33. CONTRIBUTION TO THE PALEOCENE CALCAREOUS NANNOFOSSIL BIOGEOGRAPHY OF THE CENTRAL AND SOUTHWEST ATLANTIC OCEAN (CEARÁ RISE AND SÃO PAULO PLATEAU, DSDP LEG 39)

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ABSTRACT

Paleocene calcareous nannofossil biogeography of DSDP Sites 354 and 356 is delineated and compared with the overall biogeographic patterns of the Atlantic Ocean. *Q*-mode varimax factor analysis defines five major Paleocene assemblages, four of which are similar to those recognized in the low to mid latitudes of the rest of the Atlantic. A fifth assemblage (***Prinsius*** aff. ***P. dimorphosus***) becomes dominant in upper Danian. Temporal dominance of various assemblages conforms to the overall latitudinal migrationary patterns recorded for the Atlantic (Haq and Lohmann, 1976) and confirm that the early Paleocene was relatively warm, followed by a cool period in middle Paleocene and a marked warming trend in the late Paleocene.

INTRODUCTION

During Deep Sea Drilling Project Leg 39 seven sites (353-359) were drilled in the central and southwest Atlantic Ocean. Calcareous microfossils were recovered from all sites, including well-preserved Paleocene calcareous nannofossils from Site 354 on the Ceará Rise (5°53.95'N, 44°11.78'W in 4052 m water depth) and Site 356 on the São Paulo Plateau (28°17.22'S, 41°05.20'W in 3193 m water depth) (Figure 1). Assemblages affected by dissolution were recovered from Site 358 in the Argentine Basin (37°39.31'S, 35°57.82'W, 4990 m water depth). Data from these three sites, especially Site 356, allowed us to extend our knowledge of the Paleocene nannofossil biogeography to these, formerly little known, areas. The early Cenozoic calcareous nannofossil biogeography of the Atlantic Ocean has already been delineated by Haq and Lohmann (1976), mainly on the basis of earlier DSDP legs (Legs 1-4, 10-12, 14, 15). More recently the study of the biogeography of parts of the early Cenozoic has been extended to the areas of more recent DSDP legs in the Atlantic (Leg 36: Haq et al., in press; Leg 38: Haq and Lohmann, in press). In this chapter we present the Paleocene biogeographic data from Leg 39 and compare it with biogeographic patterns from the rest of the Atlantic Ocean. We then interpret these patterns in terms of Paleocene climatic history of the mid latitudes of the southwestern Atlantic.

Our methodology was described in some detail in Haq and Lohmann (1976) and is not repeated in detail here. Briefly, it involves gathering of quantitative distributional data (numbers of specimens of nannolith taxa or groups of taxa) from each sample, then

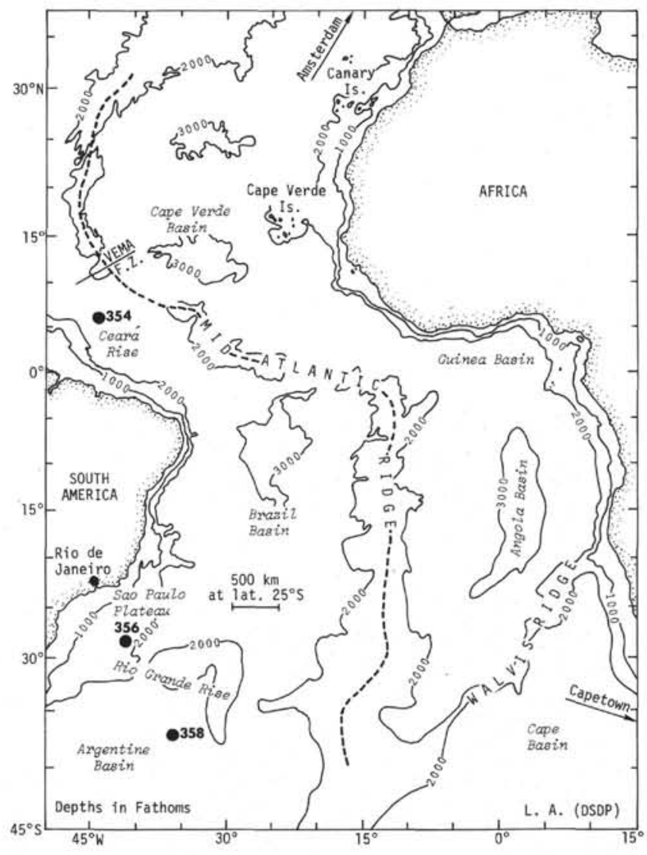

Figure 1. *Location of DSDP Leg 39 Sites including Site 354 (Ceará Rise), Site 356 (São Paulo Plateau), and Site 358 (Argentine Basin).*

reduction of these data by Q-mode varimax factor analysis. This resolves the raw data into those assemblages which contribute most to the samples, in an attempt to approximate natural taxonomic associations. Major variations in the latitudinal distribution of these assemblages through time are interpreted in terms of response to climatic change.

DISTRIBUTIONAL DATA AND BIOGEOGRAPHY OF ASSEMBLAGES

From Sites 354 and 356 we chose 15 samples for biogeographic analysis. Our choice of samples depended mainly on the preservation of nannoliths and their biostratigraphic position. Only those samples with relatively well-preserved, delicate coccoliths were considered and horizons were chosen from as many of the Paleocene biostratigraphic zones as possible (see Perch-Nielsen, this volume, for details of biostratigraphy). On the basis of these factors we have considered five horizons (NP1 to NP5 zones) from Site 356 and two horizons (NP9 Zone) from Site 354 (see Table 1). From Site 358 only less well preserved samples from two horizons (NP3/4 and NP5 Zones) were available. An absolute age is estimated for each sample (the uncertainty of these estimates is reflected by the lengths of the bars in Figures 2-6). Nannofossil census data (species or groups of species) are presented in Table 1. Approximately 300 specimens were counted in random traverses of smear slides made directly from raw samples.

We recognized the following assemblages in the relatively mid-latitude Site 356 and low-latitude Site 354.

1) Thoracosphaerid Assemblage: This assemblage is composed predominantly of thoracosphaerids with smaller amounts of *Markalius astroporus*. It is characteristic of the early Danian when many open ocean to near-shore sites at all latitudes have a "thoracosphaerid flood zone." In more near-shore to epicontinental areas, however, braarudosphaerids are more common than thoracosphaerids (i.e., the Braarudosphaerid Assemblage of early Danian near-shore sites, see Haq and Lohmann, 1976). Thoracosphaerids are common at Site 356 between 65 and 63.5 m.y.B.P. (Figure 2).

2) *Ericsonia subpertusa* Assemblage: This assemblage is dominated by *Ericsonia subpertusa* with lesser amounts of *Coccolithus pelagicus* (s. ampl.). It first became a dominant assemblage in early Paleocene sediments of low to mid latitudes, losing importance in the late Paleocene sediments. At Site 356 it is significant only for a relatively short period (between 62.5 to 59 m.y.B.P.) (Figure 3).

3) *Prinsius* aff. *P. dimorphosus* Assemblage: This assemblage contains overwhelming numbers of a group of small circular coccoliths referred to as *P.* aff. *P. dimorphosus* (Figure 4a). This assemblage is unique to the Danian (64-61.5 m.y.B.P.) and has not yet been encountered at any other Atlantic site of the same age (Figure 4b) investigated by our methods.

4) *Prinsius martinii* Assemblage: This high latitude assemblage is dominated by *Prinsius martinii* and occurs through most of the Paleocene sediments. During the later part of early Paleocene *Prinsius martinii* is found in significant numbers and at Site 356 it becomes dominant in sediments deposited between 62 and 58 m.y.B.P. Below these horizons the assemblage is insignificant at this and other mid-latitude sites (Figure 5).

5) *Toweius craticulus* Assemblage: This assemblage is dominated by the small coccolith taxon *Toweius craticulus* but also contains fewer, though still large numbers of *Coccolithus pelagicus*. At mid latitudes of Site 356 the assemblage forms a significant portion of the nannofossils from 60 to 58 m.y.B.P. and in low latitudes of Site 354 it predominates from 56 to 54.5 m.y.B.P. (late Paleocene-*Discoaster multiradiatus* Zone) (Figure 6).

6) *Discoaster-Cyclococcolithus formosus* Assemblage: This is a minor assemblage in the Paleocene which becomes a dominant mid latitude assemblage in the Eocene sediments. It occurs as a minor constituent in the Site 354 late Paleocene samples considered here.

BIOGEOGRAPHIC PATTERNS AND PALEOCENE CLIMATES OF SOUTHWEST ATLANTIC

Biogeographic patterns for four selected "time-slices" during the Paleocene are shown in Figure 7a-d. These maps are similar to those presented in Haq and Lohmann (1976) for the same "time-slices" but contain the additional biogeographic information, wherever available, for the more recent Atlantic DSDP legs. This is particularly the case for the late Paleocene (56-53.5 m.y.B.P.) "time-slice" where there is now enough latitudinal data to allow coverage of most of the Atlantic with biogeographic patterns (Figure 7d).

From Figures 2 to 7 we see that after the earliest Paleocene when the Thoracosphaerid Assemblage (and its near-shore counterpart the Braarudosphaerid Assemblage) dominates all latitudes, the remainder of early Paleocene (62-61 m.y.B.P.) is characterized by latitudinally differentiated assemblages. This is followed by a decrease in the latitudinal differentiation and expansion of high latitude assemblages to mid and low latitudes (between 61 and 58.5 m.y.B.P.), which, in turn, is followed by a more differentiated pattern and an expansion of low latitude assemblages into mid and high latitudes.

Haq and Lohmann (1976) have shown that there are major migrations of latitudinally well-defined assemblages occurring at specific latitudes throughout the Paleocene, and interpret these shifts as a response to major changes in climate. Following a relatively warm climate in the early Paleocene (64-62 m.y.B.P.) when assemblages are more latitudinally restricted, the high latitude assemblages (*Prinsius martinii* and a minor *P. bisulcus* Assemblage) invade the low latitudes, starting at about 62 m.y.B.P., and reach a peak low latitude expansion between 59 and 57 m.y.B.P. This is interpreted as a time of major cooling in the mid Paleocene. This cooling episode in confirmed by the occurrence of large numbers of individuals of the *Prinsius martinii* Assemblage at Site 356 between 61 and 58 m.y.B.P. (see Figures 5 and 7c).

TABLE 1
Qualitative Biogeographic Data from Selected "Time-Slices" of Sites 354 and 356 (Dissolution Assemblages from Site 358 Were Not Considered for Biogeography)

Samples (Zones, Age) / Taxa	Site 356													358		Site 354	
	NP1			NP2			NP3		NP4		NP5			3/4	5	NP9	
	Early Paleocene								Mid Paleocene							Late Pal.	
	65-64.5 m.y.	64.75-64.25 m.y.	64.5-64 m.y.	64-63.25 m.y.	64-63.25 m.y.	63.5-62.5 m.y.	62.5-61.5 m.y.	62-61 m.y.	61-60 m.y.	60.5-59.5 m.y.	59.5-58.5 m.y.	59.5-58.5 m.y.	59-58 m.y.	(Not considered)		56-55 m.y.	55.5 54.5 m.y.
	356-29-3, 20 cm	356-29-2, 99 cm	356-29-1, 100 cm	356-29-1, 81 cm	356-29-1, 60 cm	356-28-6, 94 cm	356-28-3, 100 cm	356-27-3, 70 cm	356-26-4, 100 cm	356-25-4, 70 cm	356-23-4, 100 cm	356-21-4, 101 cm	356-19-4, 106 cm	358-13-5, 56 cm	358-13-1, 45 cm	354-16-4, 100 cm	354-16-2, 100 cm
1. *Coccolithus pelagicus* (s. ampl.)						38	12	96	22	45	18	32	19	154	106	65	82
2. *Toweius craticulus*											102	117	135		62	124	100
3. *Prinsius martinii*							2	140	137	208	80	66	74			13	16
4. *Ericsonia subpertusa*							25	12	56	15	47	11	10	11	37	4	3
5. *Thoracosphaera* spp.	238	212	160	40	32	20	2	4	2	1	2	1	1	2		1	5
6. *Fasciculithus* spp.											1	3	2		12	45	31
7. *Prinsius bisulcus*									2	3		2	1				1
8. *Chiasmolithus* spp.							1	12	9	8	2	9	13	105	65	3	3
9. *Cruciplacolithus tenuis* (s. ampl.)				37	43	29	9	8	14	4	19	3	4	7	2		
10. *Discoaster* spp.																11	13
11. *Markalius astroporus*	13	60	17	5	3									2	5		
12. *Zygodiscus* spp.			8	24	16	9	3	9	2	3	7	13		13	6		
13. *Cyclococcolithus formosus*																1	2
14. *Coccolithus eopelagicus*											3	3	1			2	5
15. *Toweius eminens*													3				
16. *Prinsius* aff. *P. dimorphosus*			98	140	188	191	238		8								
17. *Sphenolithus* spp.												2	3		3	2	15
18. *Braarudosphaera* spp.	2		7	41	1	2											
19. Others	47	28	10	13	17	10	8	19	49	13	23	30	34	6	2	32	39

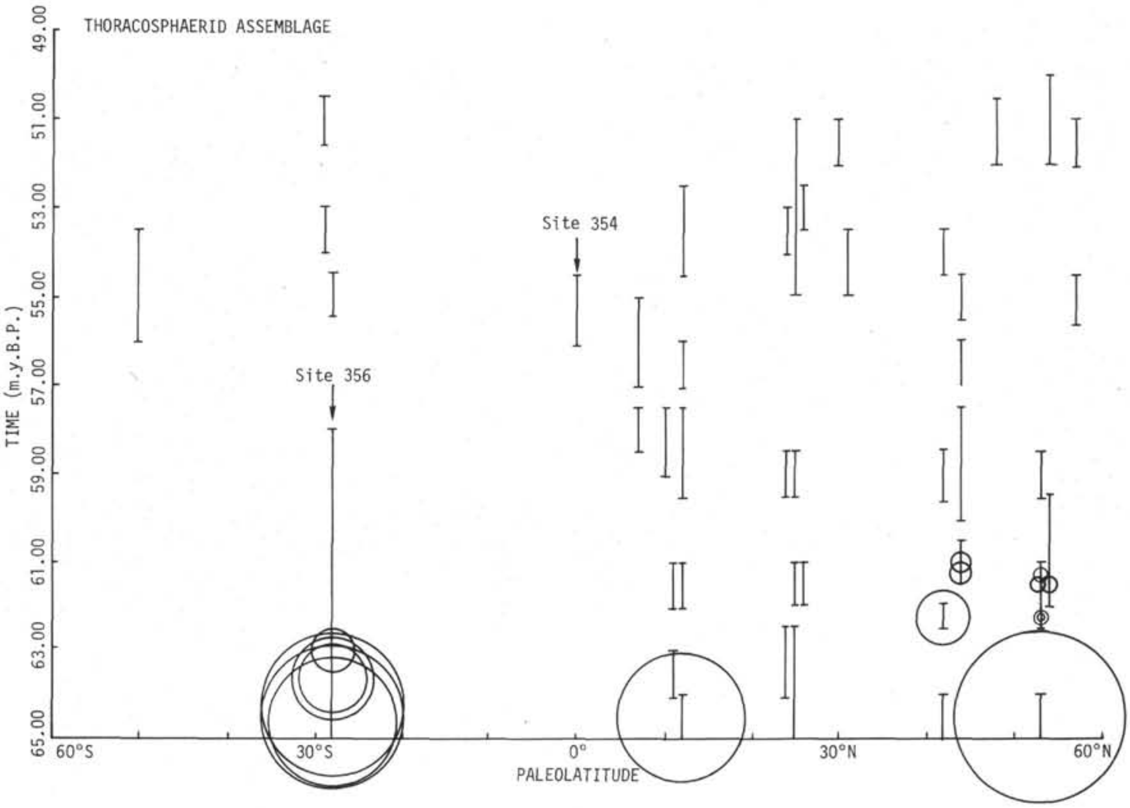

Figure 2. *Distribution of the earliest Paleocene Thoracosphaerid Assemblage. Sample positions are indicated by vertical line-segments, whose greater lengths reflect greater uncertainty of the ages estimated for the samples (for Biochronology, see Haq and Lohmann, 1976). Prevalence of a given assemblage in each sample is indicated by the size of the circle enclosing it. A circle whose diameter spans 20° of latitude represents a flora comprised of the Thoracosphaerid Assemblage 100%. (For list of samples, see Haq and Lohmann, 1976, in press and Haq et al, in press.)*

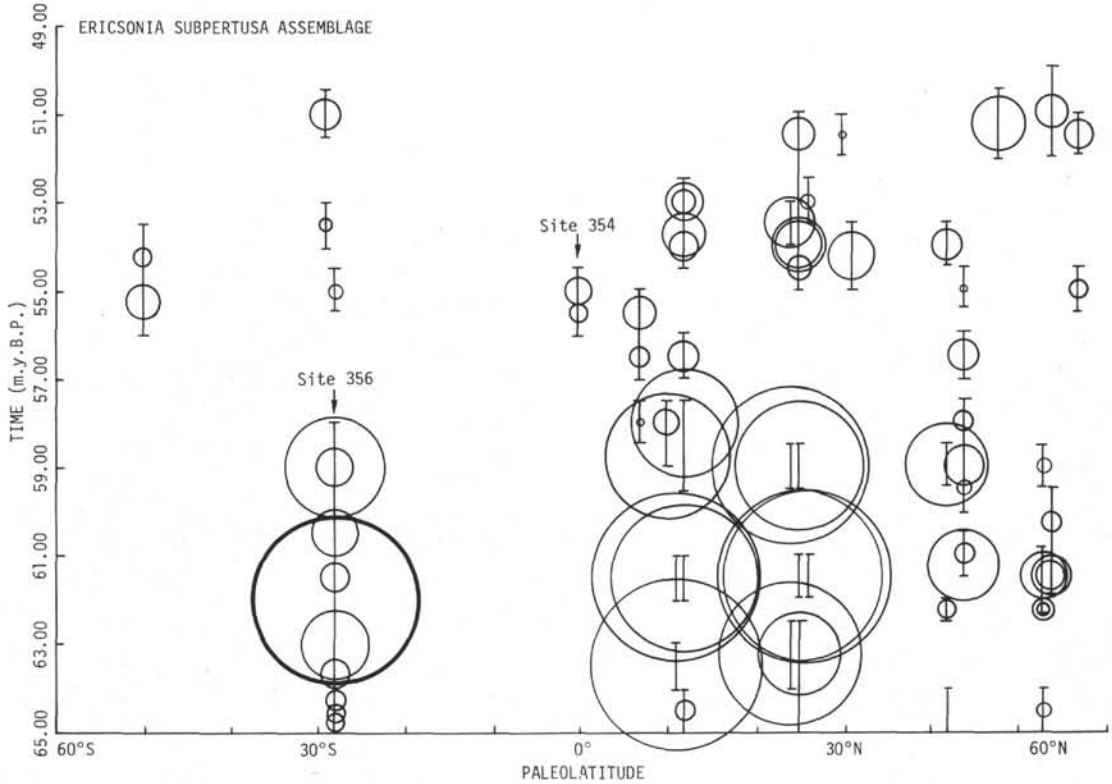

Figure 3. *Time and latitudinal distribution of the mid latitude* Ericsonia subpertusa *Assemblage. (For explanation, see caption of Figure 2.)*

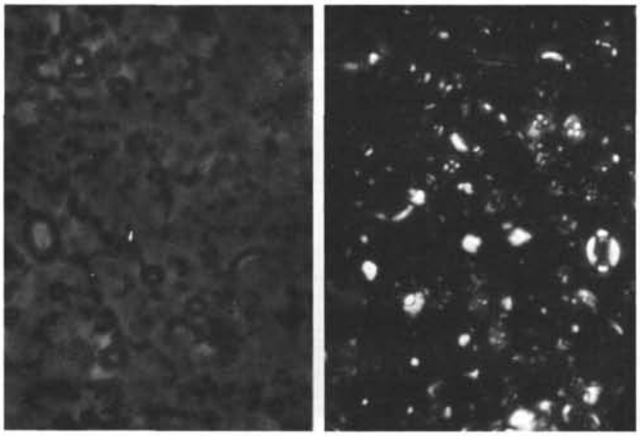

Figure 4a. *The small coccoliths of* Prinsius *aff.* P. dimorphosus *under phase-contrast and cross-polarized light, × 1250.*

This cooling trend is reversed after 57 m.y.B.P. as evidenced by the spread of the low latitude *Toweius craticulus* Assemblage into mid and high latitudes and indicates a peak warming at about 51 m.y.B.P. in early Eocene. This trend is once again confirmed by the patterns at Sites 356 and 354. At Site 356 *Toweius craticulus* occurs in significant numbers in sediments deposited between 60 and 57.5 m.y.B.P. (It is the second most dominant assemblage after *Prinsius martinii* Assemblages.) At the low latitude Site 354 *Toweius craticulus* predominates in sediments deposited between 56 and 54.5 m.y.B.P. (late Paleocene).

CONCLUSIONS

The Paleocene biogeographic patterns at the mid latitudes of Site 356 and low latitudes of Site 354 conform to the the overall biogeographic patterns delineated for the rest of the Atlantic by Haq and Lohmann (1976). The changes in the dominant assemblage through time are very similar to those observed in similar latitudes of the North Atlantic, including the short-term predominance of *Prinsius* aff. *P. dimorphosus* in the lower Danian at Site 356 and which was also observed in the Danian of Denmark. The changes in the biogeographic patterns recorded at Site 356 show a relatively warm early Paleocene, followed by a cooling in mid Paleocene and a marked warming trend in the late Paleocene. We have confirmed that the earliest Paleocene (earliest Danian) is characterized by a "thoracosphaerid flood zone." During this time these spherical nannoliths (considered to be calcareous dinoflagellates by Fütterer, 1976) "bloomed" in rock-forming quantities. This "bloom" is more easily detected in the open ocean sites, because in near-shore and epicontinental areas the braarudosphaerids were dominant and diluted the thoracosphaerids. Thus these two assemblages together (see Haq and Lohmann, 1976, Figure 5a, b) dominated all latitudes during the earliest Danian and can be usefully

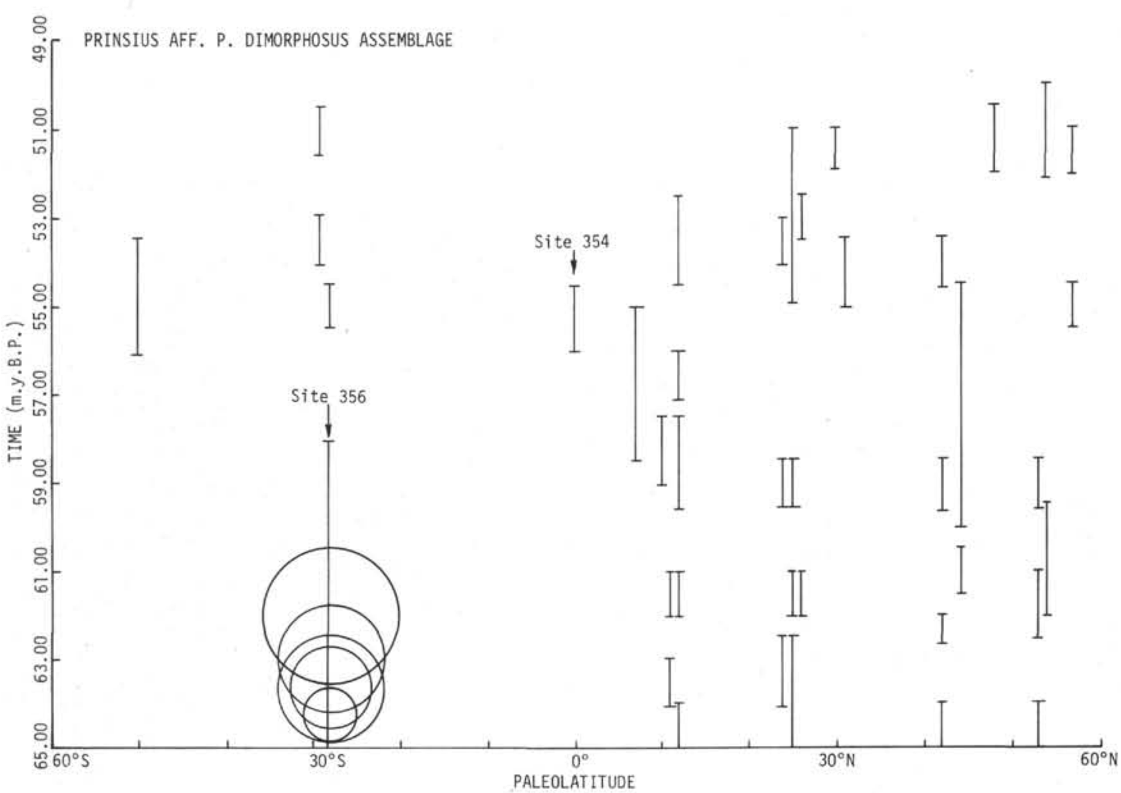

Figure 4b. *Time and latitudinal distribution of the* Prinsius *aff.* P. dimorphosus *Assemblage. Notice its predominance for a relatively short time (64-61.5 m.y.B.P.). (For explanation, see caption of Figure 2.)*

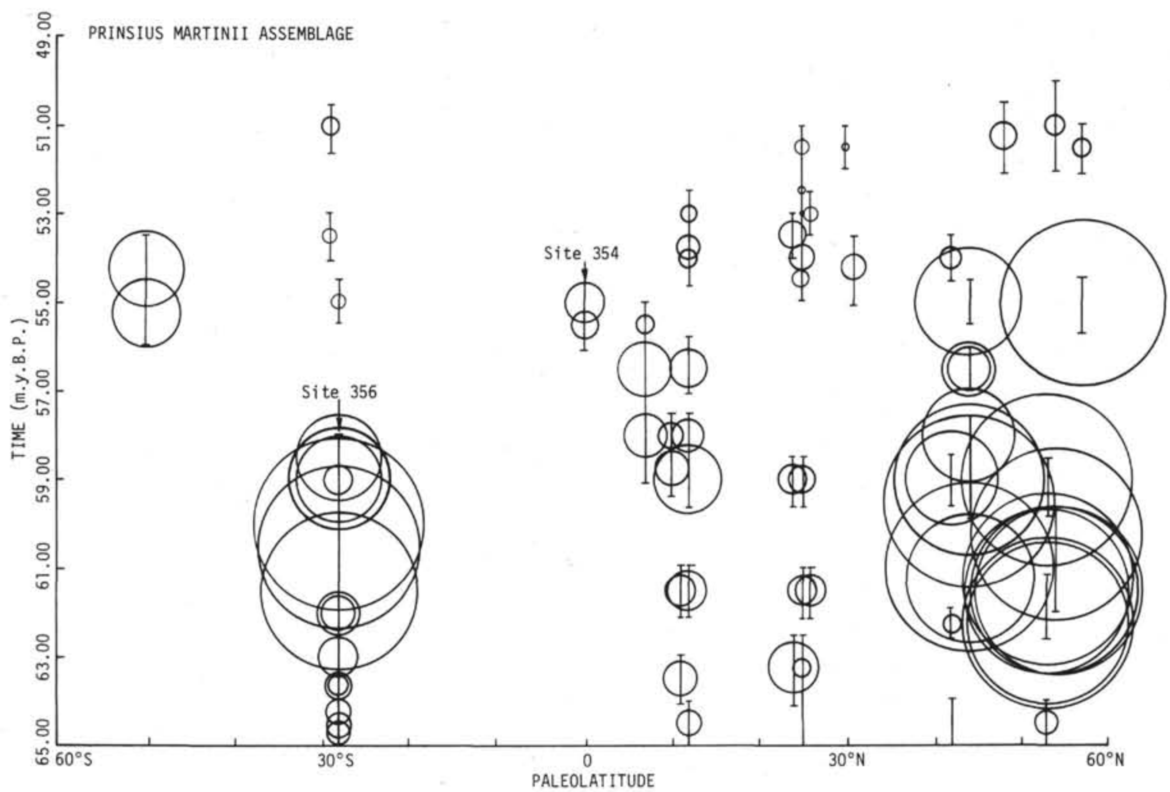

Figure 5. *Time and latitudinal distribution of the high latitude* Prinsius martinii *Assemblage. It dominates the Site 356 sediments deposited between 62 and 58 m.y.B.P. and is an important component up to 57.5 m.y.B.P. (For explanation, see caption of Figure 2.)*

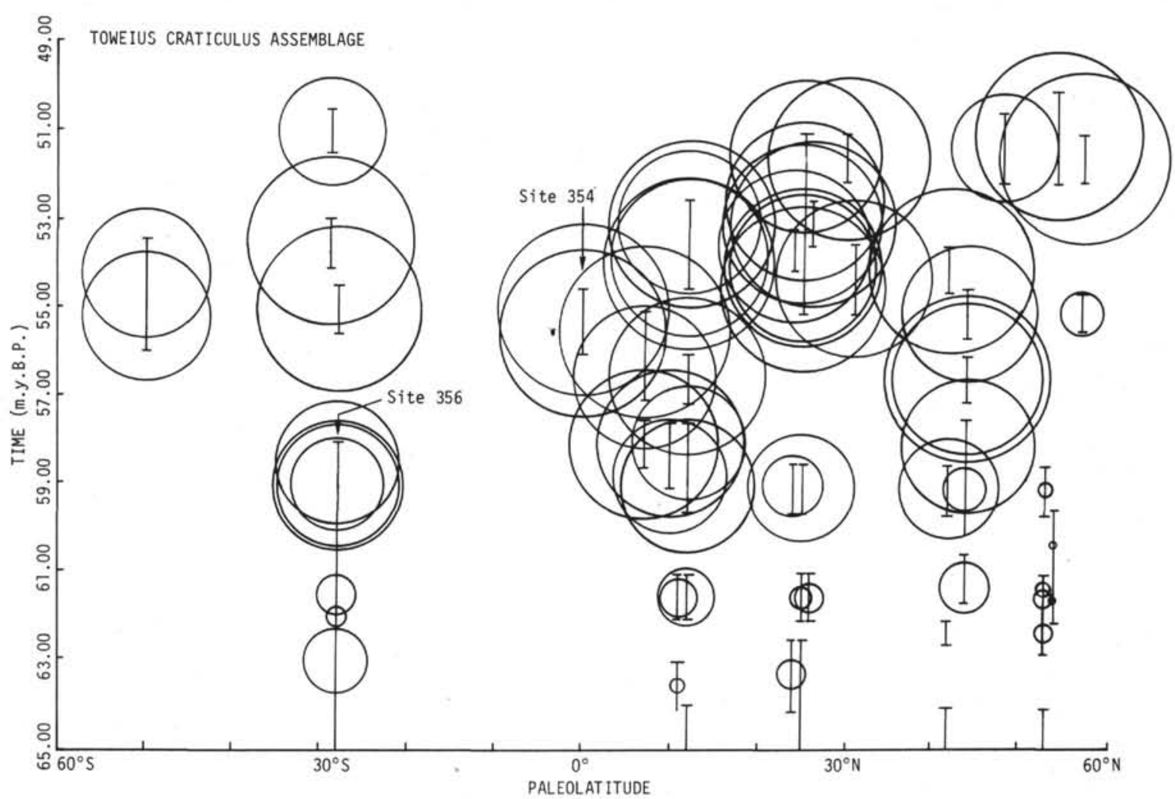

Figure 6. *Time and latitudinal distribution of the low latitude* Toweius craticulus *Assemblage. It is a significant component of the sediments at Site 356 deposited between 59.5 and 57.5 m.y.B.P., but predominates in late Paleocene (56-54.5 m.y.B.P.) samples of Site 354. Its peak invasion of high latitudes occured at about 52 m.y.B.P. (early Eocene). (For explanation, see caption of Figure 2.)*

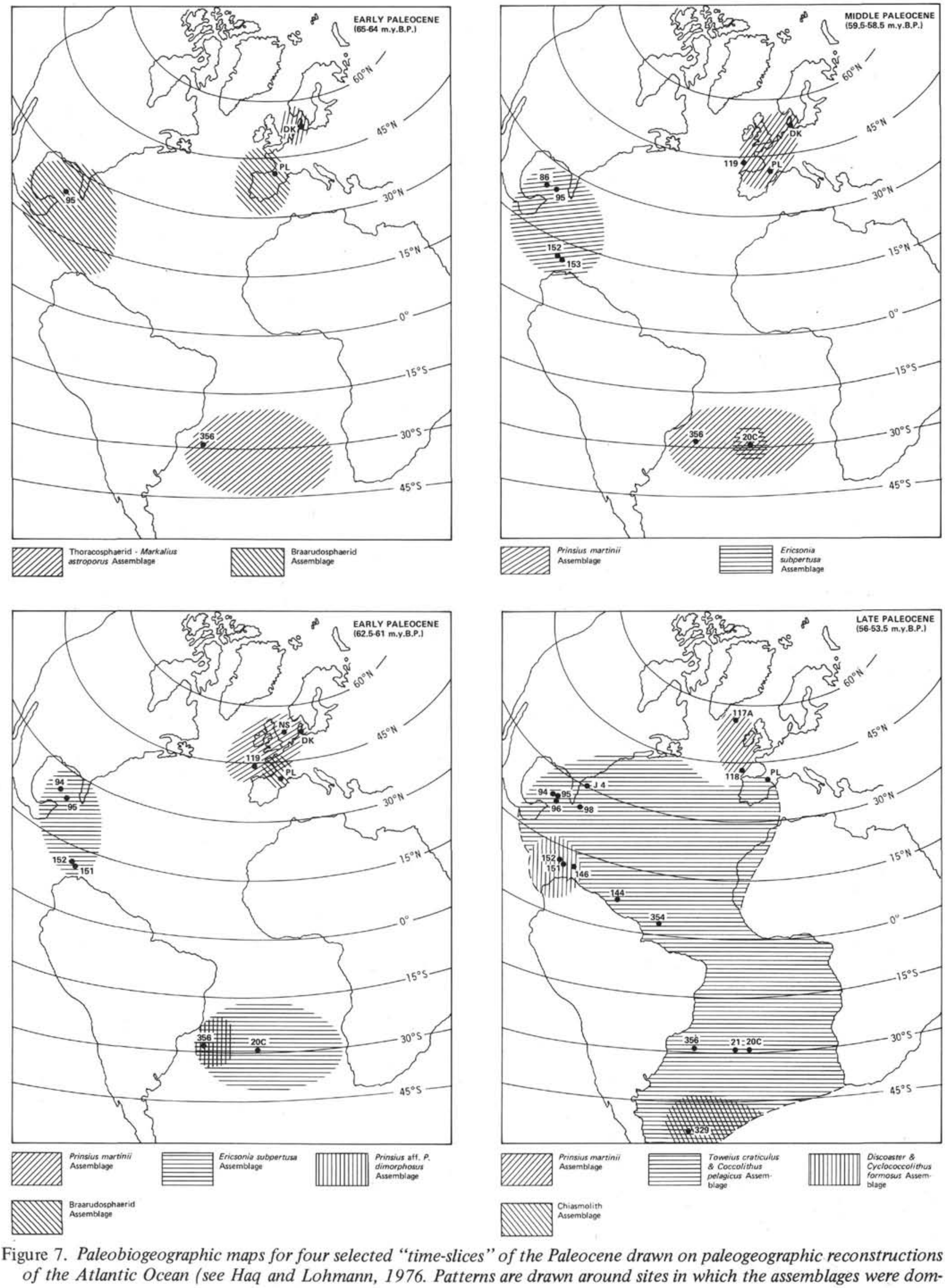

Figure 7. *Paleobiogeographic maps for four selected "time-slices" of the Paleocene drawn on paleogeographic reconstructions of the Atlantic Ocean (see Haq and Lohmann, 1976. Patterns are drawn around sites in which the assemblages were dom-*

inant. (a.) Earliest Paleocene (65-64 m.y.B.P.) patterns. Latitudinal differentiation of open ocean vs. near-shore only. (b.) Early Paleocene (62.5-61 m.y.B.P.). Latitudinal differentiation is well developed. (c.) Middle Paleocene (59.5-58.5 m.y. B.P.). Latitudinal differentiation decreased due to expansion of high-latitude Prinsius martinii *Assemblage into mid latitudes. (d.) Late Paleocene (56-53.5 m.y.B.P.) patterns show latitudinal differentiation increased again. However, most mid to low latitudes are occupied by the relatively low-latitude* Toweius craticulus *Assemblage. The boreal assemblage is still dominated by* Prinsius martinii *and an austral assemblage is characterized by a dominance of chiasmoliths (Site 329).*

employed as a biostratigraphic criterion to recognize this time interval of 65 to 64 m.y.B.P.

ACKNOWLEDGMENTS

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