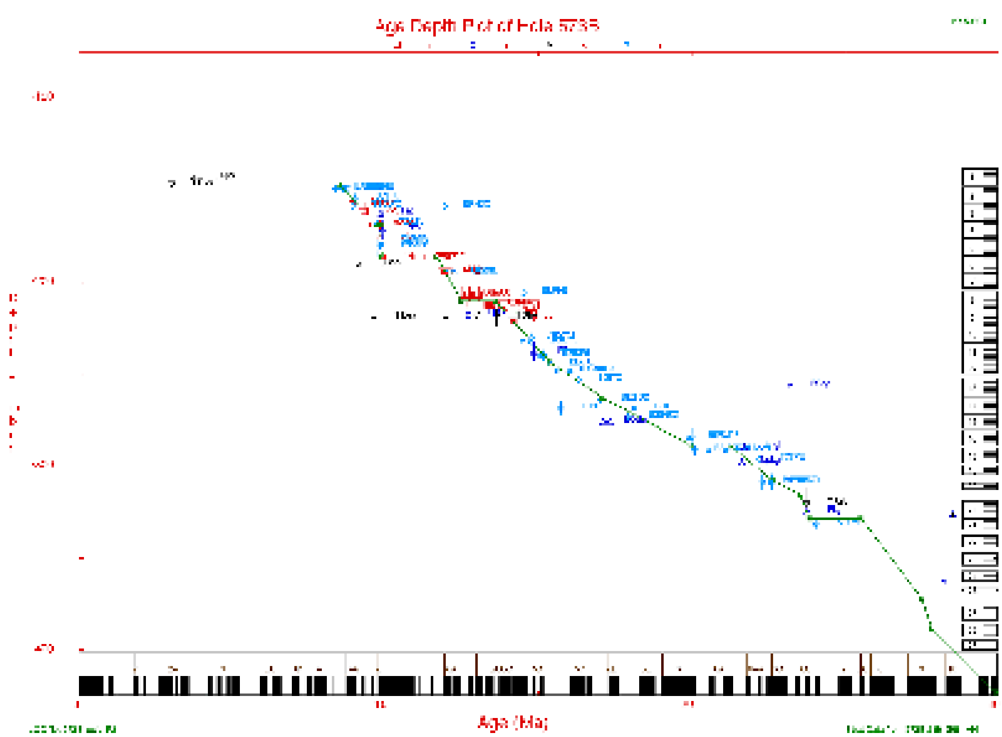
573A 19952507

AGE	DEPTH
11	
0.05029568	1.4114E-08
0.7771717	14.5753
1.05502857	16.4931
1.15515294	18.2192
1.606375	22.2358
1.77260182	25.1761
1.93092818	26.6462
2.57209114	34.5205
3.0416	40.8493
3.324159	44.3798
4.92924	57.8867

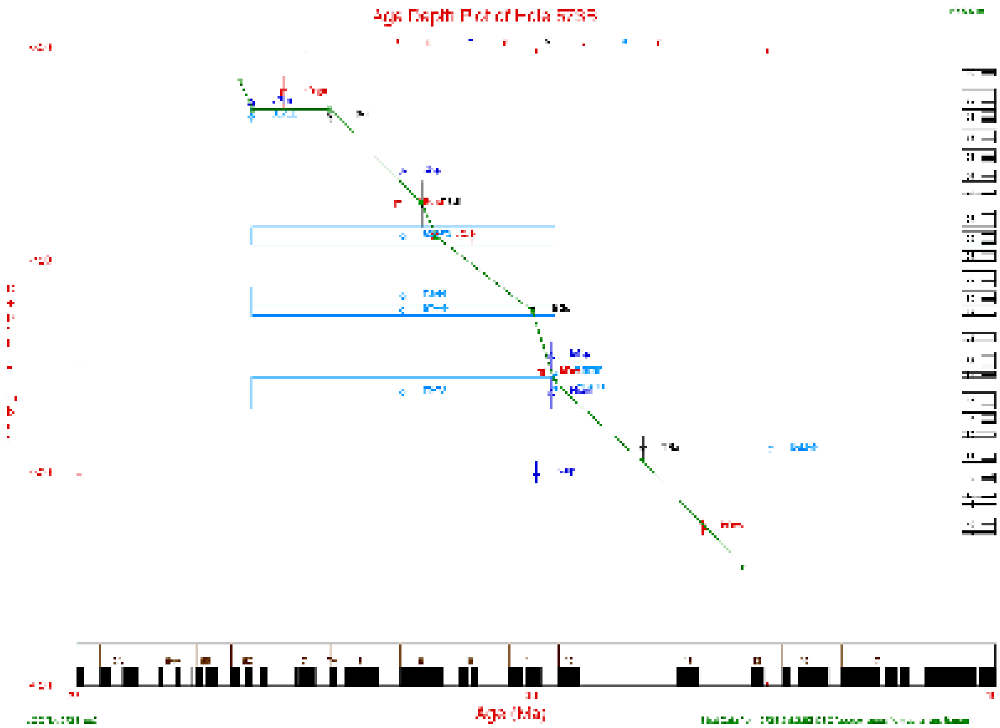


573B 19952407

AGE	DEPTH
15	
8.4604102	147.32
9.68035883	168.453
9.83038587	168.453
9.87402667	186.371
11.6691908	186.371
12.4703315	210.26
13.5554809	210.26
15.3774358	243.548

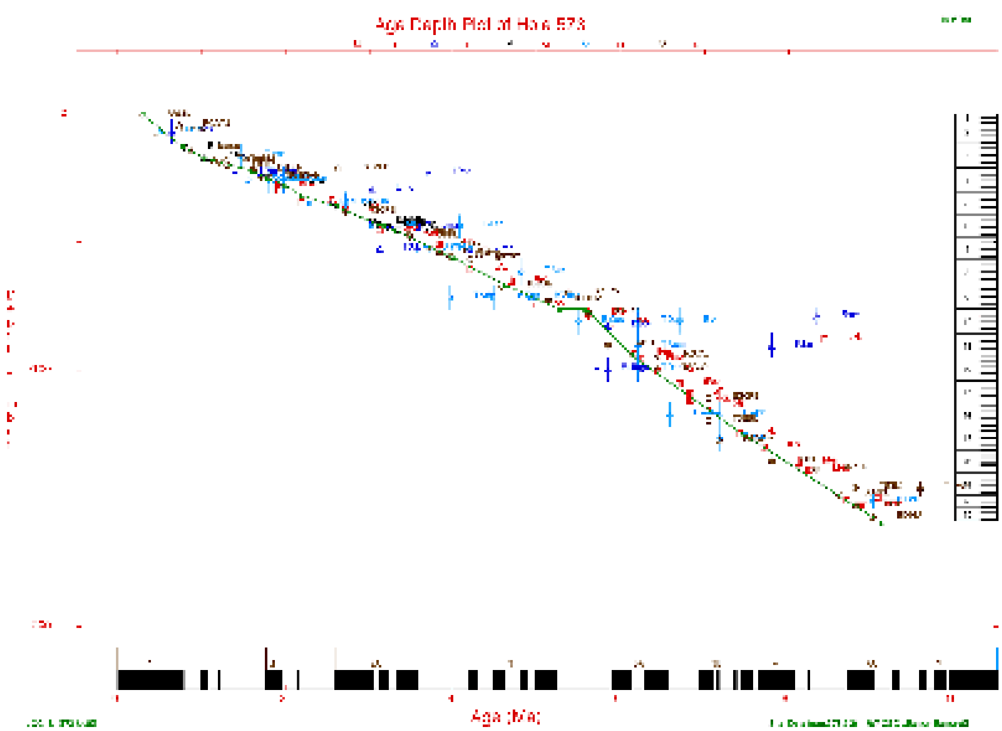


17.0787334	262.769
19.9599845	288.591
21.2687491	288.591
22.5886885	308.04
24.5519033	347.043
26.0815351	347.043
36.03924	543.683



573 19952507

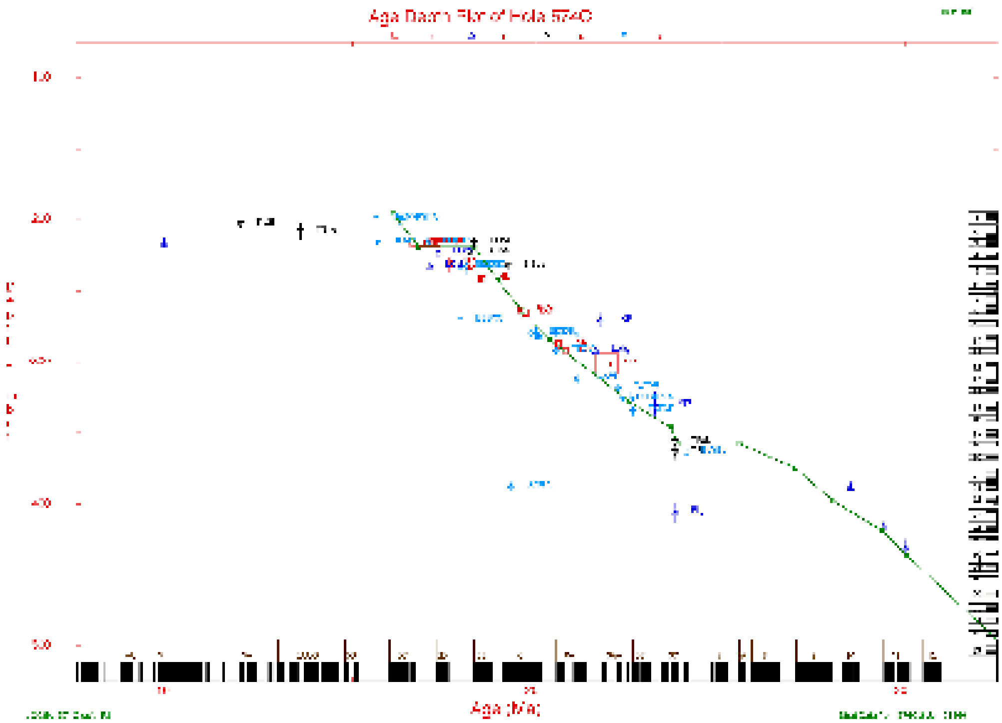
AGE	DEPTH
17	
0.29917808	0.51
0.78361317	12.7419
1.02575086	17.1774
1.60206176	22.0521
1.78543909	25.0383
1.97989229	27.5651
2.20811108	31.853
2.5934644	35.8346
3.17876222	43.7903
3.324797	45.5645
3.9908125	56.2097
4.624995	66.7688
5.27888414	76.0337
5.58053476	76.0337

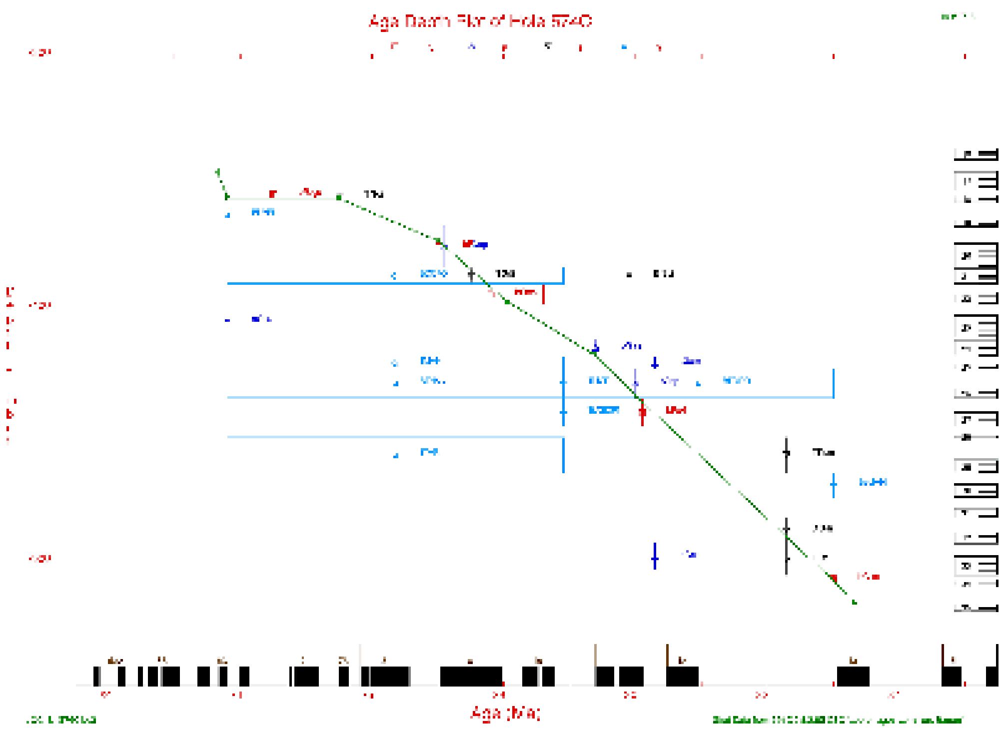


6.115724	93.9516
7.459755	124.866
9.12527575	159.812

574C 19950725

AGE	DEPTH
10	
16.1049	195.789
16.7903	218.76
18.2815	218.76
18.9118	242.273
19.5991	264.012
20.362	284.227
22.5078	327.016
24.4247	385.835
28.5054	385.835
34.3266	520.597



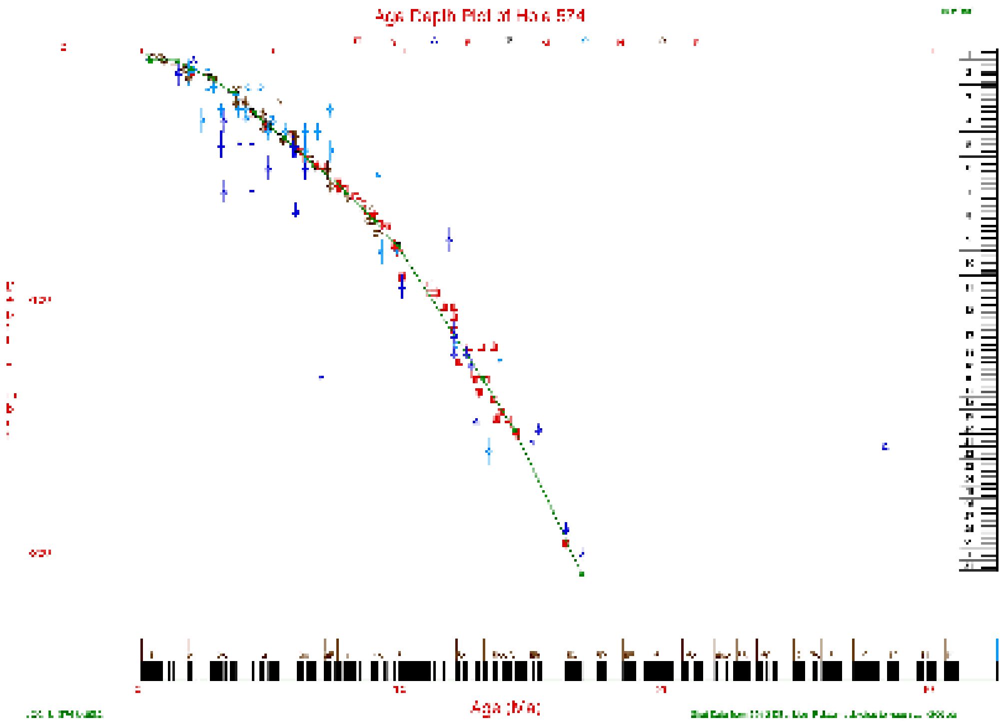


574 19950725

AGE	DEPTH

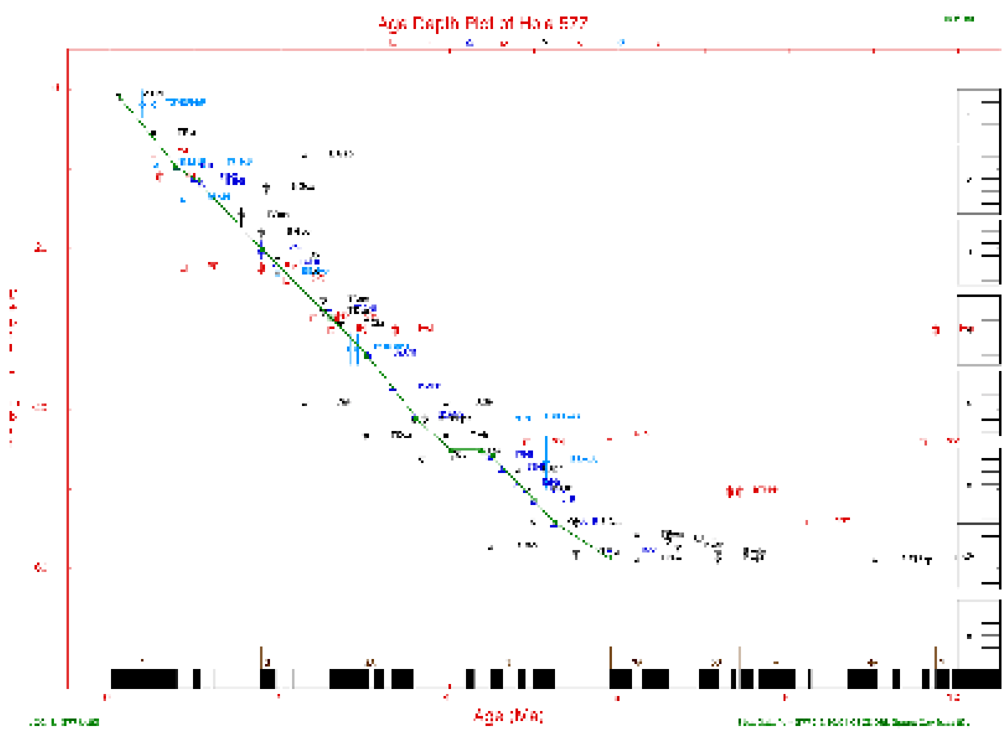
15

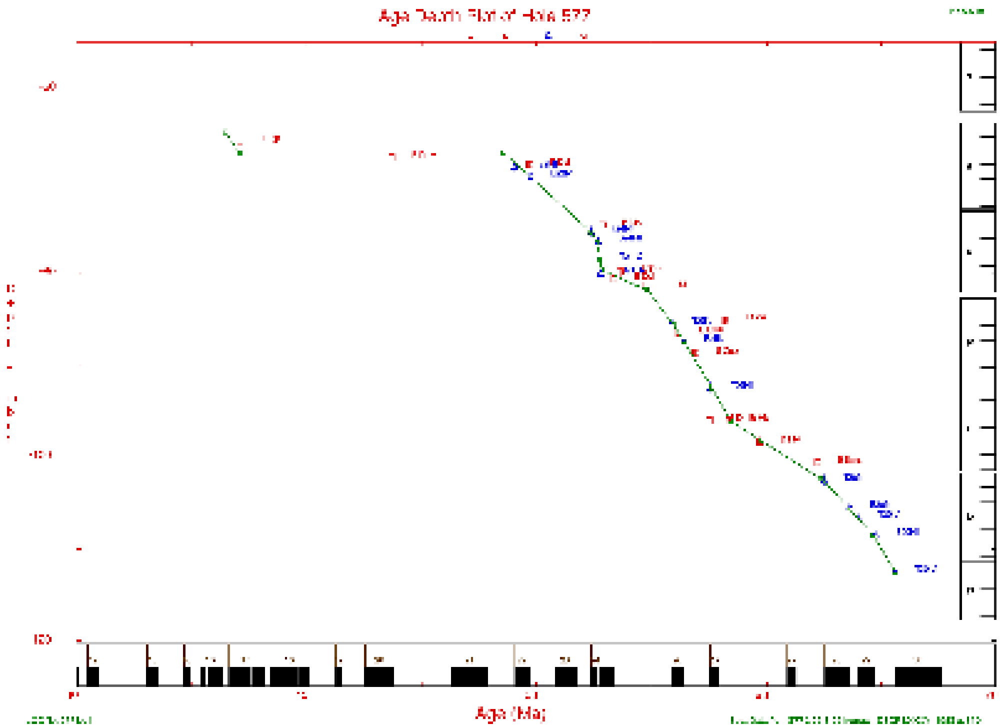
.235068	3.445
.295065	4.5023
1.34111	4.5023
1.7856	7.81011
2.66708	12.0368
3.53242	18.1048
4.24741	25.6355
5.43856	35.4391
6.56324	45.8805
7.81077	56.6256
8.90698	68.9522
9.73687	78.3333
12.91	130.2
14.1958	151.387
16.6846	207.504



577 19952507

AGE	DEPTH
30	
0.09082192	0.875
0.77624211	9.62365
1.02118171	11.3441
1.79018455	19.9462
2.600941	28.5484
3.030973	33.2796
3.6157125	41.2365
4.0175	45.023
4.35227615	45.023



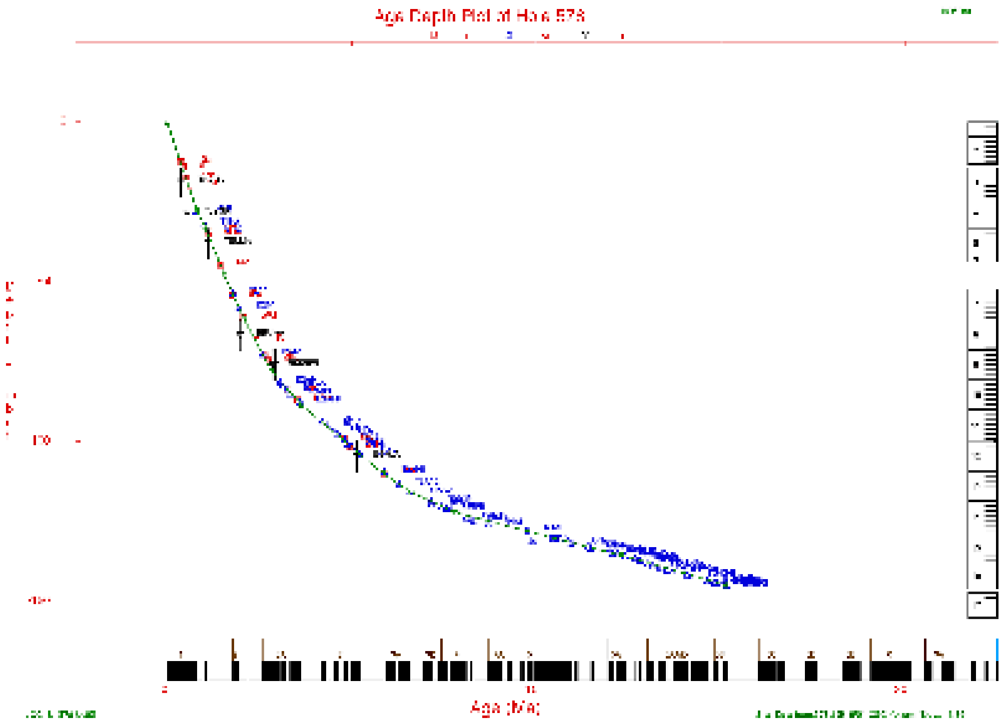


4.49847	45.9677
4.9905	51.3441
5.23801379	54.0995
5.87812124	58.5299
34.9487527	58.5299
36.446	64.7652
37.0691	66.9394
48.5955	66.9394
52.3592	75.5758
52.6194	76.697
52.7843	78.6515
52.8268	79.7121
54.8247	81.9394
55.9299	85.6515
56.3975	87.4545
57.6302	92.6515
58.4506	96.0833
59.7374	98.25
62.3911	102.409
64.644	108.561
65.578	112.5

578 19952507

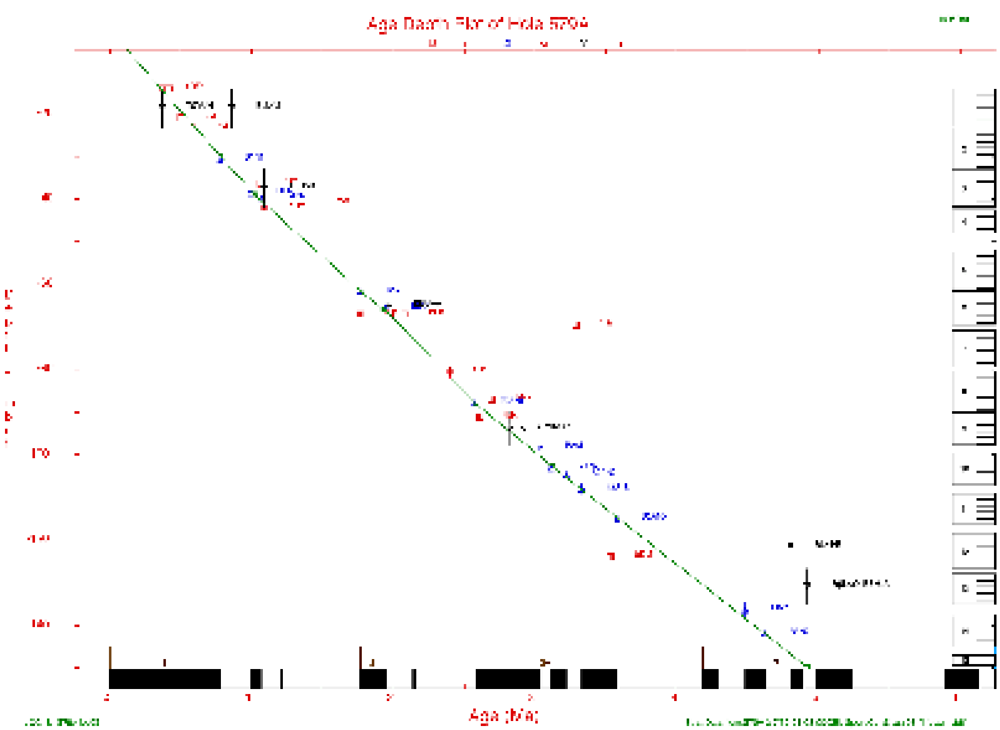
AGE	DEPTH
12	
-0.0095231	2.8229E-08
0.78635833	27.3813
0.99368914	32.5268
1.55028235	48.147

2.0707349	61.6935
2.8150594	78.1011
3.642725	88.6559
5.83493834	109.709
6.61827383	115.957
7.81642502	122.177
12.3023485	135.618
15.155	144.91



579A 19952507

AGE	DEPTH
8	
-0.0071163	0.134415
0.7785554	30.1075
1.02029486	38.9433
1.77545727	61.8836
1.93129636	65.7427
2.5816528	87.9032
3.12113444	102.688
4.919385	149.786



581 19952507

AGE	DEPTH
6	
4.6785675	181.011

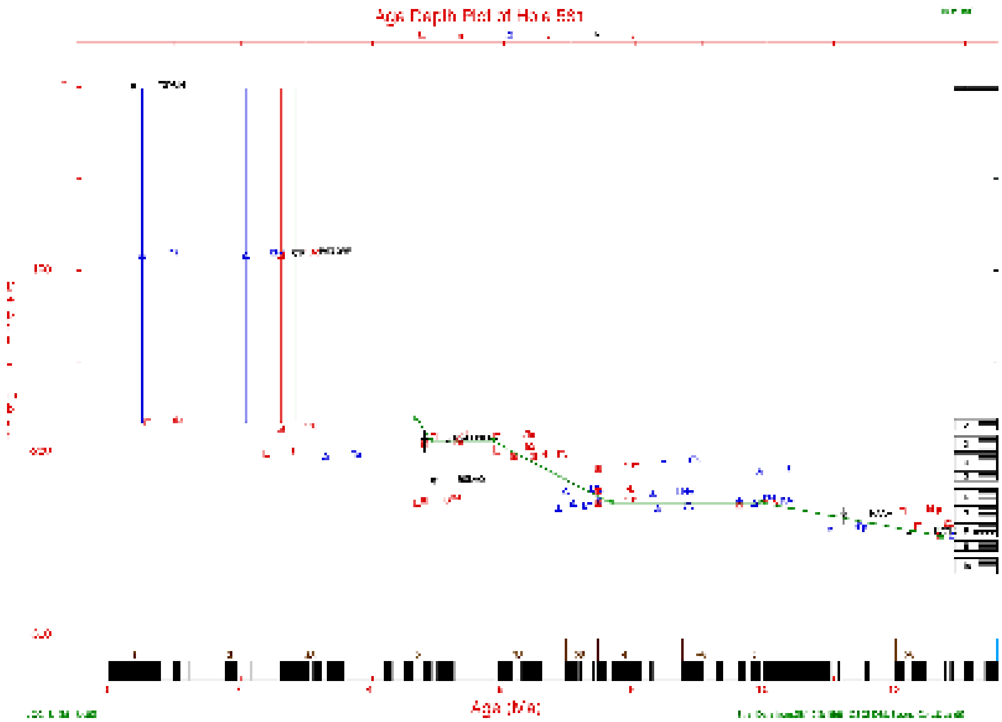
4.87891714 193.415

5.82646662 193.415

7.61546629 227.626

9.90826667 227.626

12.6305026 245.237



586B 19952507

AGE DEPTH

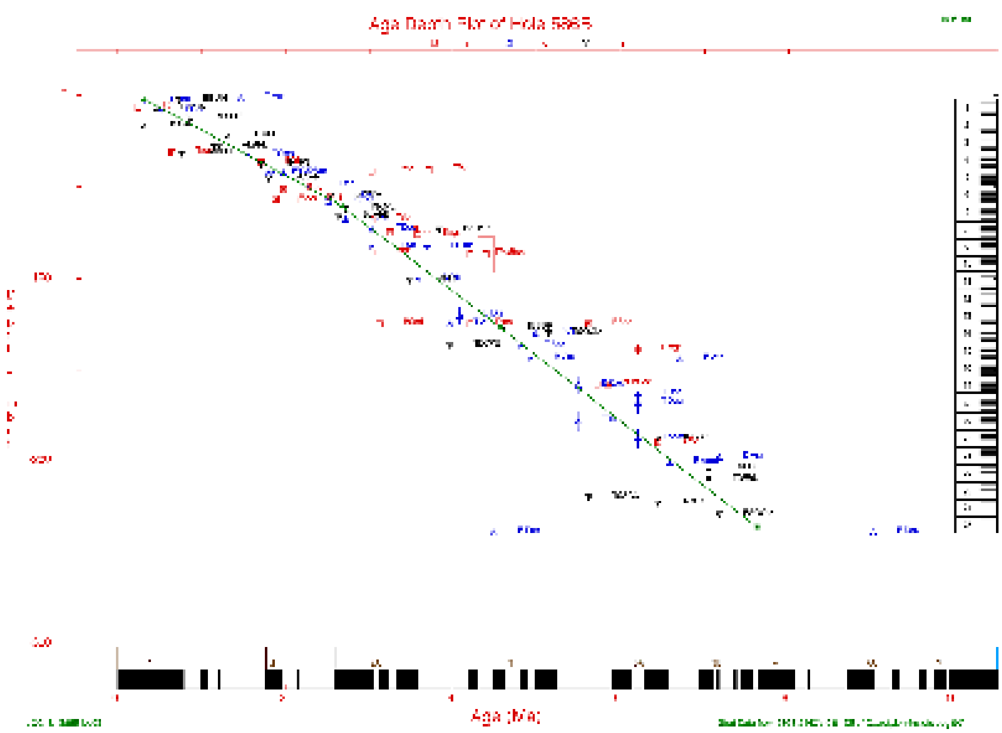
4

0.30229808 1.64384

2.655 1642 60

4.57751 127.397

7.626064 235.89



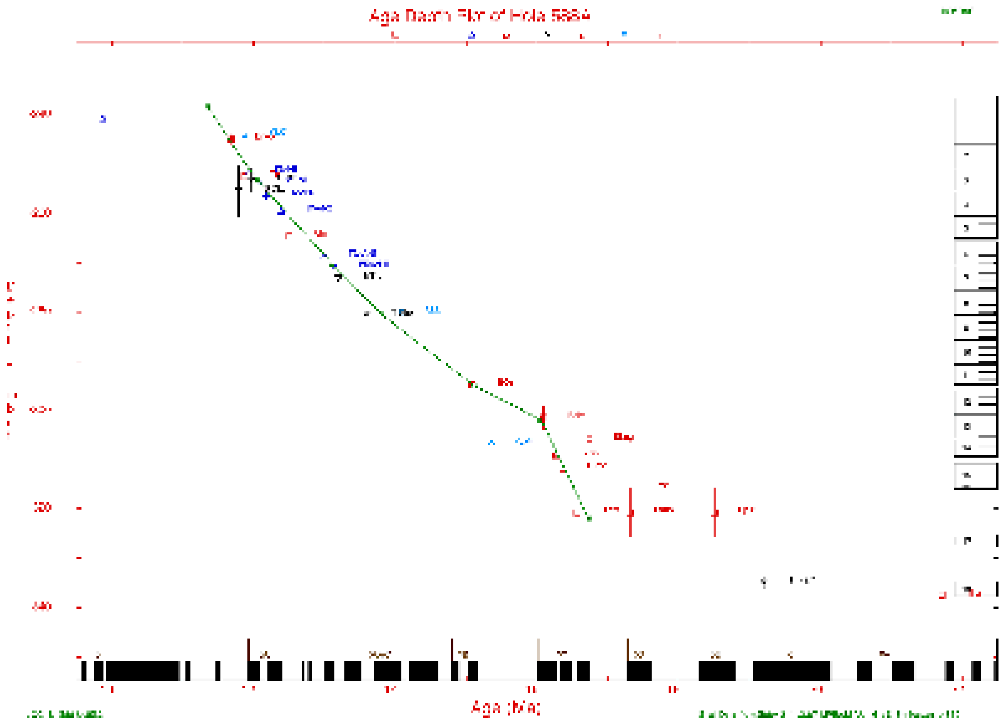
588A 19952407

AGE DEPTH

7

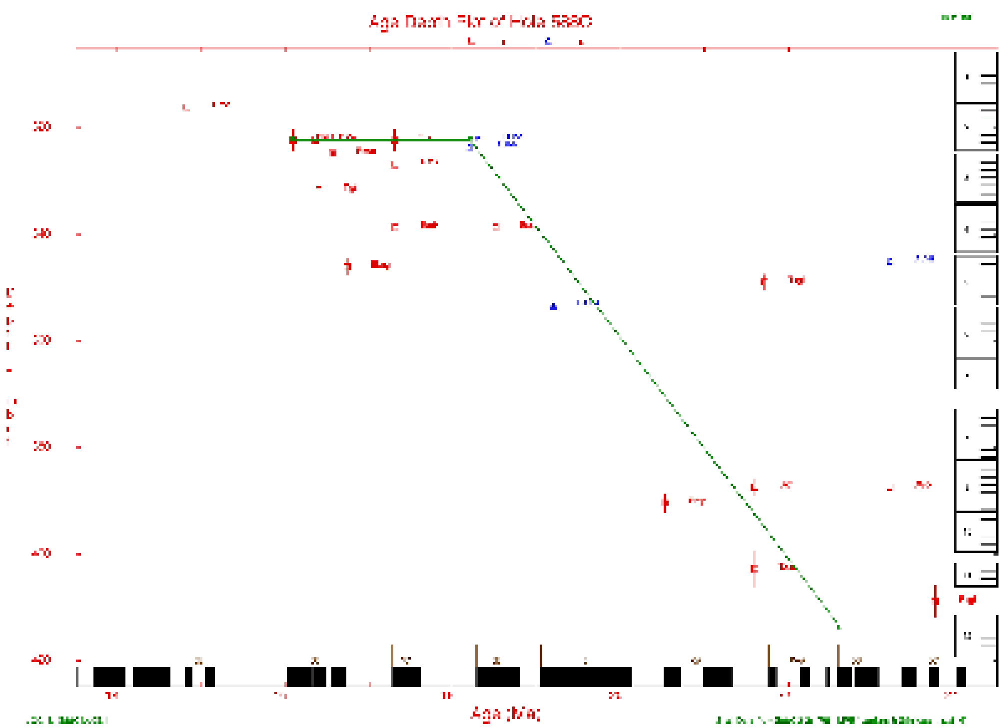
9.8853 239.839

12.0394694	253.065
13.1073444	270.161
14.4181152	281.263
15.118095	294.892
16.049526	301.761
16.7227889	321.975

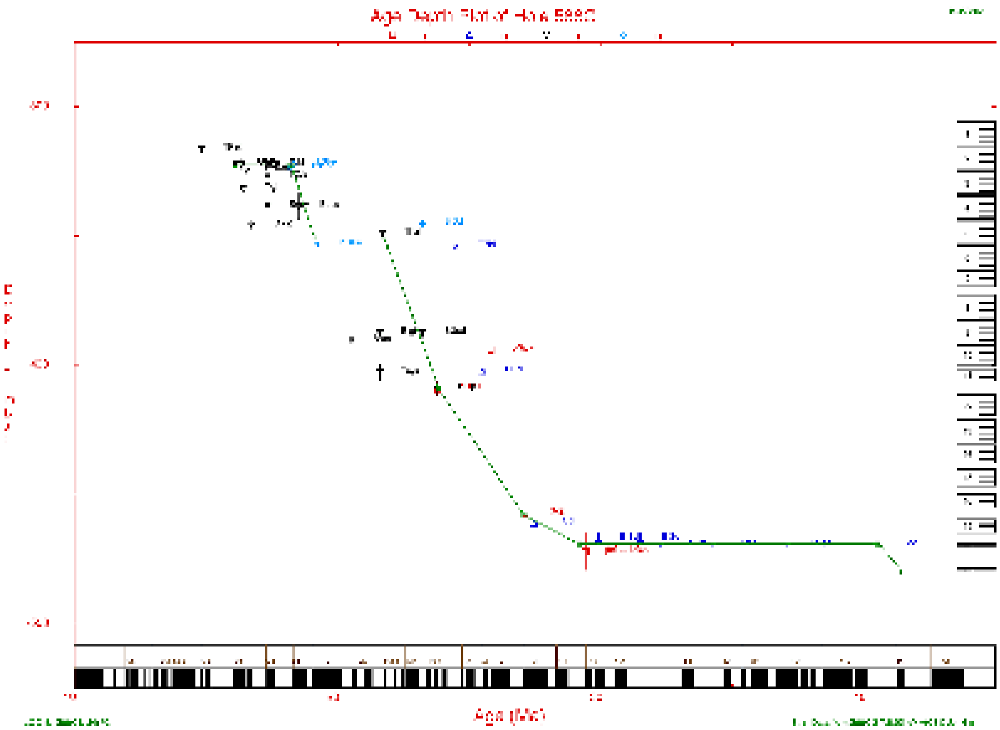


588C 19950802

AGE	DEPTH
9	
16.0858	322.258
18.2017	322.258
19.1126	350.379
21.7535	350.379
23.8363	409.091
27.0723	457.955

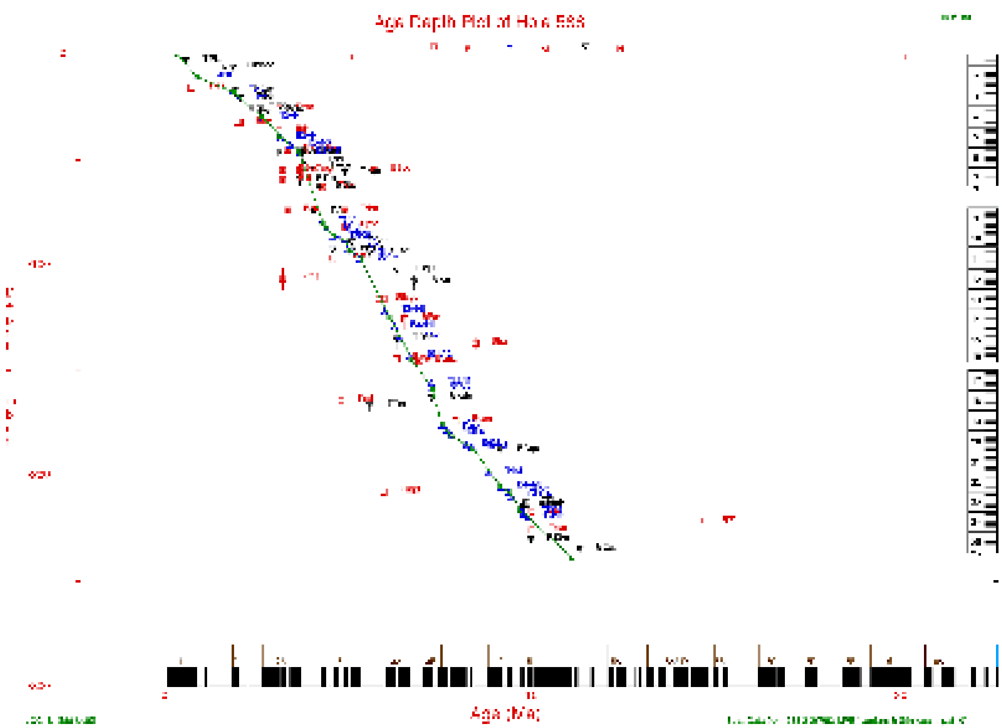


29.2083	468.977
40.5367	468.977
41.4665	479.786



588 19952507

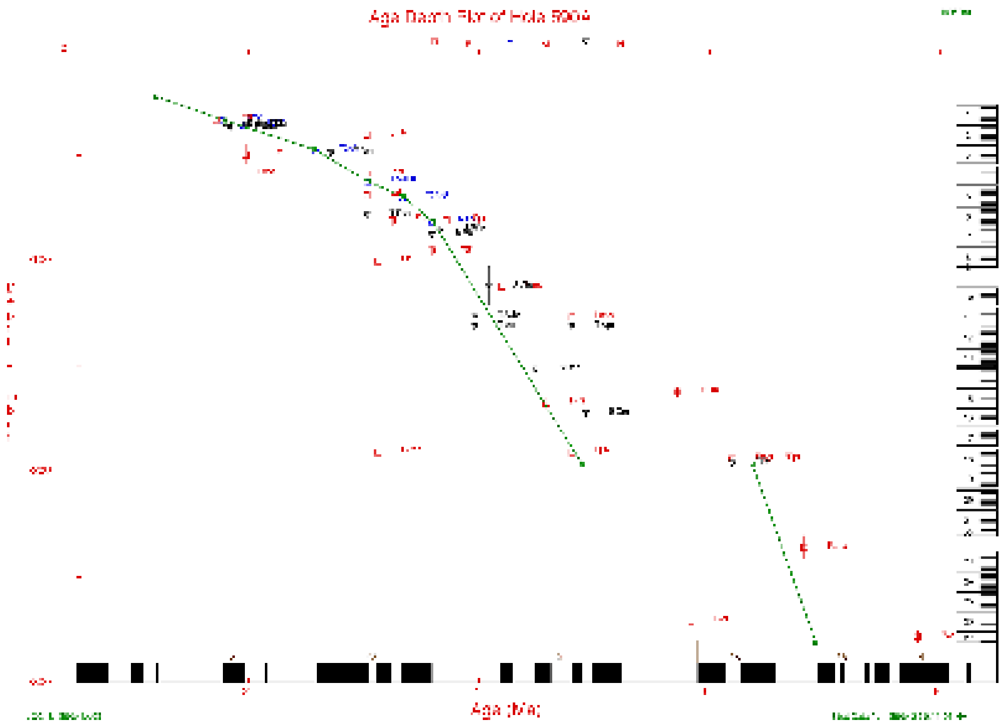
AGE	DEPTH
22	
0.27136414	2.5876E-08
0.77338603	10.4441
1.82999727	17.856
2.57403761	29.9847
3.0341758	38.4073
3.57639773	46.1562
4.18697889	79.3415
4.29672308	82.879
4.48159	86.0796
4.8	88.2695
4.924146	92.3124
5.2278125	96.3553
6.003971	124.579
6.61926783	144.355



7.16871308	158.576
7.4171053	174.885
7.69418242	181.048
8.27060278	186.371
9.02869	204.747
9.24030467	206.585
9.56333029	215.773
10.9826883	238.441

590A 19952507

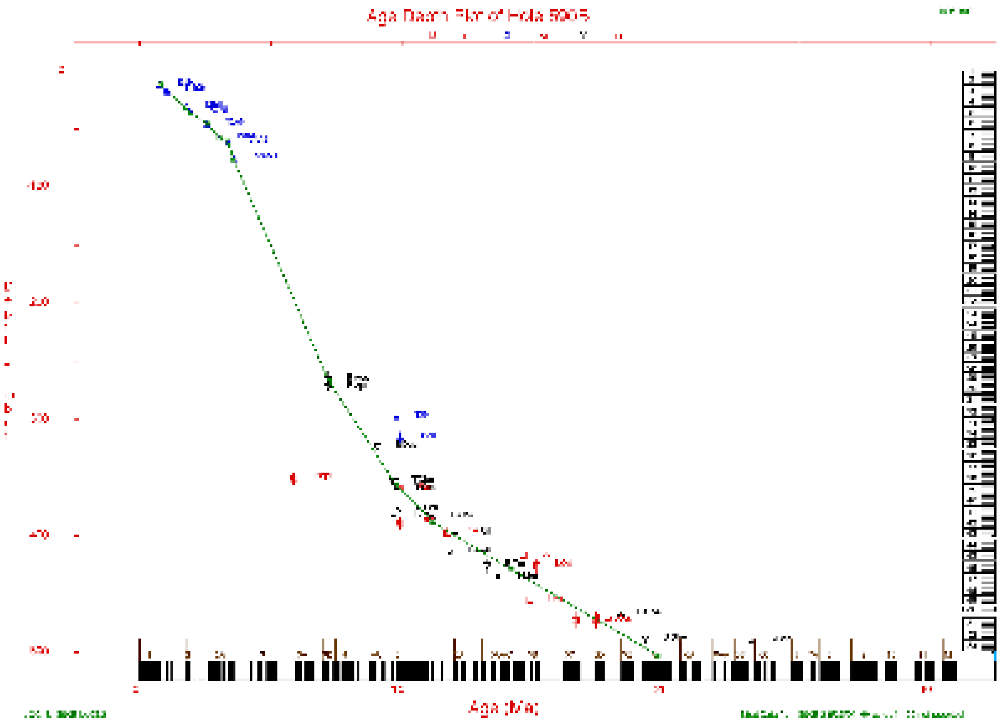
AGE	DEPTH
9	
1.19500147	22.043
1.78467818	33.3333
2.57882893	47.4462
3.0362974	62.5
3.34585227	70.0269
3.5893375	81.3172
4.88739	196.102
6.36707038	196.102
6.9224615	280.779



590B 19950803

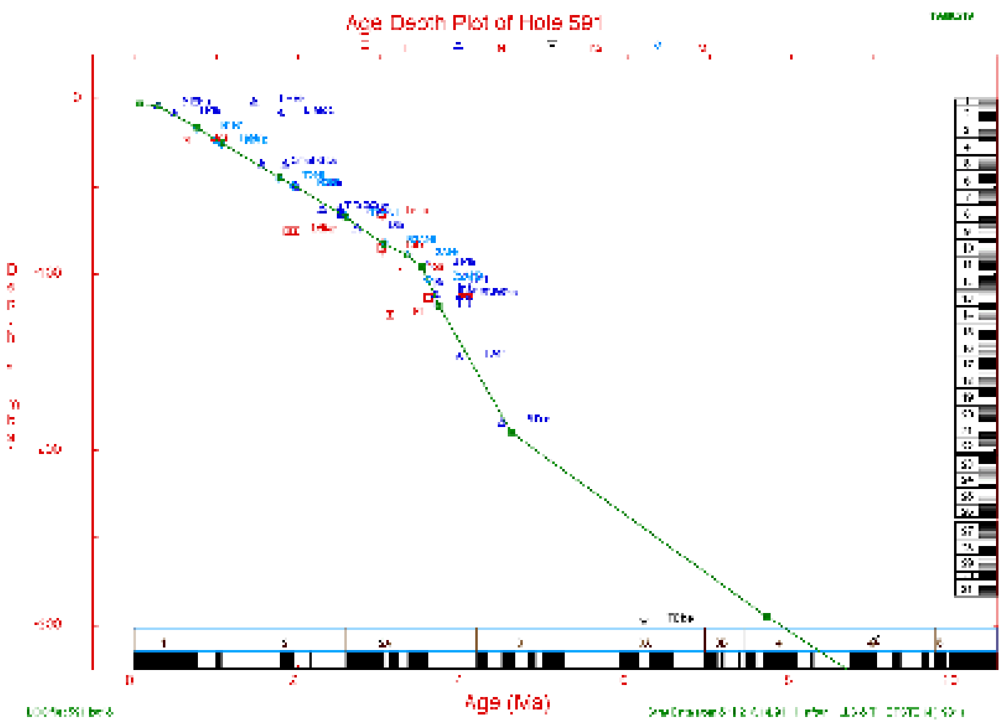
AGE	DEPTH
12	
.768099	11.5591
1.75824	31.6667
1.95369	35.8064
2.57121	45.8602
3.03085	57.3925

3.33574	61.2365
3.58045	75.7258
7.17487	267.075
9.74211	356.508
11.0875	387.902
14.1169	429.041
19.6691	502.603



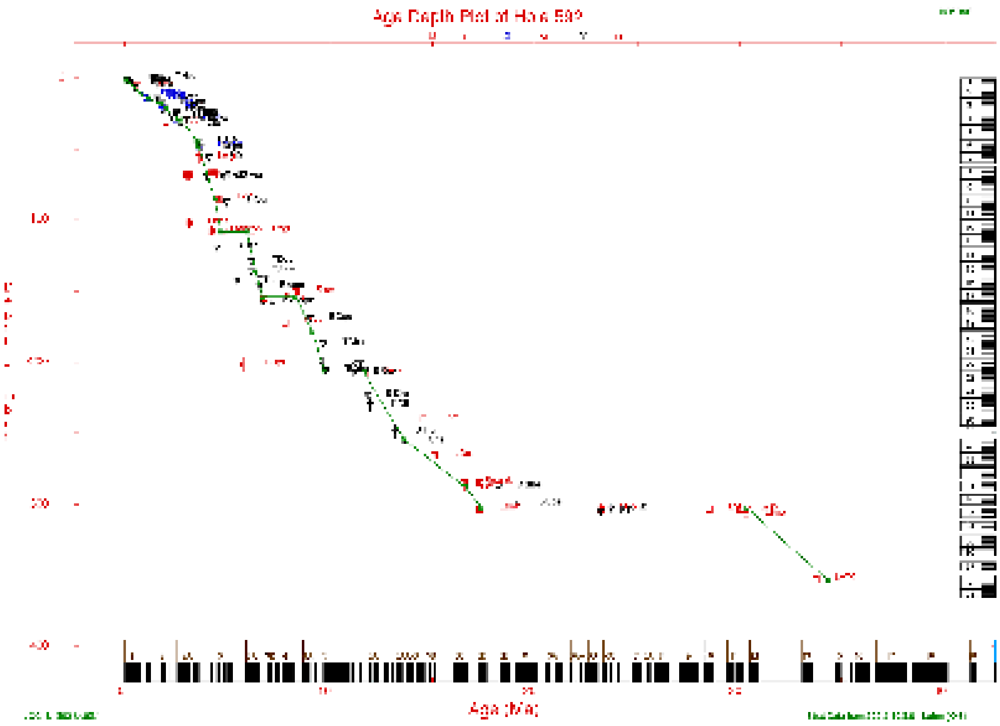
591 19952507

AGE	DEPTH
16	
0.0779516	2.82259
0.29754436	3.89784
0.7785554	16.6667
0.995248	23.3871
1.07318809	25.4032
1.77666818	44.8925
1.95368975	49.5968
2.5816528	67.0699
3.04082	82.5269
3.324797	89.2473
3.50827273	95.7121
3.7136375	117.917
4.58829	189.893
7.68561484	294.793



9.78029667	358.346
14.8491822	449.464

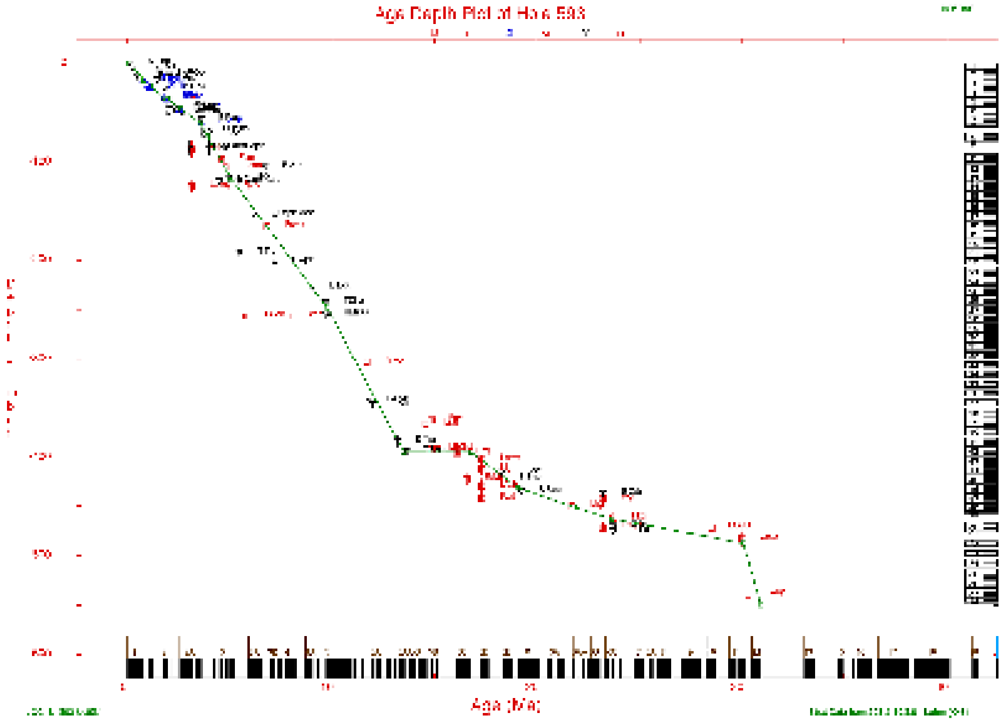
592 19950725

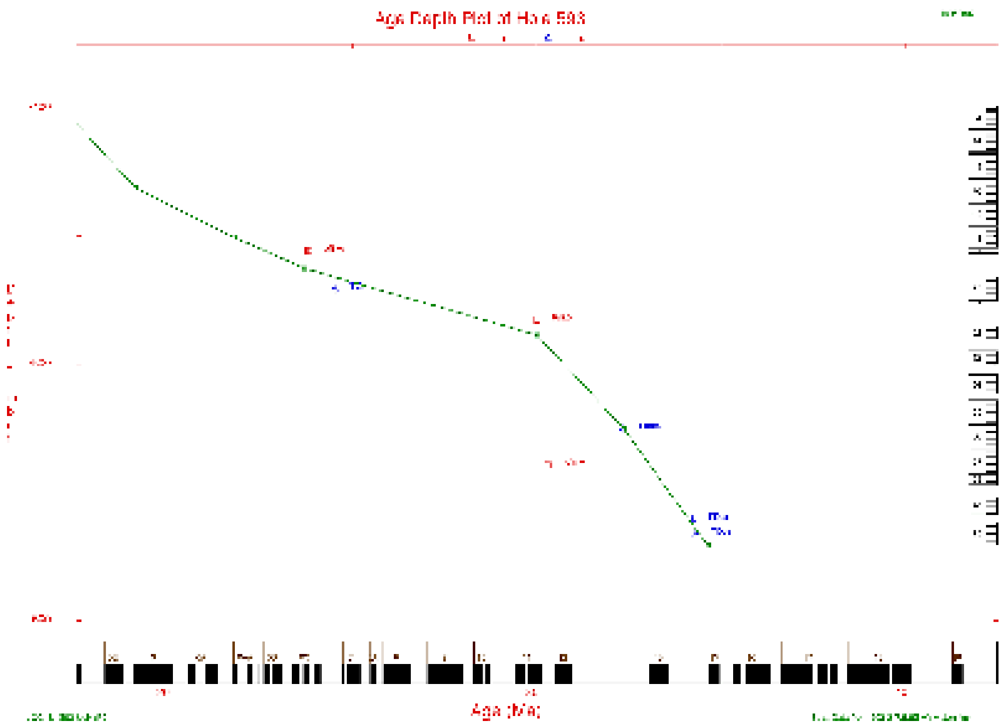


AGE	DEPTH
23	
.101452	1.45161
.777172	10.8602
1.08611	14.086
1.76671	18.9247
1.94769	21.8817
2.58227	28.3333
2.73865	29.589
3.51773	43.8356
3.58088	47.6882
4.39367	86.5591
4.68229	108.064
5.97639	108.064
6.33172	134.274
6.69506	153.763
8.34621	153.763
9.18248	178.63
9.75776	207.123
11.6334	207.123
13.6187	253.864
16.5966	287.273
17.4002	302.273
30.3561	302.273
34.2536	352.545

593 19950802

AGE	DEPTH
18	
9.08219e-2	.03
.799269	16.2366
1.07624	22.6882
1.78306	33.9785
1.94769	35.0538
2.58227	45.8064
3.54813	59.7849
3.8985	73.6559
5.08569	116.343
9.74238	247.645
13.4769	394.545
16.7857	394.545
19.1019	430.985
21.7932	450.415
23.7043	462.5
30.	488.636
32.3486	524.962
34.6227	570.903

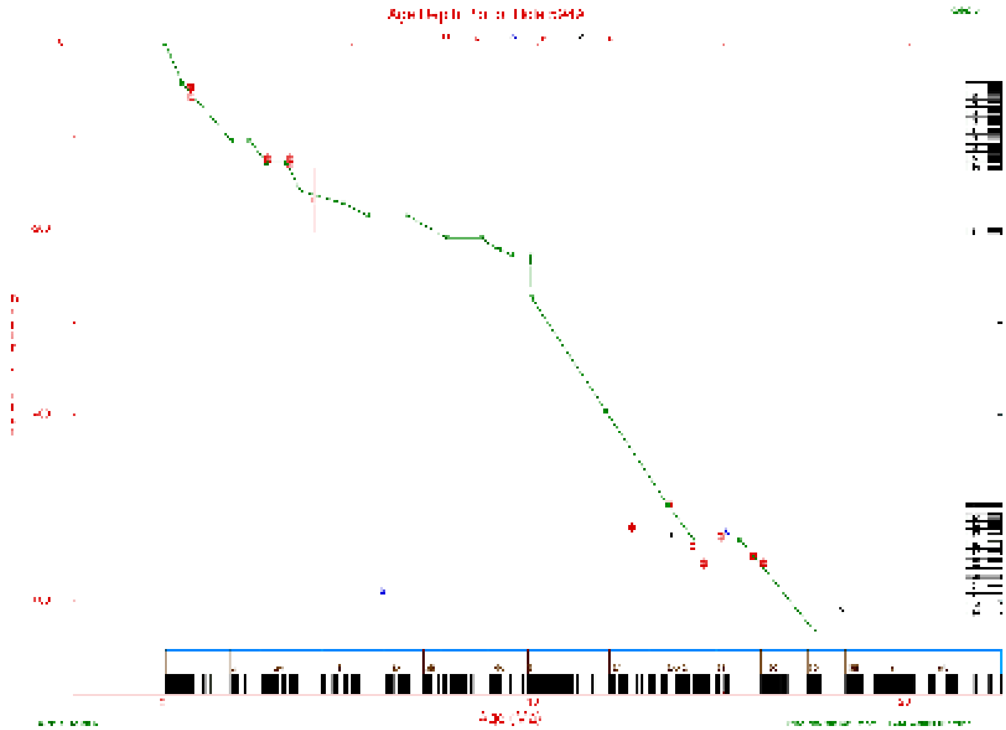




594A 19952507

AGE	DEPTH
21	
5.6594E-07	4.7047E-08
0.45419721	43.951

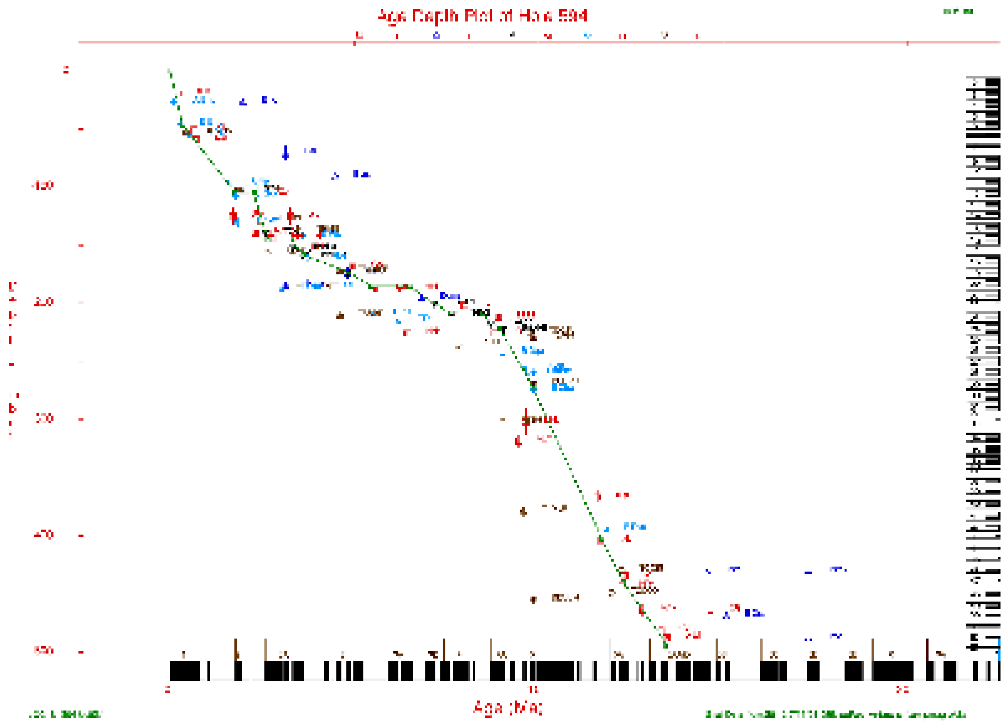
1.76051912	104.747
2.25941459	104.747
2.7064498	127.565
3.268774	127.565
3.6024875	158.652
4.79643375	172.818
5.44970386	184.763
6.47276105	184.763
7.59911086	209.265
8.48852682	209.265
8.95168155	222.818
9.31007238	227.412
9.81005227	227.412
9.84377733	273.354
11.8602283	395.559
13.522587	497.397
14.2159278	533.844
15.4730108	533.844
17.4801073	633.537



594 19950804

AGE	DEPTH
17	
5.6594e-7	4.7047e-8
.339205	46.8606
1.76052	104.747
2.25941	104.747
2.63589	144.87
3.26877	144.87

3.60249	158.652
4.79643	172.818
5.4497	184.763
6.47276	184.763
7.59911	209.265
8.48853	209.265
8.95168	222.818
9.84378	273.354
11.7045	403.091
12.2902	440.276
13.454	493.874



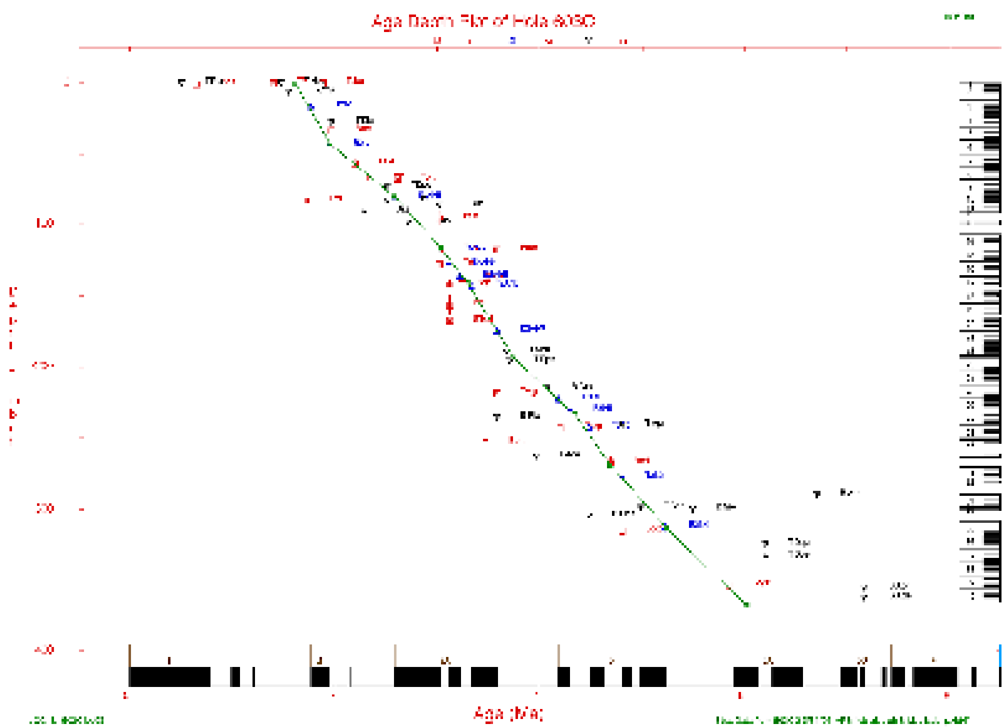
Next Section...

To download full-size diagrams, open the following directory and choose the file (named by hole number). File naming convention is 62A_PICT.GIF (62A = hole number).
DIRECTORY: adps_app

Holes 603C-699A

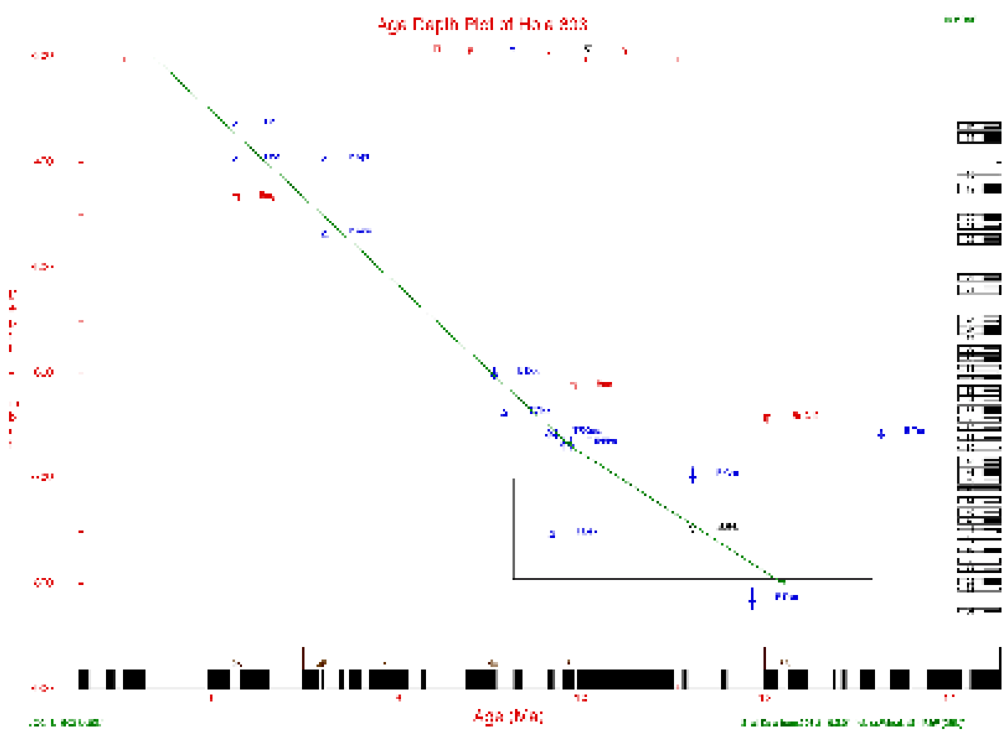
603C 19952507

AGE	DEPTH
10	
1.61673088	1.22511
1.95158285	42.2665
2.57743859	80.245
3.023374	115.773
3.294965	140.888
3.7374125	192.343
4.34467615	233.384
4.69230375	268.952
5.226125	312.5
6.021494	367.534



603 19950726

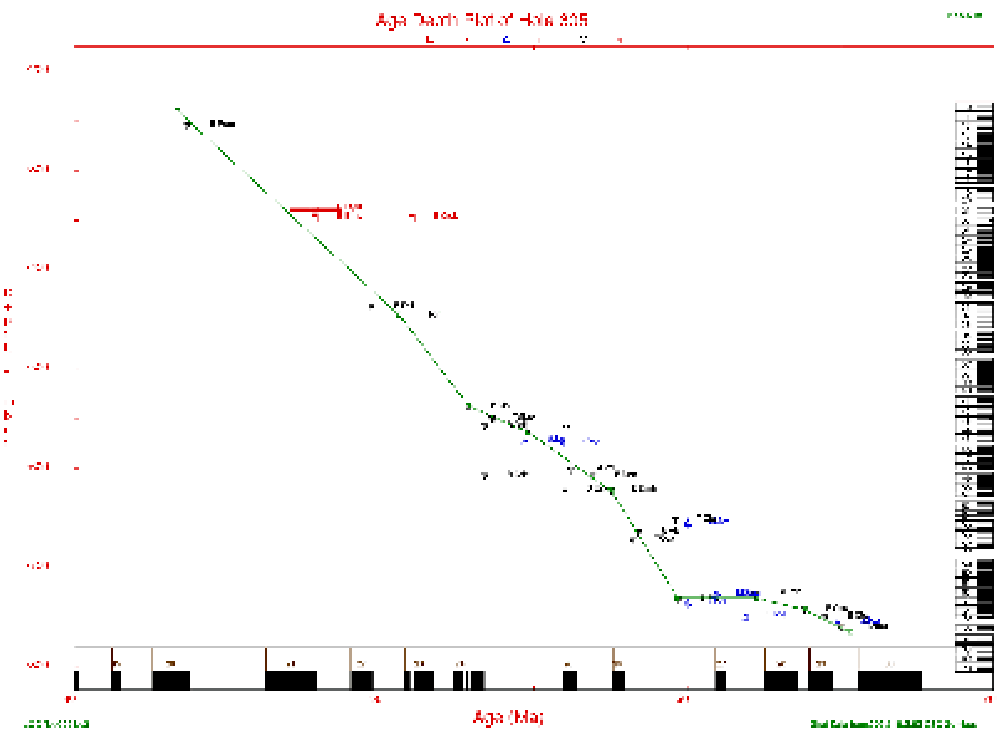
AGE	DEPTH
15	
1.5038	0
1.77882	17.3387
1.96349	35.4839
2.30241	69.3548
2.5227	70.5645
2.56361	81.4516
3.0363	115.323
3.34352	141.935
3.6962	195.161



4.05271	215.726
4.49092	239.919
4.81995	263.4
5.28041	296.478
9.81513	667.534
12.1318	798.775

605 19950718

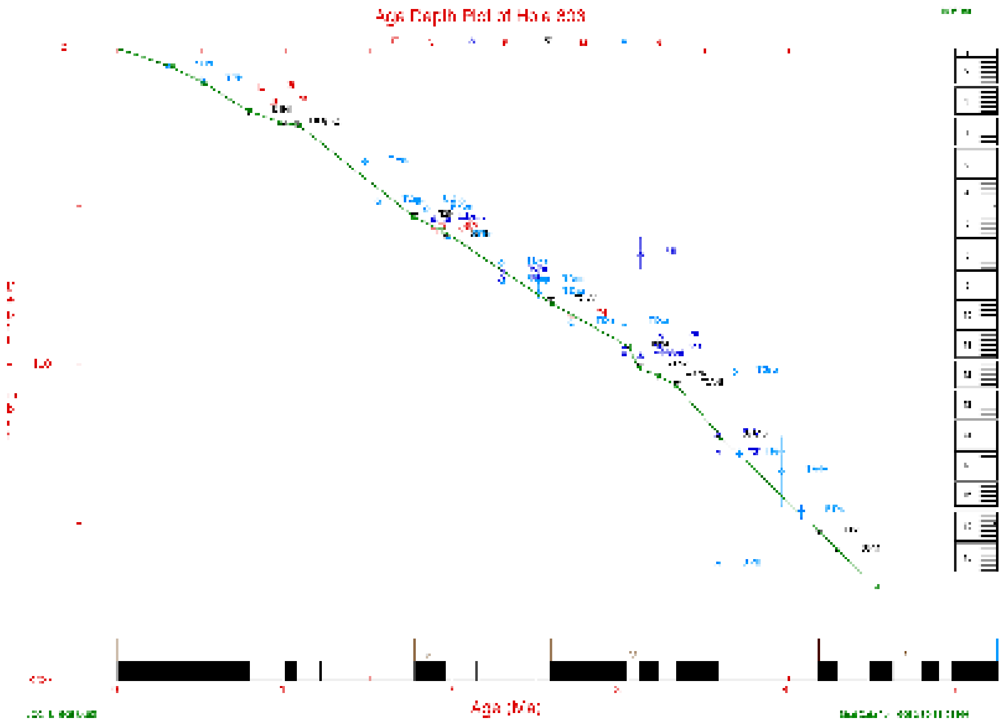
AGE	DEPTH
9	
43.3794	240.429
50.5845	446.248
52.8445	537.879
54.8025	564.394
57.4874	622.833
59.6775	731.394
62.2269	731.394
63.8025	743.682
65.3046	765.742



606 19952507

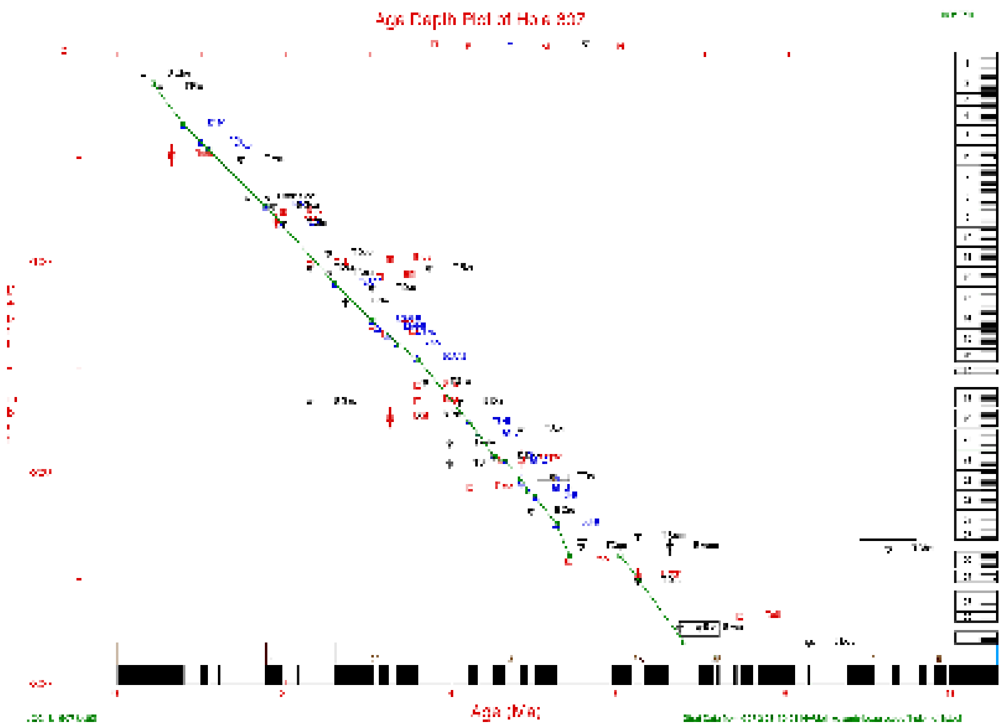
AGE	DEPTH
15	
0	0
0.3232117	5.91397
0.51143318	10.6183
0.78361433	20.0269
0.9662945	23.3871
1.07776794	24.0591
1.762825	52.957

1.94045182	57.6613
2.5861918	80.5107
3.04527	93.9516
3.10399	101.344
3.222035	103.36
3.329692	106.72
3.5982375	122.849
4.52413	169.892



607 19950707

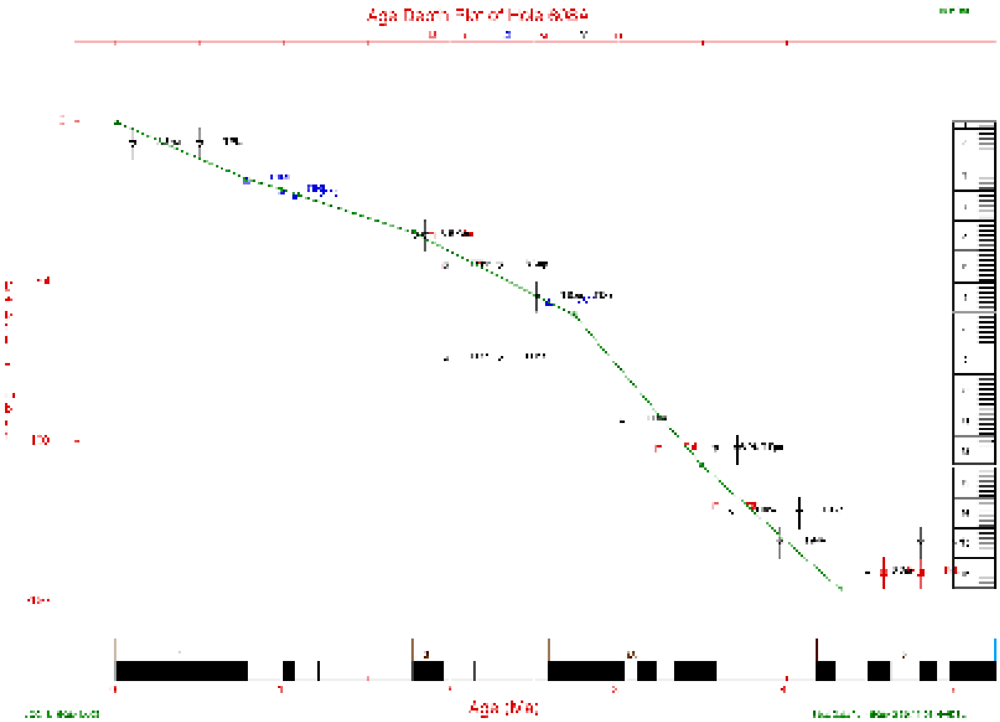
AGE	DEPTH
19	
0.41637148	14.5161
0.77760658	34.2742
1.08509426	46.5054
1.762825	72.8494
2.57905353	109.504
3.0362974	127.419
3.35394318	138.71
3.57870455	145.661
4.19835778	176.344
4.29730769	180.372
4.48796	191.942
4.6131	194.22
4.80438429	202.066
4.900989	208.333



4.976319	210.744
5.23312538	223.76
5.37928552	238.507
5.9916185	238.507
6.7584515	279.764

608A 19952507

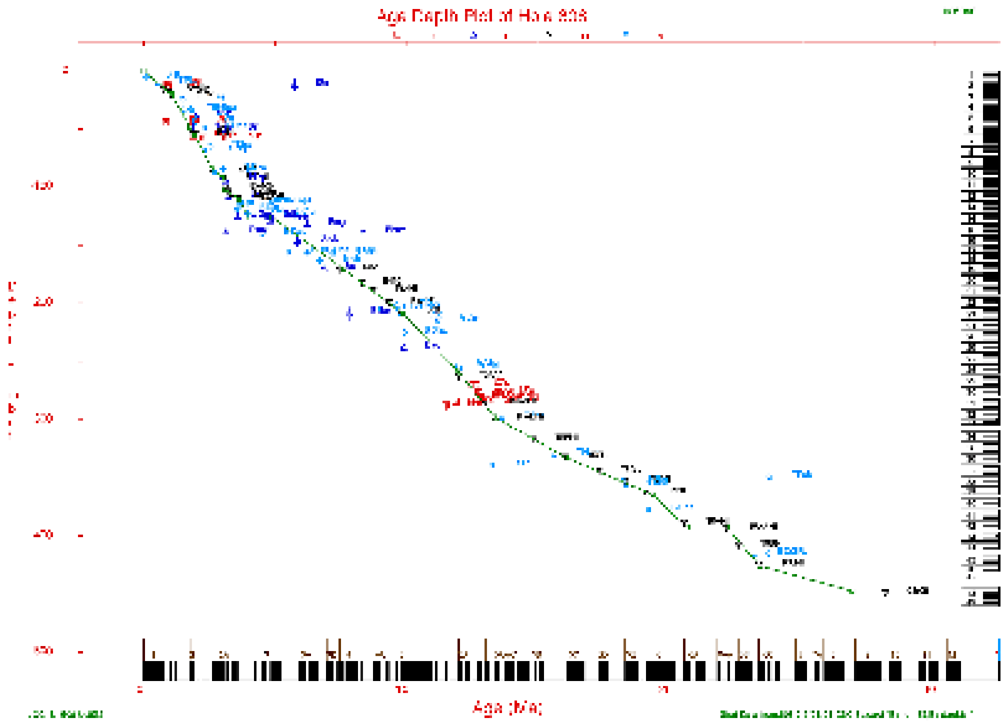
AGE	DEPTH
8	
0	0
0.7785554	18.0107
0.995248	21.371
1.07965176	22.9862
1.77002455	34.7741
2.730124	60.4126
3.48914773	107.269
4.32025385	146.169

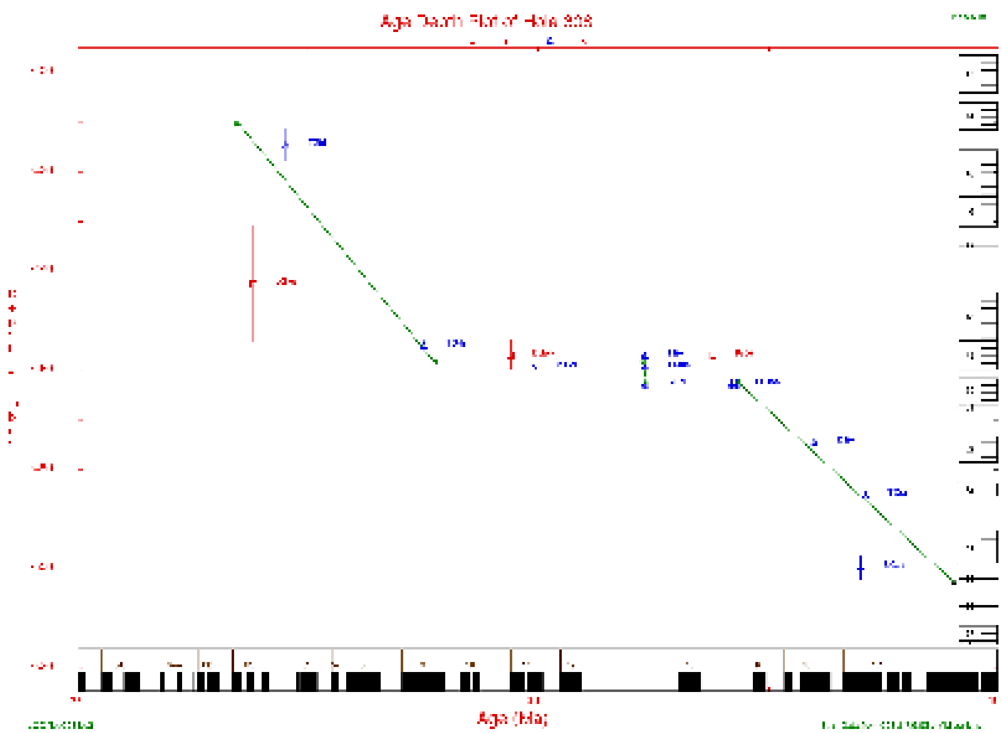


608 19950802

AGE	DEPTH
24	
-7.1163e-3	.134415
1.07777	20.0269
1.76831	48.9247
1.94845	55.6451
2.59073	84.543
3.01543	92.6075
3.09687	101.344
3.586	110.081

3.9897	125.806
4.88853	125.806
7.56096	170.161
9.81618	208.333
11.9546	258.871
13.2969	297.312
16.0294	332.5
19.3025	363.844
20.625	392.5
22.1324	392.5
23.3824	425.833
27.7365	458.424
32.2636	458.424
32.3486	462.364
34.3252	462.364
39.0223	502.742

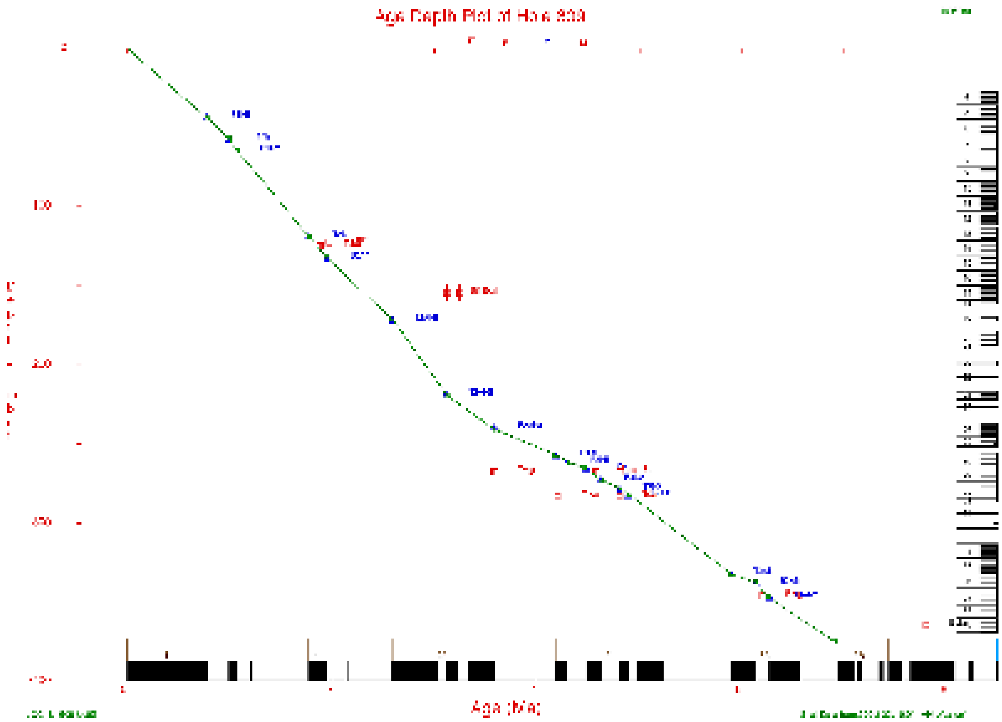




609 19952507

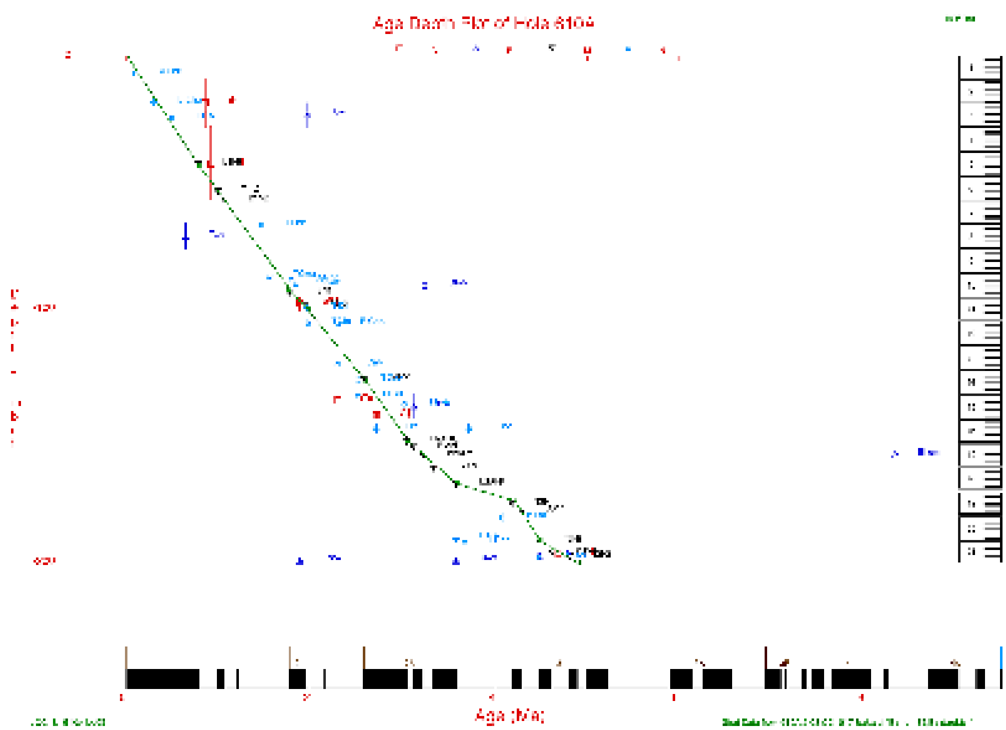
AGE	DEPTH
19	
0	0
0.78361317	43.9516
0.99805371	56.8181

1.06558629	64.2562
1.76831176	118.952
1.94845364	132.258
2.57882893	170.968
3.12222222	219.355
3.6004625	241.129
4.17875	256.855
4.31889462	261.364
4.47003231	265.083
4.62102375	272.521
4.79940375	277.419
4.896543	281.818
5.8926949	332.025
6.131789	337.603
6.2635968	346.901
6.905599	374.793



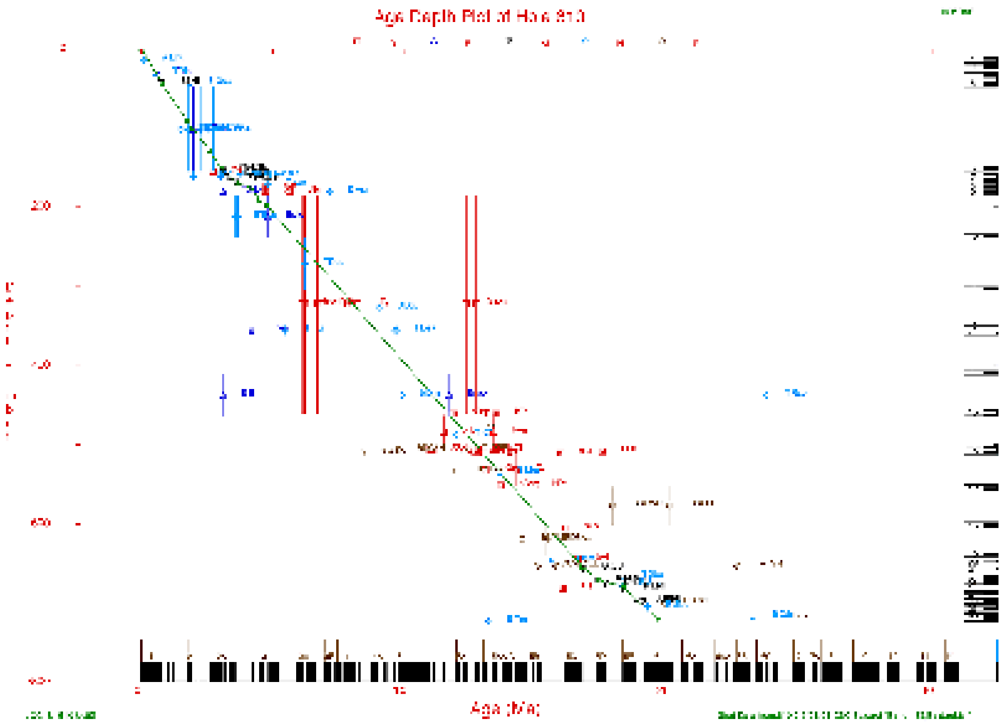
610A 19952507

AGE	DEPTH
10	
7.1044E-07	9.6876E-08
0.78048067	42.7308
1.77002455	91.8467
1.96329378	100.196
2.5878952	127.701
3.04705 151.747	
3.5879625	168.959
4.20923556	175.269
4.4921	191.398



4.894887	199.902

610 19952407

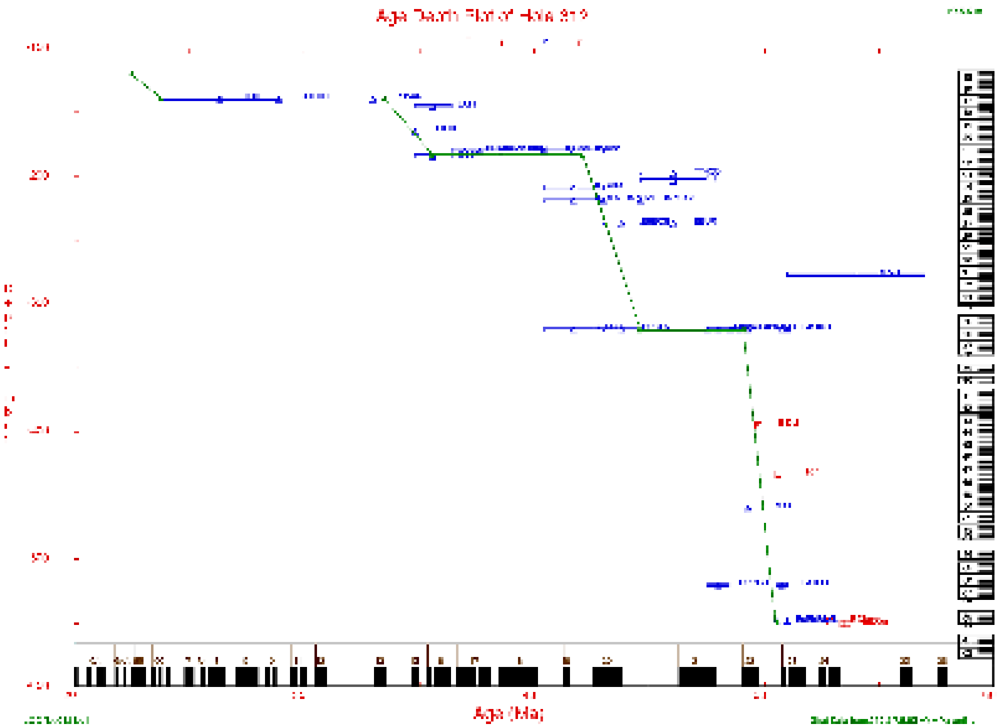


AGE	DEPTH
14	
7.1044E-07	9.6876E-08
0.78048067	42.7308
1.77002455	91.8467
1.96329378	100.196
2.5878952	127.701
3.04705	151.747
3.5879625	168.959
4.20923556	175.269
4.4921	191.398
4.77957	199.018
16.7284281	653.831
17.3728691	671.12
18.2655609	678.978
19.6353798	721.414

612 19950718

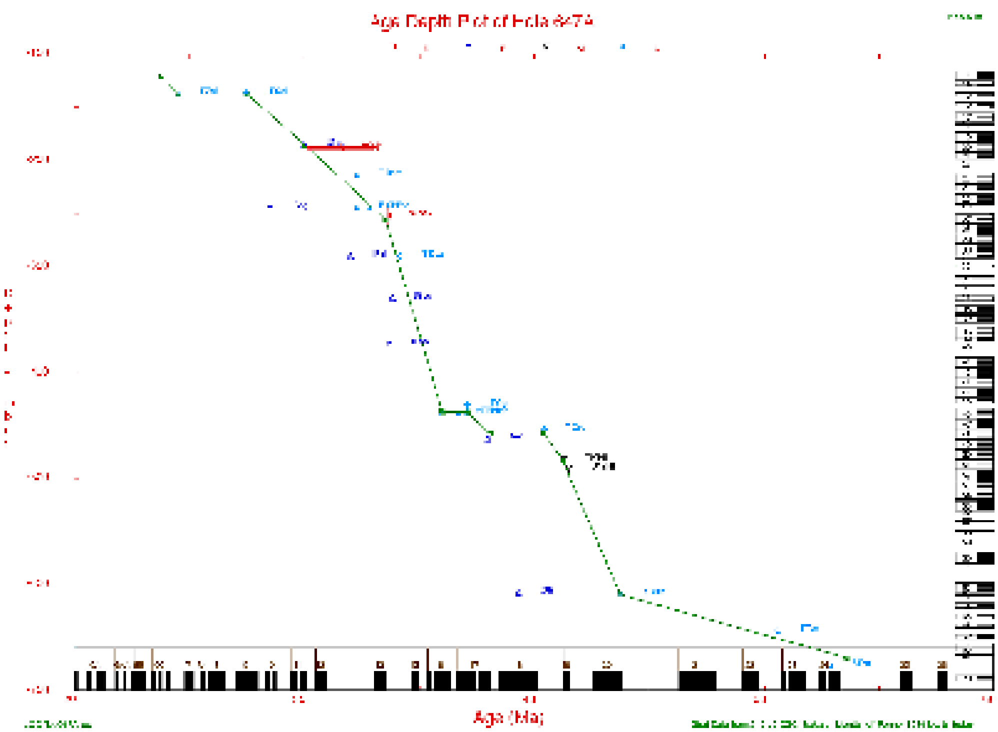
AGE	DEPTH
10	
22.423	119.142
23.7832	138.285
33.4325	138.285
35.5579	182.695
42.1041	182.695
44.6121	320.521
49.0755	320.521

50.4729	549.833
66.1211	549.833
68.406	566



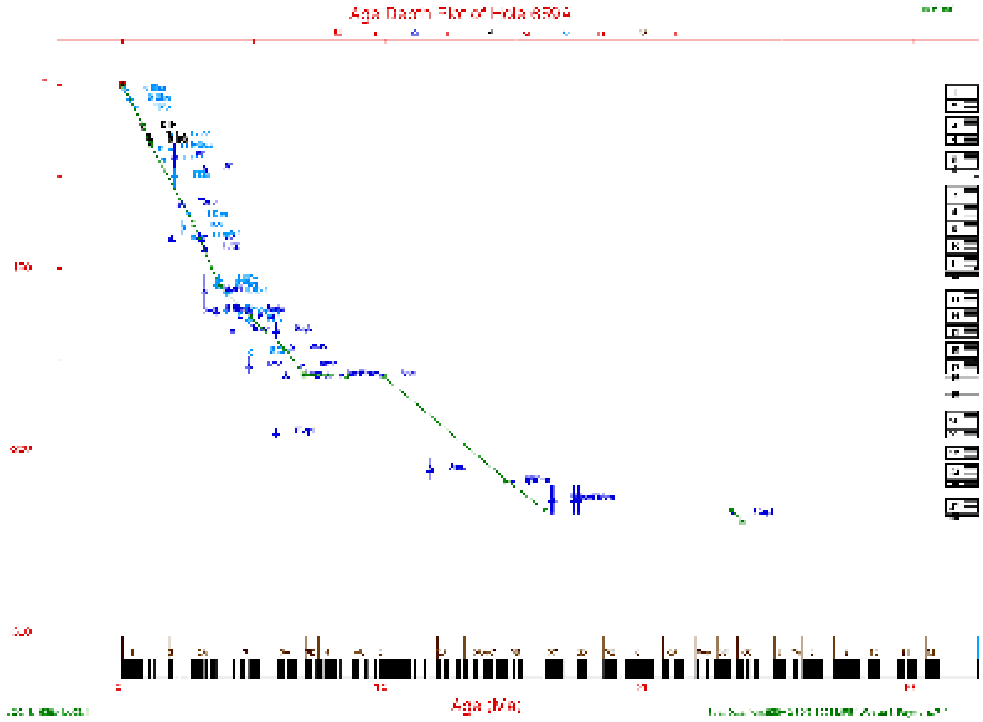
647A 19950718

AGE	DEPTH
13	
23.7832	120.214
24.5058	136.753
27.4814	136.753
30.0319	185.452
33.5175	255.283
35.983	436.294
36.0255	437.213
37.0882	437.213
38.0659	457.427
40.4038	457.427
41.2115	482.236
43.7194	609.035
53.5813	668.759



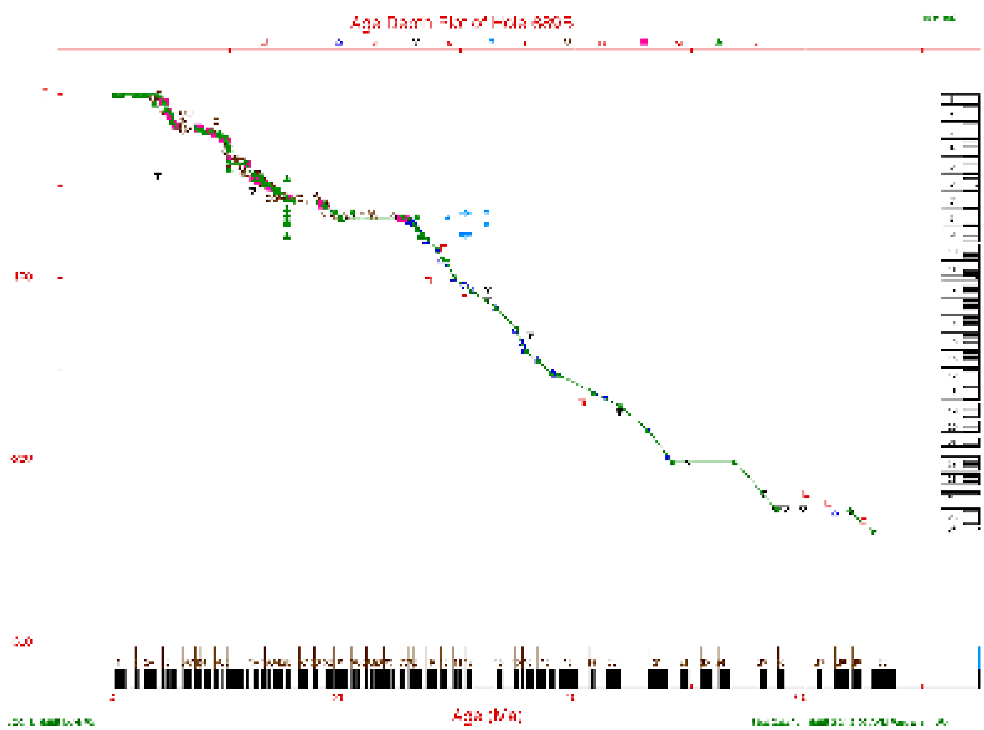
659A 19950803

AGE	DEPTH
14	
-.008891	.537641
.800717	22.9839
1.04983	32.3925
2.68383	75.7576
3.71324	110.758
4.81618	126.667
6.17647	144.167
6.875	158.485
8.49265	159.015
9.88971	159.015
14.5588	215.758
16.0662	232.727
23.125	232.727
23.532	239.382



689B 19950802

AGE	DEPTH
59	
2.98552e-2	3.78784e-2
.169284	5.79708e-2
3.83359	5.79708e-2
4.2905	4.43182
4.47897	8.71212
4.62747	9.73485
4.79309	11.4394
4.88448	11.8182
4.98157	15.1894



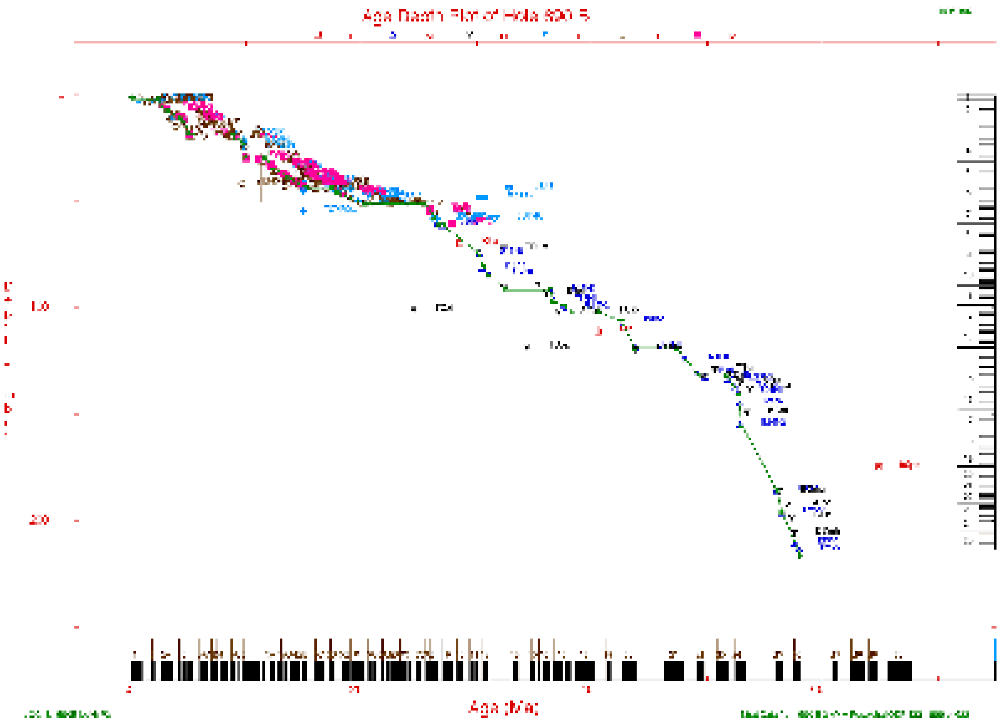
5.31542	17.7795
7.09735	17.7795
7.16589	18.8208
7.42861	19.0046
8.26817	20.1685
8.70223	22.2511
9.31906	23.7825
9.5932	23.7825
9.73598	24.7014
9.83824	29.8333
9.88235	34.3333
9.88971	37.3333
11.3971	37.3333
11.9485	46.
12.83	48.55
13.01	48.8
13.2	49.55
13.46	50.77
13.69	51.8
14.08	52.27
14.2	52.55
15.1471	57.2727
15.7604	58.7862
17.7237	58.7862
18.2553	61.2273
19.5841	67.0455
24.8388	67.0455
25.625	68.7576
26.0063	70.3333

26.5609	76.0303
27.0347	79.303
27.9706	84.8788
28.2941	89.8485
28.7673	91.8182
29.4034	100.273
30.9286	106.818
33.0712	116.818
34.7184	128.182
35.5898	139.667
36.6844	145
37.8534	152.273
38.4378	153.182
41.5728	162.727
43.9107	170.909
46.2487	183.182
48.2511	201
53.792	201
57.3487	227
63.6134	227
65.8555	239.545

690 B 19950802

AGE	DEPTH
48	
0	0
.172814	1.93308
2.41719	1.93308
2.59424	4.96212

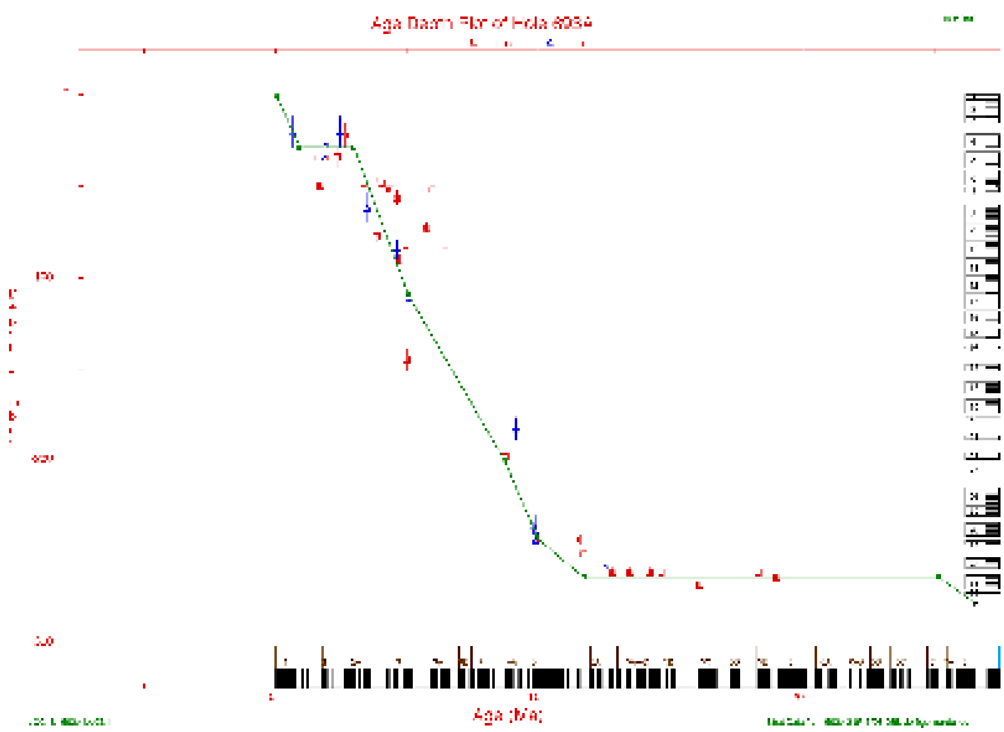
3.0283	6.59091
3.11968	7.00757
4.18769	10.2651
4.2905	10.5303
4.48468	11.25
4.61604	11.7803
4.97586	18.3333
5.29829	19.053
8.70794	19.053
9.02207	20.1136
9.71198	22.0074
9.93925	29.697
11.662	29.697
12.1926	33.5606
13.4938	37.9545
15.1404	43.75
17.4219	43.75
17.6176	44.6212
17.8741	45.7576
18.2858	46.6288
20.2082	50.9697
25.5768	50.9697
26.1594	56.9091
26.5592	60.25
27.0047	61.0985
30.0956	73.8897
30.4727	80.9091
30.9989	83.8438
32.4422	91.5454



36.3456	91.5454
36.6197	96.5682
37.6155	99.4545
38.2742	101.553
40.4107	101.553
42.5389	106.273
43.6712	118.636
47.2416	118.636
49.1711	131.7
51.6419	131.7
52.678	139.74
52.8905	154.671
55.9724	185.299
56.3975	195.635
58.1509	216.692

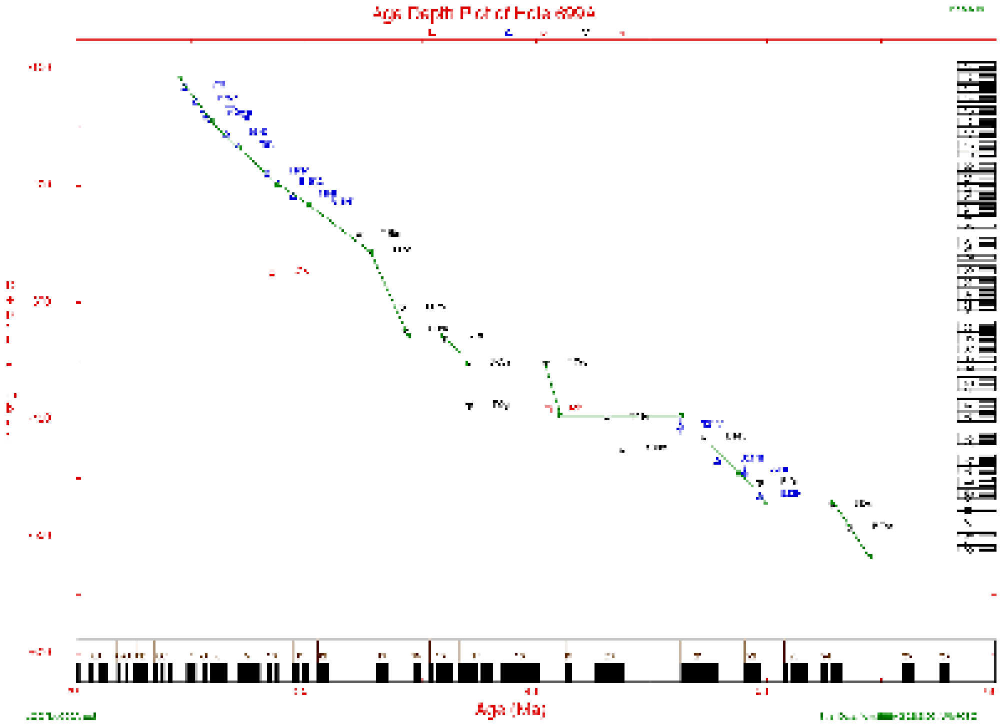
693A 19930913

AGE	DEPTH
9	
2.12766e-6	7.14451e-8
1.08396	29.1217
3.20935	29.1217
4.65462	104.006
8.20404	197.843
10.1594	241.654
11.9235	263.944
25.1753	263.944
26.5994	278.867



699A 19950719

AGE	DEPTH
16	
24.5	108.365
25.8449	145
27.067	167.5
28.7416	198.515
30.1488	216.667
32.8055	256.667
34.3996	328.333
35.9936	328.333
37.0457	351.667
40.3613	351.667
41.0414	396.667
46.2487	396.667
48.834	446.248
49.9681	470.
52.9012	470.
54.474	517.5



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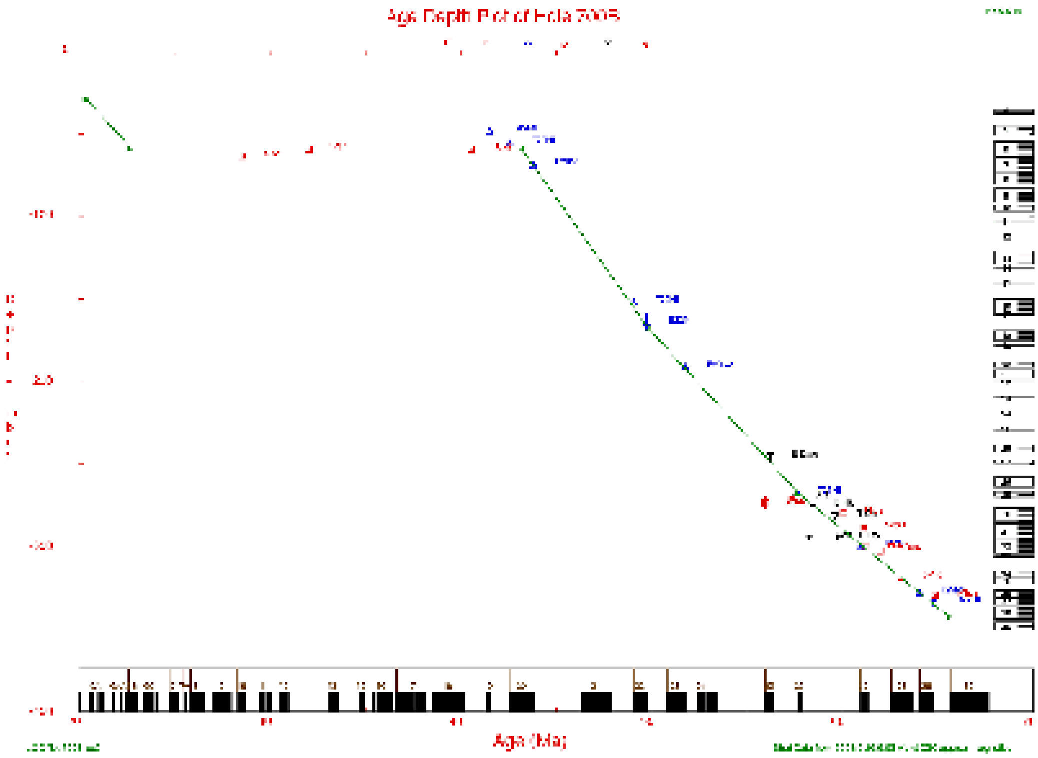
DIRECTORY: adps_app

Holes 700B-736A

700B 19950719

AGE	DEPTH
6	
20.3188	28.7902
22.7336	58.7424
43.1137	58.7424
49.7556	167.228
57.6196	267.075
65.5898	342.42

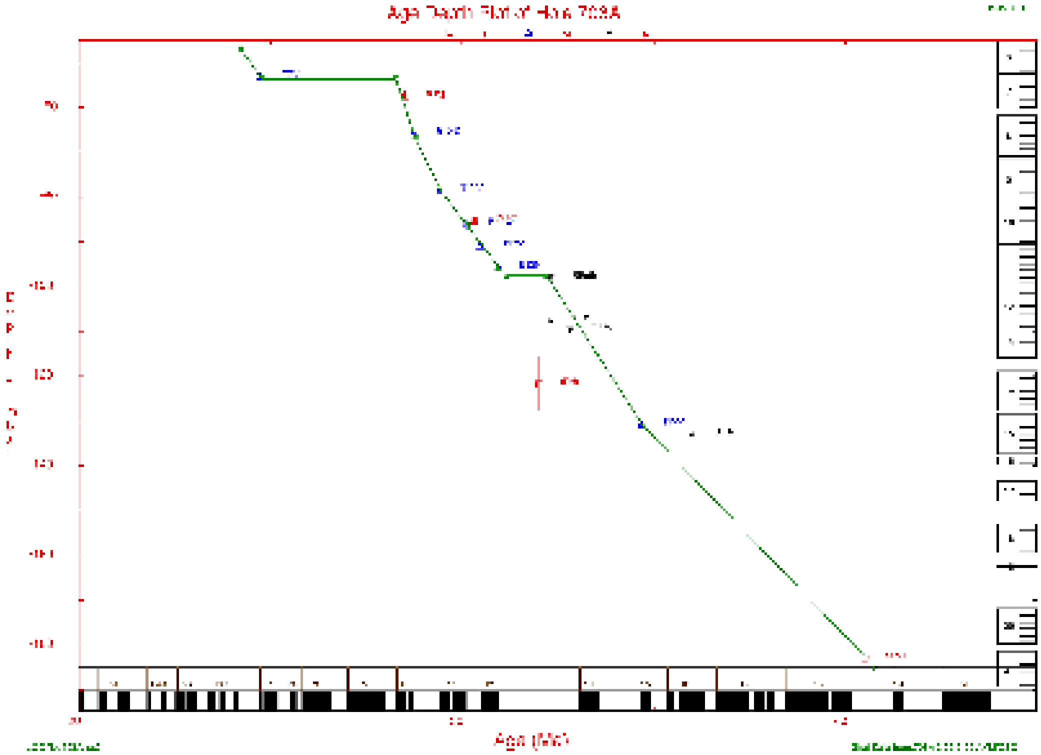


703A 19950719

AGE	DEPTH
11	
24.1977	46.8606
24.7556	53.5988
28.2625	53.5988
28.7673	66.7687
29.4049	78.1818
30.1222	86.3636
30.9724	95.8652
31.1583	97.5
32.1945	97.5

34.7184 131.087

40.8023 185.299



707A 19950720

AGE DEPTH

6

23.3209 136.636

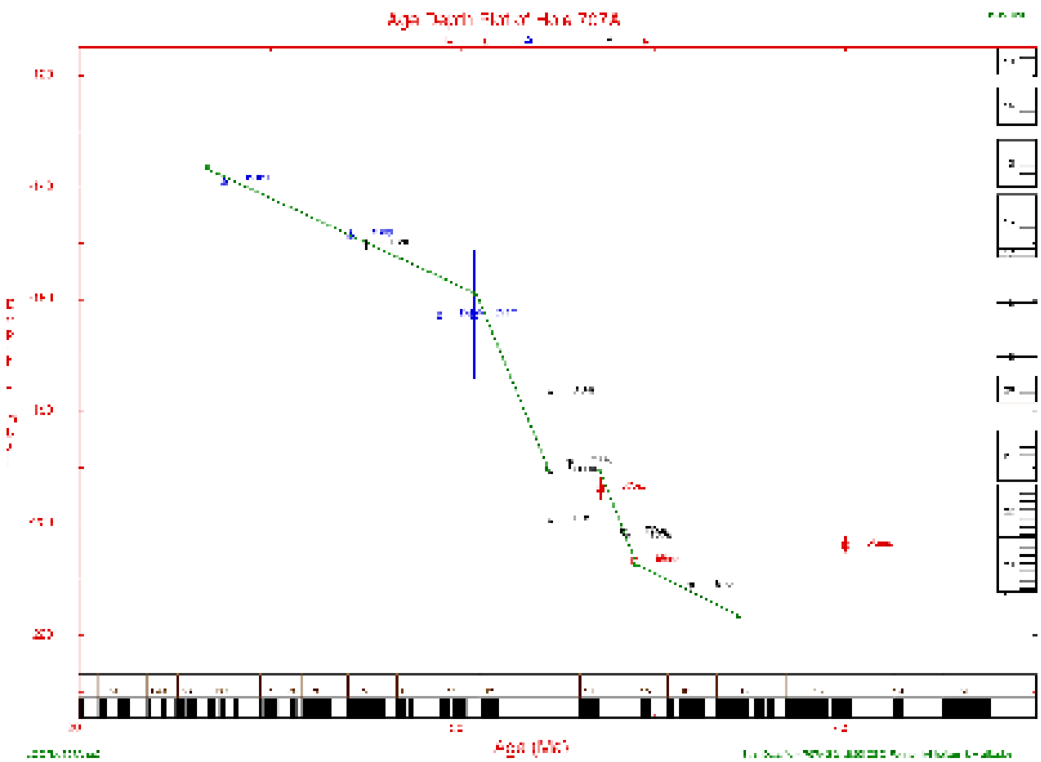
30.3613 159.

32.2476 190.273

33.576 190.273

34.5273 207.167

37.2059 216.5

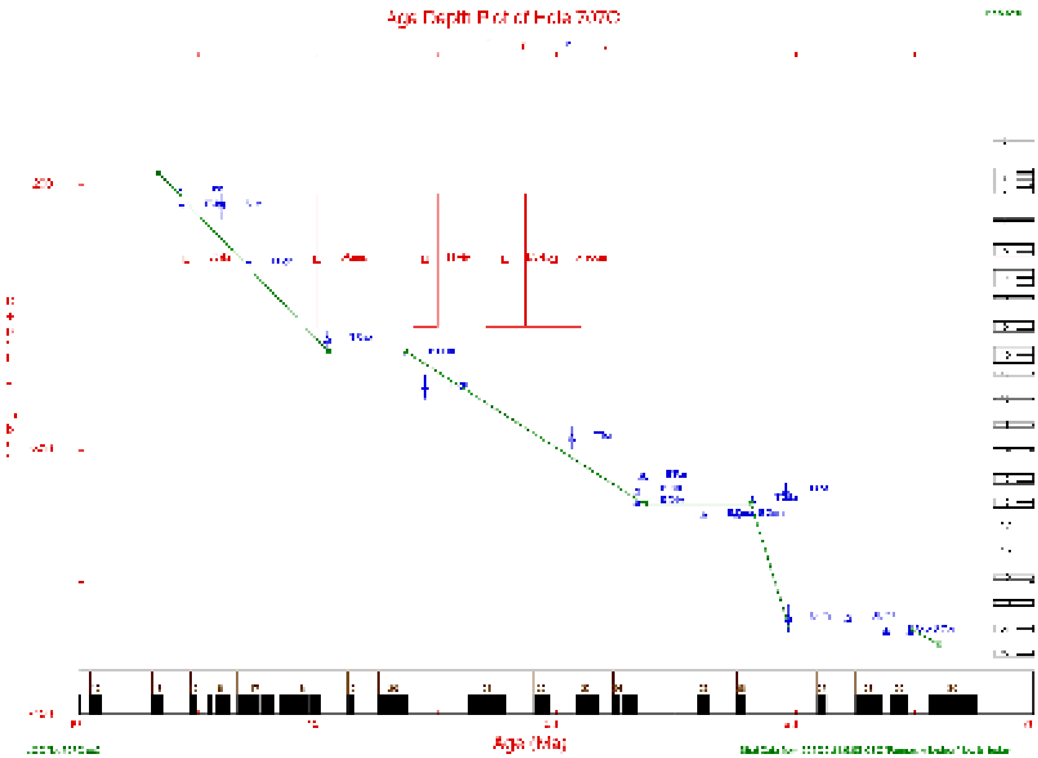


707C 19950720

AGE DEPTH

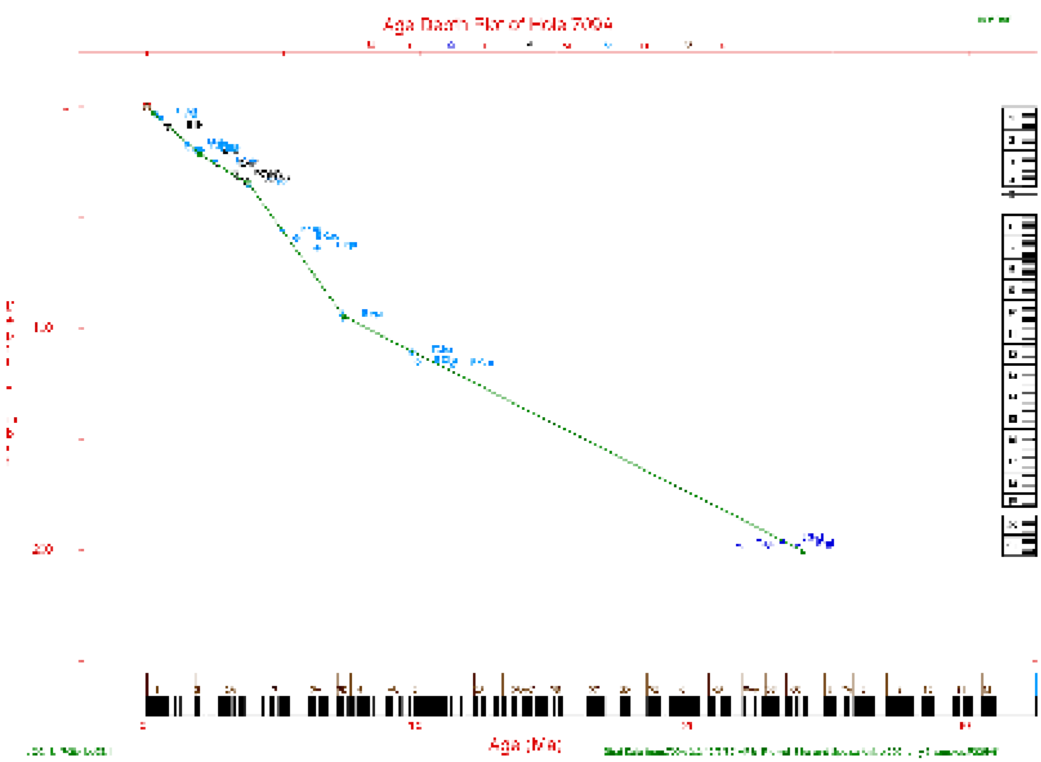
8

33.3794	195.833
40.4357	262.5
43.6451	262.5
53.661	320.455
58.1403	320.455
59.7715	367.727
64.9256	367.727
66.0149	373.182



709A 19950803

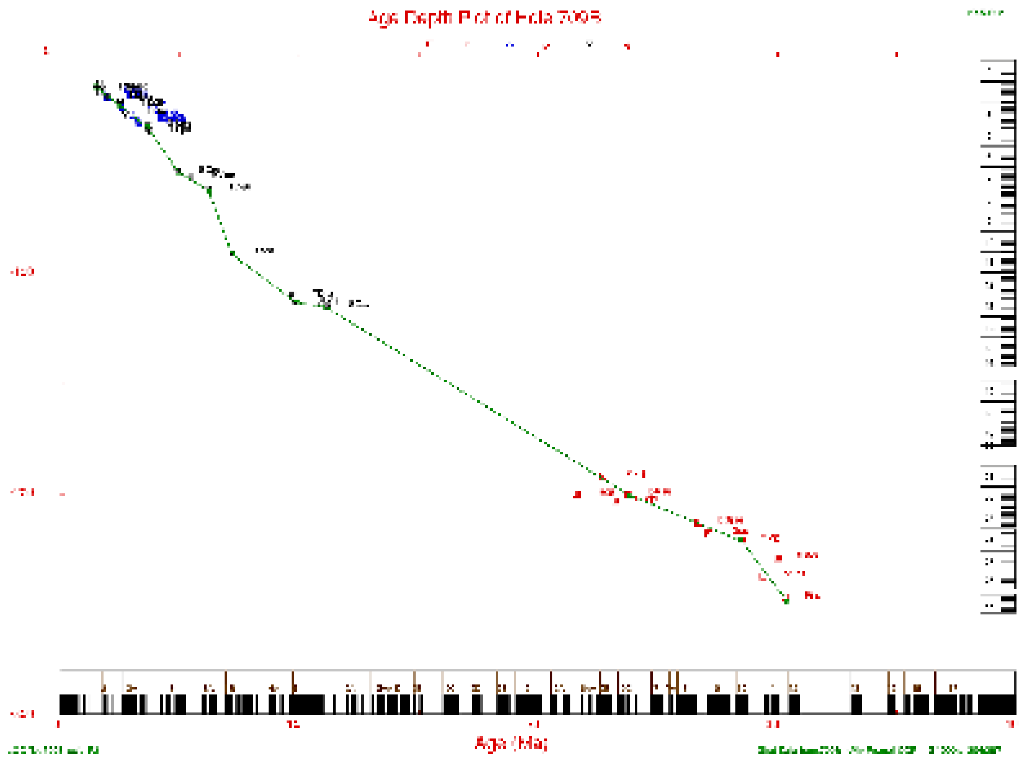
AGE	DEPTH
5	
.275	2.6
1.92171	20.6989
3.71324	34.5454
7.16912	94.0909
23.9706	200.



709B 19950802

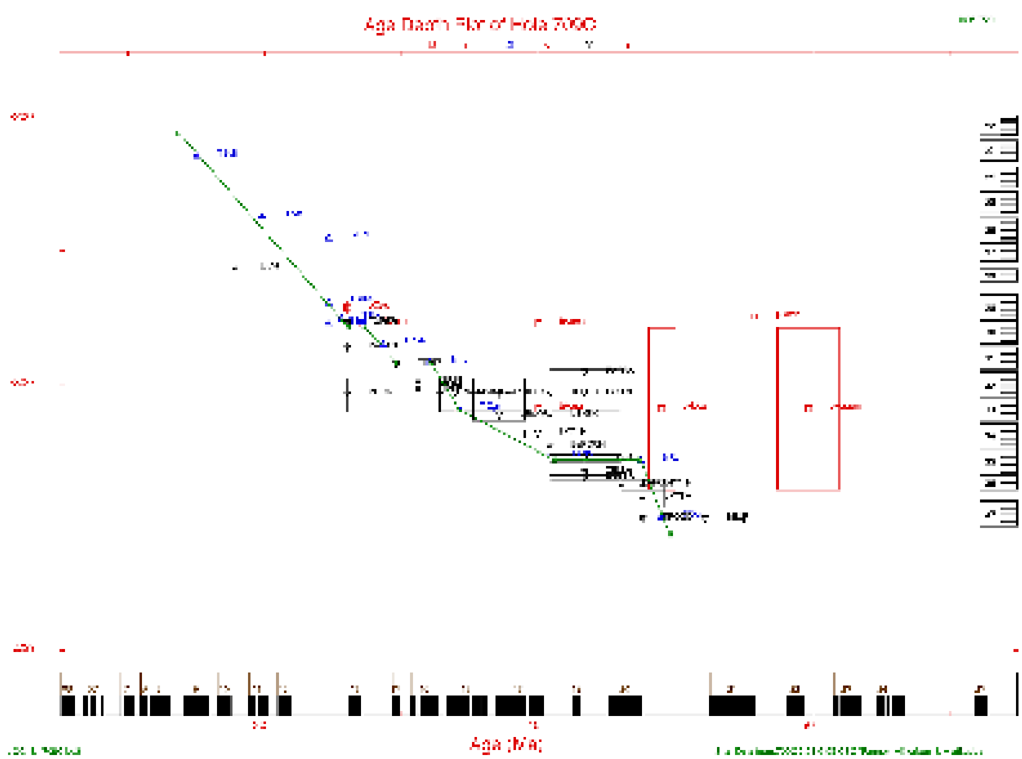
AGE	DEPTH
11	
1.4958	15.5455

2.4916	24.0909
3.67647	33.9091
4.93698	54.2727
6.21008	62.4545
7.18067	91.3636
9.89496	113.409
11.1513	115.182
23.792	200.227
28.4958	220.955
30.4286	248.909



709C 19950720

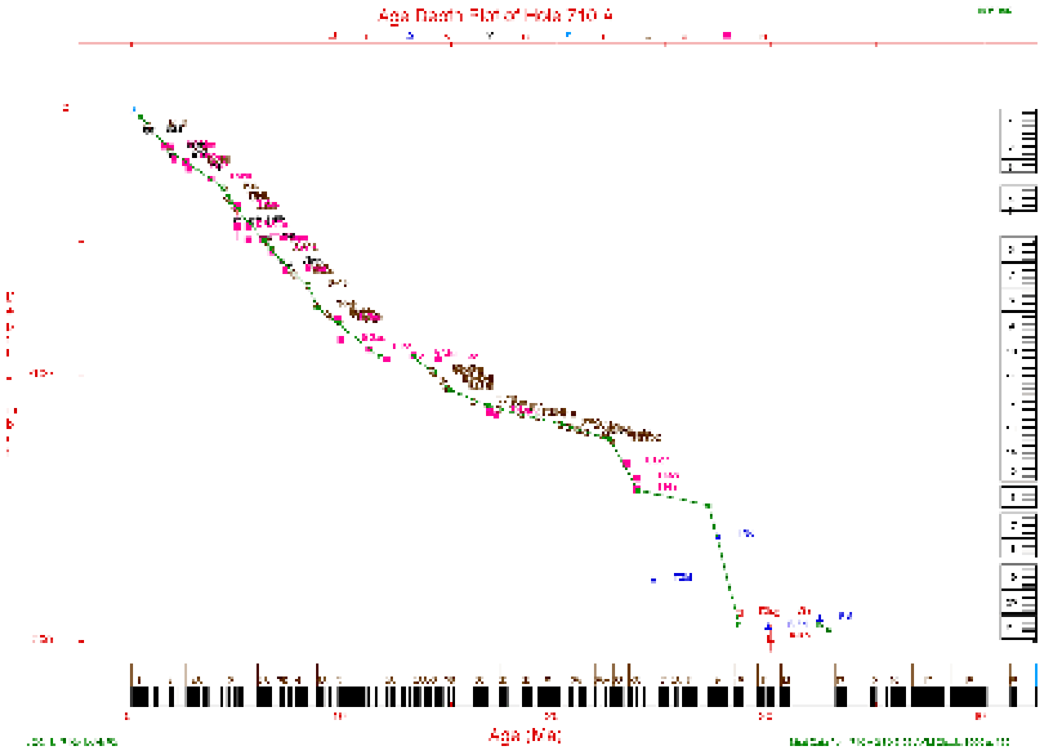
AGE	DEPTH
9	
26.8571	205.667
33.021	278.333
33.6134	278.333
34.8361	292.
36.0662	292.
37.0956	309.364
40.562	328.273
43.7132	328.273
44.7794	356.439



710 A 19950802

AGE	DEPTH
23	
.414918	3.

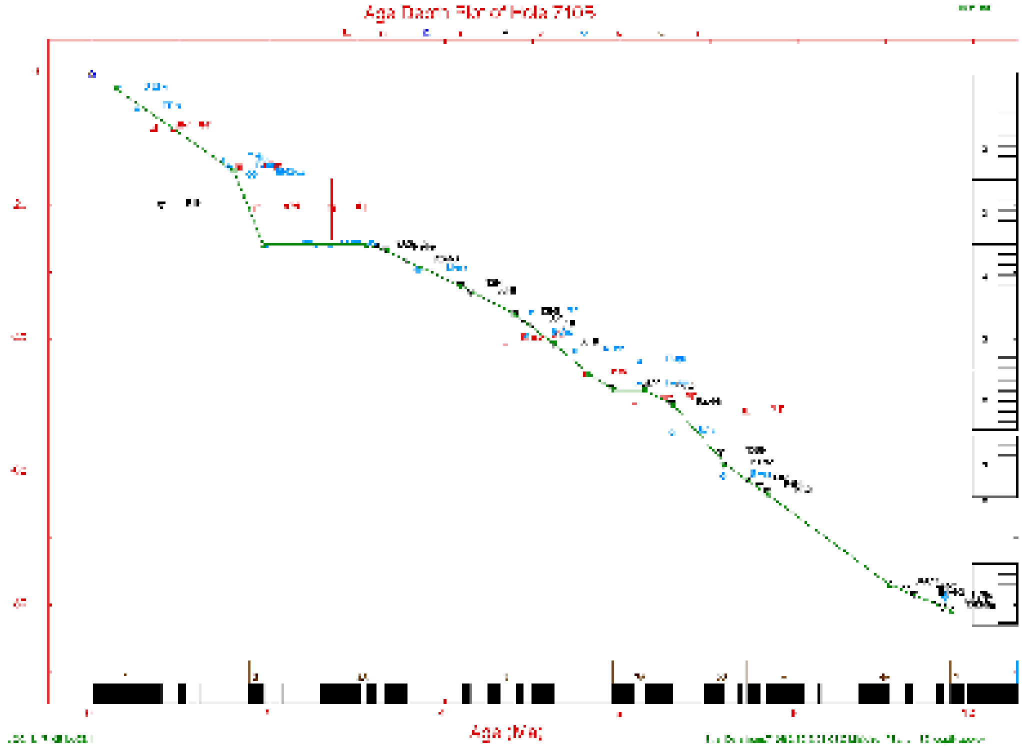
1.80672	15.6667
4.30147	29.6667
4.4853	33.
4.6166	34.3333
4.98425	38.
6.24475	49.6667
6.53362	52.6667
8.26681	66.3333
8.71324	74.3333
9.71114	80.5
11.6807	93.1667
13.2038	93.1667
14.1754	98.8333
14.8866	105.318
16.7647	111.864
20.105	118.273
22.4748	124.136
23.7479	143.091
27.1092	148.712
28.5084	193.894
32.3025	193.894
32.7258	195.379



710B 19950803

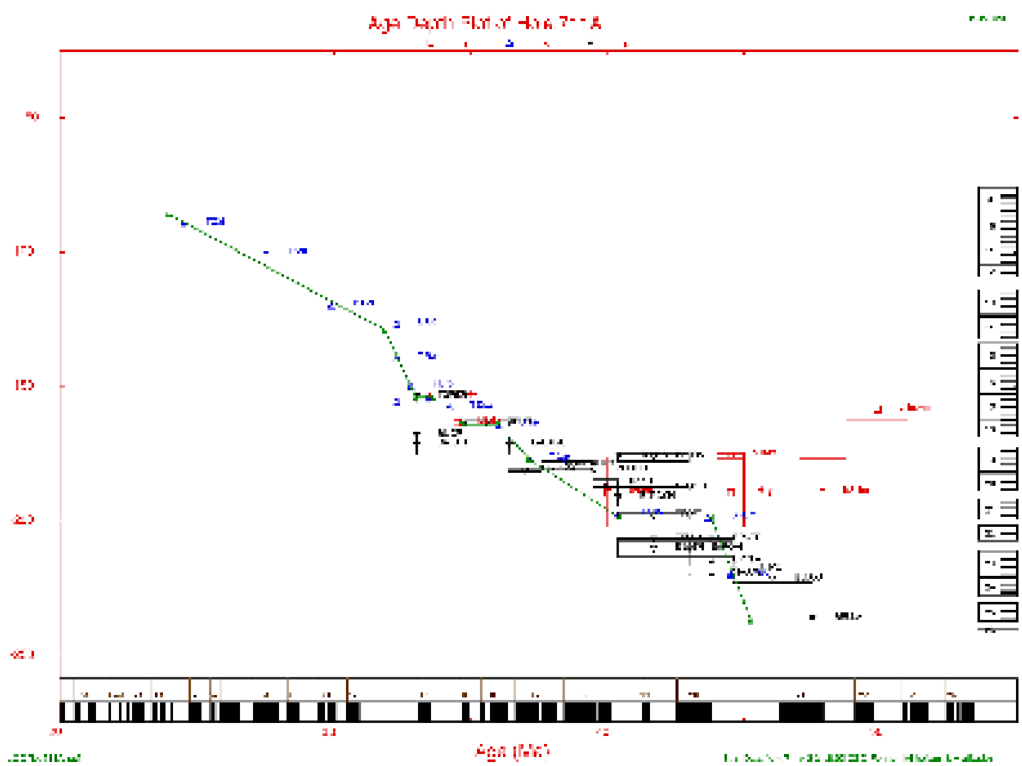
AGE	DEPTH
16	
.28	2.45
1.60177	14.697

1.93302	25.7576
3.10955	25.7576
3.33801	26.8182
4.1947	32.1212
4.78868	36.2121
5.23416	40.7576
5.63396	45.1515
5.91952	47.7273
6.27362	47.7273
6.58204	49.8485
7.17601	58.7879
7.65576	63.3333
9.04933	76.9697
9.75753	80.9091



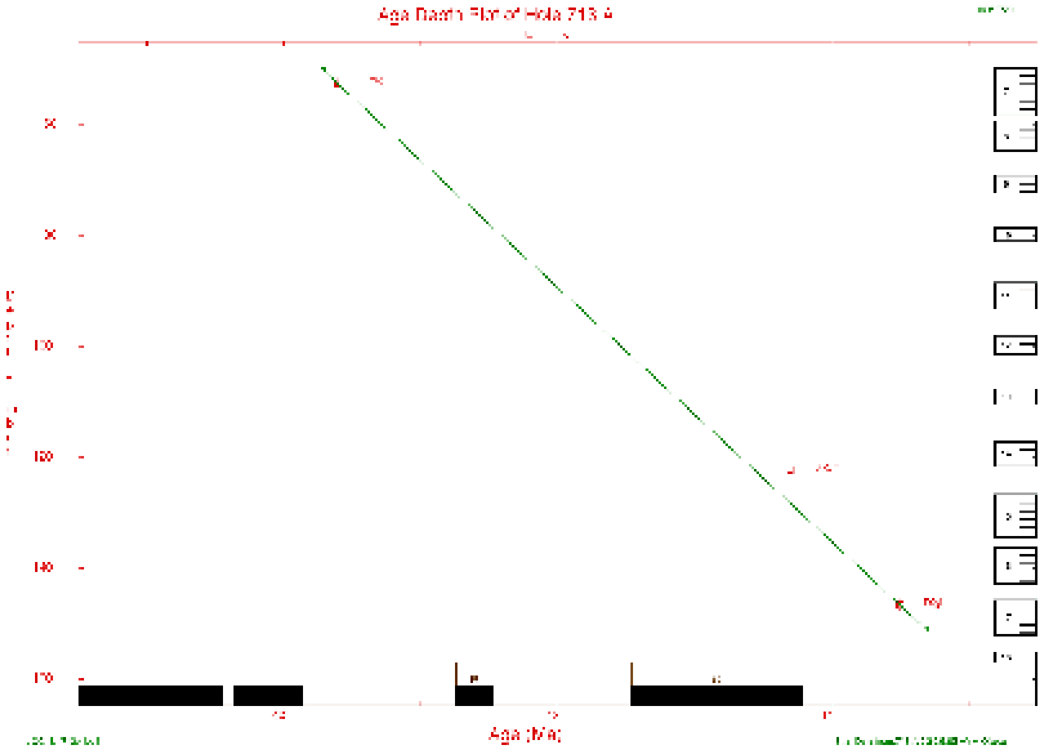
711A 19950720

AGE	DEPTH
10	
23.9426	85.5283
31.865	128.714
32.9748	153.682
33.6504	153.682
34.6546	163.936
35.9936	163.936
37.1376	176.97
40.3939	198.03
43.7553	198.03
45.2521	237.121



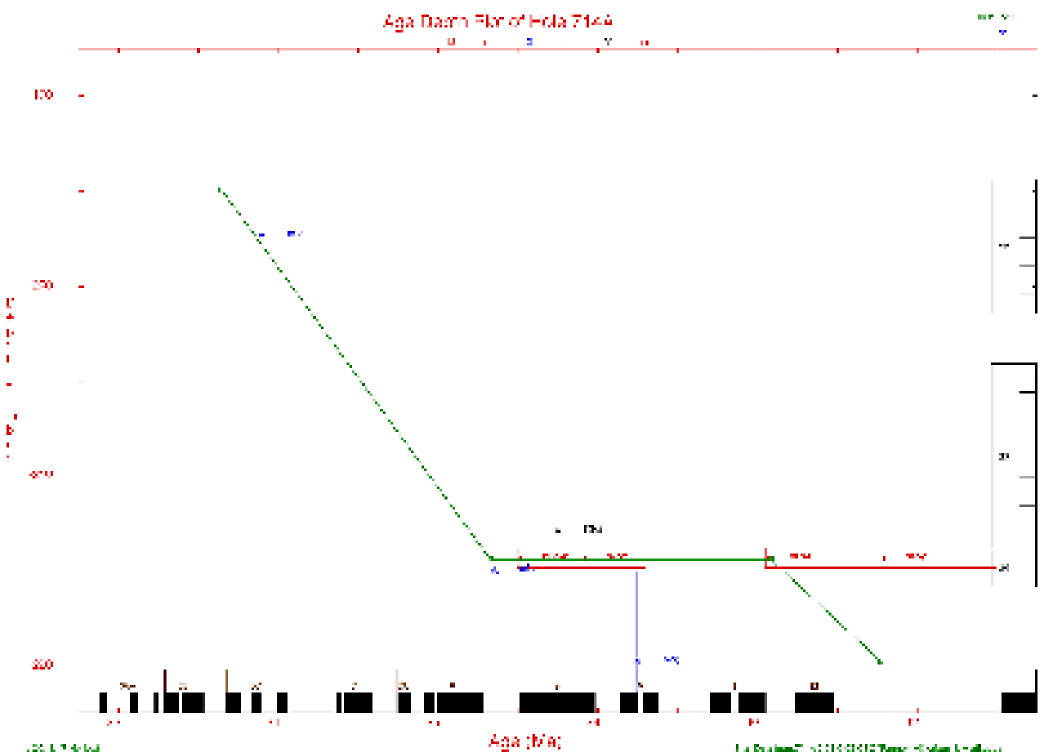
713 A 19950720

AGE	DEPTH
2	
40.2868	50.0909
44.6912	151.



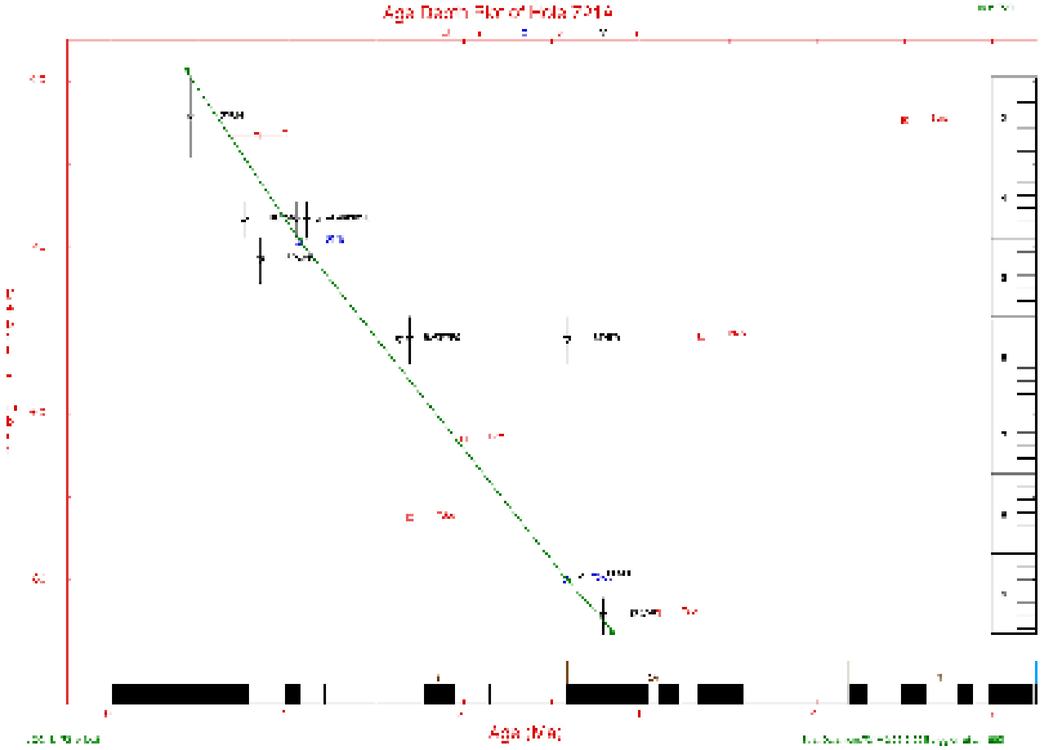
714A 19950720

AGE	DEPTH
4	
23.291	194.917
26.6555	214.386
30.166	214.386
31.55	219.725



721A 19950729

AGE	DEPTH



4

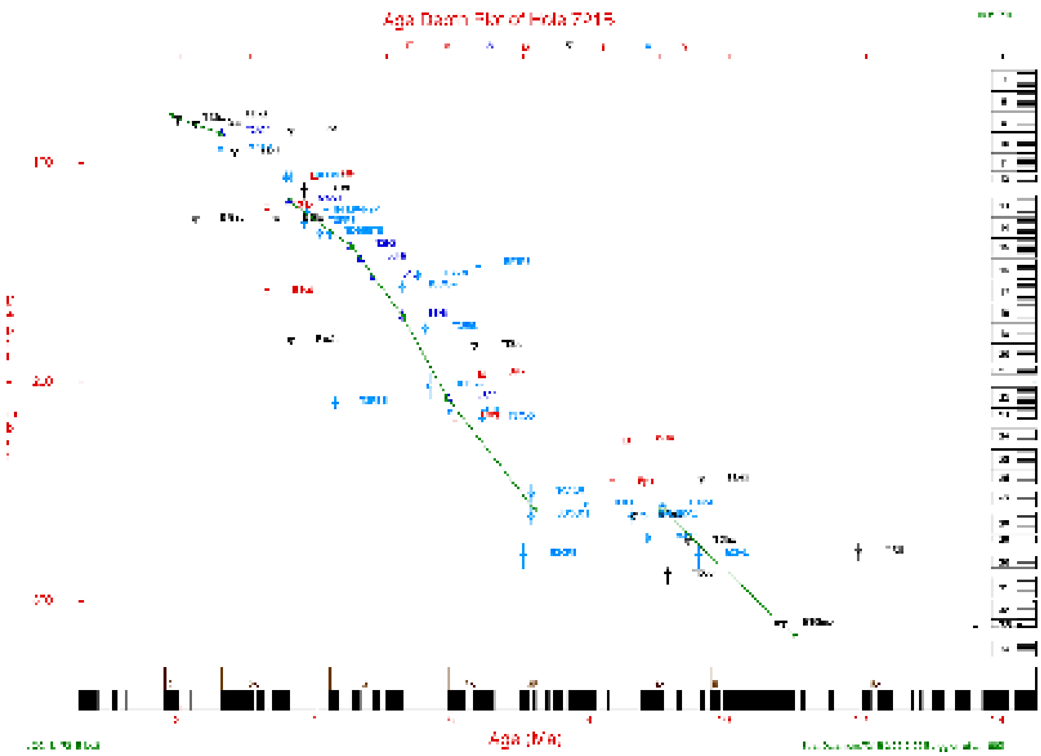
.423936 18.7576

1.06932 39.2424

2.58853 80.0909

2.84554 86.1515

721B 19950731



AGE DEPTH

9

1.85294 78.5606

2.59296 86.3333

3.59193 117.381

4.48459 137.596

5.22848 170.061

5.89496 207.427

7.16177 258.333

9.02941 258.333

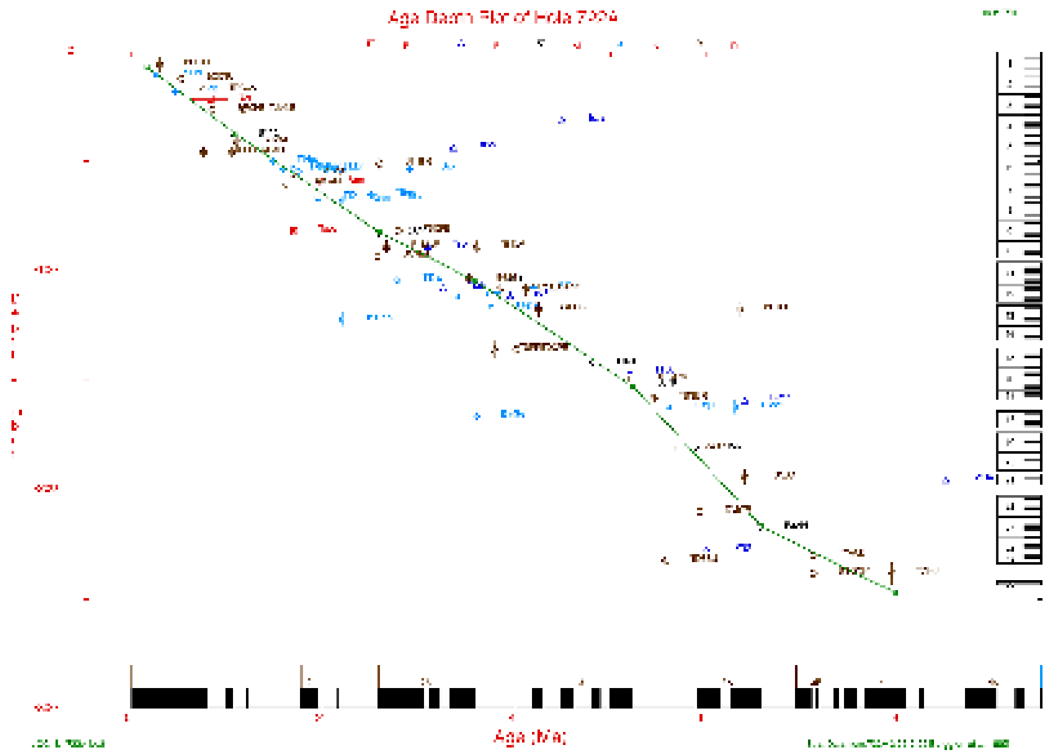
10.9671 315.85

722A 19950731

AGE DEPTH

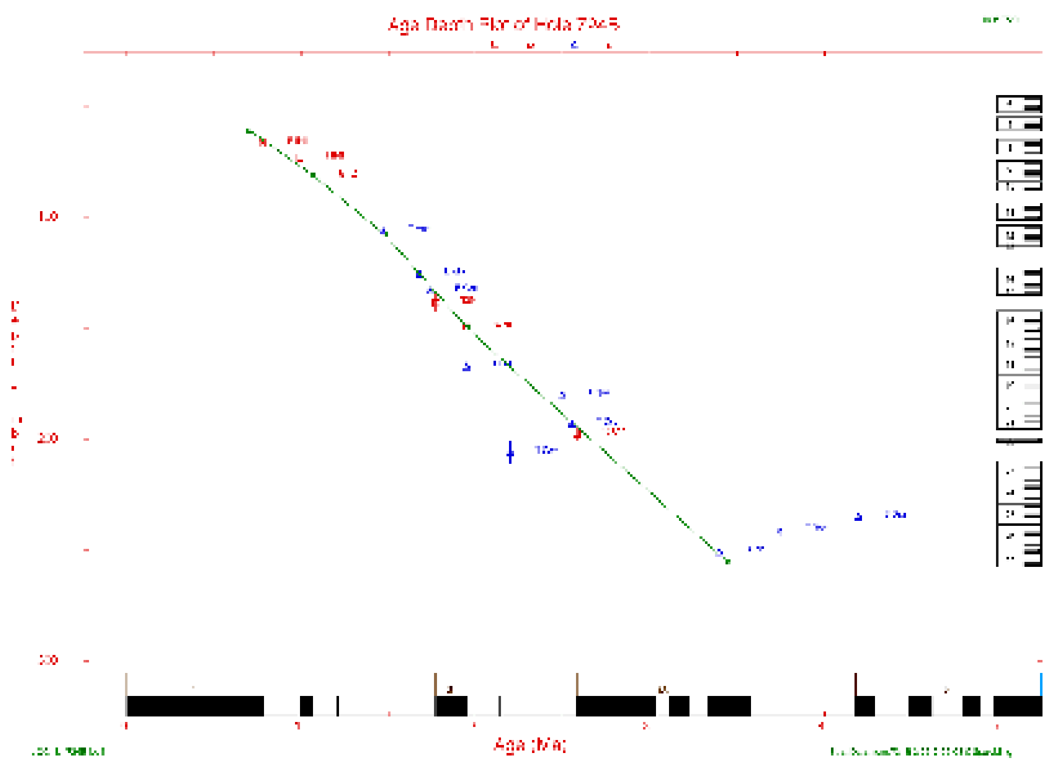
7

.161766	6.89127
1.09769	37.6723
2.59454	82.6952
3.59244	104.747
5.22479	152.527
6.56933	216.386
7.96639	246.707



724B 19950729

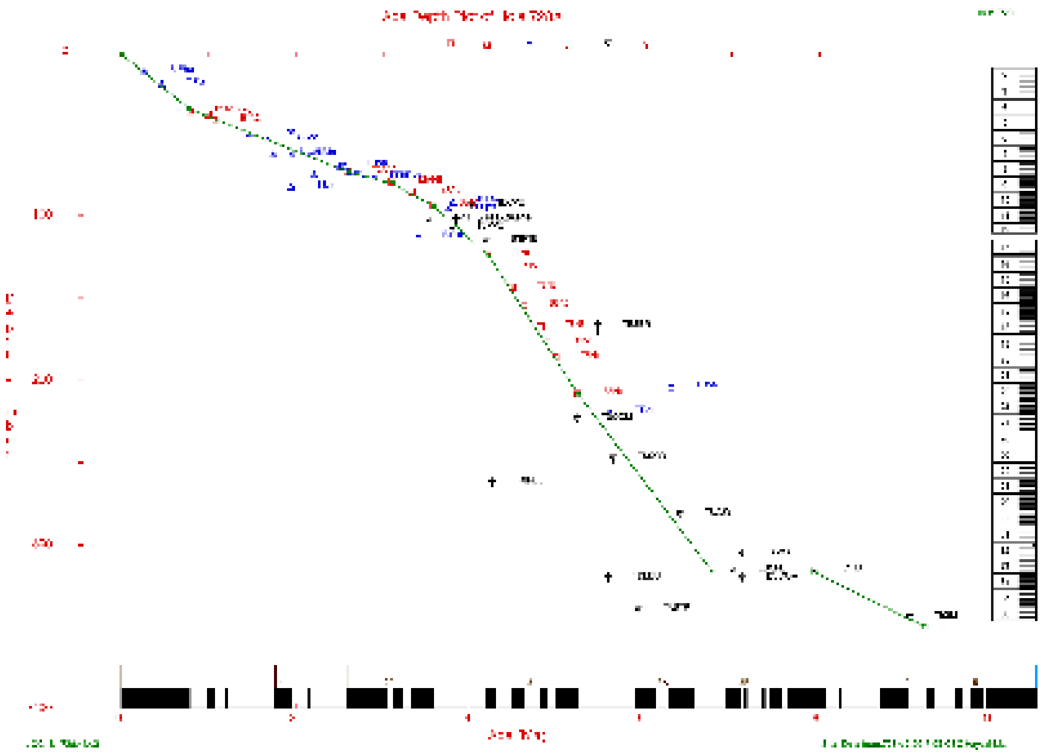
AGE	DEPTH
5	
.703257	60.4545
1.073	80.9091
1.47742	107.273
1.95116	149.545
3.45326	255.455



728A 19950729

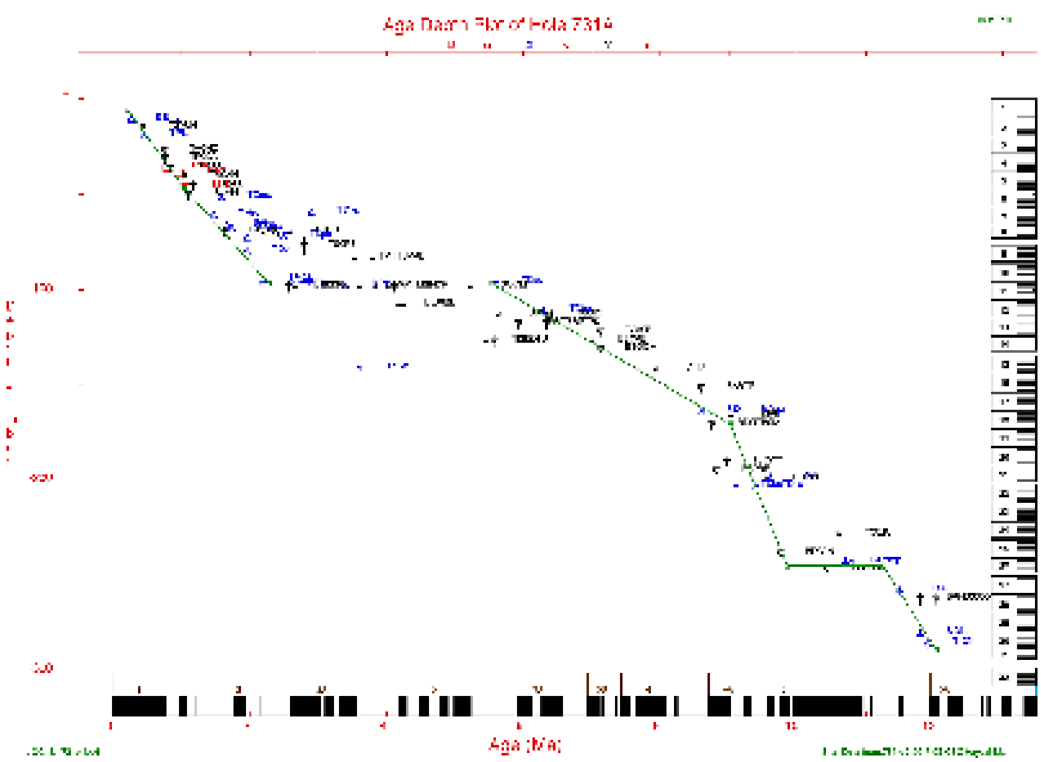
AGE	DEPTH
10	
8.40446e-3	1.83767

.782564	34.9158
2.59664	72.8943
3.10504	80.245
3.57878	93.7213
4.20273	123.737
5.24265	208.882
6.77941	316.692
7.94643	316.692
9.21744	349.77



731A 19950731

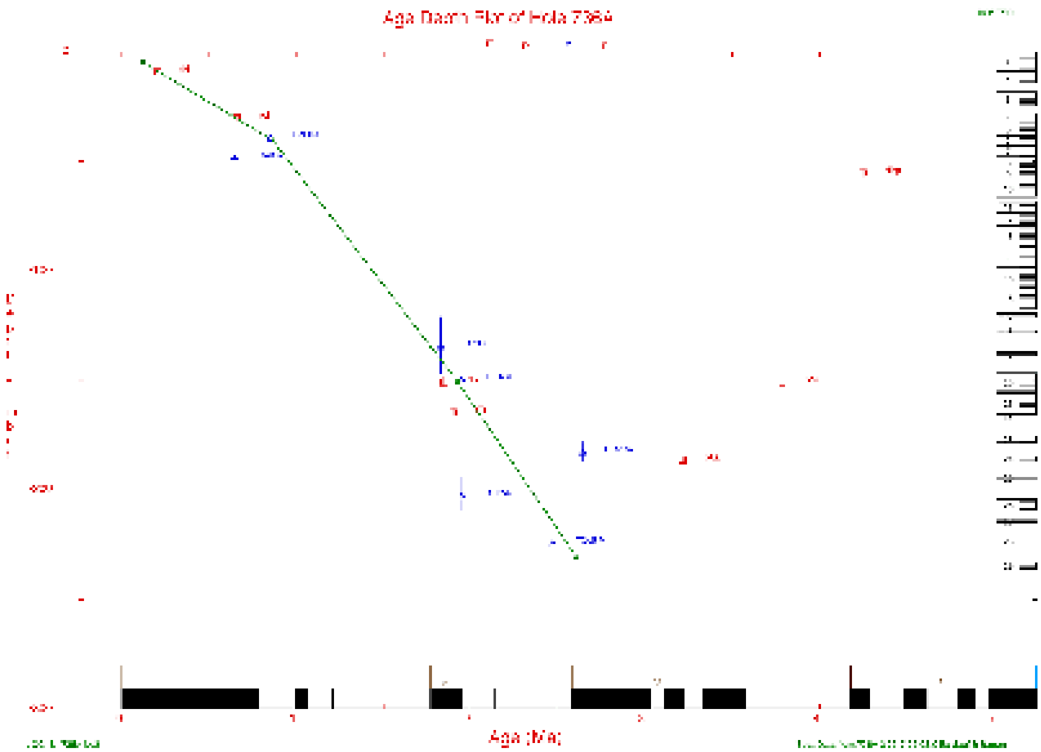
AGE	DEPTH
8	
.224791	5.51302
1.02942	45.9091
2.27941	97.0454
5.55147	97.0454
9.01681	170.903
9.85189	245.635
11.25	245.635
12.0221	290



736A 19950730

AGE	DEPTH

4	
.125526	5.0536
.859244	39.9694
1.92227	150.23
2.60399	230.168



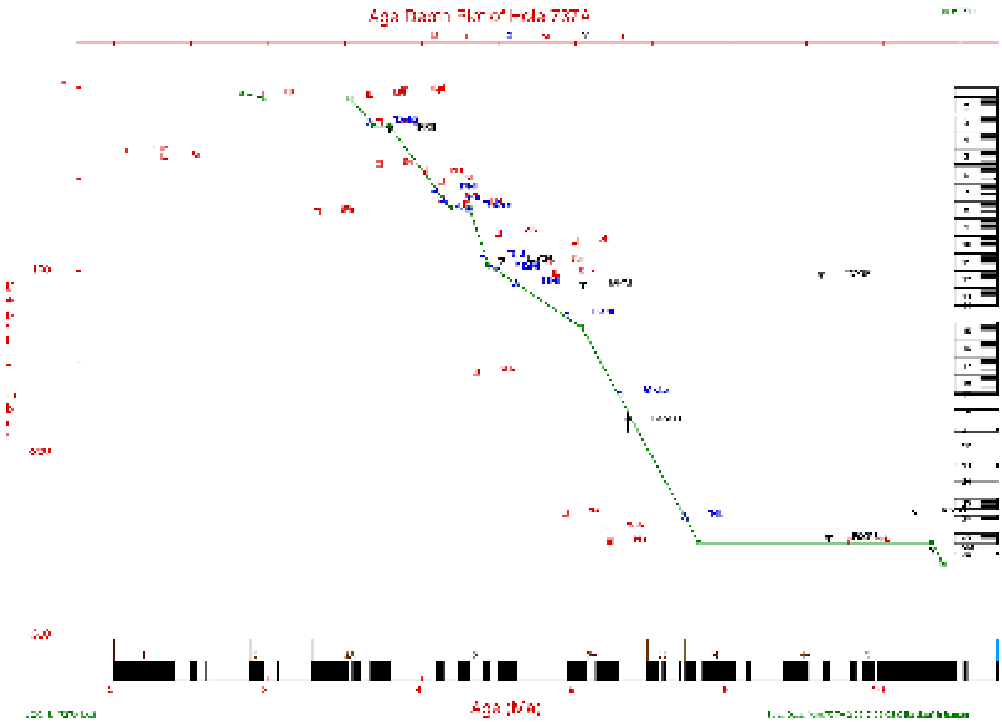
Next Section...

To download full-size diagrams, open the following directory and choose the file (named by hole number). File naming convention is 62A_PICT.GIF (62A = hole number).
DIRECTORY: adps_app

Holes 737A-797B

737A 19950730

AGE	DEPTH
12	
1.65546	2.72728
1.95693	5.83333
3.06618	5.83333
3.38393	21.
3.58613	21.
4.36607	65.5
4.61765	65.5
4.86975	96.9697
6.07983	131.164
7.60504	249.167
10.6429	249.167
10.7815	261.364

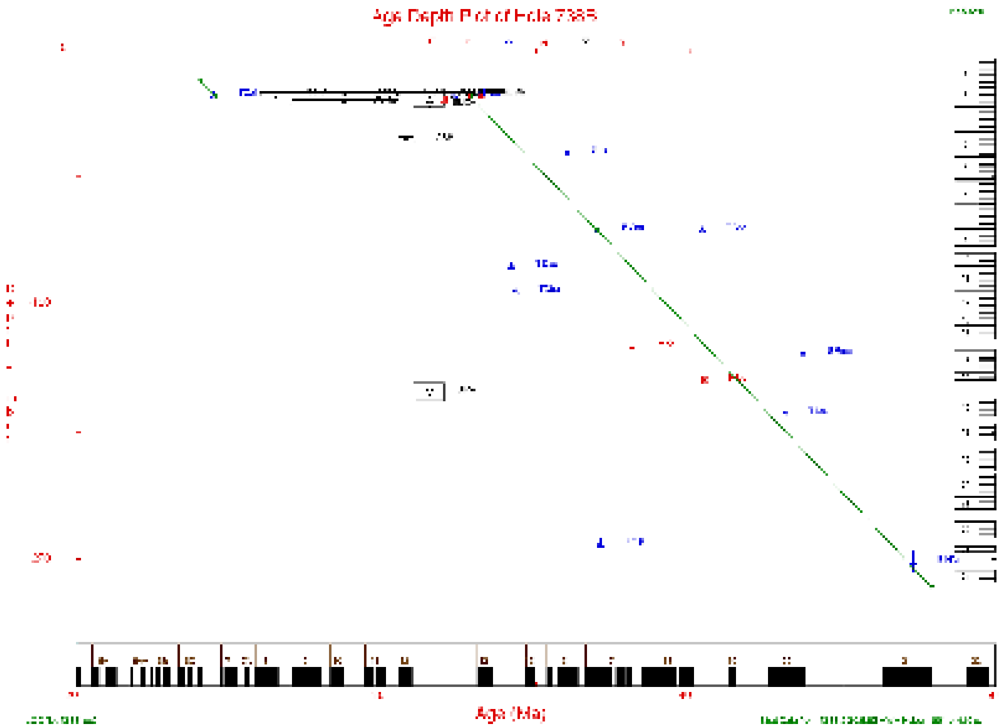


738B 19950720

AGE	DEPTH
5	
24.0074	12.634
24.5093	18.5455
32.825	18.5455

36.9607 70.8269

47.8959 211.332



738C 19950721

AGE DEPTH

6

49.1711 213.17

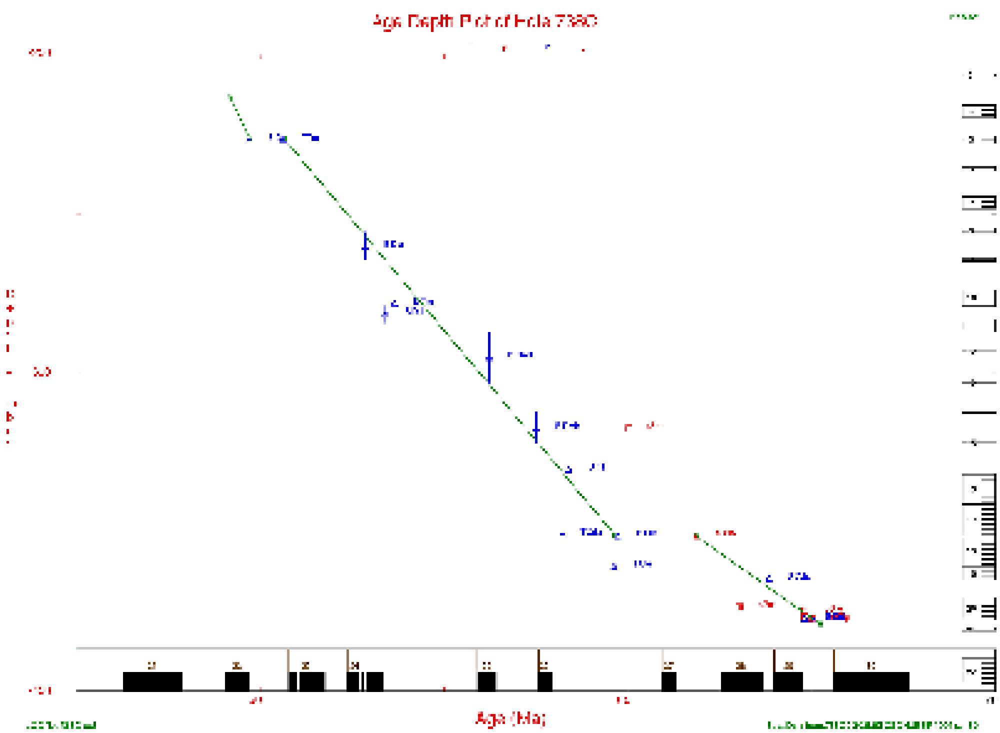
49.7024 226.34

50.6323 226.34

59.6387 350.995

61.8385 350.995

65.1913 378.56



744A 19950730

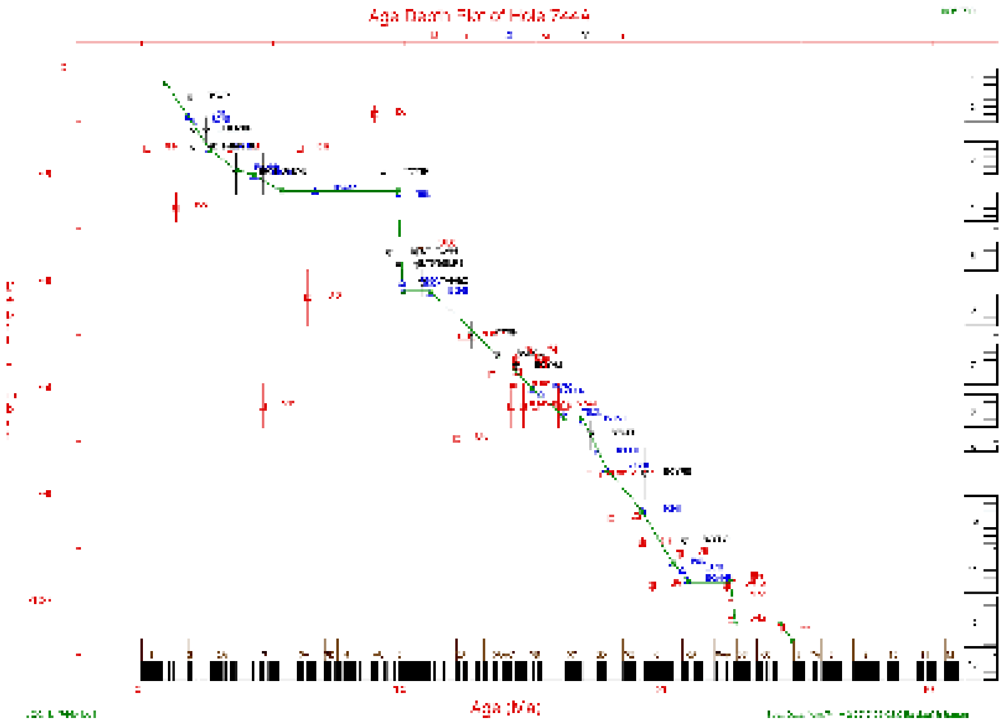
AGE DEPTH

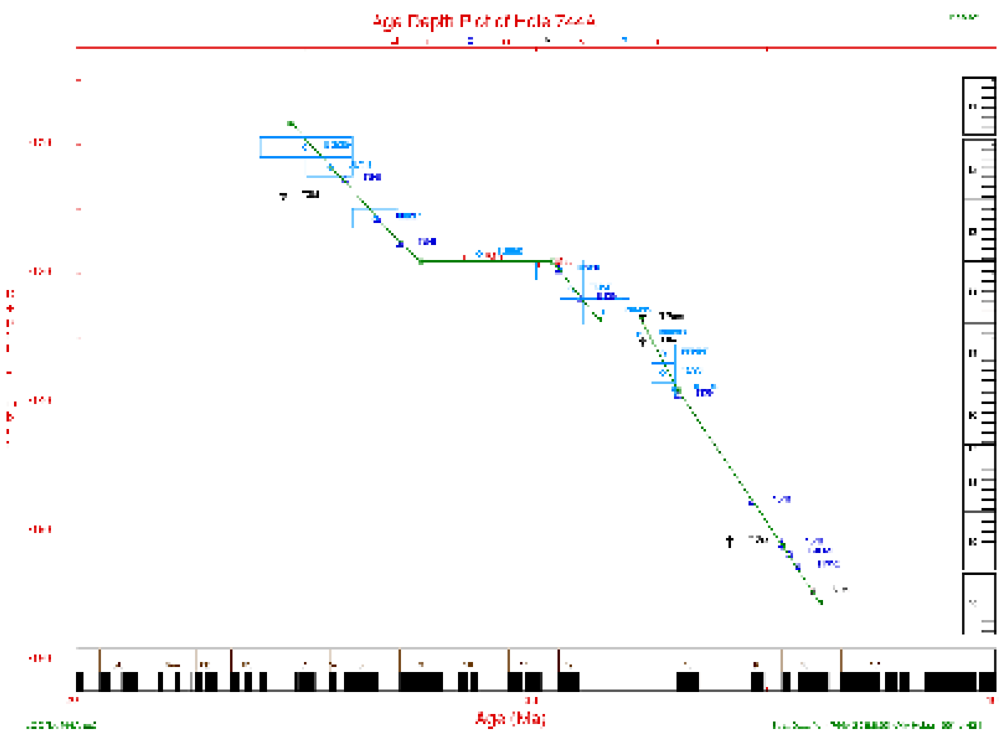
26

.919121 2.63636

2.57353 15.1818

3.5893	19.0455
4.29751	20.0682
5.29128	23.0682
9.71184	23.0682
9.92647	41.7273
10.9559	41.7273
14.8162	59.9091
16.0767	65.5454
16.7332	65.5454
17.6471	75.1818
19.0021	83.1212
20.1576	92.8182
20.7878	96.4545
22.3634	96.4545
22.521	104.333
24.2279	104.333
24.7269	107.606
27.0563	115.455
27.4853	118.182
30.3507	118.182
32.0085	130.758
33.0712	138.788
35.3454	162.273
36.153	171.212

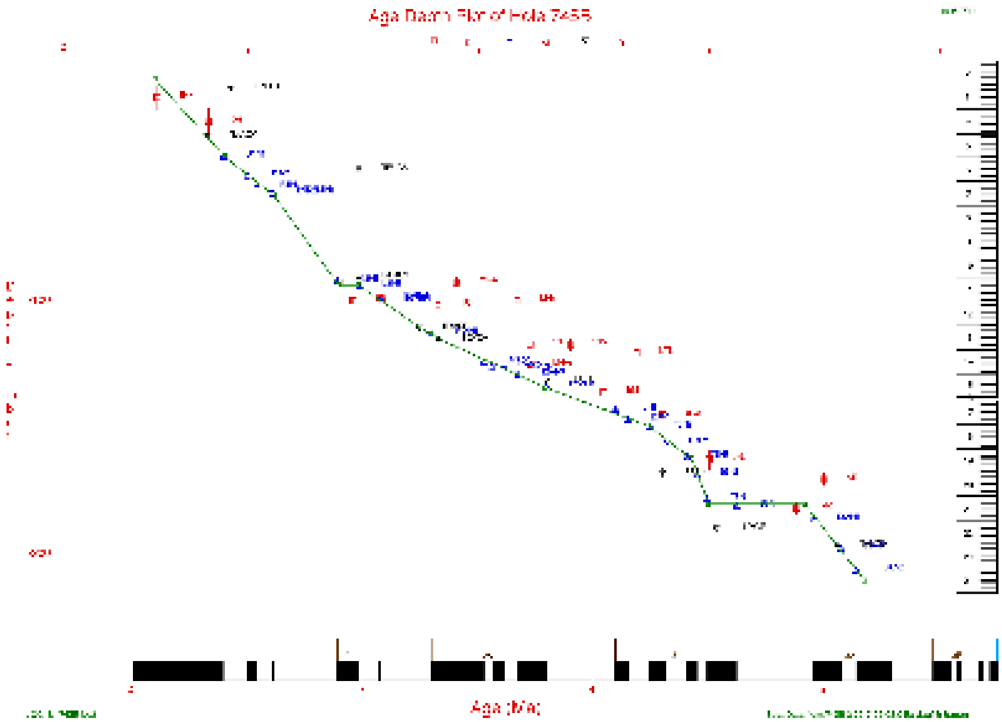




745B 19950730

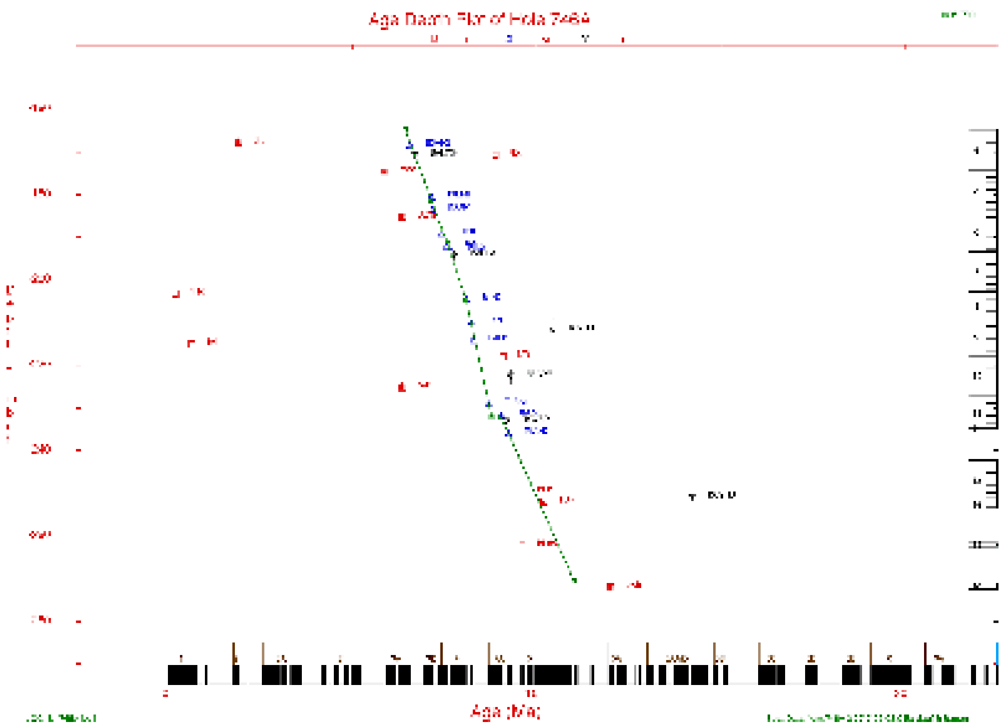
AGE	DEPTH
12	
.182774	11.8683

.781514	42.4962
1.21219	57.8101
1.77941	93.415
1.95798	93.415
2.57773	112.94
3.57563	133.997
4.46639	148.928
4.83613	161.945
4.9958	179.939
5.81933	179.939
6.33824	210.184



746A 19950730

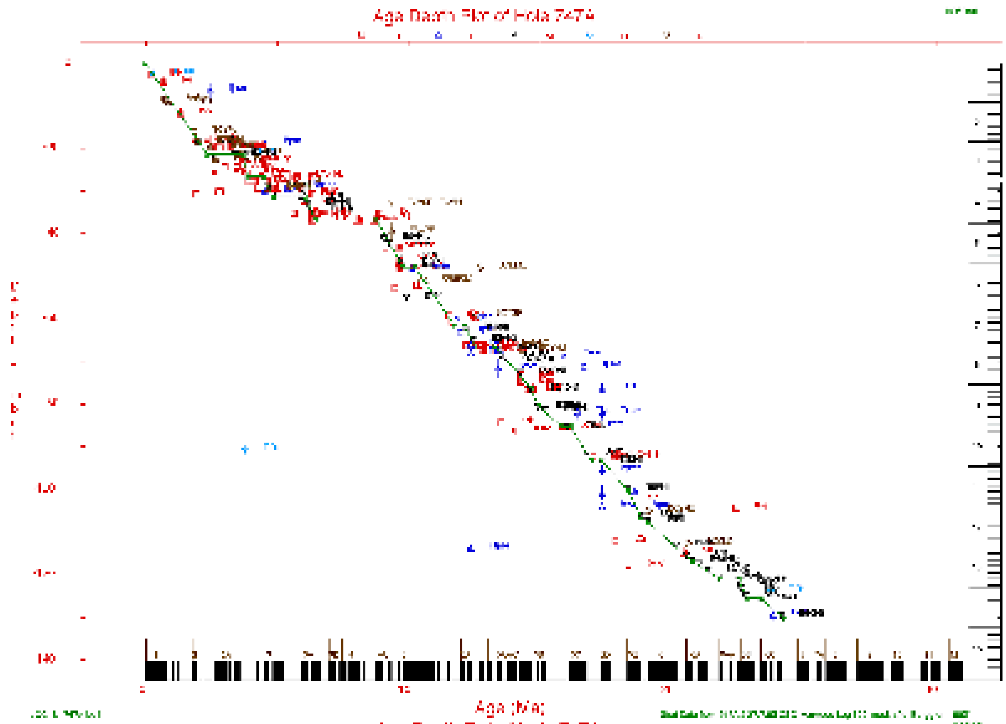
AGE	DEPTH
7	
6.41597	164.773
7.13866	181.364
7.57563	191.591
8.08298	204.773
8.76891	232.045
9.02101	232.045
11.0042	270.455

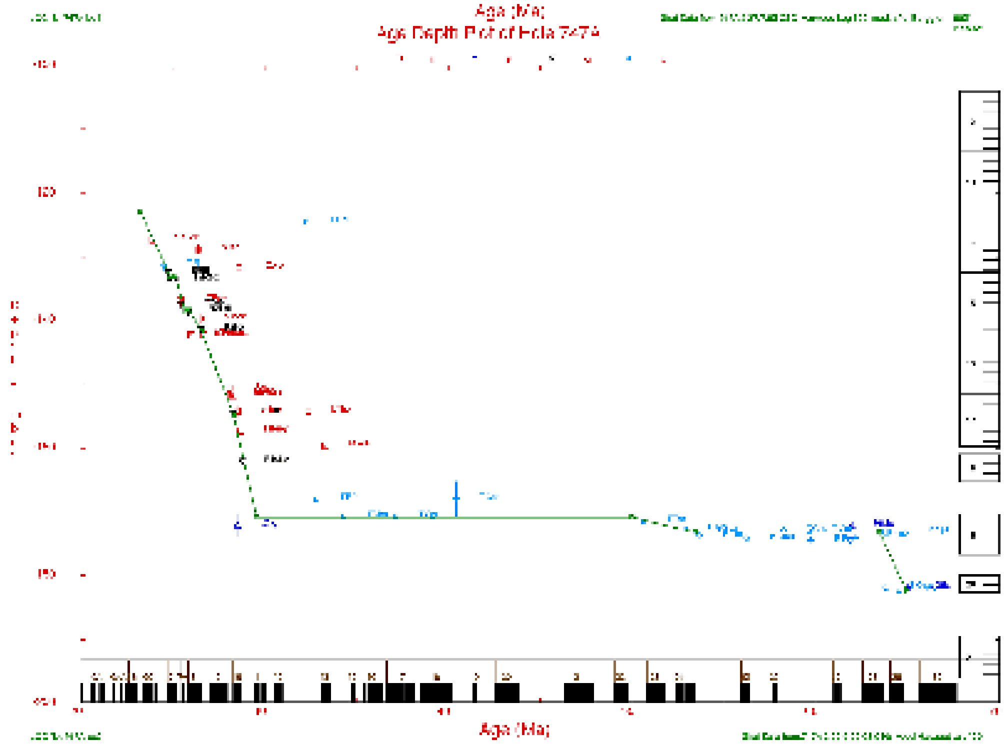


747A 19950801

AGE	DEPTH
41	
-3.27093e-2	9.09087e-2
2.32165	21.2955

3.67446	21.2955
3.86734	26.6136
4.45457	26.6136
4.83255	31.4545
6.03167	31.4545
6.41589	36.7045
8.75649	36.7045
9.73053	47.9545
10.203	47.9545
11.7222	61.7954
12.0929	61.7954
12.4688	66.4167
13.2521	66.4167
14.5966	76.2727
14.874	80.5151
15.8057	85.1136
16.0856	85.1136
16.8845	93.0909
17.2941	93.0909
18.2868	99.9091
18.7721	106.318
19.0809	107.727
20.7279	116.886
21.7941	121.121
22.4874	121.121
22.7899	125.364
23.3571	125.364
24.2794	130.455
24.8088	132.925

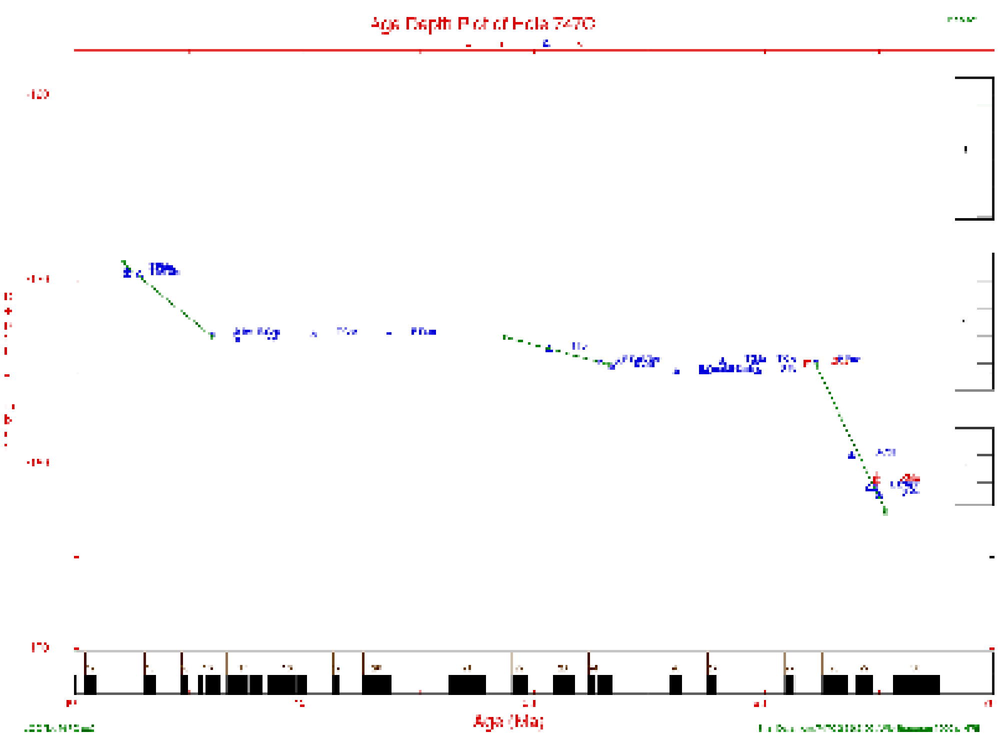




25.1765	132.925
25.6282	138.285
25.8908	138.285
26.5525	141.654
28.2857	154.671
29.543	170.917
49.9628	170.917
53.3581	173.197
63.4006	173.197
64.8831	182.53

747C 19950721

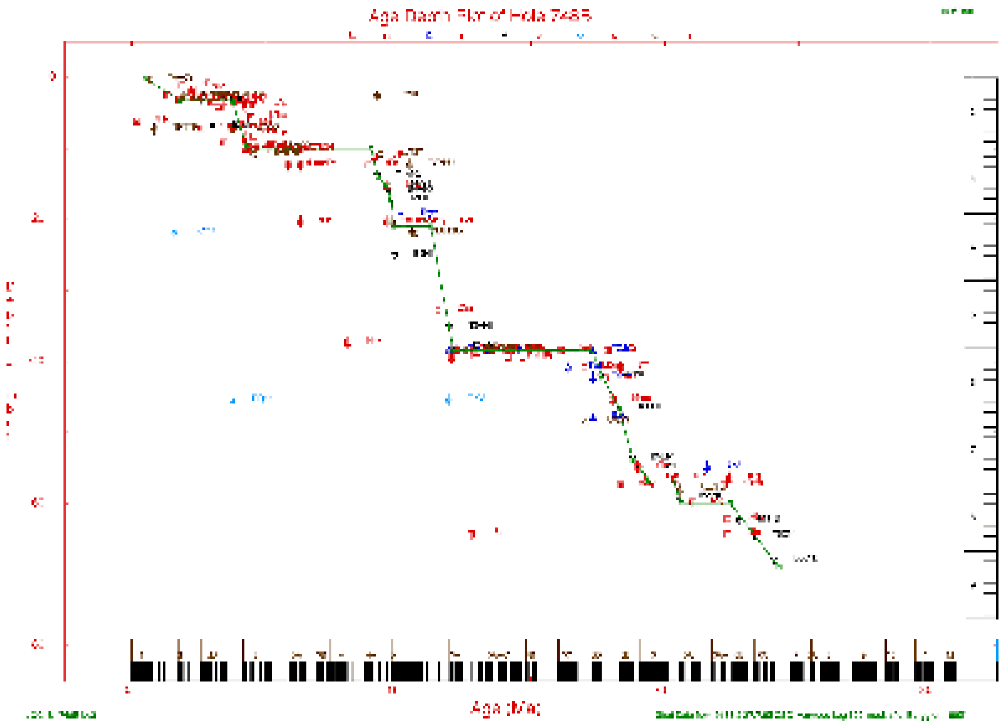
AGE	DEPTH
6	
32.1219	169.061
36.0347	173.091
48.7885	173.091
53.2944	174.576
62.2321	174.576
65.2816	182.583

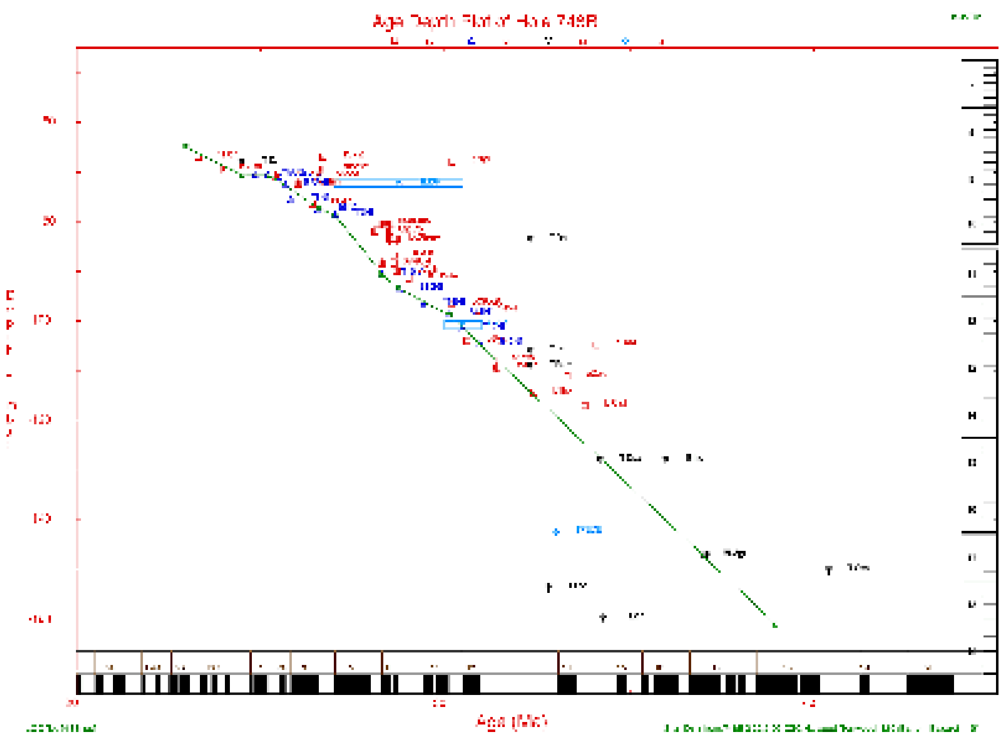


748B 19950801

AGE	DEPTH
27	
.528038	.209091
1.48754	2.78939
2.59554	2.78939

3.41797	10.0379
8.99844	10.0379
9.23105	13.9697
9.57165	15.1364
9.74611	17.2045
9.8458	20.9697
11.2082	20.9697
12.0888	38.3106
17.2871	38.3106
17.6184	41.9545
18.2695	46.3864
18.798	53.7727
19.4003	56.6136
20.337	56.6136
20.6111	59.8864
22.4325	59.8864
24.5252	70.6667
25.2248	70.6667
26.5767	77.2424
27.021	78.7273
28.2891	90.5
28.7321	93.2576
30.1222	98.7727
38.9692	160.818

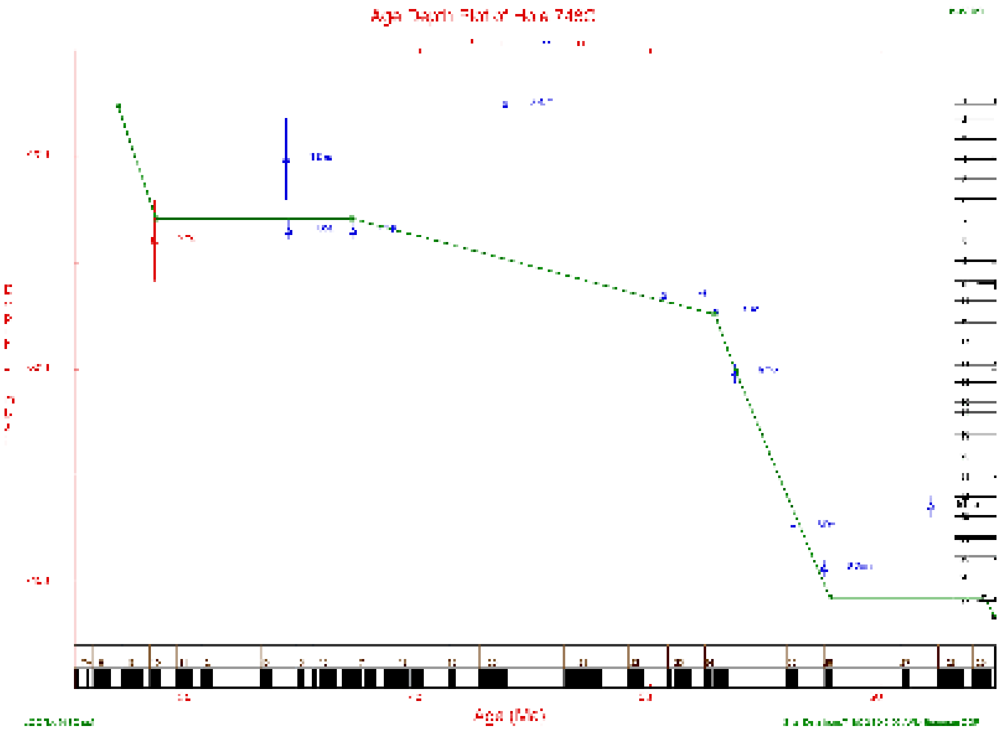




748C 19950723

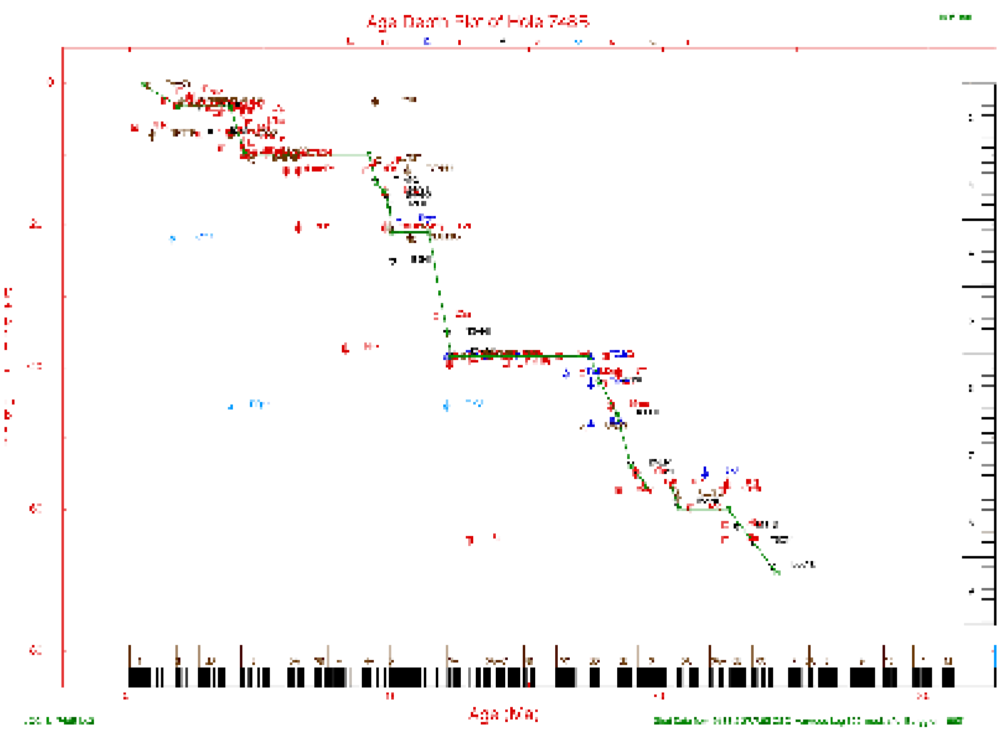
AGE	DEPTH
8	
26.8704	176.187

28.5282	229.479
37.0723	229.479
52.8002	274.502
53.6929	301.149
57.7736	407.274
64.4899	407.274
64.9575	416.003



749B 19950723

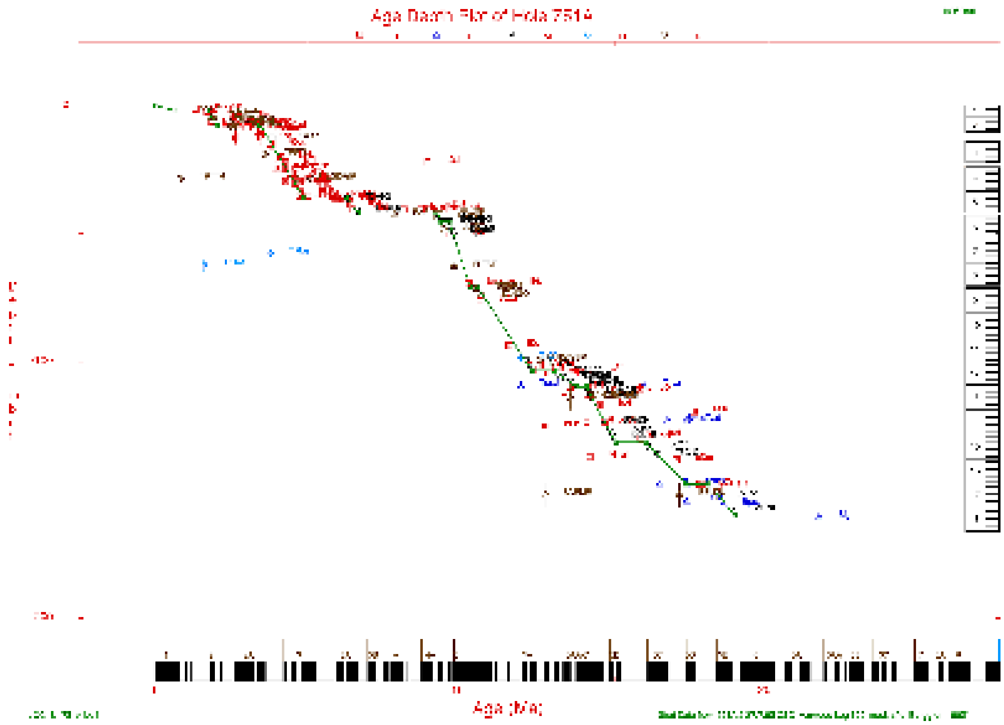
AGE	DEPTH
6	
23.8078	.363637
24.5156	6.28788
28.4283	6.28788
30.0234	15.7197
34.1019	15.7197
41.166	77.7727



751A 19950801

AGE	DEPTH
22	
2.54424e-2	8.33337e-2
.642265	1.75

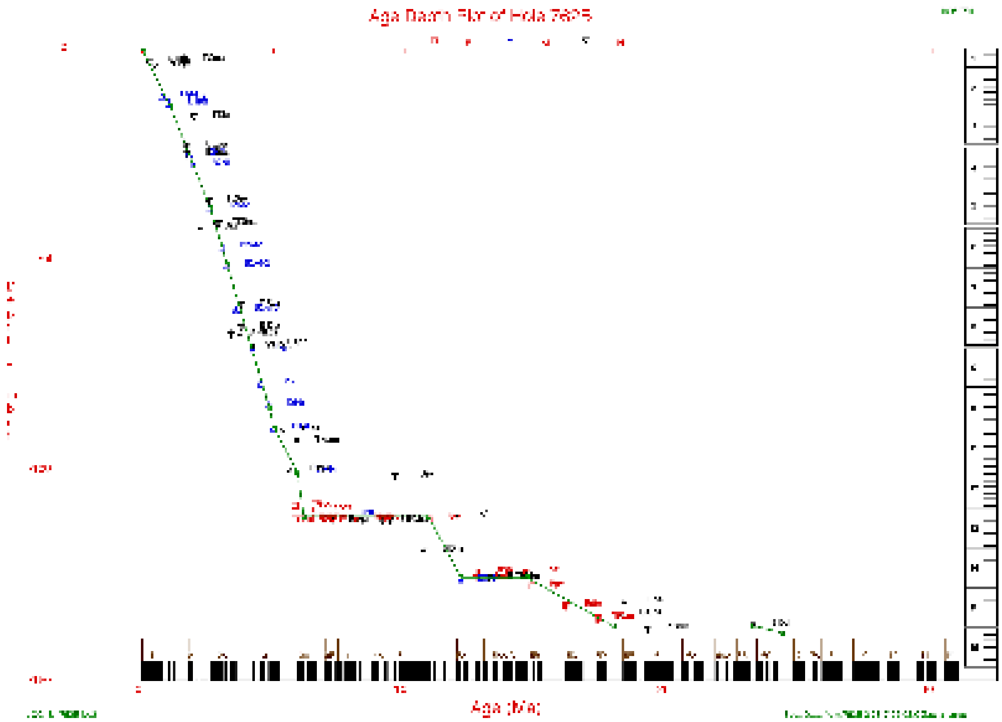
1.69315	1.75
2.01298	7.41667
3.42437	7.41667
4.81153	35.6667
6.20509	35.6667
6.6163	41.8333
9.16355	41.8333
9.32347	44.9167
9.57477	44.9167
10.2201	70.2727
10.4989	70.2727
12.2526	103.364
12.9685	103.364
13.74	109.833
14.0063	109.833
14.9963	131.333
15.959	131.333
17.2941	147.841
18.	147.841
18.8655	159.848



762B 19950731

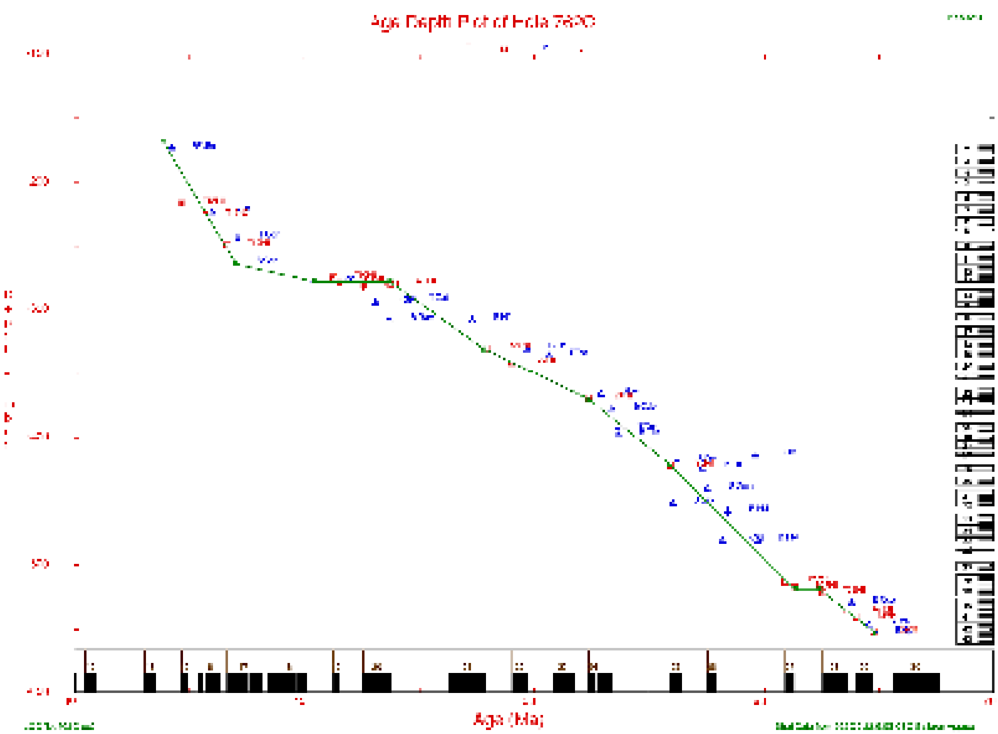
AGE	DEPTH
14	
3.67681e-2	.757579
1.06618	13.4848
2.57353	37.7273
3.22269	51.2121
4.81092	84.9394

4.9874	90.0303
5.91176	100.636
6.14772	110.917
10.8824	110.917
12.0776	125.5
14.6324	125.5
17.9224	136.833
23.2353	136.833
24.3015	138.515



762C 19950723

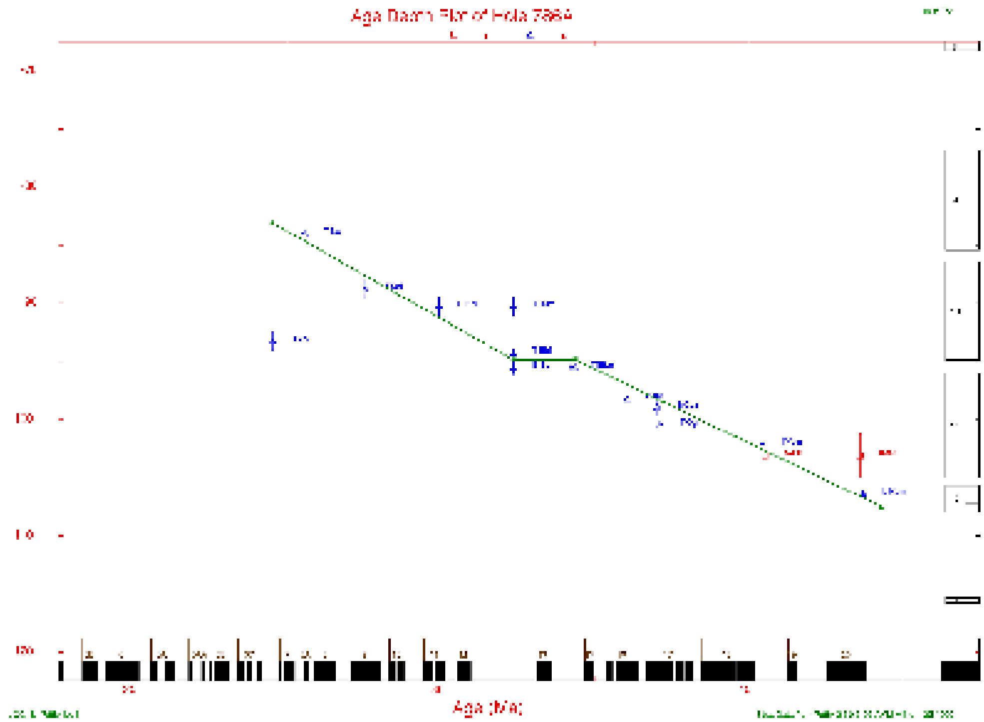
AGE	DEPTH
10	
33.8718	168.182
37.0231	263.864
40.458	277.727
43.7513	277.727
47.8108	330.475
52.3592	369.525
55.9013	420.455
61.3157	519.045
62.4076	519.045
64.8514	553.273



786A 19950724

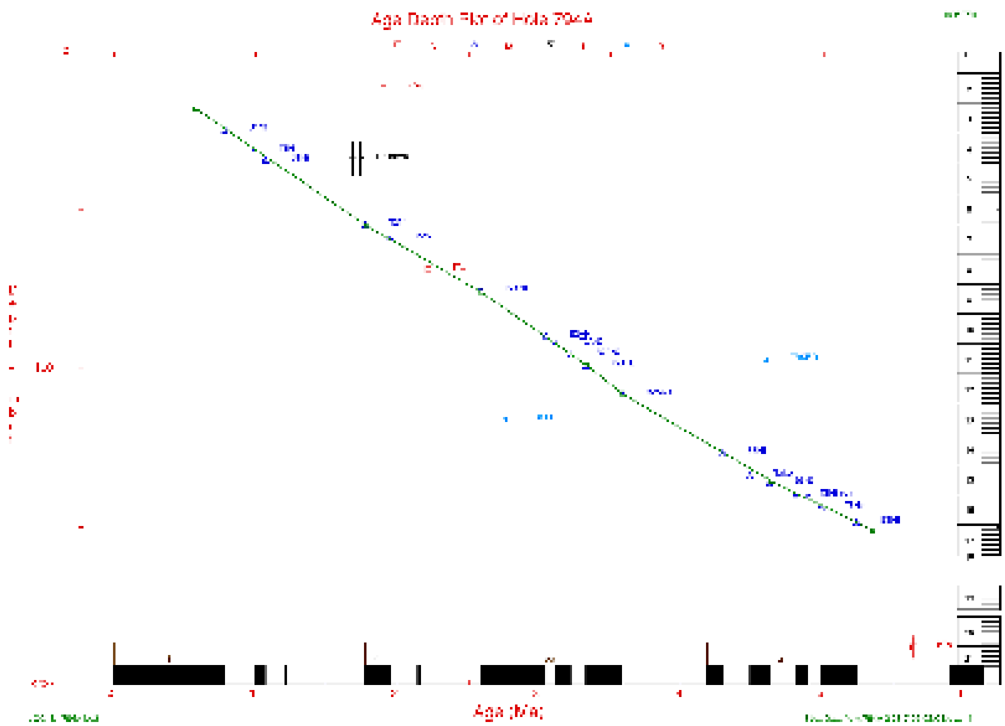
AGE DEPTH

4	
24.4328	83.
32.3109	94.8333
34.3277	94.8333
44.3172	107.5



794A 19950731

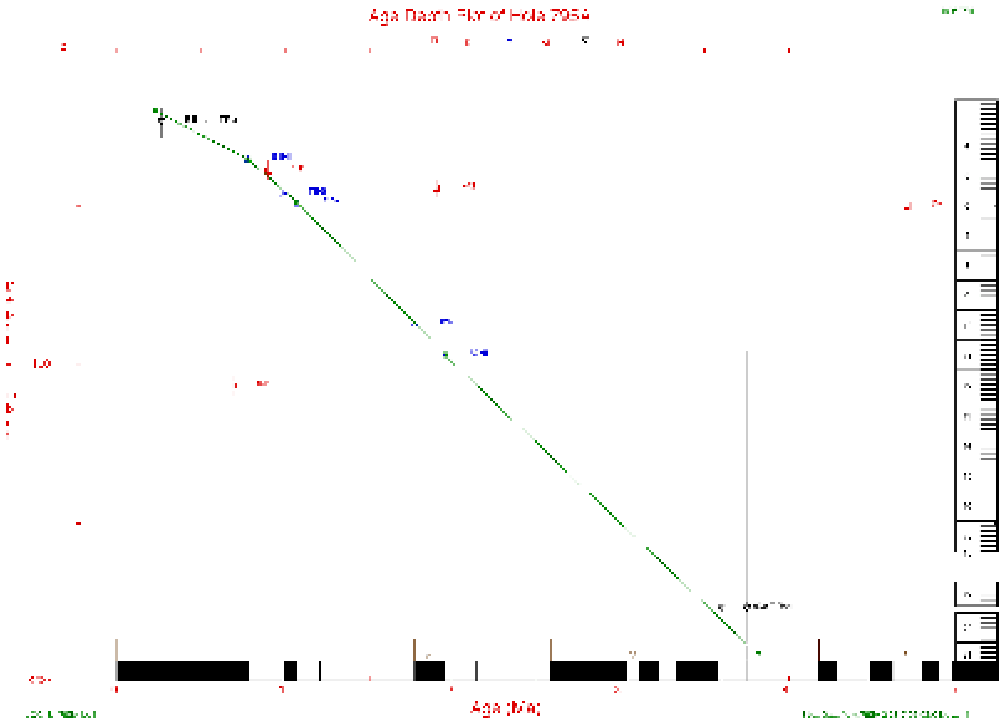
AGE	DEPTH
7	
.576156	17.7642
1.77101	54.5176
2.58351	75.6508
3.33456	98.928
3.58036	107.81
4.63183	135.375
5.34191	150.995



795A 19950731

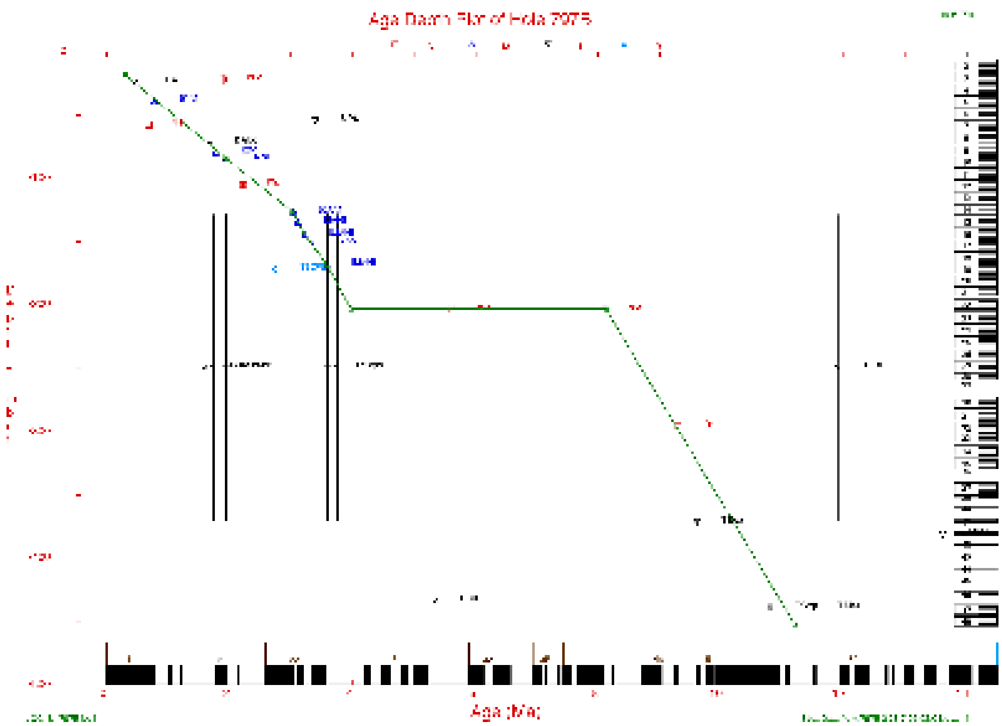
AGE	DEPTH
5	

.229517	19.9081
.778362	34.9158
1.073	48.6983
1.95116	96.7841
3.81723	191.424



797B 19950731

AGE	DEPTH
8	
.319329	18.3767
1.93855	83.6363
3.03519	126.364
3.21849	143.951
3.58088	167.688
3.97479	202.91
8.1187	202.91
11.1912	451.761



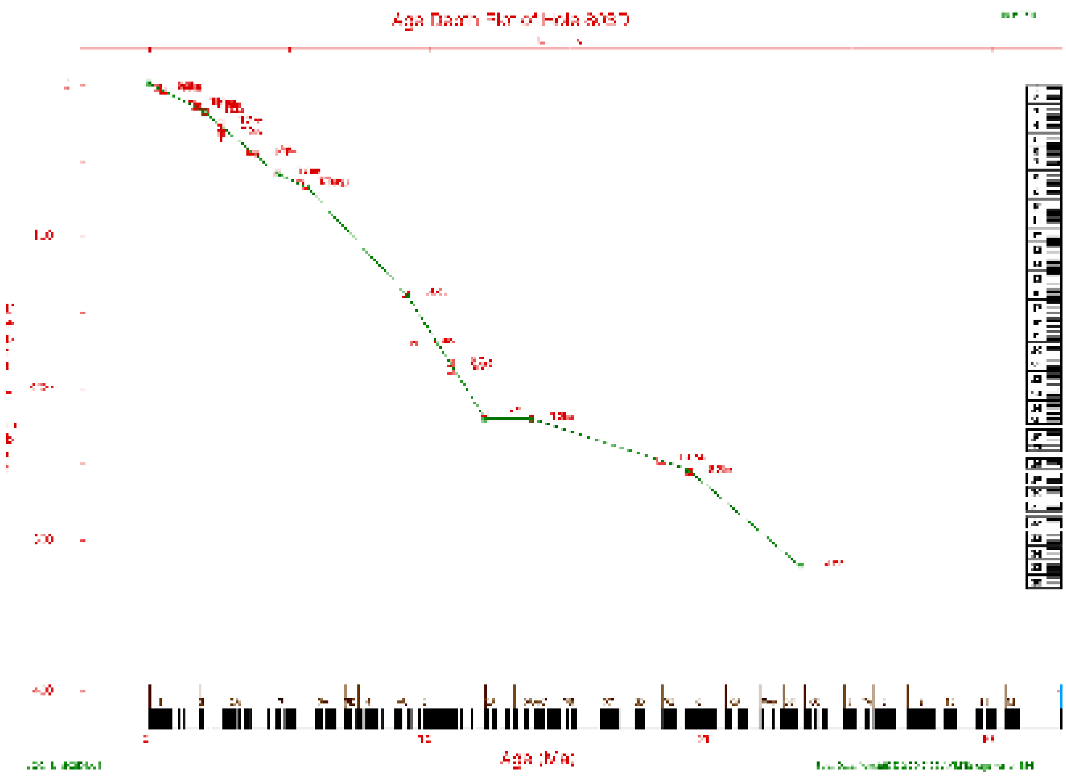
Next Section...

To download full-size diagrams, open the following directory and choose the file (named by hole number). File naming convention is 62A_PICT.GIF (62A = hole number).
DIRECTORY: adps_app

Holes 803B-841B

803D 19950731

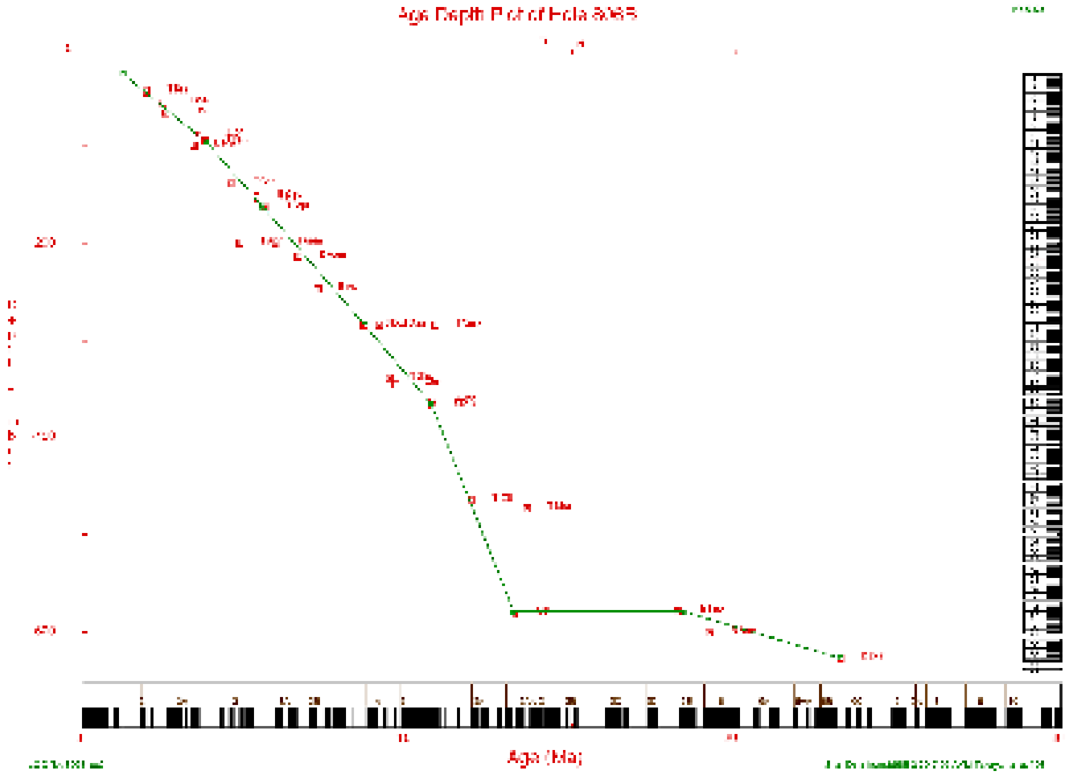
AGE	DEPTH
9	
-.073526	1.81819
1.95717	16.9545
4.56257	58.1364
5.59528	66.7273
9.15441	137.955
11.9485	219.773
13.6397	219.773
19.1764	253.139
23.1934	317.458



806B 19950731

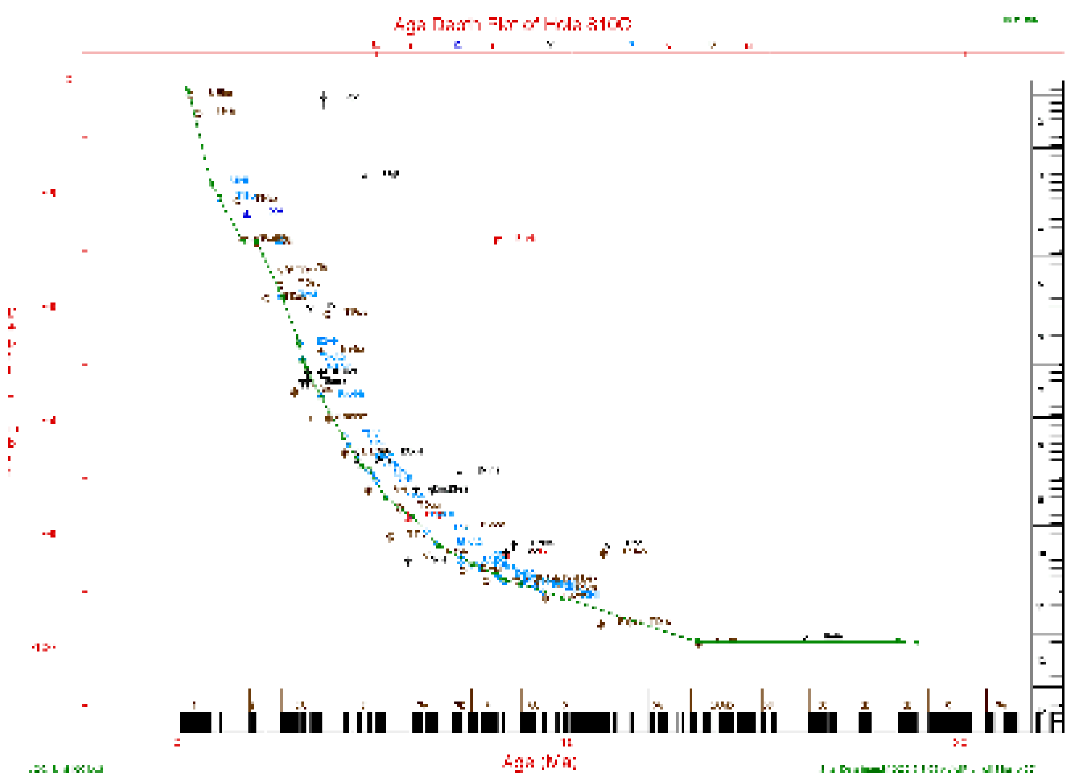
AGE	DEPTH
8	
1.25	24.6554
3.75	94.3338
5.51471	161.868
8.63975	284.073
10.6748	365.682
13.1987	578.867

18.3824	578.867
23.2	627.63



810C 19950807

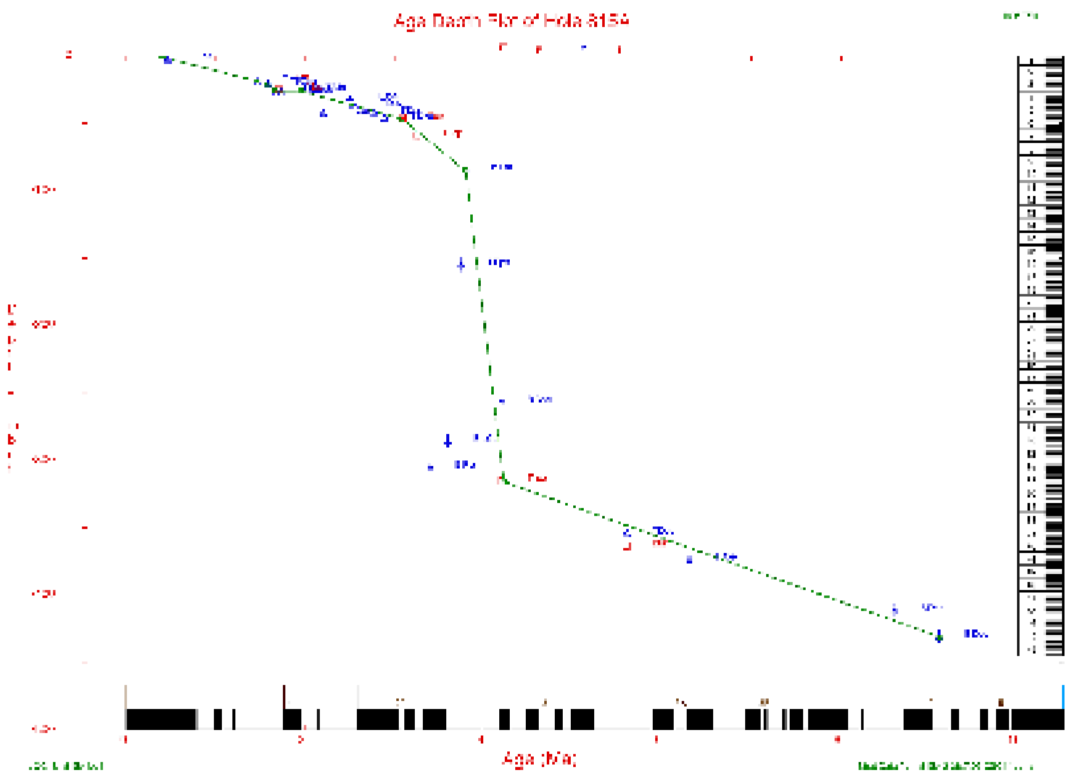
AGE	DEPTH
24	
.212617	1.37121
.778038	18.0758
.983645	20.6742
1.59112	28.4167
1.95561	28.4167
2.58178	38.
3.04097	46.2727
3.11085	49.1818
3.21989	50.8182
3.59244	55.9091
4.17523	62.75
4.61656	67.8636
4.79829	68.4773



5.24685	73.5454
5.89953	76.8182
6.55374	81.7045
7.43224	85.0758
8.06776	87.197
8.25935	88.1818
8.69393	88.5606
9.74055	90.9697
13.1513	98.8182
18.2983	98.8182
18.7447	99.1818

815A 19950731

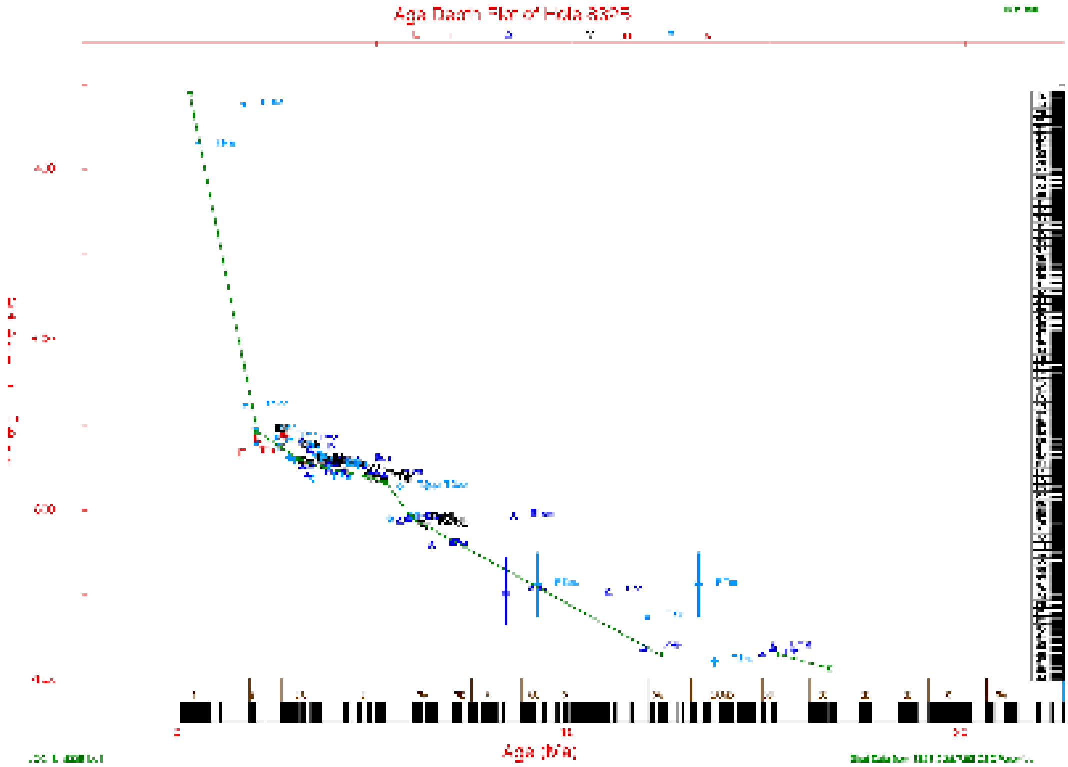
AGE	DEPTH
8	
.404206	1.13636
1.58178	20.5
1.67523	25.8182
1.96028	25.8182
3.09112	46.6818
3.79412	84.9158
4.22584	315.833
9.1	430.34



832B 19950801

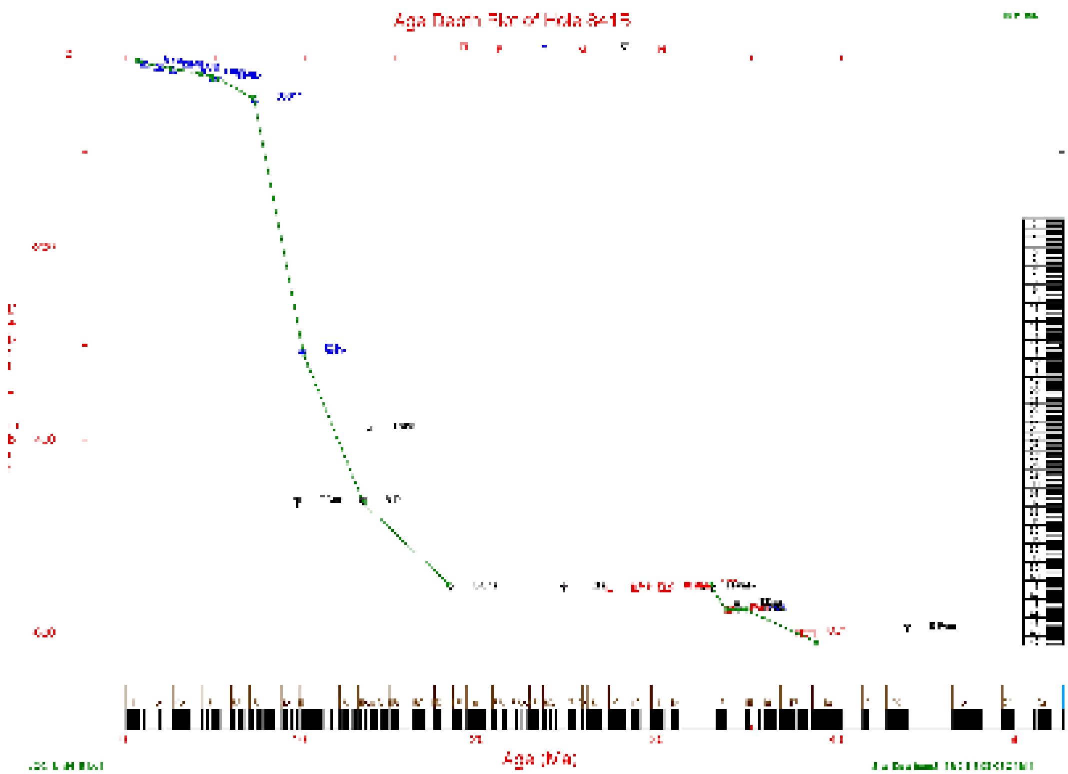
AGE	DEPTH
10	

.257355	311.818
1.96219	707.045
3.04622	740.227
3.59244	748.864
4.80252	759.773
5.24685	767.273
5.89496	808.864
12.2059	969.091
15.2784	969.091
16.5389	985.454



841B 19950802

AGE	DEPTH
14	
.678572	6.83333
2.58508	14.1667
4.16807	18.5
4.80357	22.1667
4.97689	24.5
5.21954	24.5
7.17227	45.1667
9.92122	309.801
13.2721	464.165
18.1243	549.364
32.6621	549.364
33.5547	574.273
34.7059	574.273



38.5767	607.81