

## Palaeoclimatic control of Upper Pliocene Discoaster assemblages in the North Atlantic

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**ABSTRACT** - Abundance variations of six Pliocene species of the nannofossil genus *Discoaster* were analyzed over the time interval 1.89-2.95 Ma at five sites in the North Atlantic; DSDP 552 (56°N), DSDP 607 (41°N), ODP 659 (18°N), ODP 658 (20°N) and ODP 662 (1°S). Individual species are compared between the five sites as a percentage of the total *Discoaster* assemblage, using age models based mainly on *Discoaster* datums (3 control points used at each site). The sampling interval is approximately 3 kyrs.

*Discoaster brouweri*, the only species covering the complete time interval became a less significant component of the assemblages with increasing latitude during the interval prior to 2.3 Ma. *Discoaster triradiatus* shows a distinct abundance acme at all sites between 1.89-2.7 Ma. *Discoaster surculus* increased in relative abundance with higher latitudes and upwelling conditions (ODP Site 658).

*Discoaster pentaradiatus* is an important component of the assemblages at all sites, but displays an inverse abundance relationship with *D. surculus* as a function of increasing latitude and upwelling conditions. *Discoaster tamalis* and *Discoaster asymmetricus* are reduced at low latitudes and in upwelling conditions and increase relative to *D. brouweri* at higher latitudes, where there is strong evidence for taxonomic affinity.

### INTRODUCTION

Discoasters are considered to be the calcareous discs of an extinct group of enigmatic phytoplankton which were presumably related to the coccolithophorids. The last two surviving representatives of the genus *Discoaster* disappeared globally at 1.89 Ma (Takayama, 1970; Backman & Shackleton, 1983; Backman *et al.*, 1986 and Backman & Pestiaux, 1987).

In this study we are investigating the individual species as a percentage of the total *Discoaster* assemblage at five contrasting sites in the North Atlantic in the one million years prior to their final extinction. The data for the absolute abundances of the individual *Discoaster* species and the total *Discoaster* assemblage is shown by Chepstow-Lusty *et al.*, (1989).

Many studies have concluded that high *Discoaster* abundance is related to warm water masses since they are especially common in low-latitude sediments (Haq & Lohmann, 1976; Bukry, 1978). Chepstow-Lusty *et al.*, (1989) demonstrated for the first time that the high variation, particularly in the Tropics, cannot only be related to temperature changes, but must also involve productivity controls.

The sampling interval used is approximately 3 kyrs. The smear slide preparation and counting method used here is

described in Backman & Shackleton (1983). The same paper gives a succinct taxonomy of the six species of discoasters referred to in the present paper (Plate 1).

### SITES SELECTED

The five sites selected (Fig. 1, Table 1) contrast with each other either in terms of latitude or upwelling versus non-upwelling situations. Sampling was at 10 cm intervals except for Sites 607 and 658, which were at 15 cm and 30 cm intervals respectively.

Site 662 is located close to the Equator on the upper, eastern flank of the Mid-Atlantic Ridge. Site 659 was chosen as the non-upwelling, open ocean reference site, and is located on the top of the Cape Verde Plateau. Site 658 is a contrasting, high productivity, upwelling site in close proximity to Site 659, located 160 km west of Cape Blanc and lying beneath a major, highly productive cell of oceanic upwelling.

Site 607 is located along the northernmost part of the present-day Subtropical Gyre, but in the Late Pliocene it was subjected to major circulation changes and lower temperatures (Ruddiman, Sarnthein *et al.*, 1988) Site 552 is the northernmost site selected and is located on the southwest margin of the Rockall Plateau. For further information concerning these sites

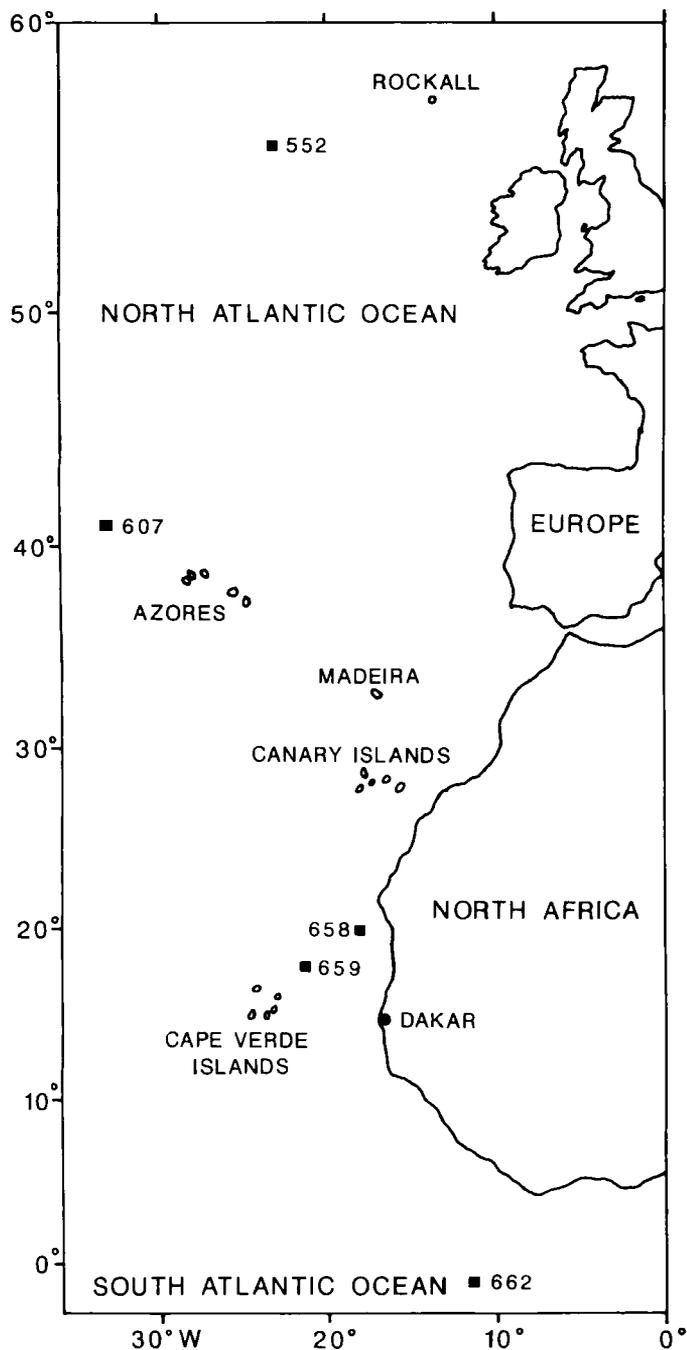


Fig 1. Location of sites studied in the North Atlantic.

refer to Roberts, Schnitker *et al.* (1984); Ruddiman, Kidd, Thomas *et al.* (1987) and Ruddiman, Sarnthein *et al.* (1988).

#### AGE MODELS AND SEDIMENTATION RATES

To compare the five sites age models had to be constructed. This process is discussed in great detail in Chepstow-Lusty *et al.* (1989).

At Sites 659 and 662 magnetostratigraphic data was not available, and at Site 658 it was found to be inaccurate, so that all age models for these sites are based on biostratigraphic datums. Sites 607 and 552 had reliable magnetic stratigraphies. The age models constructed are based on only three stratigraphic datums at each site. Biostratigraphic datums were selected preferentially if possible, especially *Discoaster* datums (Table 2). The logic behind this procedure was to obtain age models that were consistent between the five sites (Table 3). The datums for *Globoquadrina altispira* at Sites 658 and 662, an extremely useful planktonic foraminiferal datum, come from Weaver & Raymo (1989). Sedimentation rates are very high at the upwelling site, Site 658, and lowest at the highest latitude site, Site 552.

#### COMPARISON OF SPECIES

##### COMPOSITION WITHIN THE *DISCOASTER* ASSEMBLAGE BETWEEN SITES

The absolute abundances of total discoasters and *D. brouweri* shown by Chepstow-Lusty *et al.* (1989) display marked differences of abundance between high and low latitudes, and between upwelling versus non-upwelling situations. Trends in the other species show different patterns, but there is always a sudden reduction in abundance of all species of *Discoaster* studied between 41° and 56°N. Discoasters as a group do not favour cool water masses, but by representing individual *Discoaster* species as a percentage of the total *Discoaster* assemblage, some of the trends in the absolute abundance data may be further refined to yield additional information. The absolute abundance differences in discoasters between, e.g. Site 552 (56°N) and Site 662 (1°S), present major scaling problems, and therefore this technique also provides an alternative method of making comparisons.

TABLE 1

North Atlantic sites selected, their geographic positions and water depth.

Hole	Location	Depth (m)	Reference
662A	1°S 11°W	3,824	Ruddiman, Sarnthein, <i>et al.</i> , 1988
659A	18°N 21°W	3,067	"
658A	20°N 18°W	2,263	"
607	41°N 33°W	3,427	Ruddiman, Kidd, Thomas, <i>et al.</i> , 1987
552A	56°N 23°W	2,304	Roberts, Schnitker, <i>et al.</i> , 1984

TABLE 2

Summary of *Discoaster* events between 3.00 and 1.89 Ma, based on previous work (e.g. Backman & Shackleton, 1983; Backman, *et al.*, 1986). \* Estimate for extinction from this study.

Species	Age (Ma)	Event
<i>D. brouweri</i>	1.89	Extinction
<i>D. triradiatus</i>	1.89	Extinction
<i>D. triradiatus</i>	2.07	Peak Abundance began
<i>D. pentaradiatus</i>	2.43-2.33	Extinction
<i>D. surculus</i>	2.46-2.42	Extinction
<i>D. surculus</i>	2.39	Extinction*
<i>D. asymmetricus</i>	2.65	Abundance decline
<i>D. tamalis</i>	2.65	Extinction
<i>D. variabilis</i>	2.93-2.87	Extinction

Species are shown only for the time interval through which they range. Reworked species in low abundance intervals of *D. brouweri* can result in high percentage representation, which distorts the apparent species distribution in time, and may potentially cause confusion. However this type of representation may prove a useful way of investigating the cyclicity of reworking. Discontinuities in the plots indicate loss of material at core breaks.

#### ***Discoaster brouweri* and *Discoaster triradiatus***

Both these species become extinct at 1.89 Ma. *D. brouweri* is the only species occurring throughout the complete time-interval studied (3.00-1.89 Ma). Apart from the brief acme of *D. triradiatus*, *D. brouweri* is the sole surviving *Discoaster* species between approximately 2.35 and 1.89 Ma (Fig. 2). An interesting feature of the other *Discoaster* species is that before 2.35 Ma they form a greater component of the total *Discoaster* assemblage with increasing latitude. It appears that shortly after the initiation of major glaciation in the North Atlantic at 2.4 Ma (Shackleton *et al.*, 1984), essentially only *D. brouweri* continues, as the last surviving *Discoaster* species.

*D. triradiatus* is insignificant in abundance until 2.07 Ma (Backman & Shackleton, 1983), when it increases to the proportion of 20% relative to *D. brouweri* (Fig. 3). This acme is observed at all sites including Site 552, where the time resolution and abundances are however very low. These two species are believed to be strongly related taxonomically. Their final extinction of may be slightly disguised by reworking of them in very low numbers, but producing anomalously high percentages. Absolute abundances should therefore also be referred to when defining this event.

#### ***Discoaster pentaradiatus* and *Discoaster surculus***

These two species have been compared in different cores and ocean basins by Backman & Shackleton (1983), Backman *et al.* (1986) and Backman & Pestiaux (1987). Their extinctions are estimated to occur between 2.45 and 2.35 Ma. The general

consensus is that *D. surculus* disappeared slightly earlier than *D. pentaradiatus*, which is also the case at the five sites studied here. Anomalous percentages beyond the extinction events specified here are due to reworking during periods of low abundances of *D. brouweri*.

In the time-interval 3.0-2.3 Ma, *D. pentaradiatus* (Fig. 4) constantly forms a high proportion of the *Discoaster* assemblage from low to high latitudes and from upwelling to non-upwelling situations. An apparent trend, however, is an increase in the proportion of *D. pentaradiatus* within the complete *Discoaster* assemblage between 2.50 and 2.38 Ma as a function of increasing latitude and upwelling conditions.

At Sites 659, 658, 607 and 552 a distinct and synchronous extinction of *D. pentaradiatus* was recorded at approximately 2.38 Ma. However, at Site 662 the extinction event was less easy to define owing to reworking, but was estimated to occur between 2.41 and 2.34 Ma.

*D. surculus* was found to end with a final sharp peak at the end of its range in Sites 658, 659 and 662, which is assumed to be synchronous (Fig. 5). At Site 659, where the Plio-Pleistocene sedimentation rate appears to be constant (Ruddiman, Sarnthein *et al.*, 1988), the Last Appearance Datum (LAD) of *D. surculus* was found to be the only biostratigraphic datum that did not fit the apparently linear sedimentation rate. The age estimate of *D. surculus*, when adjusted to fit the linear sedimentation rate gave a value of 2.39 Ma for the final peak (Chepstow-Lusty *et al.*, 1989), which is within the range of estimates obtained from Core V32-127 (Backman & Shackleton, 1983). The age of 2.39 Ma for this final peak of *D. surculus* has therefore been applied to all the age models for internal consistency (Table 3).

The final peak of *D. surculus* is clearly shown in the absolute abundances at Sites 658, 659 and 662, but not at Sites 607 or 552. However, by representing *D. surculus* as a percentage of the complete *Discoaster* assemblage the final peak is also well defined at the two latter sites. Sites 607 and 658 once again demonstrate the problem of reworking in a low abundance interval of *D. brouweri*, after approximately 2.39 Ma.

*D. surculus* shows a clear trend of increasing abundance within the *Discoaster* assemblage as a function of increasing latitude and upwelling conditions. Bukry (1978) noted that *D. surculus* favoured the cooler end of the spectrum occupied by the warm water genus *Discoaster*, and this is clearly confirmed here.

In all five sites *D. pentaradiatus* and *D. surculus* were frequently observed to display an inverse abundance relationship (Backman & Shackleton, 1983). These two species are believed to have different ranges of ecological tolerance. *D. surculus* is therefore finally represented here as a plot of its percentage as a proportion of the sum of *D. surculus* and *D. pentaradiatus* (Fig. 6). This emphasizes that *D. surculus* increases with latitude and upwelling conditions, and further defines the final peak at 2.39 Ma.

TABLE 3

Summary of control points used in age-models.  
(mbsf = metres below sea floor)

Datum	Age (Ma)	Depth (mbsf)	Event	Sedimentation Rate
HOLE 659A				
<i>D. brouweri</i>	1.89	54.8	Extinction	3.2 cm/kyrs
<i>D. triradiatus</i>	2.07	60.6	Peak Abundance began	
<i>D. tamalis</i>	2.65	79.4	Extinction	
HOLE 658A				
<i>D. brouweri</i>	1.89	126.4	Extinction	7.9 cm/kyrs
<i>D. surculus</i>	2.39	166.0	Extinction	9.6 cm/kyrs
<i>G. altispira</i>	2.95	220.0	Extinction	
HOLE 662A				
<i>D. brouweri</i>	1.89	123.2	Extinction	5.6 cm/kyrs
<i>D. surculus</i>	2.39	151.4	Extinction	3.1 cm/kyrs
<i>G. altispira</i>	2.95	168.5	Extinction	
HOLE 607				
<i>D. brouweri</i>	1.89	82.86	Extinction	4.8 cm/kyrs
<i>D. surculus</i>	2.39	106.78	Extinction	4.0 cm/kyrs
Kaena	2.99	130.73	base	
HOLE 552A				
<i>D. brouweri</i>	1.89	35.2	Extinction	1.4 cm/kyrs
<i>D. surculus</i>	2.39	42.5	Extinction	1.0 cm/kyrs
Kaena	2.99	48.6	base	

#### *Discoaster asymmetricus* and *Discoaster tamalis*

The absolute abundance plots (Chepstow-Lusty *et al.*, 1989) demonstrated that these two species co-vary almost identically. Backman & Shackleton (1983), Backman *et al.* (1986) and Backman & Pestiaux (1987) have also recorded this phenomenon, and it is widely agreed that these species are taxonomically

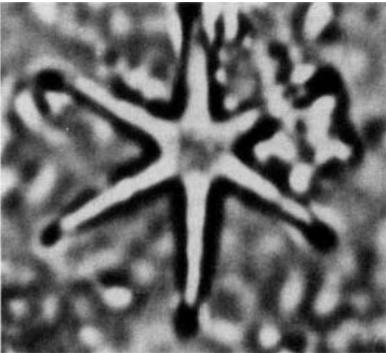
related. This co-variation can also be demonstrated by comparing the percentage abundance plots of these two species (Fig. 7 and 8). Furthermore, these two species also co-vary with *D. brouweri* to which they appear to be related.

The extinction event for *D. tamalis*, and abundance decline of *D. asymmetricus*, at 2.65 Ma is slightly disguised by rework-

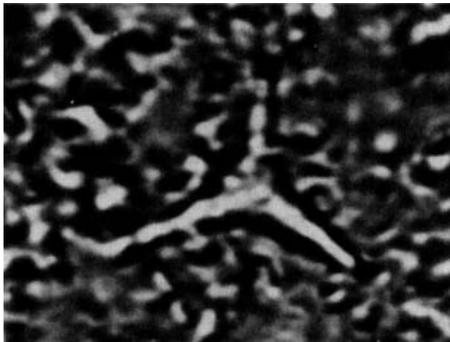
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#### Explanation of Plate 1

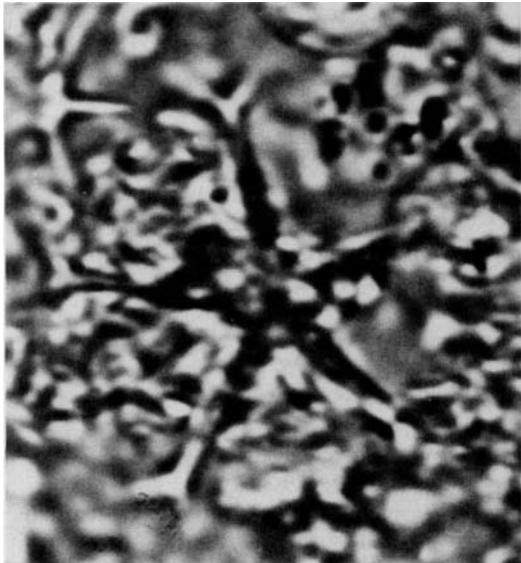
Fig. 1 *Discoaster brouweri* Tan Sin Hok. Fig. 2. *Discoaster triradiatus* Tan Sin Hok. Fig. 3. *Discoaster pentaradiatus* Tan Sin Hok. Fig. 4. *Discoaster surculus* Martini & Bramlette. Fig. 5. *Discoaster asymmetricus* Gartner. Fig. 6. *Discoaster tamalis* Kamptner.



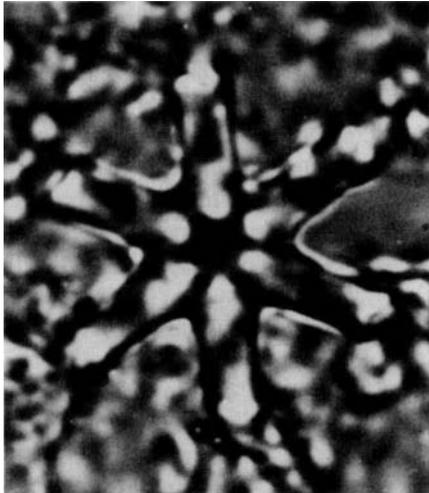
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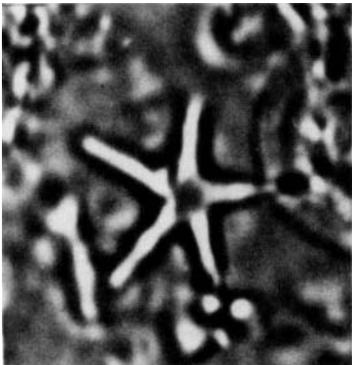
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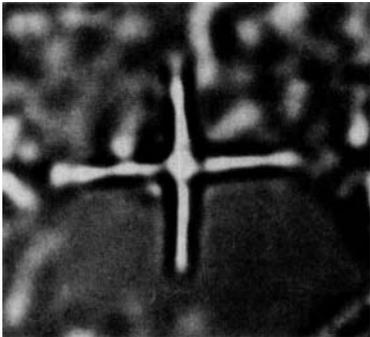
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10μ

ing, or presence in low numbers, except at Sites 659 and 662. The trend to notice is the percentage increase in abundance within the complete *Discoaster* assemblage for both these species with increasing latitude, but not with upwelling conditions. This can be further emphasized by representing *D. tamalis* as a percentage of the sum of *D. tamalis*, *D. asymmetricus* and *D. brouweri*, which may in fact be one biological species (Fig. 9). Similarly, the same trend can be shown by representing the sum of *D. tamalis* and *D. asymmetricus* as a percentage of the sum of these two species and *D. brouweri* (Fig. 10). Upwelling appears to suppress the production of these two species at Site 658. Site 662, which is located within the Equatorial Divergence, should be affected by upwelling to some degree, causing a similar suppression.

### CONCLUSIONS

Prior to 2.35 Ma, *Discoaster brouweri* decreases as a percentage of the complete *Discoaster* assemblage with increasing latitude. The related species *Discoaster tamalis* and *Discoaster asymmetricus* reached a critical threshold at 2.65 Ma following which these forms stopped being produced or were produced very rarely. Prior to 2.65 Ma the production of these two types of discs was favoured by cooler water masses unassociated with upwelling.

Until approximately 2.3 Ma, *Discoaster pentaradiatus* forms a major stable component of the total *Discoaster* assemblage across both latitude and upwelling versus non-upwelling conditions. Prior to approximately 2.39 Ma, *Discoaster surculus* increased as a component of the total *Discoaster* assemblage with both higher latitudes and upwelling conditions. Major changes in the *Discoaster* assemblage, leaving *D. brouweri* as the sole survivor from shortly afterwards, correlate with the strong changes in Northern Hemisphere climate at 2.4 Ma.

Representing *Discoaster* species as a percentage of the total *Discoaster* assemblage reveals additional ecological information not clearly shown by the absolute abundances. Similar research is being carried out on cores with high time resolution from the Pacific and Indian Oceans at Sites 677, 716 and 709. It will be interesting to see if the latitudinal and upwelling versus non-upwelling trends revealed in the Atlantic are applicable globally.

### ACKNOWLEDGEMENTS

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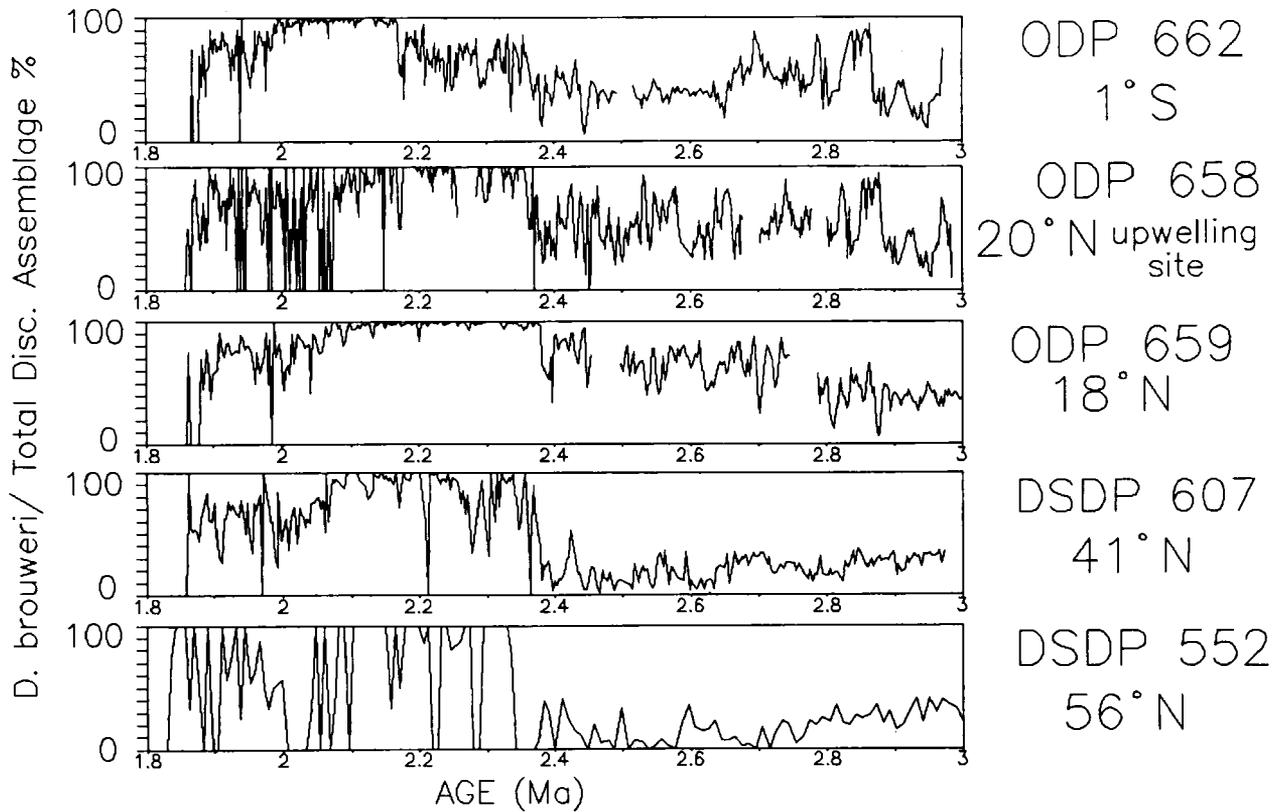


Fig. 2. Percentage abundance plots of *D. brouweri* at Sites 552, 607, 659, 658 and 662. Gaps in plots are core breaks.

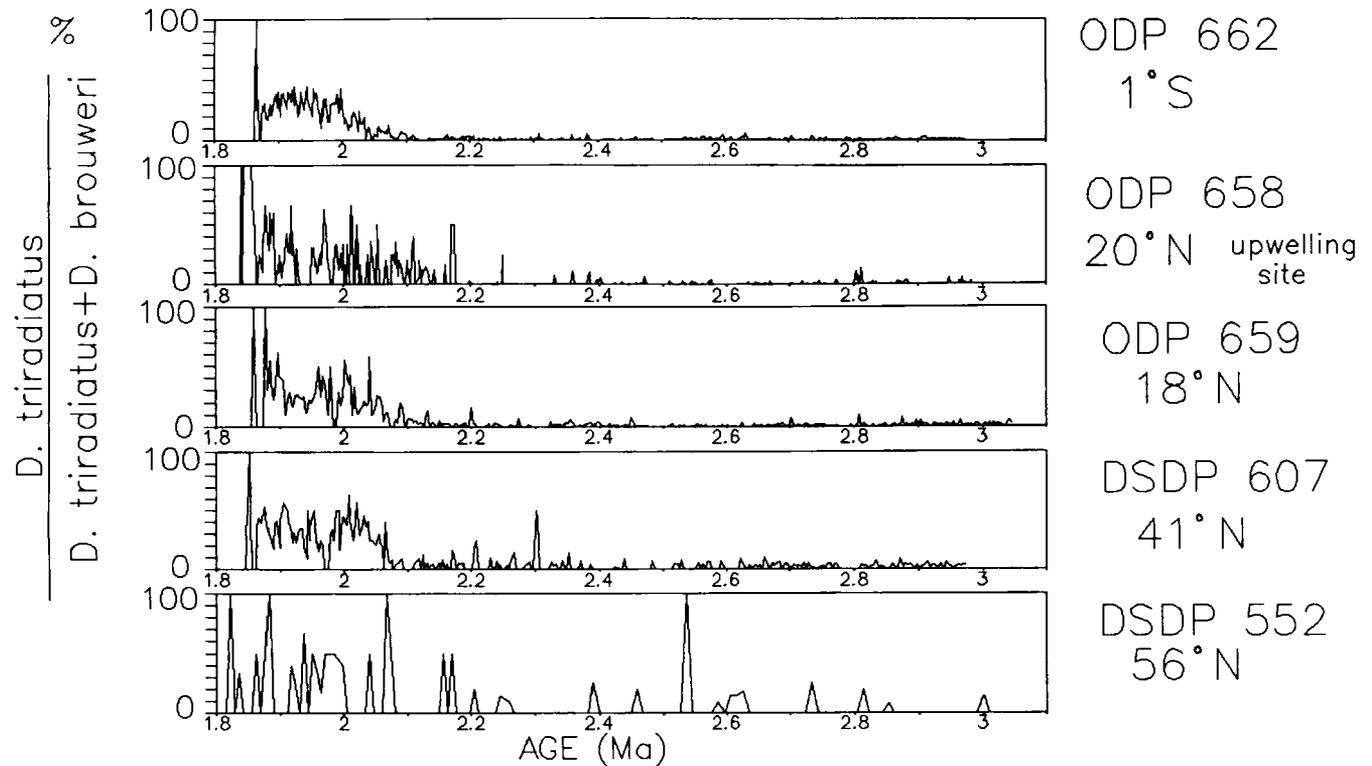


Fig. 3. Percentage plots of *D. triradiatus* as a percentage of the sum of *D. triradiatus* and *D. brouweri* at Sites 552, 607, 659, 658 and 662.

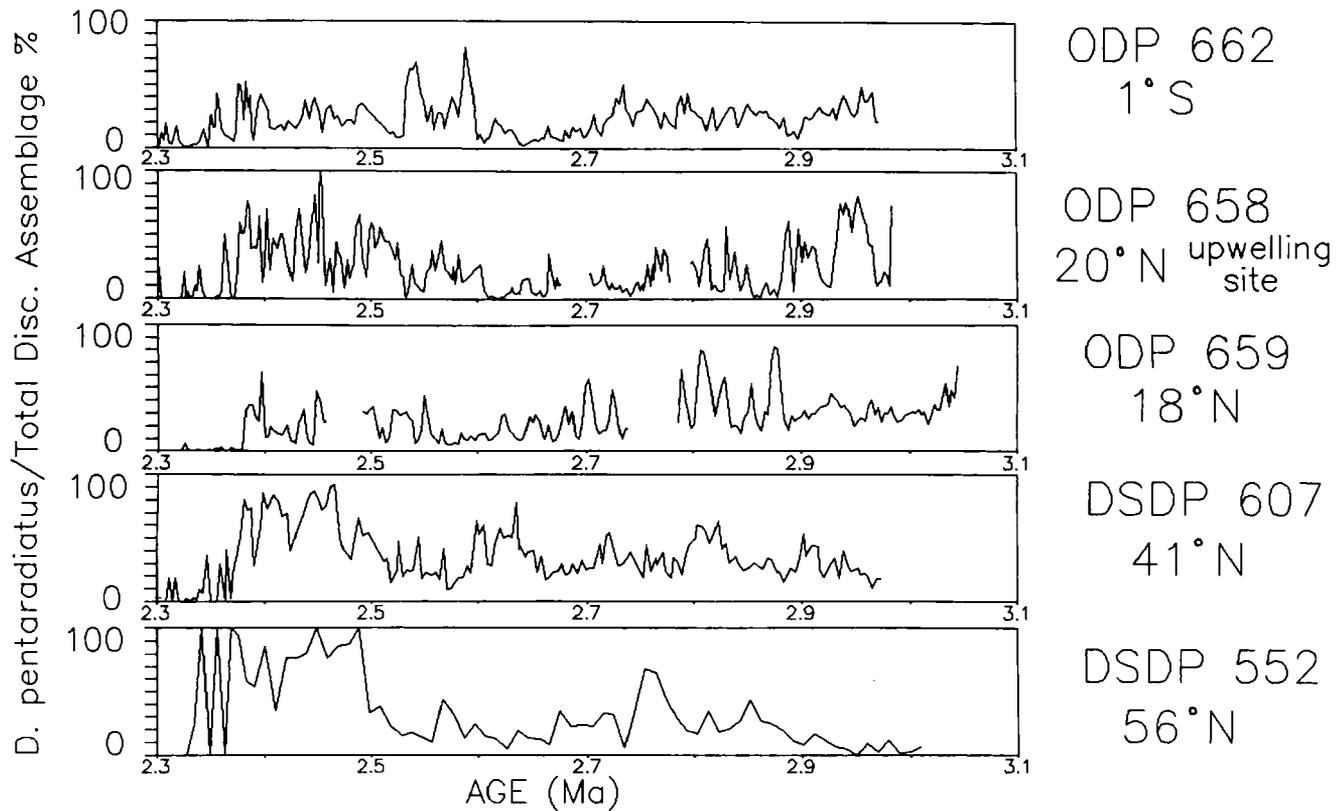


Fig. 4. Percentage abundance plots of *D. pentaradiatus* at Sites 552, 607, 659, 658 and 662.

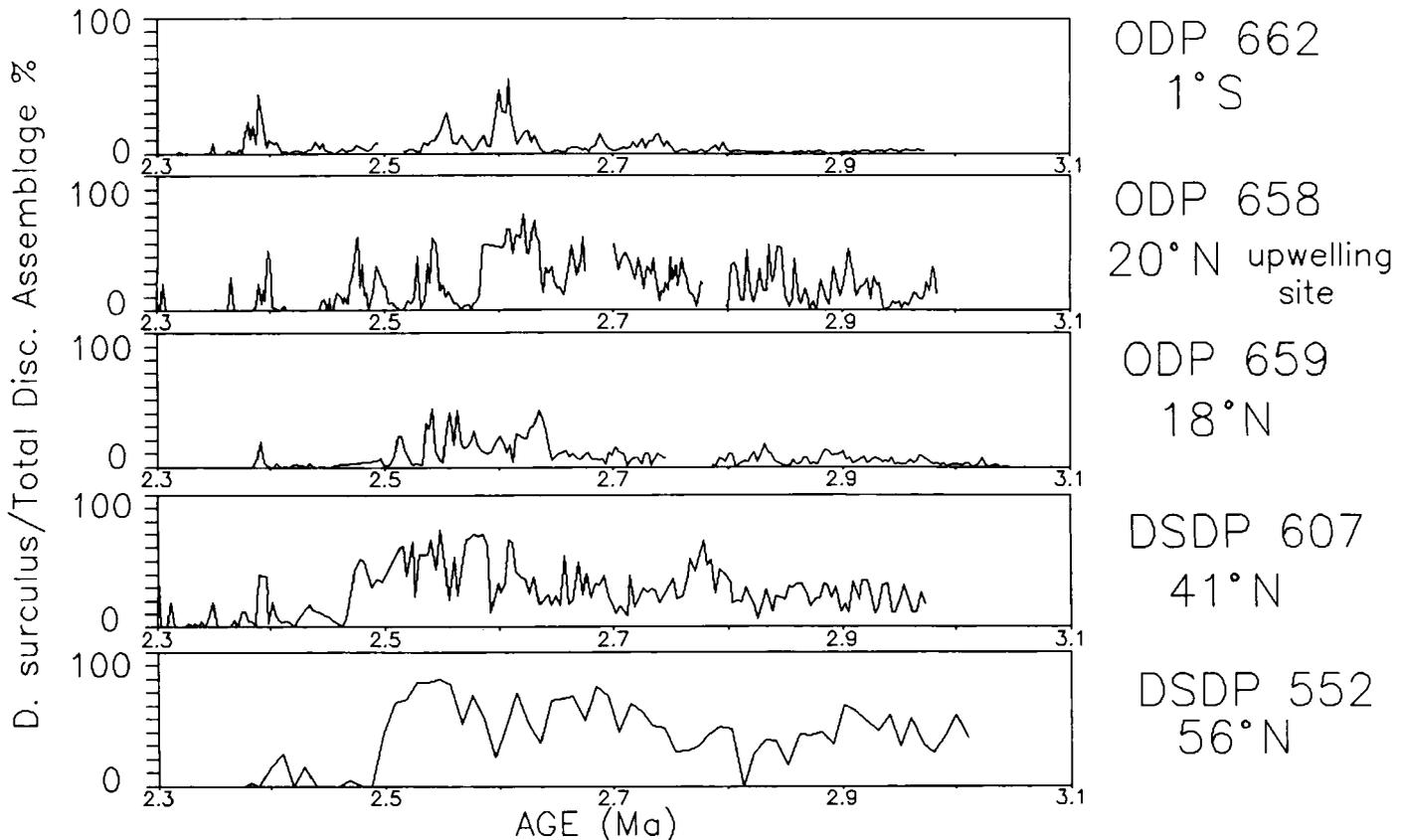


Fig. 5. Percentage abundance plots of *D. surculus* at Sites 552, 607, 659, 658 and 662.

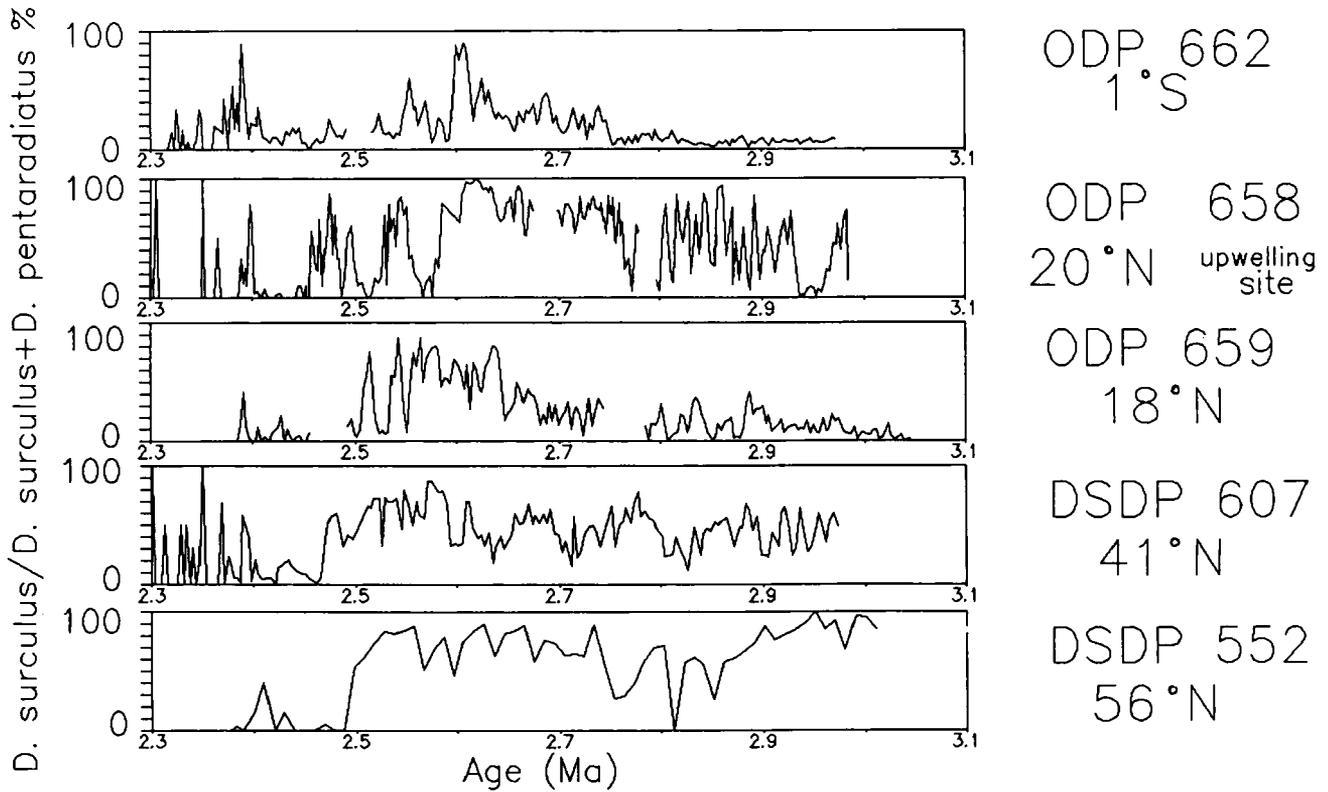


Fig. 6. Abundance plots of *D. surculus* as a percentage of the sum of *D. surculus* and *D. pentaradiatus* at Sites 552, 607, 659, 658 and 662.

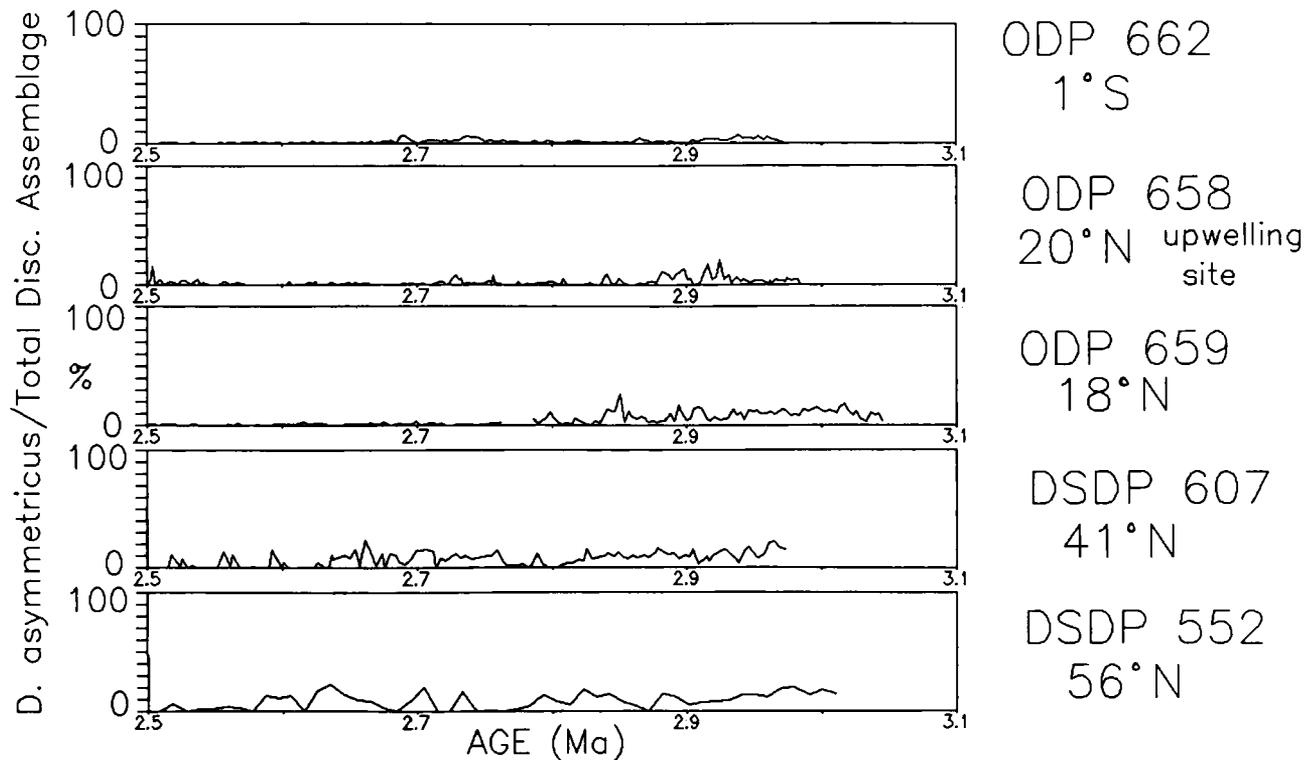


Fig. 7. Percentage abundance plots of *D. asymmetricus* at Sites 552, 607, 659, 658 and 662.

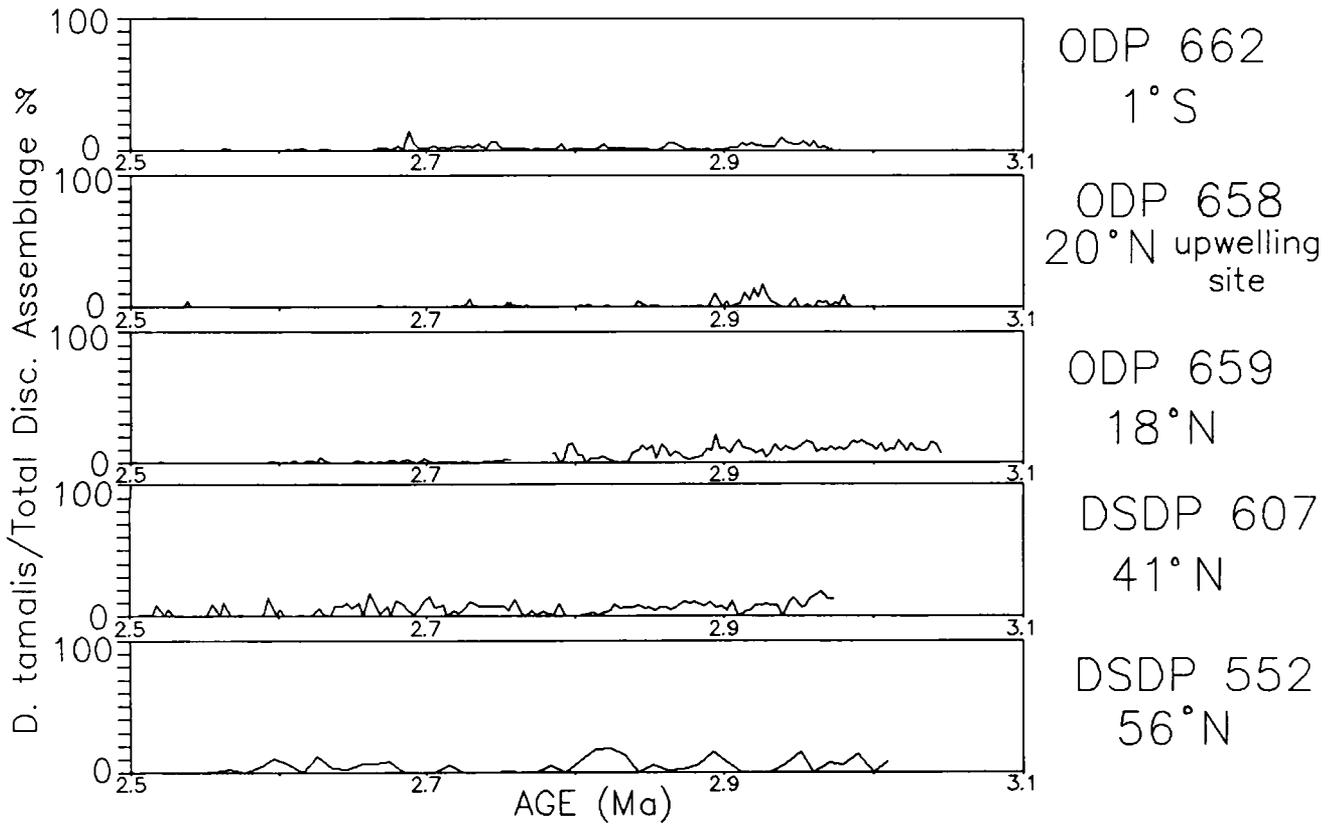


Fig. 8. Percentage abundance plots of *D. tamalis* at Sites 552, 607, 659, 658 and 662.

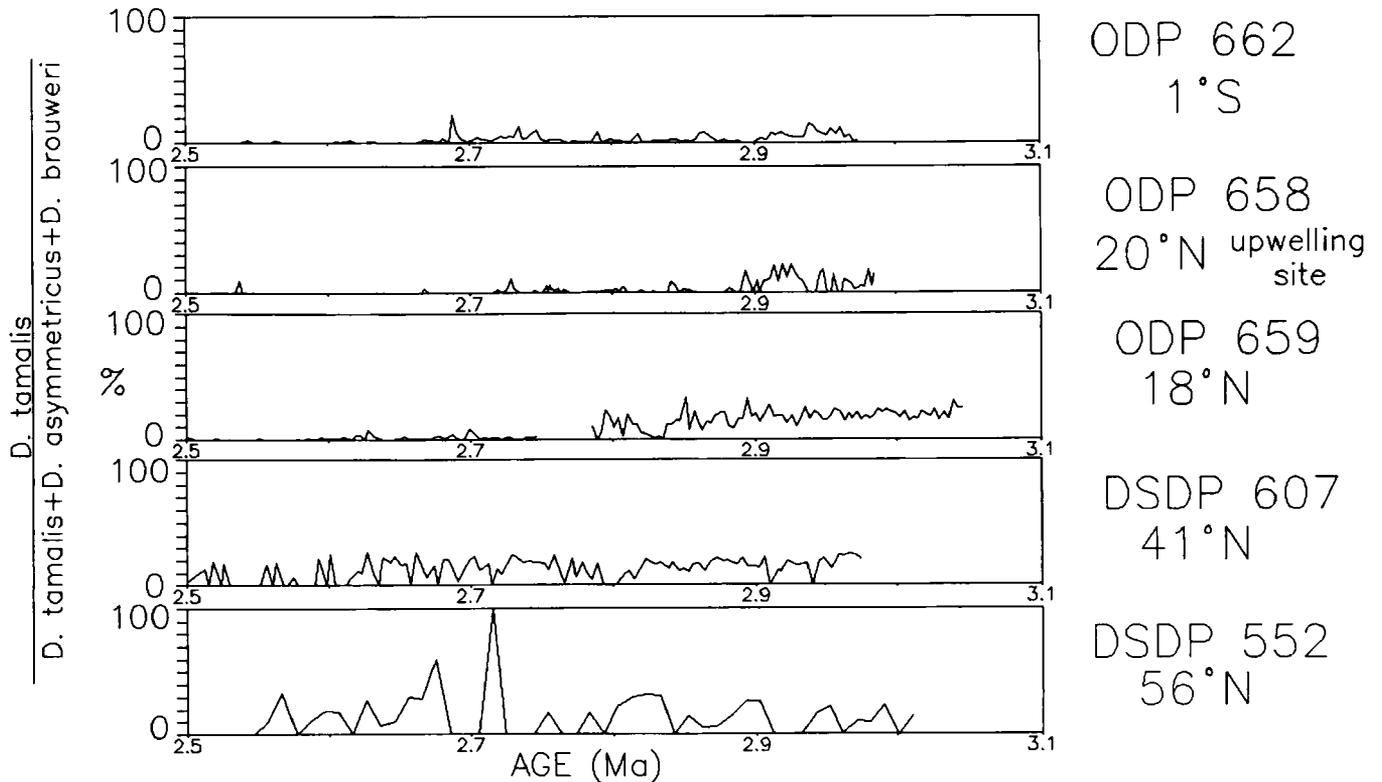


Fig. 9. Abundance plots of *D. tamalis* as percentage of the sum of *D. tamalis*, *D. asymmetricus* and *D. brouweri* at Sites 552, 607, 659, 658 and 662.

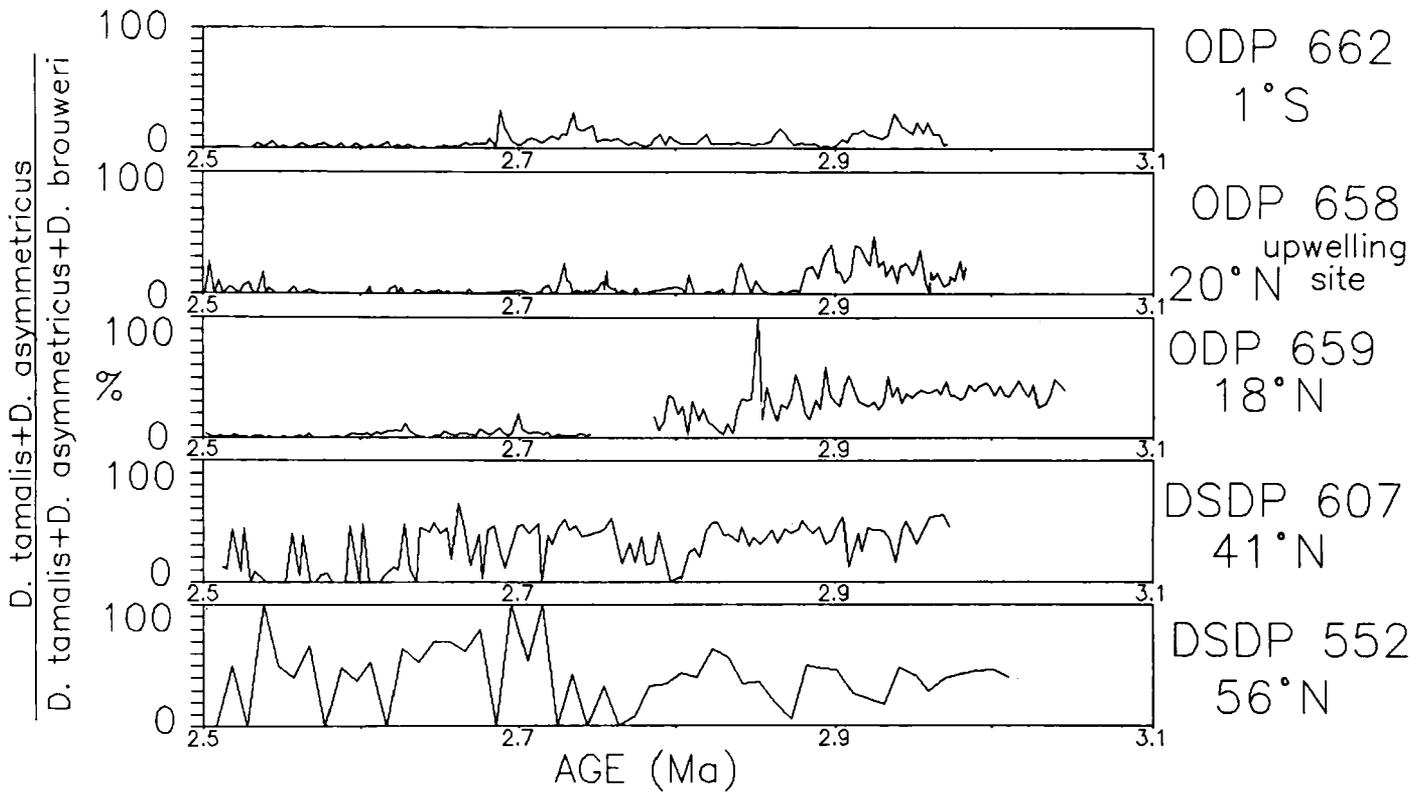


Fig. 10. Abundance plots of *D. tamalis* and *D. asymmetricus* as a percentage of the sum of these two species and *D. brouweri* at Sites 552, 607, 659, 658 and 662.