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UPPER PLIOCENE *DISCOASTER* ABUNDANCE VARIATIONS FROM THE ATLANTIC, PACIFIC AND INDIAN OCEANS: THE SIGNIFICANCE OF PRODUCTIVITY PRESSURE AT LOW LATITUDES

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Key words: *Discoaster*, *Pliocene*, *paleoecology*.

ABSTRACT

Variations in the abundance of six species of Pliocene discoasters are compared at three sites close to the equator in different oceans using a sampling interval of 3 ka. The time interval analysed is approximate-

ly the million years prior to the extinction of discoasters (*i.e.* 1.89-3.00 Ma).

Age-models were developed using biostratigraphic controls, mostly datums whose ages were originally estimated from Pacific sites with magnetostratigraphy. *Discoaster* datums were selected for internal consistency between the three sites. ODP Site 709 (Indian) displays extremely high abundances; ODP Site 662 (Atlantic) has abundances suppressed by the South Equatorial Current and equatorial divergence; ODP Site 677 (Pacific) is strongly influenced by upwelling and the abundances are greater though comparable with Site 662.

At all sites cyclic variation in *Discoaster* abundance is observed that is probably in response to orbital forcing. This high variability at low latitudes suggests that varying productivity pressure may be a major influence since temperature variability was presumably small.

RIASSUNTO

Vengono comparate le variazioni di abbondanza di sei specie di *Discoaster* pliocenici in tre successioni, localizzate in prossimità dell'equatore di diversi oceani, usando una campionatura ad intervalli di 3ka. L'intervallo di tempo analizzato è approssimativamente il milione di anni che precede l'estinzione dei discoaster (cioè 1.89 - 3.00 Ma).

Sono stati sviluppati modelli di età sulla base di eventi biostratigrafici tarati prevalentemente in successioni del Pacifico con controllo magnetostratigrafico. Gli stessi eventi basati sui discoaster sono stati analizzati in tre successioni. La successione del Site 709 ODP (Oceano Indiano) mostra abbondanze estremamente elevate; quella del Site 662 ODP (Oceano Atlantico) ha abbondanze limitate dalla Corrente

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Equatoriale e dalla divergenza equatoriale; il Site 677 ODP (Oceano Pacifico) è fortemente influenzato da *upwelling* e l'abbondanza è maggiore, per quanto confrontabile con il Site 662.

In tutte le successioni si nota variazione ciclica nell'abbondanza di *Discoaster* che è probabilmente collegabile alle variazioni dei parametri orbitali della terra. Questa alta variabilità, osservata a basse latitudini, è probabilmente da collegare fondamentalmente a variazioni di produttività biologica in quanto la temperatura è rimasta presumibilmente pressoché costante.

INTRODUCTION

Discoasters are an enigmatic group of phytoplankton, presumably related to the coccolithophorids, known in the oceanic record from the

upper Palaeocene to the upper Pliocene. The last two members of the genus disappeared synchronously 1.89 Ma, just below the base of the Olduvai (*e.g.*, TAKAYAMA, 1970). Discoasters are important in oceanographic studies because they are more dissolution resistant than planktonic foraminifera or coccoliths (LOHMANN and CARLSON, 1981) and provide valuable biostratigraphic datums for constructing age-models. Many studies have shown that discoasters are especially common in low latitude sediments and were thought to favour warm water masses (*e.g.*, HAQ and LOHMANN, 1976).

In this study individual species and total abundances of discoasters are compared between three sites close to the equator in different oceans. The data are used furthermore to compare individual

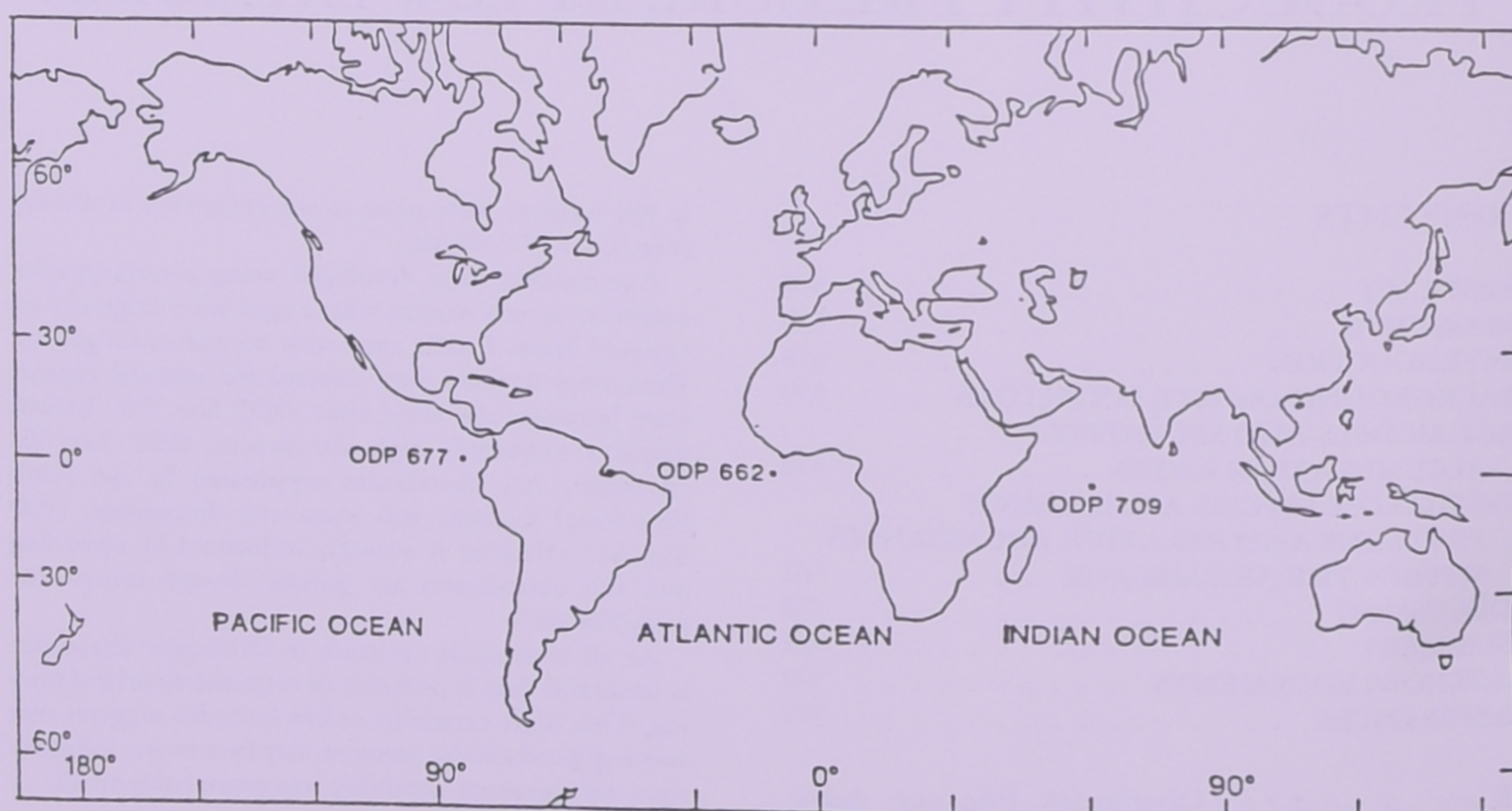


FIG. 1 - Location of sites studied.

TABLE 1 - Equatorial sites selected, their geographic positions and water depth

HOLE	LOCATION	DEPTH (M)	REFERENCE
ATLANTIC SITE			
662A	1°S 11°W	3,824	RUDDIMAN, SARNTHEIN <i>et al.</i> , 1988.
INDIAN SITE			
709C	4°S 61°W	3,038	BACKMAN, DUNCAN <i>et al.</i> , 1988.
PACIFIC SITE			
677A	1°N 84°W	3,461	BECKER, SAKAI, MERRILL <i>et al.</i> , 1988

species as a percentage of the total *Discoaster* assemblage. The time interval investigated is approximately the million years preceding the extinction of the discoasters *i.e.* between 1.9-3.0 Ma (1.9-3.5 Ma for Site 709) using closely spaced samples.

The primary purpose of this work is to investigate how changing palaeoceanographic conditions are reflected in the *Discoaster* record. Secondary to this it is interesting to assess the possibility of biostratigraphic correlation on a global scale.

BACKGROUND ON SITE LOCALITIES

The three sections selected (Fig. 1, Table 1) represent sites with the best Pliocene sequences available today close to the equator. Preservation is very good at all three sites, which are above the CCD, and hence diagenetic modifications do not influence *Discoaster* abundance fluctuations. Sites 662 and 677 were sampled at 10 cm intervals and Site 709 at 5 cm intervals (*i.e.* Site 662, 10 cm $\approx$ 2ka; Site 677, 10 cm $\approx$ 0.2 ka; Site 709, 5 cm $\approx$ 0.5 ka).

Site 662 is located close to the equator on the upper eastern flank of the mid-Atlantic Ridge (RUDDIMAN, SARNTHEIN *et al.*, 1988). The interval analysed has a lithology of nannofossil and foraminifer ooze. This site is influenced by the South Equatorial Current and is within the equatorial divergence, and hence upwelling conditions and high productivity.

Site 709 is located in the western equatorial Indian Ocean and is situated in a small basin perched near the summit of the Madingley Rise, a regional topographic high between the Carlsberg Ridge and the northern Mascarene Plateau (BACKMAN, DUNCAN *et al.*, 1988). The irregular basement topography is draped with sediments, varying in thickness from less than 50 m to over 400 m. The sediments alternate from clay bearing

nannofossil oozes to nannofossil oozes. This site is thought to be located in a stable warm water mass of modest productivity.

Site 677 is located about 3 km south of Site 504 in the eastern equatorial Pacific between the Ecuador and Panama Fracture Zones in a major upwelling area (BECKER, SAKAI *et al.*, 1988). The sediments are composed of siliceous calcareous nannofossil ooze of pelagic origin. Site 677 has been shown (MOORE *et al.* 1973) to be located in an area representing a latitudinal band of high biological activity for at least several hundred thousand years, associated with the Peru Current and equatorial divergence.

SHACKLETON and HALL (1983) obtained a high resolution (2.5 ka sampling interval) oxygen isotopic record of climatic variation for the eastern equatorial Pacific Ocean from Hole 504B. They demonstrated that the Pliocene sediments in this region may preserve an unusually good isotopic record from a high sedimentation rate environment. Site 677 should therefore contain a record of *Discoaster* abundance variability which is unusually rich in detail.

AGE-MODELS AND SEDIMENT ACCUMULATION RATES

Magnetostratigraphic data obtained were poor or were lacking at all sites. The age-models are based therefore on biostratigraphic datums, especially those related to *Discoaster* events for internal consistency.

SITE 662

The synchronous extinction of *Discoaster brouweri* and *Discoaster triradiatus* was clearly defined (Fig. 2, Table 2). Some events such as the base of the *D. triradiatus* acme at 2.07 Ma were difficult to define due to reworking. *Discoaster pentaradiatus* was found to be heavily reworked

TABLE 2 - Datum levels used to construct Figs. 2, 3 and 4

Datum levels used to construct Fig. 2 HOLE 662A			
Number	Datum level	Depth (mbsf)	Age (Ma)
2	LAD <i>D. brouweri</i> & <i>D. triradiatus</i>	122.2-123.2	1.89
3	Base of <i>D. triradiatus</i> acme	130.4-133.5	2.07
4	LAD <i>G. miocenica</i>	137.5-140.5	2.20
*5	LAD <i>D. pentaradiatus</i>	148.3-152.1	2.33-2.43
*6	LAD <i>D. surculus</i>	151.4	2.39
7	LAD <i>D. tamalis</i>	159.5-160.5	2.65
9	LAD <i>G. altispira</i>	166.9-168.5	2.95

TABLE 2 - (continued)

Datum levels used to construct Fig. 3 HOLE 709C			
Number	Datum level	Depth (mbsf)	Age (Ma)
1	LAD <i>C. macintyre</i>	15.45	1.45
2	LAD <i>D. brouweri</i> & <i>D. triradiatus</i>		
	acme	17.90	1.89
3	Base of <i>D. triradiatus</i> acme	19.25	2.07
*5	LAD <i>D. pentaradiatus</i>	22.85	2.38
*6	LAD <i>D. surculus</i>	23.05	2.39
7	LAD <i>D. tamalis</i>	26.00	2.65
+8	LAD <i>D. variabilis</i>	28.35	2.90
9	LAD <i>G. altispira</i>	28.50	2.95
10	LAD <i>R. pseudoumbilica</i>	35.85	3.56
Datum levels used to construct Fig. 4 HOLE 677A			
2	LAD <i>D. brouweri</i> & <i>D. triradiatus</i>	73.68	1.89
3	Base of <i>D. triradiatus</i> acme	90.50	2.07
*6	LAD <i>D. surculus</i>	96.50	2.39
D	abrupt decline in diatoms	104.20	2.50 $\neq$
7	LAD <i>D. tamalis</i>	113.80	2.65
+8	LAD <i>D. variabilis</i>	128.00	2.90
9	LAD <i>G. altispira</i>	130.20	2.95

* LADs for *D. surculus* and *D. pentaradiatus* taken as 2.39 Ma and 2.38 Ma respectively from Site 659.
 + LAD for *D. variabilis* as approximately 2.90 Ma estimated from Site 662.
 $\neq$ inferred from age-depth plot.

TABLE 3 - Summary of control points used in age-models

Hole 662A (Sampling interval = 10 cm)				
Datum	Age (Ma)	Depth (mbsf)	Event	Sedimentation Rate
<i>D. brouweri</i>	1.89	123.2	Extinction	
<i>D. surculus</i>	2.39	151.4	Extinction	5.6 cm/kyrs
<i>G. altispira</i>	2.95	168.5	Extinction	3.1 cm/kyrs
Hole 709C (Sampling interval = 5 cm)				
<i>C. macintyre</i>	1.45	15.45	Extinction	
<i>D. brouweri</i>	1.89	17.90	Extinction	5.6 cm/kyrs
<i>D. triradiatus</i>	2.07	19.25	Peak Abundance began	7.5 cm/kyrs
<i>D. surculus</i>	2.39	23.05	Extinction	11.9 cm/kyrs
<i>D. tamalis</i>	2.65	26.00	Extinction	11.3 cm/kyrs
<i>D. variabilis</i>	2.90	28.35	Extinction	9.4 cm/kyrs
<i>R. pseudoumbilica</i>	3.56	35.85	Extinction	11.4 cm/kyrs
Hole 677A (Sampling interval = 10 cm)				
<i>D. brouweri</i>	1.89	73.68	Extinction	
<i>D. triradiatus</i>	2.07	90.50	Peak Abundance began	93.4 cm/kyrs
<i>D. surculus</i>	2.39	96.50	Extinction	18.8 cm/kyrs
<i>D. tamalis</i>	2.65	113.80	Extinction	66.5 cm/kyrs
<i>G. altispira</i>	2.95	130.20	Extinction	54.7 cm/kyrs

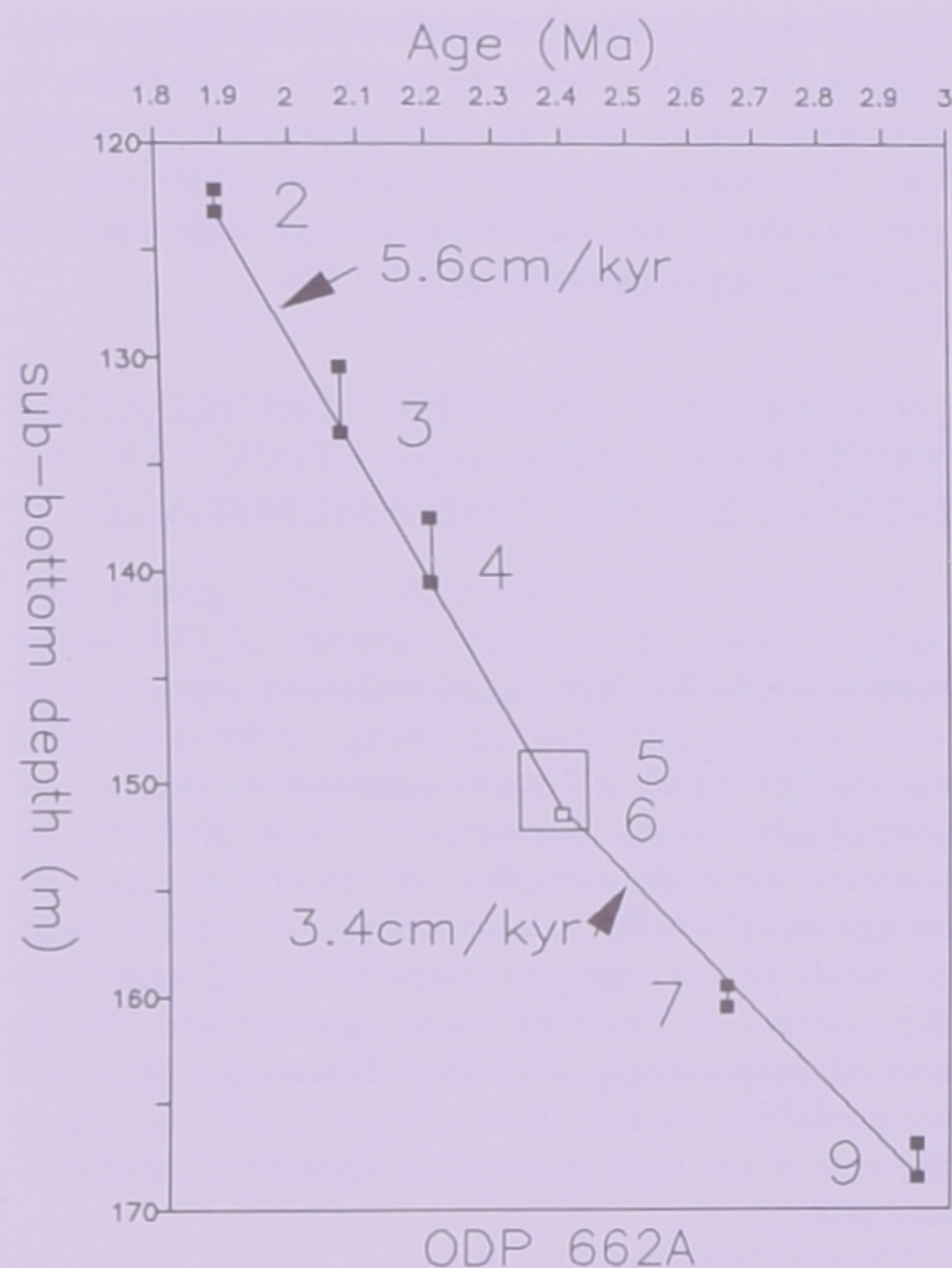


FIG. 2 - Age/depth relationships of biochronologic control points in ODP Hole 662A. Refer to Table 2 for control points used.

through the interval, but the distinct final abundance peak of *Discoaster surculus* allowed the former event to be identified. The distinct extinction event of *D. surculus* is given the age of 2.39 Ma as recorded at Site 659 (CHEPSTOW-LUSTY *et al.*, 1989) and extrapolated from Core V32-127 (BACKMAN and SHACKLETON, 1983).

Discoaster tamalis produced a clear extinction. For the age-model (Table 3), the extinction datums of *D. brouweri*, *D. surculus* and *Globoquadri- na altispira* (WEAVER and RAYMO, 1989) were selected from the age-depth plot (CHEPSTOW-LUSTY *et al.*, 1989). From the age-model, the LAD (Last Appearance Datum) of *Discoaster variabilis* occurred approximately at 2.90 Ma. *Discoaster variabilis* was used in constructing the age-depth plots for the other two sites in conjunction with the LAD of *G. altispira* at 2.95 Ma. *Globoquadri- na altispira* may be prone to dissolution, low abundances or reworking.

SITE 709

A longer time interval of between approximately 1.80-3.50 Ma was analysed (Fig. 3, Table 2). *Calcidiscus macintyre* (LAD 1.45 Ma) and *Re-*

ticulofenestra pseudoumbilica (LAD 3.56 Ma), both coccolith datums, are included in the age-model (Table 3). Clearly defined datums were provided by the LAD's of *D. brouweri*, *D. triradiatus*, *D. tamalis* and the base of the acme of *D. triradiatus*. The LAD of *D. pentaradiatus* at 2.38 Ma by extrapolation from Site 659 fits the age-depth plot well. No distinctive final peak however is ascertained for *D. surculus* in relation to the *D. pentaradiatus* extinction. The LAD's of these two species is thought to be very close (CHEPSTOW-LUSTY *et al.*, 1989) with *D. surculus* disappearing of the order 10-20 ka prior to *D. pentaradiatus*. By interpolation between the LAD of *D. pentaradiatus*, the minor peak of *D. surculus* at 23.05 mbsf (metres below sea-floor) is assumed to represent its LAD at 2.39 Ma. Specimens recorded after this event were mostly worn, and are considered reworked. For the age-model, *D. variabilis* (2.90 Ma) was used instead of *G. altispira* (2.95 Ma) because the former is determined with better precision and the latter introduced a minor change in sedimentation rate.

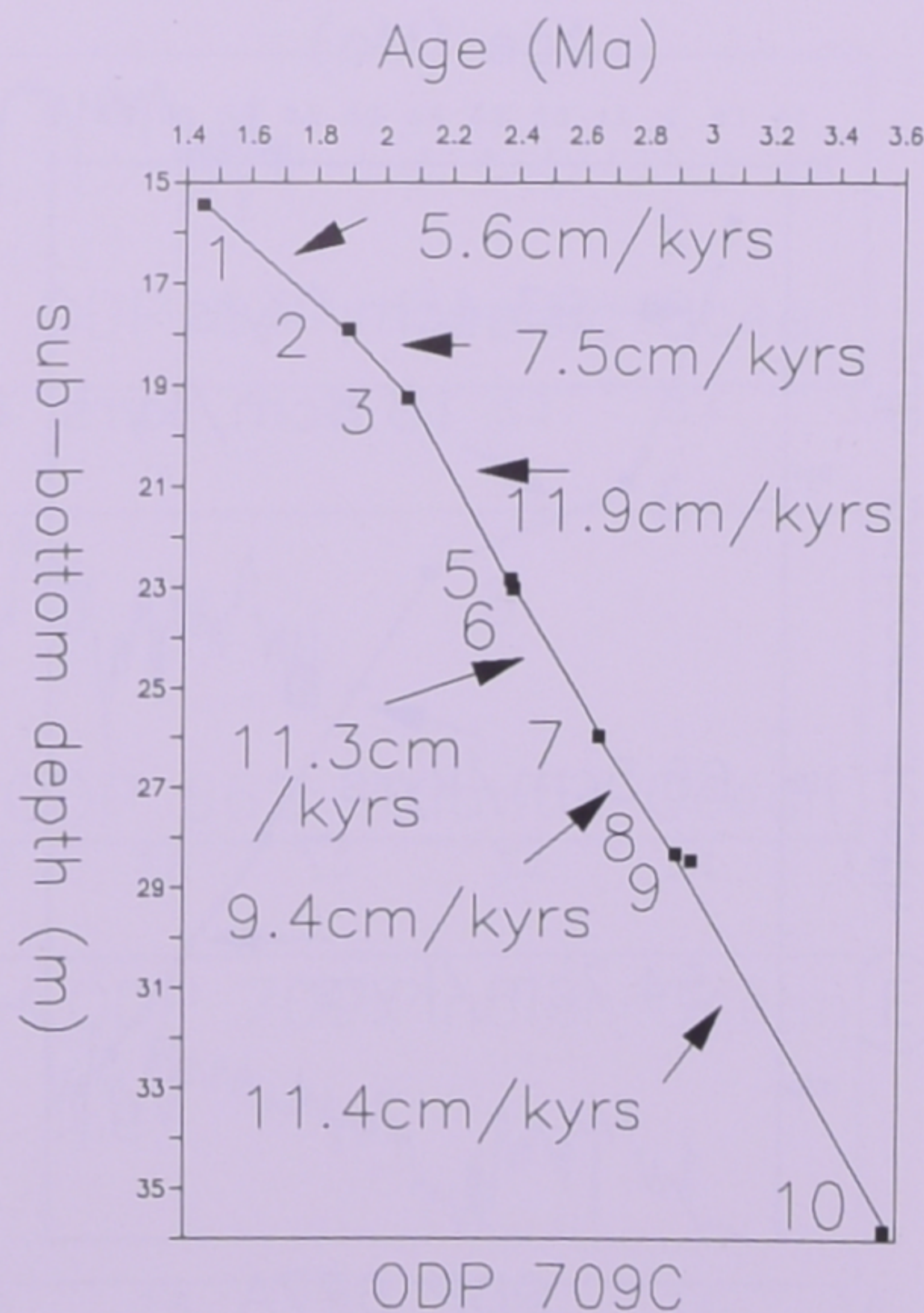


FIG. 3 - Age/depth relationships of biochronologic control points in ODP Hole 709C. Refer to Table 2 for control points used.

SITE 677

High sedimentation rates characterize this upwelling site. The mutual extinction of *D. brouweri* and *D. triradiatus* is clearly defined (Fig. 4, Table 2). Prior to their extinctions, the abundances of these taxa are low. The event is unlikely to be the result of reworking, since *D. triradiatus* occurs in such low abundances further down the core. These events are almost invisible when plotted on the same scale as Site 709.

When *D. triradiatus* is plotted as a percentage (divided by the sum of itself and *D. brouweri*) the extinction event and the base of the acme at 2.07 Ma can both be clearly seen.

Between the LAD of *D. brouweri* and the base of the *D. triradiatus* acme, there is an unusually high sedimentation rate of 93.4 cm/kyr. This is reduced to 18.8 cm/kyr between the latter datum and the LAD of *D. surculus* at 2.39 Ma, identified by a distinctive abundance peak. This reduced rate is still much higher than observed at any of the other sites. Strangely, *D. pentaradiatus* is extremely rare in sediments younger than approximately 2.9 Ma.

The sedimentation rate is at least three times higher between 2.39 and 2.95 Ma at Site 677 than

in the corresponding intervals at Sites 709 and 662. Clearly defined LAD's for *D. surculus*, *D. tamalis*, *D. variabilis* and *G. altispira* fall almost on a straight line. A sudden reduction in diatom abundance at 104.20 mbsf is inferred from the age-depth plot as occurring approximately at 2.50 Ma.

DISCOASTER SPECIES ABUNDANCE PATTERNS AND RELATIVE ABUNDANCES WITHIN THE ASSEMBLAGE

BACKMAN and SHACKLETON (1983) give a succinct taxonomy of the seven species of *Discoaster* investigated. We have also followed their smear slide preparation and counting technique. The number of fields of view counted is related to overall abundance patterns at each site and is constant between samples. A relatively constant background density is maintained at a view field diameter of 0.3 mm. At Sites 677, 662 and 709, the number of fields of view counted are 30, 40 and 20, respectively. The abundances for *Discoaster variabilis* are not shown since it only occurs at the end of the time interval analysed for Sites 677 and 662.

Discoaster brouweri and *Discoaster triradiatus*

These two species have a synchronous extinction at 1.89 Ma (e.g., BACKMAN and SHACKLETON, 1983), and are the last two species of the genus *Discoaster* to disappear. *Discoaster brouweri* (Fig. 5) is the only species covering the complete time interval investigated, and besides the brief acme with *Discoaster triradiatus* between 1.89 and 2.07 Ma, it is the sole survivor after approximately 2.38 Ma. Prior to 2.38 Ma, *D. brouweri* is a major component of the complete *Discoaster* assemblage (Fig. 6), especially at the Pacific site. The Indian Ocean site possesses greater abundances of all species than the Pacific or the Atlantic sites. In comparison with Site 677, located in a major upwelling area, Site 662 reveals generally lower abundances. Upwelling associated with the Equatorial Divergence may be significant here. All these sites demonstrate abundance reduction through time of *D. brouweri*, especially during the 200 ka prior to the extinction event. Abundance peaks appear to correlate between the three sites at approximately 2.20, 2.65 and 2.78 Ma.

Discoaster triradiatus has distinct acmes at all three sites (Fig. 7), which is emphasised clearer by the percentage relationship (Fig. 8). In agreement with the probable taxonomic relationship of *D. triradiatus* with *D. brouweri* (BACKMAN and PESTIAUX, 1987), the abundances of *D. triradiatus* are greater at the Indian Ocean site than in the Atlantic or Pacific sites.

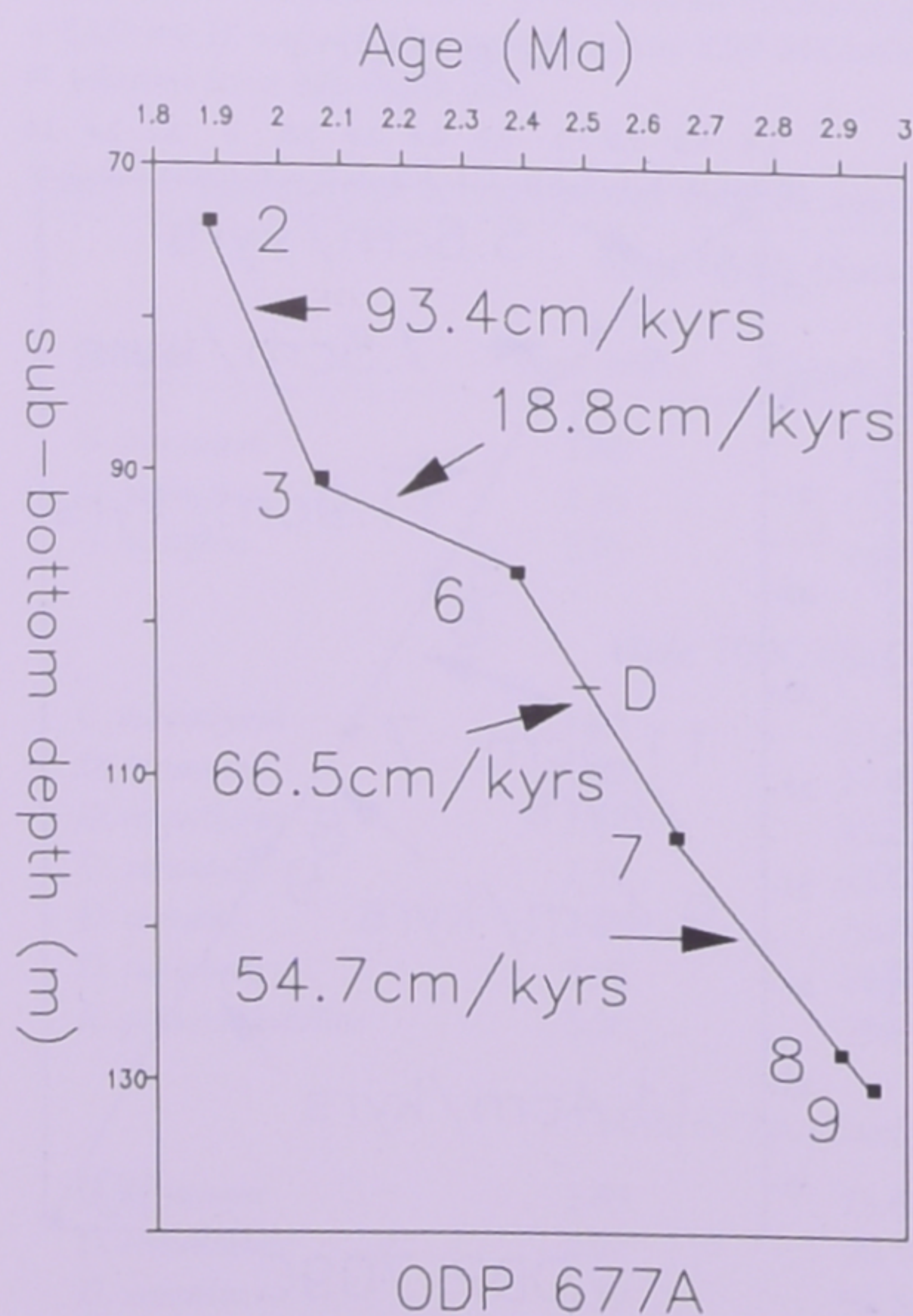
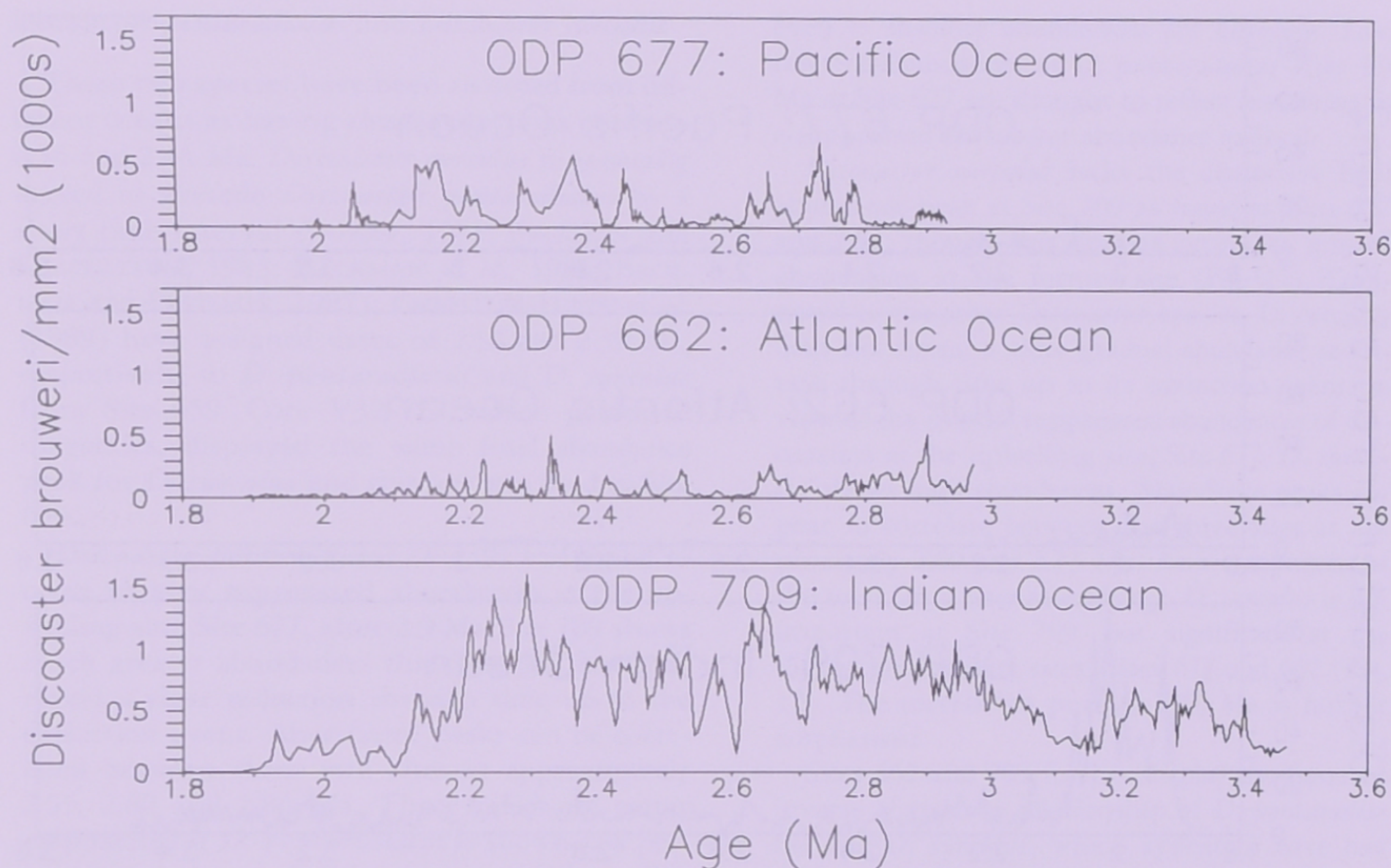
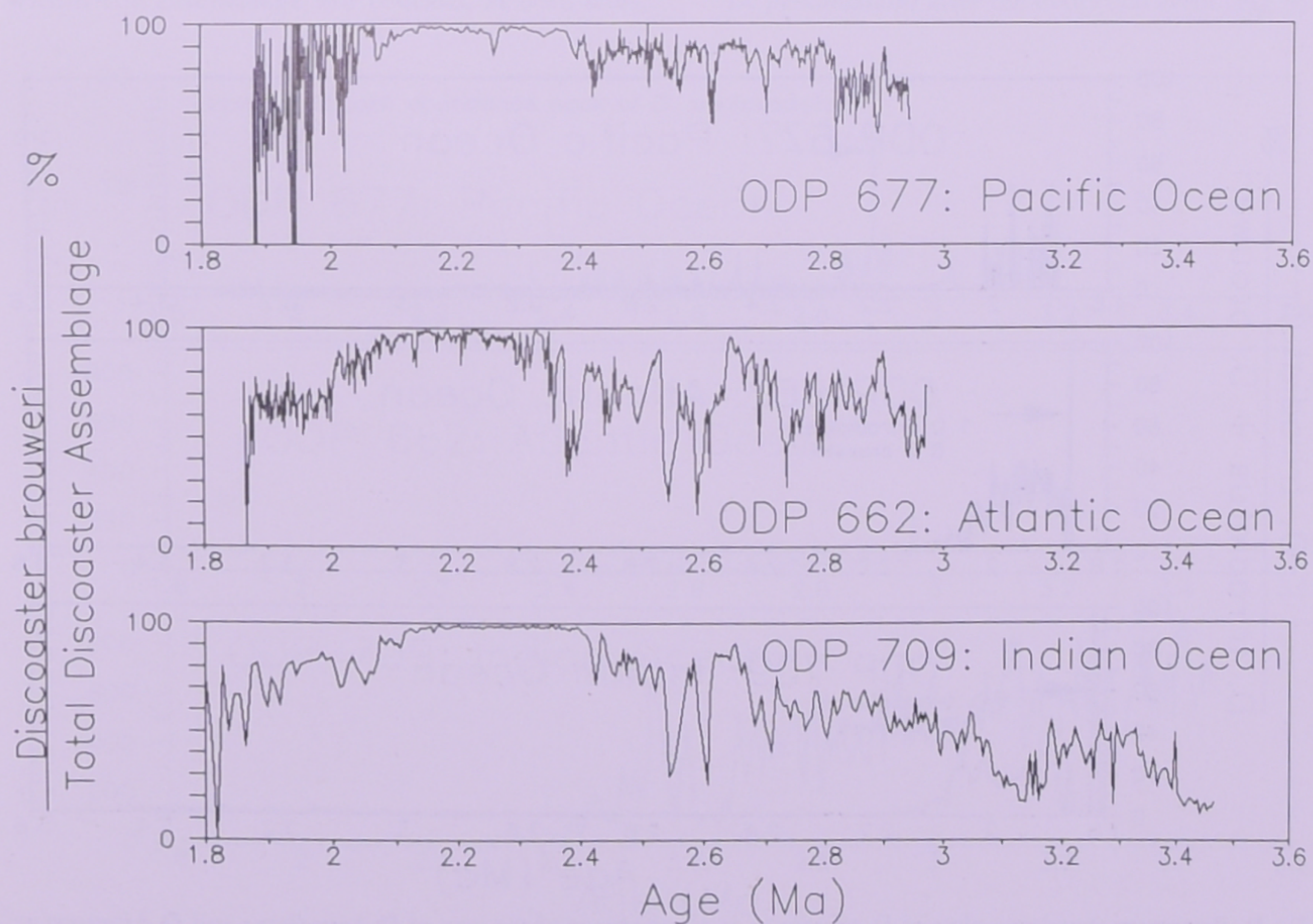


FIG. 4 - Age/depth relationships of biochronologic control points in ODP Hole 677A. Refer to Table 2 for control points used.

FIG. 5 - Abundance plots of *D. brouweri* at Sites 709, 662 and 677.FIG. 6 - Percentage abundance plots of *D. brouweri* at Sites 709, 662 and 677.

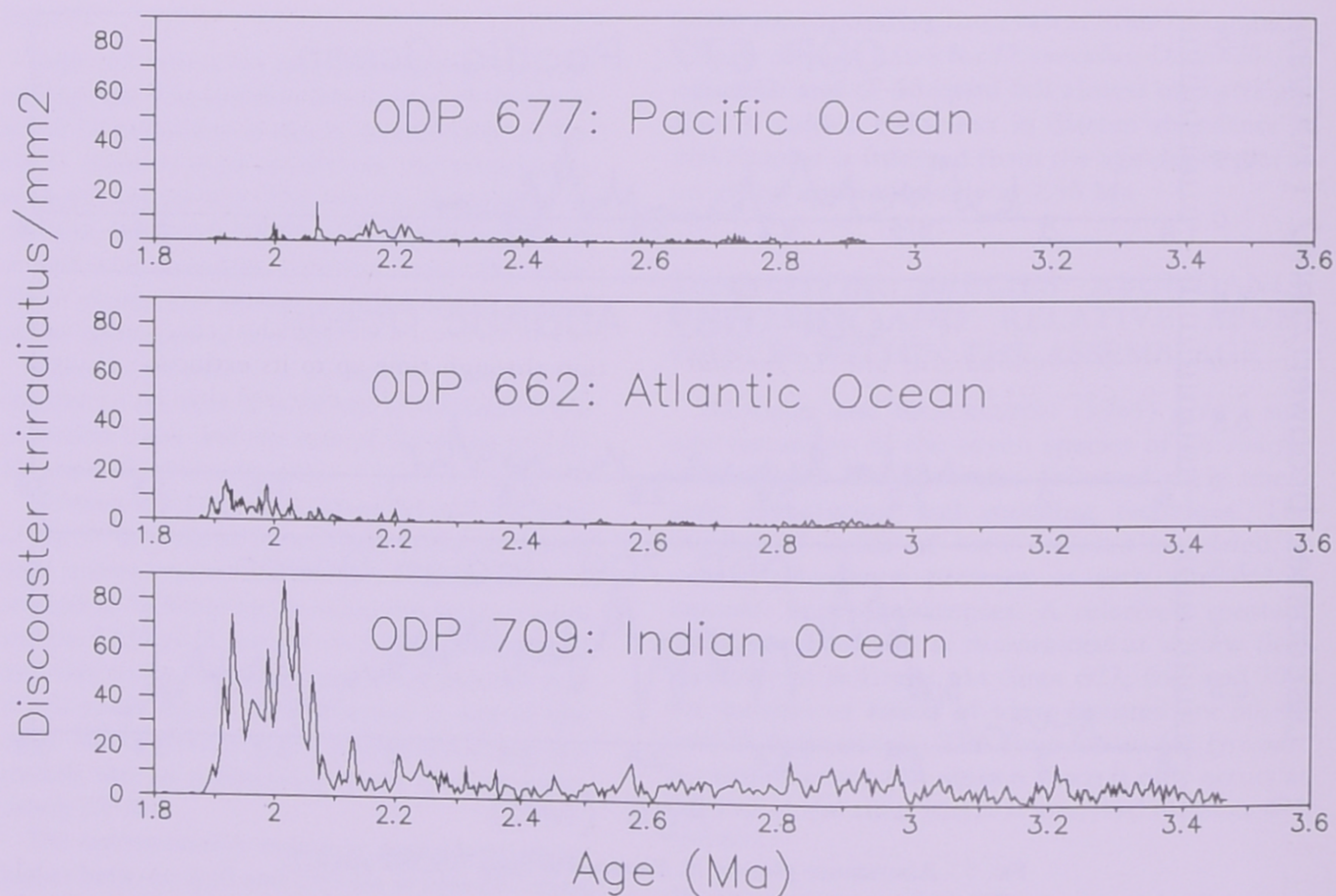


FIG. 7 - Abundance plots of *D. triradiatus* at Sites 709, 662 and 677.

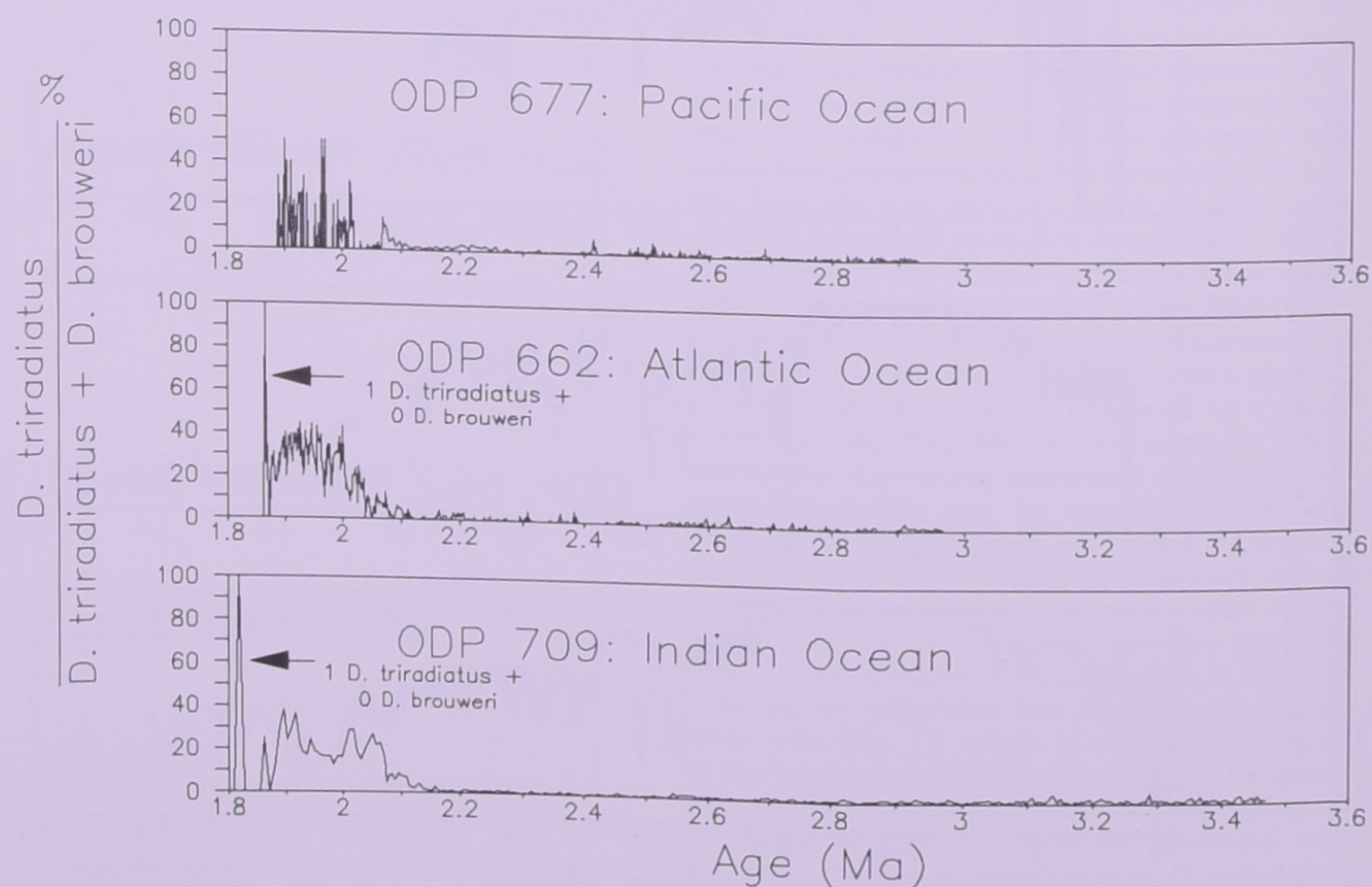


FIG. 8 - Percentage abundance plots of *D. triradiatus* as a percentage of the sum of *D. triradiatus* and *D. brouweri* at Sites 709, 662 and 677.

Discoaster pentaradiatus and *Discoaster surculus*

These two species have been recorded from different oceans as having close extinctions between 2.35 and 2.45 Ma. *Discoaster surculus* is generally agreed to precede *Discoaster pentaradiatus* by a short time interval (BUKRY, 1973; BACKMAN and SHACKLETON, 1983; BACKMAN *et al.*, 1986; BACKMAN and PESTIAUX, 1987). CHEPSTOW-LUSTY *et al.* (1989) have assigned dates of 2.38 and 2.39 Ma, respectively, to *D. pentaradiatus* and *D. surculus* from Site 659. Core V32-127, which possessed magnetics, displayed the same final abundance peak for *D. surculus* and this age was used in Site 659.

Discoaster pentaradiatus (Fig. 9) was found to occur in very suppressed abundances at the upwelling site, Site 677, after 2.9 Ma. Site 709 shows much greater abundances than Site 662, but both reveal a clear reduction through time up to the extinction event. Abundance peaks can be correlated between these two sites at approximately 2.55, 2.60 and 2.80 Ma. These peaks are better emphasised if *D. pentaradiatus* is shown as a percentage of the total *Discoaster* assemblage (Fig. 10).

Similar relative abundances of *D. pentaradiatus* within the assemblage are revealed at both sites,

even if absolute abundances are different. Low relative abundances of *D. pentaradiatus* after 2.9 Ma at Site 677 are thought to reflect reworking in a suppressed *Discoaster* abundance interval.

Discoaster surculus lacks the distinctive final abundance peak at Site 709 as found at Sites 677 and 662, though this species occurs in greater abundances at the former site (Fig. 11). Compared to the other *Discoaster* species, *D. surculus* does not reveal a clear gradual abundance reduction through time up to its extinction event. In view of the overall suppressed abundances of discoasters at the upwelling site, Site 677, *D. surculus* shows high abundances. Abundance peaks appear to correlate between the three sites at approximately 2.60 and 2.73 Ma. As a component of the total *Discoaster* assemblage, *D. surculus* is unimportant at Site 709, but significant at the higher productivity sites, Sites 677 and 662 (Fig. 12). The correlation peak at 2.60 Ma is further emphasised.

Sites 662 and 709 further display the frequent inverse abundance relationship of *D. pentaradiatus* and *D. surculus*, which appear to have had different ecological requirements. This is shown best at Site 709 (Fig. 13), since Site 662 is affected by reworking, as shown by the low abundances of *D. pentaradiatus* after the extinction event (Fig. 9).

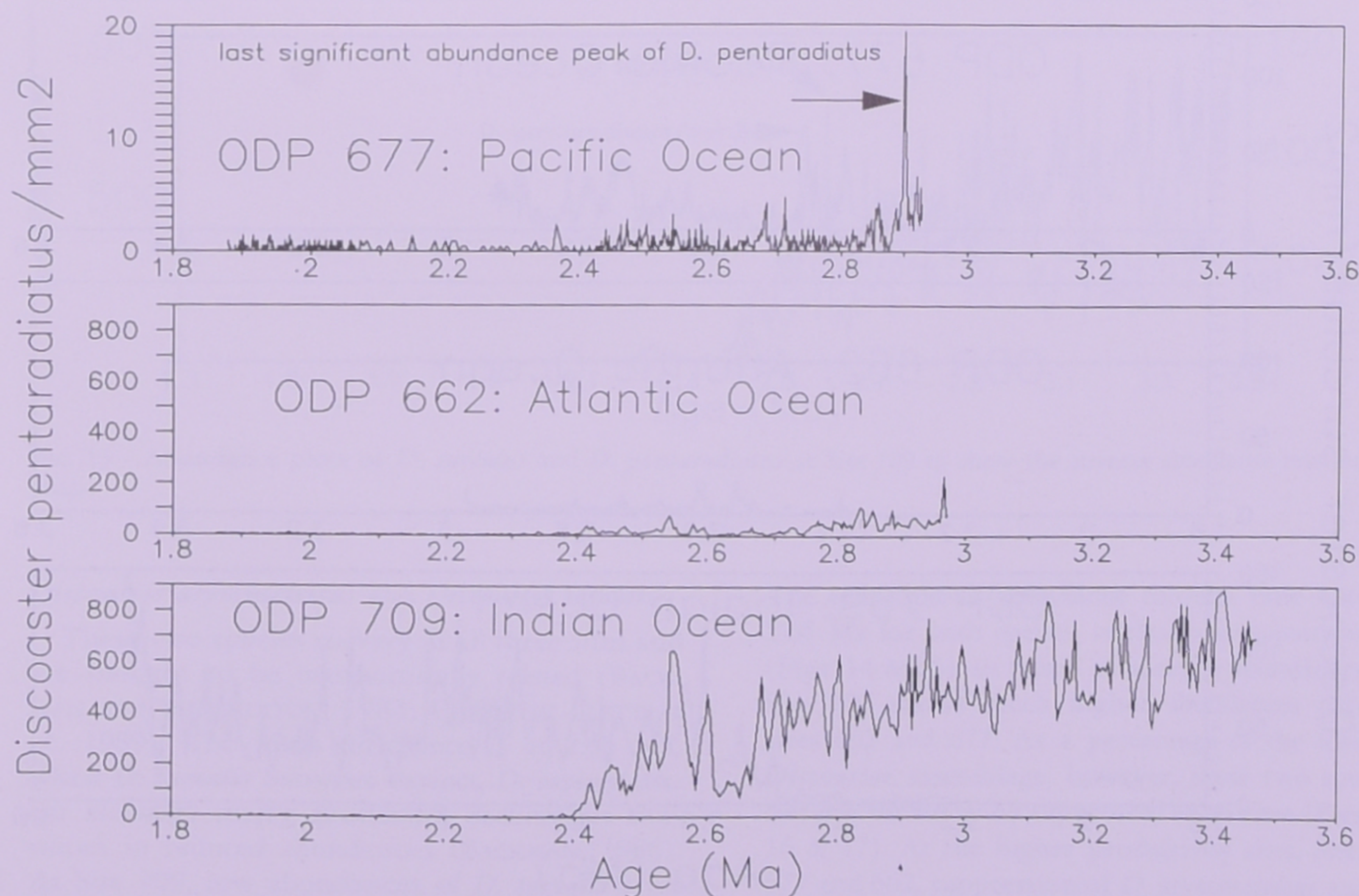


FIG. 9 - Abundance plots of *D. pentaradiatus* at Sites 709, 662 and 677.

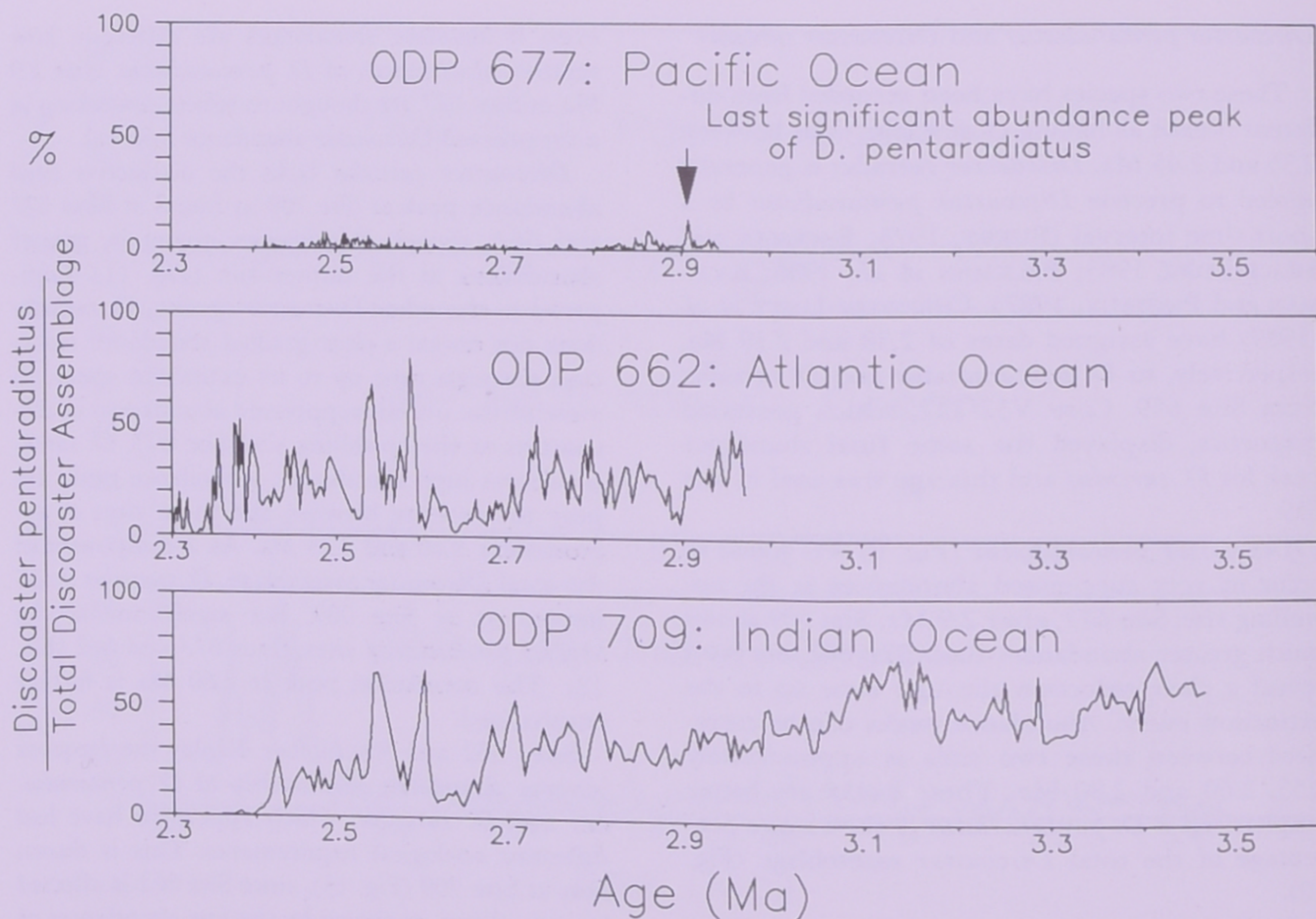


FIG. 10 - Percentage abundance plots of *D. pentaradiatus* at Sites 709, 662 and 677.

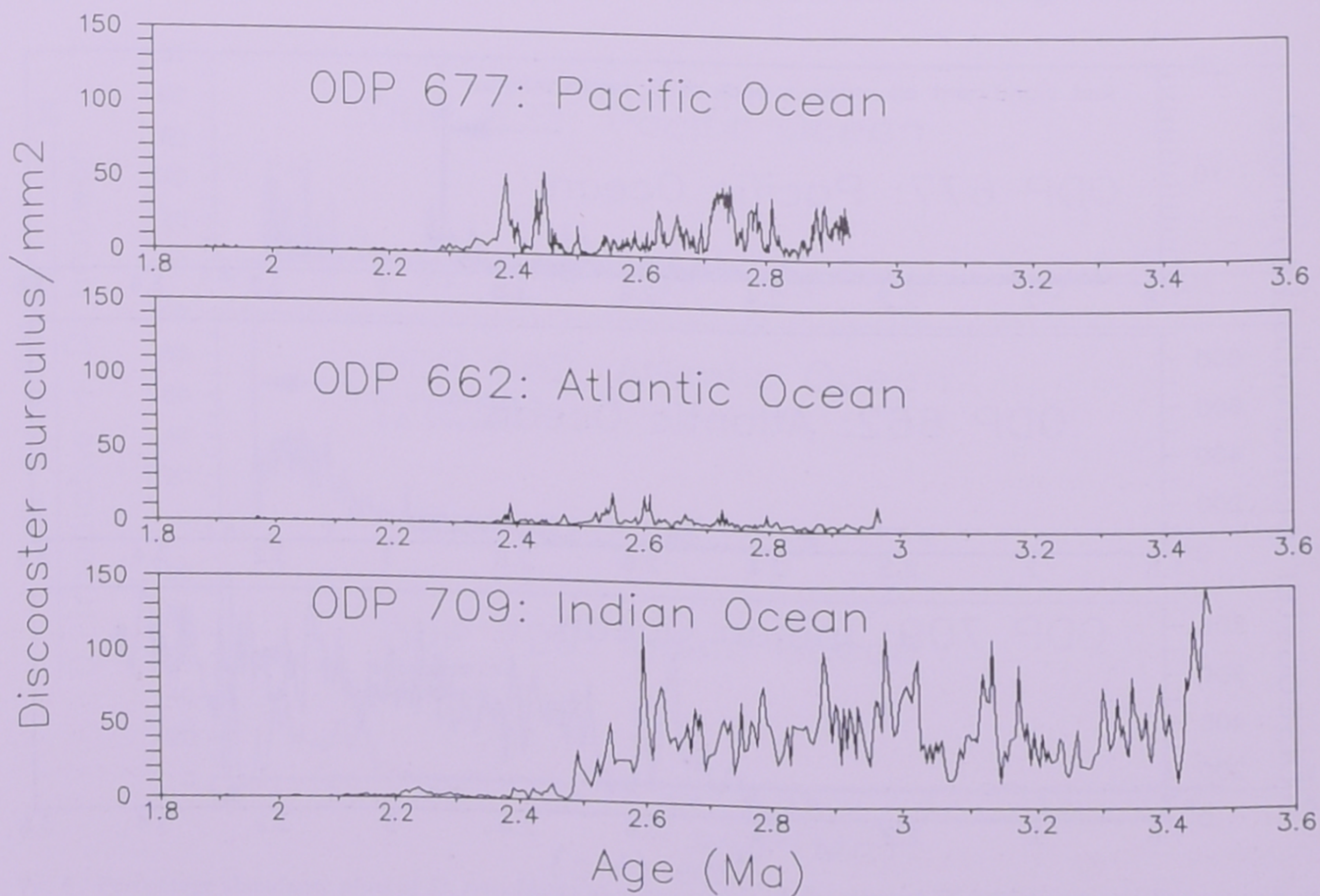


FIG. 11 - Abundance plots of *D. surculus* at Sites 709, 662 and 677.

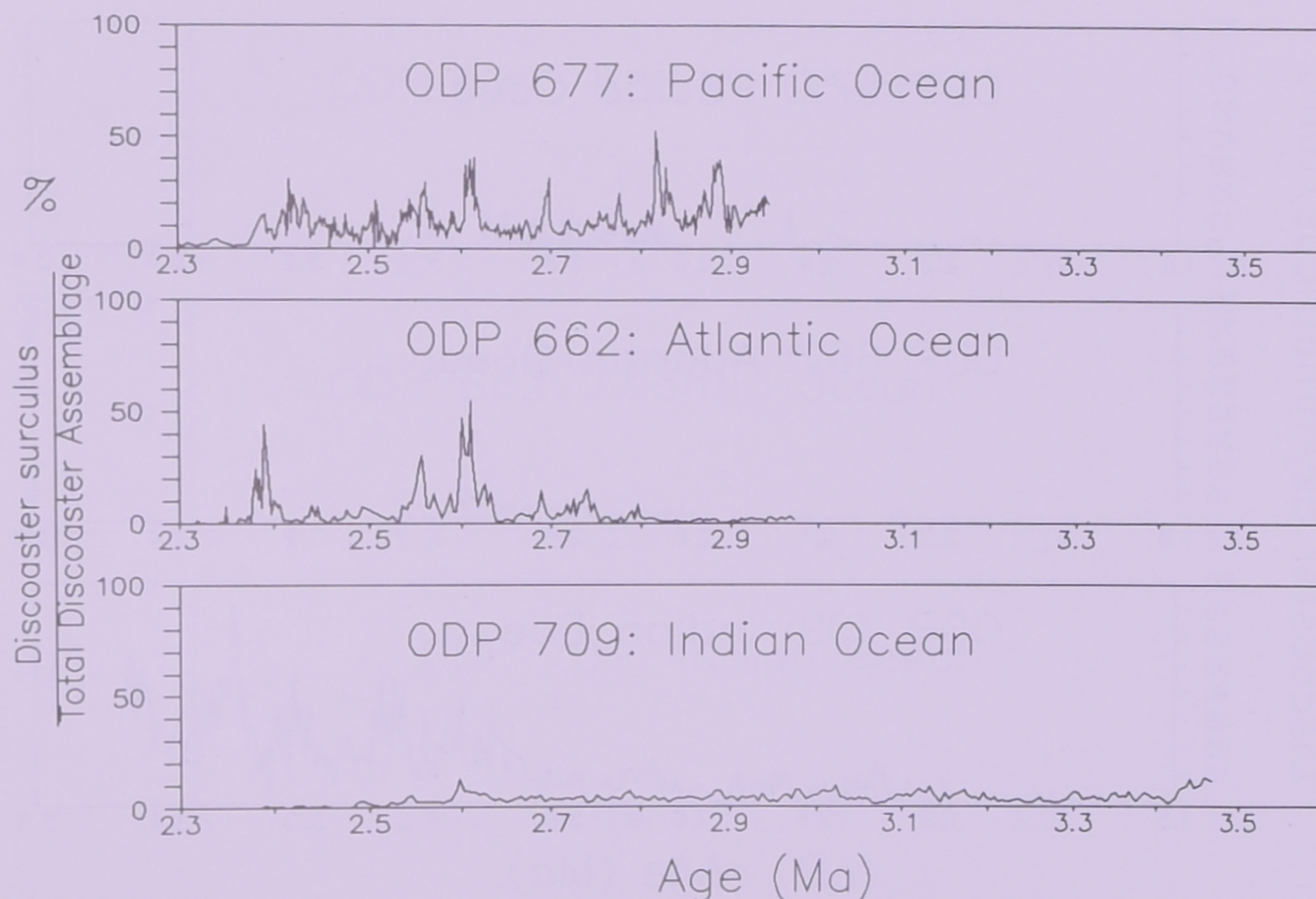


FIG. 12 - Percentage abundance plots of *D. surculus* at Sites 709, 662 and 677.

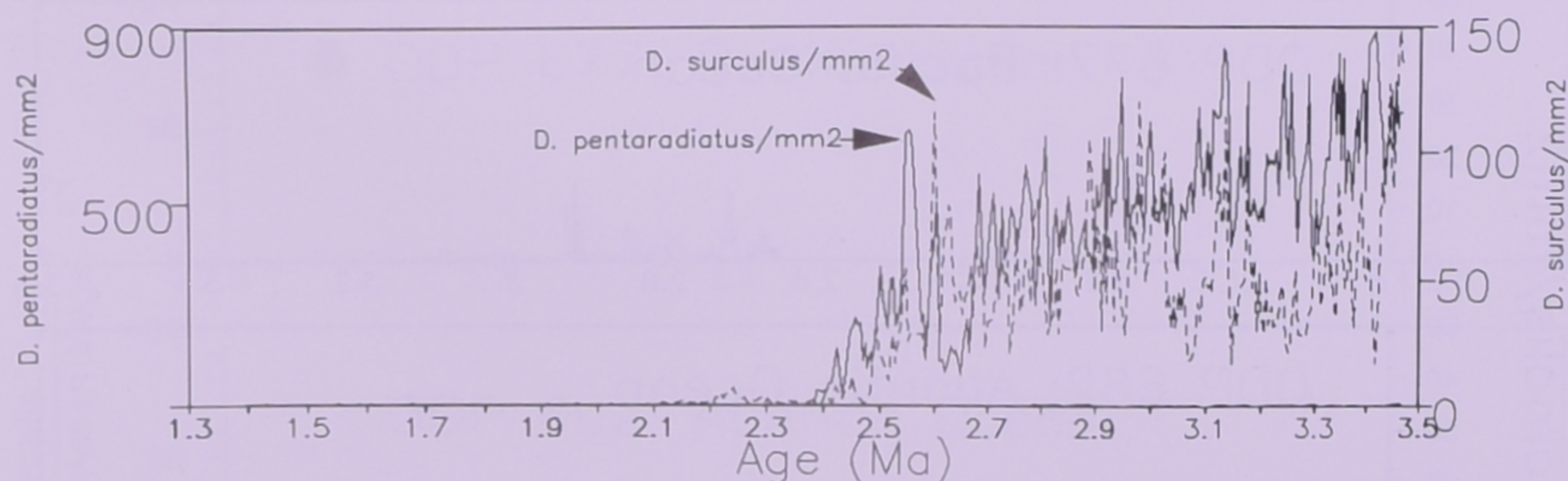


FIG. 13 - Abundance plots of *D. surculus* and *D. pentaradiatus* at Site 709 to show the inverse abundance relationship.

Discoaster asymmetricus and *Discoaster tamalis*

These two species co-vary at all three sites and are thought to be taxonomically related (BACKMAN and SHACKLETON, 1983; CHEPSTOW-LUSTY *et al.*, 1989). The main difference is at 2.65 Ma, when *D. tamalis* becomes extinct, *D. asymmetricus* shows a major abundance decline but continues in reduced abundances (BACKMAN, 1986). At Site 709, low abundances of *D. tamalis* after 2.65 Ma, is considered to represent reworking.

The reduction in abundance through time until 2.65 Ma for both species is clearly demonstrated (Figs. 14 & 15). In terms of absolute abundances, Site 709 shows much higher abundances than sites 662 and 677. As a percentage of the total *Discoaster* assemblage, however, these two species are shown to be suppressed at all sites (Figs. 16 & 17). At the higher productivity sites, Sites 677 and 662, suppression of *D. asymmetricus* and *D. tamalis* occurs to a lesser extent.

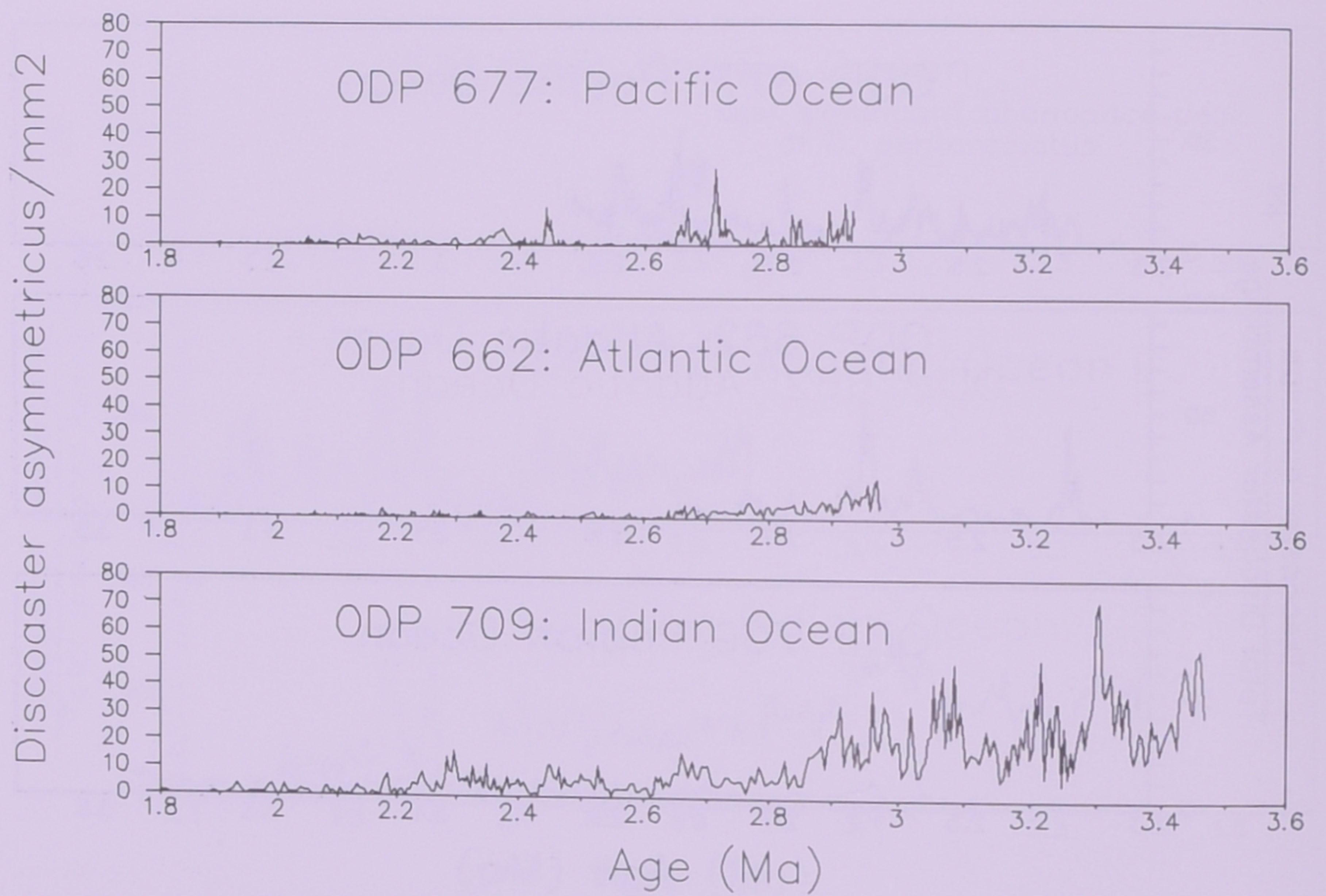


FIG. 14 - Abundance plots of *D. asymmetricus* at Sites 709, 662 and 677.

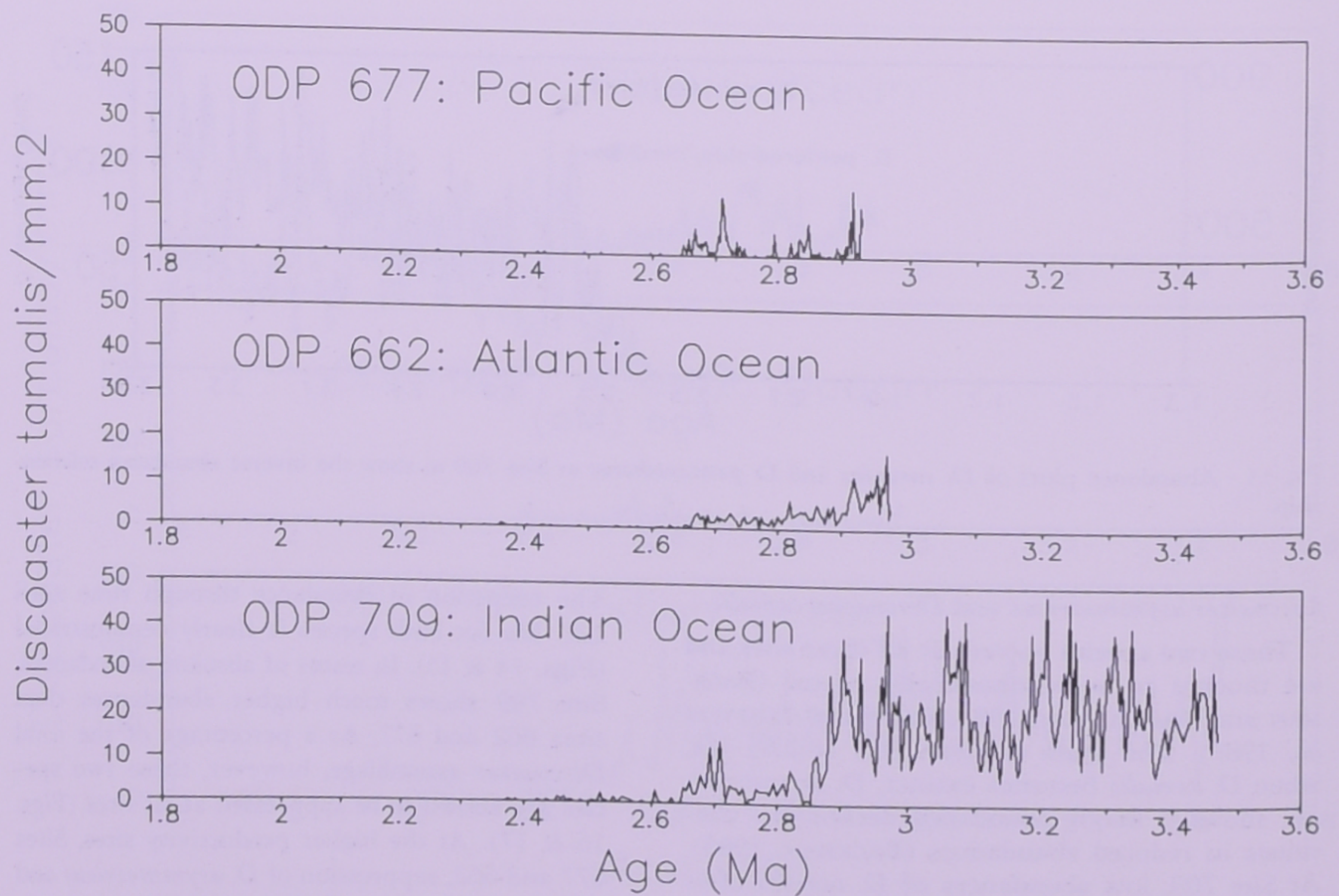


FIG. 15 - Abundance plots of *D. tamalis* at Sites 709, 662 and 677.

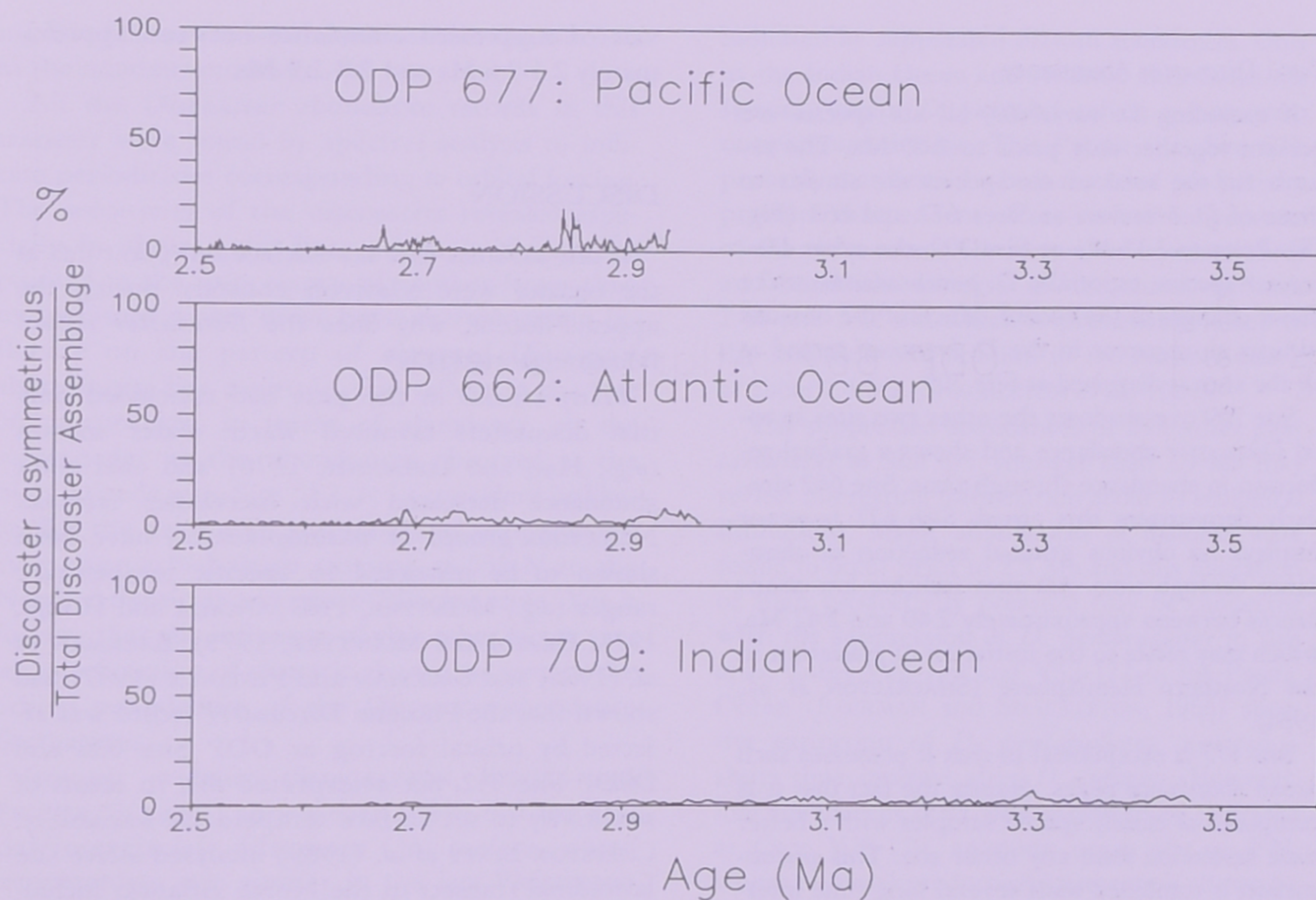


FIG. 16 - Percentage abundance plots of *D. asymmetricus* at Sites 709, 662 and 677.

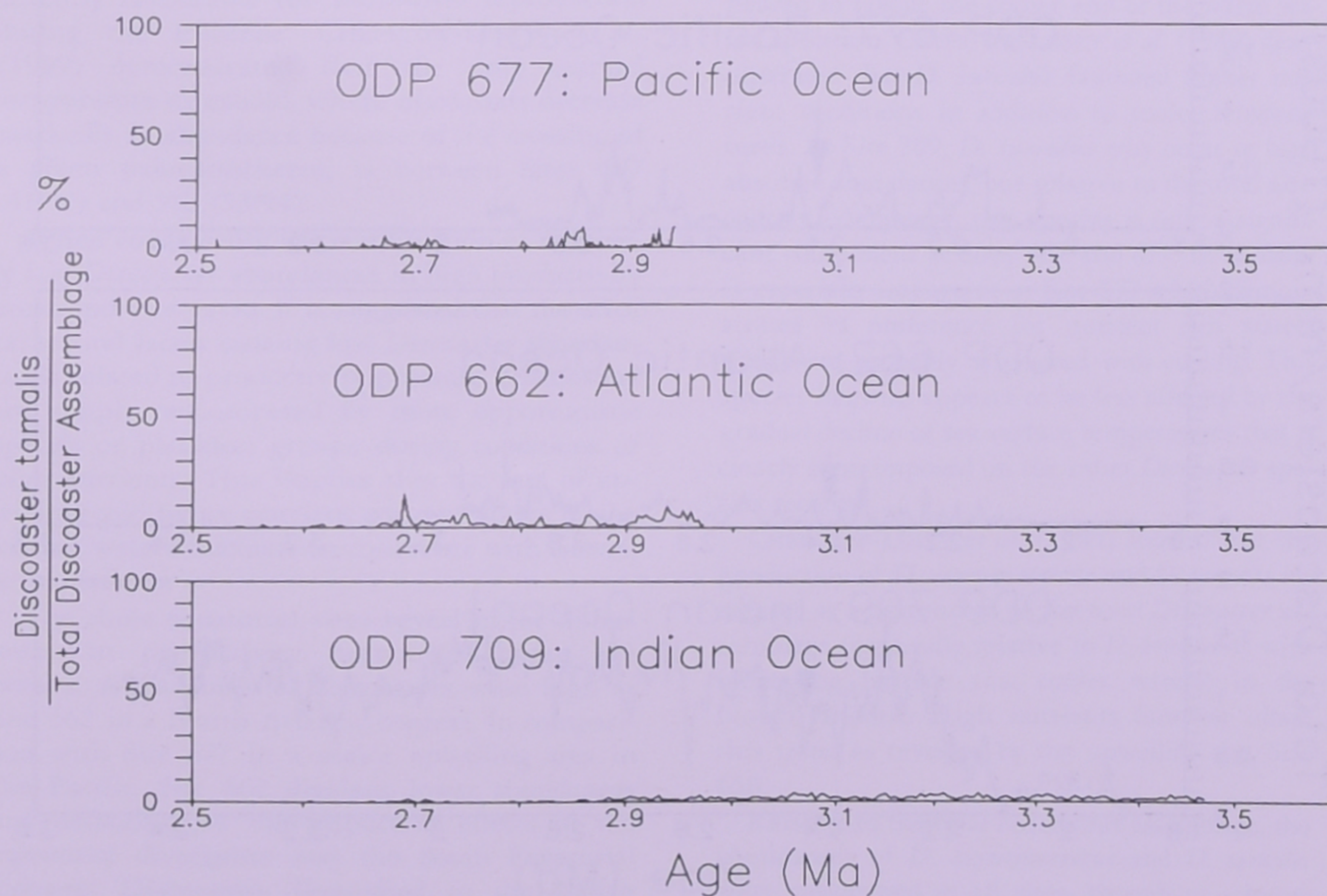


FIG. 17 - Percentage abundance plots of *D. tamalis* at Sites 709, 662 and 677.

Total *Discoaster* Abundance

If excluding *D. variabilis*, all six species are present together only prior to 2.65 Ma. The records for the total of six species are similar to those of *D. brouweri* at Sites 677 and 662 (Fig. 18). Prior to 2.35 Ma at Site 709, the other *Discoaster* species, especially *D. pentaradiatus*, make major changes to the record. Much of the obvious cyclicity so apparent in the *D. brouweri* record at all the sites is disguised at Site 709.

Site 709 overshadows the other two sites in total *Discoaster* abundance and shows a gradual reduction in abundance through time. Site 662 similarly demonstrates this trend. Site 677 however displays no obvious gradual reduction in abundance through time. All sites indicate low abundances between approximately 2.40 and 2.42 Ma, which may relate to the initiation of glaciation in the Northern Hemisphere (SHACKLETON *et al.*, 1984).

Site 677 is exceptional in that it possesses such broad abundance peaks, despite the fact that it is composed of closely spaced samples with a better time resolution than any other site. This phenomenon is combined with several long time inter-

vals of suppressed abundance between approximately 2.5-2.6 Ma and 2.8-2.9 Ma.

DISCUSSION

If one assumes that sea-surface temperatures at the equator were relatively constant during the upper Pliocene, why does the *Discoaster* record fluctuate so markedly?

Many studies in the past had concluded only that discoasters favoured warm water masses (*e.g.*, HAQ and LOHMANN, 1976) and that their abundance decreased with increasing latitude. Numerous groups of nannoplankton have been shown to be restricted to specific temperature ranges (*e.g.*, MCINTYRE, 1967; OKADA and HONJO, 1973; OKADA and MCINTYRE, 1979). BACKMAN *et al.* (1986) and BACKMAN and PESTIAUX (1987) had shown that the Pliocene *Discoaster* record was affected by orbital forcing at ODP Site 606 and DSDP Site 552, but interpreted this in terms of sensitivity to sea surface temperature variability. CHEPSTOW-LUSTY *et al.* (1989) analysed a five site latitudinal transect in the North Atlantic, includ-

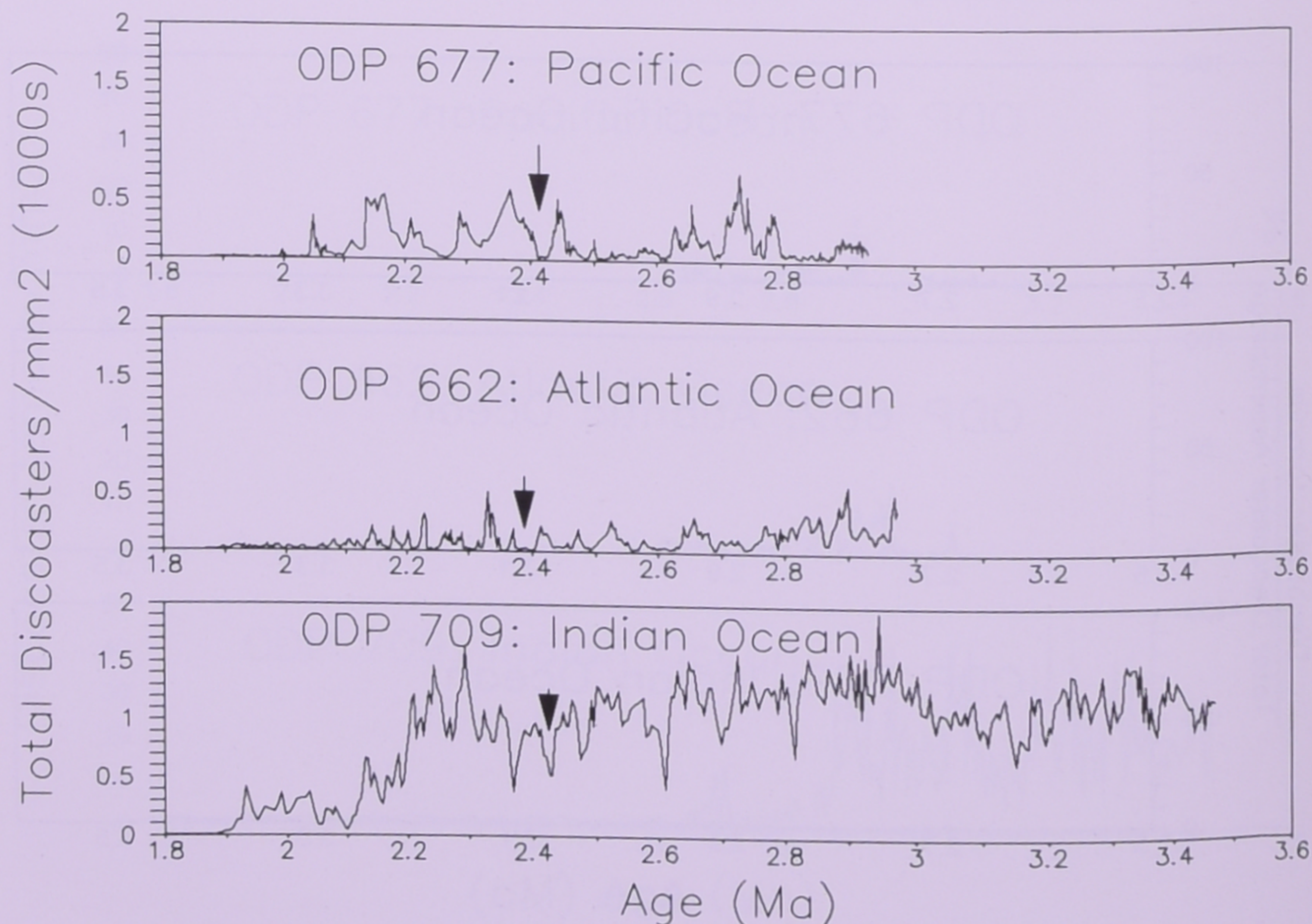


FIG. 18 - Abundance plots of total *Discoaster* assemblage at Sites 709, 662 and 677.

ing Site 662 as the southernmost site and Site 552 as the northernmost site.

All the *Discoaster* abundance records in this transect were found by spectral analysis to indicate periodicities corresponding to orbital forcing. The sensitivity of the discoasters revealed especially by their cyclic fluctuations in the tropics pointed to the importance of another factor than temperature which must have exerted strong influence on the pattern of observed *Discoaster* abundances. For example, the valleys in the Site 662 record are, in terms of abundance, on the same order as the abundances observed at the high latitude site, Site 552. It is considered unlikely that the equatorial surface water temperatures ever approached those existing at 53° N in the North Atlantic at any given Pliocene time. Yet it follows that the influence of this other factor varies as a function of climatic change, as seen in the orbital periodicities of the *Discoaster* abundance fluctuations.

Isotopic evidence (SHACKLETON, BERGER and PELTIER, in press) shows that at Site 677 the glacial/interglacial difference in surface water temperatures was similar in the late Pleistocene and the late Pliocene. The equatorial sites must have had temperature regimes which were consistently favourable for *Discoaster* reproduction during the Pliocene. CHEPSTOW-LUSTY *et al.*, (1989) demonstrated that the only marked temperature threshold, where discoasters decrease markedly in abundance because of the crossing of a given palaeoisotherm, is between Sites 607 (41°N) and 552 (53°N).

When considering the combination of relatively low *Discoaster* abundances in high productivity areas and *vice versa*, it is suggested that the critical second factor causing low *Discoaster* abundances is related to productivity pressure. Discoasters are simply outcompeted by more opportunistic species or plankton groups during conditions of high nutrients. This implies that the rate of upwelling and hence nutrient concentrations in the surface waters fluctuate in coherence with climatic oscillations.

The three equatorial sites reveal major differences in productivity pressure between the oceans. Abundances of discoasters were high at Site 662 in a North Atlantic context. In comparison with Site 677 in a major upwelling area in the Pacific, Site 662 displays lower abundances and demonstrates the important effects of the equatorial divergence and the South Equatorial Current. Discoasters flourished in the Indian Ocean at Site 709 in waters of lower productivity

indicated by suppressed diatom abundances. Only in the Indian Ocean and Atlantic sites do all the species, except *D. surculus* reflect a long term temperature decline. The Pacific site, Site 677, probably manifests the best record of productivity pressure independent of sea-surface temperature of the three sites. All three sites however show an abundance decrease in discoasters between 2.40 and 2.42 Ma which is presumably linked to the initiation of glaciation in the North Atlantic at about 2.4 Ma (SHACKLETON *et al.*, 1984).

The suppressed abundances of *Discoaster pentaradiatus* at Site 677 younger than 2.9 Ma may reflect interesting information about its ecological limitations. Major abundances of diatoms were found to occur prior to 2.5 Ma and this indication of high productivity pressure may be connected with the suppression of *D. pentaradiatus* in this area. Cores V28-179 and V32-127 in the Pacific Ocean (BACKMAN and SHACKLETON, 1983) show the extinction of *D. pentaradiatus* occurred a short time interval after *D. surculus*. However, low abundances of *D. pentaradiatus* are indicated at Core V28-179, an open ocean site at 4°N, where minimal productivity pressure is shown by the overall *Discoaster* abundances.

BUKRY (1978) observed that *D. surculus* appeared to favour the cooler end of the warm water spectrum. CHEPSTOW-LUSTY *et al.* (1989) demonstrated that *D. surculus* favoured higher nutrient conditions in addition to cooler temperatures. At Site 709, *D. surculus* may occur in high absolute abundances, but relative to the total *Discoaster* assemblage, this species is only a significant component at Sites 662 and 677. *D. surculus* is especially important at Site 677 which demonstrates its preference for nutrient rich waters which are probably associated with cooling. This species likewise appears to be less affected by the gradual decline of sea surface temperatures that is clearly superimposed on the other *Discoaster* species records.

CHEPSTOW-LUSTY *et al.* (1989) showed that the production of *D. asymmetricus* and *D. tamalis* increases as a percentage of the total *Discoaster* assemblage (especially relative to *D. brouweri*) with increasing latitude (*i.e.* cooler waters) in the North Atlantic. High nutrients however offset this trend as revealed by the upwelling site, Site 658.

Relative to the total *Discoaster* assemblage, the abundances of *D. asymmetricus* and *D. tamalis* were suppressed at all sites, though to a lesser extent at the higher productivity sites, Sites 662

and 677. Nevertheless, the relative abundances of these two species are still low due to the additional factor of productivity pressure. Further work must compare *Discoaster* abundances using accumulation rates. Initial investigation into the ratio between total *Discoaster* abundance and other coccoliths, such as *Coccolithus pelagicus* indicates that this is not a constant relationship, and is probably similarly linked to productivity pressure (CHEPSTOW-LUSTY, 1990).

Discoaster abundances in the future must always be considered within the context of productivity pressure and not just sea surface temperature. The ecological requirements of individual species independently and as a function of the total *Discoaster* assemblage can provide valuable palaeoclimatic information. Comparison with the oxygen isotope record for these sites will contribute to separating the productivity signal from the temperature signal. The sensitivity of the discoasters may provide an alternative stratigraphic framework for correlation in the upper Pliocene. Orbitally tuned timescales will further contribute to refining this correlation of productivity pressure on a global scale as more sites become available.

SUMMARY

1 - The *Discoaster* abundance fluctuations at all sites reveals the importance of productivity pressure at the equator where relatively constant sea-surface temperatures would be expected.

2 - Production of discoasters in the Indian Ocean (Site 709) is much greater than at the Pacific site, Site 677 (Upwelling site) and the Atlantic site, Site 662 (affected by the South Equatorial Current and equatorial divergence).

3 - Prior to 2.4 Ma, *Discoaster brouweri* forms the greatest component of the *Discoaster* assemblage at the Pacific site, Site 677.

4 - *Discoaster pentaradiatus* forms a major component of the *Discoaster* assemblage at Sites 662 and 709, but is very rare younger than 2.9 Ma at Site 677.

5 - *Discoaster surculus* forms its largest component of the *Discoaster* assemblage at Site 677, followed closely by Site 662 which are both influenced by higher productivity in spite of the greater absolute abundances at Site 709.

6 - *Discoaster asymmetricus* and *Discoaster tamalis* are present in greatest abundances at Site 709, but relative to the *Discoaster* assemblage they are more significant at the higher productivity sites, Sites 677 and 662.

7 - Many of the *Discoaster* abundance peaks can be used to cross-correlate between sites.

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REFERENCES

- BACKMAN J., 1986 - *Accumulation patterns of Tertiary calcareous nannofossils around extinctions*. Geologische Rundschau v. 75/1, pp. 185-196. Stuttgart.
- BACKMAN J., DUNCAN R. A., *et al.*, 1988 - Proc. ODP, Init. Repts., v. 115, pp. 459-588, College Station.
- BACKMAN J., PESTIAUX P., 1987 - *Pliocene Discoaster abundance variations from DSDP Site 606: biochronology and paleoenvironmental implications*. Init. Repts. DSDP, v. 94, pp. 903-910, (U.S. Govt. Printing Office), Washington.
- BACKMAN J., PESTIAUX P., ZIMMERMAN H., HERMELIN O., 1986 - *Pliocene palaeoclimatic and palaeo-oceanographic development in the North Atlantic: Discoaster abundance and coarse fraction data*. Spec. Pap. Geol. Soc. London, v. 21, pp. 231-242, London.
- BACKMAN J., SHACKLETON N. J., 1983 - *Quantitative biochronology of Pliocene and early Pleistocene calcareous nannofossils from the Atlantic, Indian and Pacific oceans*. Mar. Micropaleontol., v. 8, pp. 141-170, Amsterdam.
- BECKER K., SAKAI H., *et al.*, 1988 - Proc. ODP, Init. Repts., v. 111, College Station.
- BUKRY D., 1973 - *Low-latitude coccolith biostratigraphic zonation*. Init. Repts. DSDP v. 15, pp. 685-703, (U.S. Govt. Printing Office), Washington.
- BUKRY D., 1978 - *Biostratigraphy of Cenozoic marine sediment by calcareous nannofossils*. Micropaleontol., v. 24, pp. 44-60, New York.
- CHEPSTOW-LUSTY A., 1990 - *Nannoplankton as indicators of climatic variability in the Upper Pliocene*. Unpublished PhD thesis, Cambridge University.
- CHEPSTOW-LUSTY A., BACKMAN J., SHACKLETON N. J., 1989 - *Comparison of upper Pliocene Discoaster abundance variations from North Atlantic Sites 552, 607, 659, 658 and 662: Further evidence for marine plankton responding to orbital forcing*. In Init. Repts. ODP, v. 108B, pp. 121-141, (U.S. Govt. Printing Office), Washington.

- HAQ B. U., LOHMANN G.P., 1976 - *Early Cenozoic calcareous nannoplankton biogeography of the Atlantic Ocean*. Mar. Micropaleontol., v. 1, pp. 119-194, Amsterdam.
- LOHMANN G.P., CARLSON J. J., 1981 - *Oceanographic significance of Pacific late Miocene calcareous nannoplankton*. Mar. Micropaleontol., v. 6, pp. 553-579, Amsterdam.
- MCINTYRE A., 1967 - *Coccoliths as paleoclimatic indicators of Pleistocene glaciation*. Science, v. 158, pp. 1314-1317, Washington.
- MOORE T. C., HEATH R.C., KONSMAAN R.O., 1973 - *Biogenic sediments of the Panama Basin*. J. Geol., v. 81, pp. 458-472, Chicago.
- OKADA H., HONJO S., 1973 - *The distribution of oceanic coccolithophorids in the Pacific*. Deep-Sea Res., v. 20, pp. 355-374.
- OKADA H., MCINTYRE A., 1979 - *Seasonal distribution of modern coccolithophores in the western North Atlantic Ocean*. Mar. Biol., v. 54, pp. 319-328.
- RUDDIMAN W.F., SARNTHEIN M., *et al.*, 1988. In Init. Repts. ODP, v. 108, pp. 487-556, (U.S. Govt. Printing Office), Washington.
- SHACKLETON N.J., BACKMAN J., ZIMMERMAN H.G., KENT D. V., HALL M.A., *et al.*, 1984 - *Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the North Atlantic region*. Nature, v. 307, pp. 320-323, London.
- SHACKLETON N.J., BERGER A., PELTIER W.R., (in press) - *An alternative astronomical calibration of the Lower Pleistocene timescale based on ODP Site 677*. Trans. Roy. Soc. Edinburgh Earth Sciences.
- SHACKLETON N.J., HALL M.A., 1983 - *Stable isotope record of Hole 504 sediments: High resolution record of the Pleistocene*. In J.R. CANN, M.G. LANGSETH, J. HONNOREZ, R.P. VON HERZEN, S.M. WHITE, *et al.*, Init. Repts. DSDP, v. 69, pp. 431-442, (U.S. Govt. Printing Office), Washington.
- TAKAYAMA T., 1970 - *The Pliocene-Pleistocene boundary in the Lamont Core V21-98 and at Le Castella, southern Italy*. J. Mar. Geol. v. 6, pp. 70-77, Amsterdam.
- WEAVER P.P.E., RAYMO M.E., 1989 - *Late Miocene to Holocene Planktonic foraminifers from the equatorial Atlantic, Leg 108*. In W. RUDDIMAN, M. SARNTHEIN, *et al.*, Init. Repts. ODP, v. 108, pp. 71-91, (U.S. Govt. Printing Office), Washington.