

16. DIATOM BIOSTRATIGRAPHY OF SITES 434, 435, AND 436, NORTHWESTERN PACIFIC, LEG 56, DEEP SEA DRILLING PROJECT

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INTRODUCTION

We drilled and recovered sediment from three sites during Leg 56: (1) Site 434: Holes 434, 434A, and 434B; 39° 44.8' N, 144° 06.1' E. (2) Site 435: Holes 435, 435A; 39° 44.09' N, 143° 47.53' E. (3) Site 436: Hole 436; 39° 55.96' N, 145° 33.47' E. These sites are part of a transect across the Japan Trench from the oceanic plate (Site 436) and up the landward trench slope (Sites 434 and 435). Leg 57 sites continue the transect line from the slope onto the shelf.

All holes on Leg 56 recovered diatomaceous sediments. I found common to abundant and well-preserved diatoms from the highest to the lowest sample at Site 435. Diatoms are common and preservation is good in the upper parts at Site 434 and 436 but becomes worse in the lower parts; samples below Core 38 (359 m) in Hole 436 are barren.

The diatoms from the samples I examined are very similar to those reported by Koizumi (1973, 1975a) from DSDP Legs 19 and 32. The samples contain zonal marker species of both the Northwestern Pacific diatom zonation of Koizumi (1977) and the tropical Pacific diatom zonation of Burckle (1972), although the tropical taxa are usually less abundant than the northern taxa.

I used Koizumi's zonation and datum levels (1975a; 1977, Figure 1) for the middle Miocene through Pleistocene sections at Site 436 and for the lower Pliocene through Pleistocene sections at Site 435. At Site 434, however, part of the sequence of datum levels does not follow the normal pattern published by Koizumi. There are alternating assemblages which usually identify the *Denticula seminae fossilis*-*D. kamtschatica* Concurrent Range Zone and the *D. kamtschatica* Partial Range Zone. Koizumi and others (Burckle and Opdyke, 1977) have found these zonal assemblages to be nonrepetitive in many sections in the North Pacific. A detailed discussion of the possible causes of what I note in Hole 434 is in the Site 434 chapter.

Because of time restrictions and the large number of samples, some samples were examined in greater detail than others. I concentrated on Hole 434 because of its repetitious zonal assemblages and on Hole 436 because of its age continuity. Table 1 lists the diatom taxa used in this report.

PREPARATION AND EXAMINATION

On board the *Challenger* I processed samples, mainly core catcher samples, by making a smear slide of water-diluted soft sediment and mounting the cover slip with

Hydrax. Harder samples were boiled in a 30 per cent hydrogen peroxide solution until disaggregated and mounted like the preceding. Samples processed on shore were also boiled in 30 per cent hydrogen peroxide, then centrifuged to remove finer materials and mounted with Naphrax. I examined the slides in one of two ways: 1) Scanning at least half of the slide and noting the presence or absence of established marker taxa. I did this at 300 to 500 magnification, using higher magnification when needed for taxa identification. 2) Tabulation of the first 300 specimens, noting their numerical abundance, then continuing, noting presence or absence of additional taxa, until 1000 to 3000 specimens had been examined. If I found more than 15 specimens of a taxon during the first 300 specimens, I considered it abundant. I excluded *Thalassionema*, *Thalassiothrix*, *Chaetoceros*, and fresh-water taxa.

In addition, while scanning several samples from Hole 434 according to 1), I tabulated the number of specimens of *Denticula kamtschatica* and *D. seminae fossilis* to obtain their ratio.

DIATOM ZONATION

Published studies from 1970 to 1978 have added greatly to our knowledge of the diatom biostratigraphy of the Pacific. Burckle (1972), Burckle and Opdyke (1977), Koizumi (1977), and Harper (1977) have correlated many diatom datum levels to paleomagnetic stratigraphy and radiometric chronology. These zonations, datum levels, and age correlations are shown in Figure 1. Burckle's (1972) eastern equatorial Pacific marker taxa and Koizumi's (1977) Northwestern Pacific marker taxa have been found together in samples or parts of sections across the mid-latitudes of the Pacific. Such occurrences are reported by Koizumi (1975a), Burckle and Opdyke (1977), Barron et al. (1978), and Harper (1978). Harper (1978) has also shown that the first appearance of *Denticula kamtschatica* is older in the Northwest Pacific than in California coastal area. Diatom biostratigraphy of sections near the geographic limits of the northern and equatorial provinces must be done carefully. Neither the paleomagnetic nor the radiometric assignments of datum levels always apply strictly in such areas; rather, they represent age limits, because the taxon may have existed at the edge of its geographic distribution for only part of its total time range.

Site 434

We drilled at this site on the landward accretionary wedge of the Japan Trench. We recovered only 18 to 19

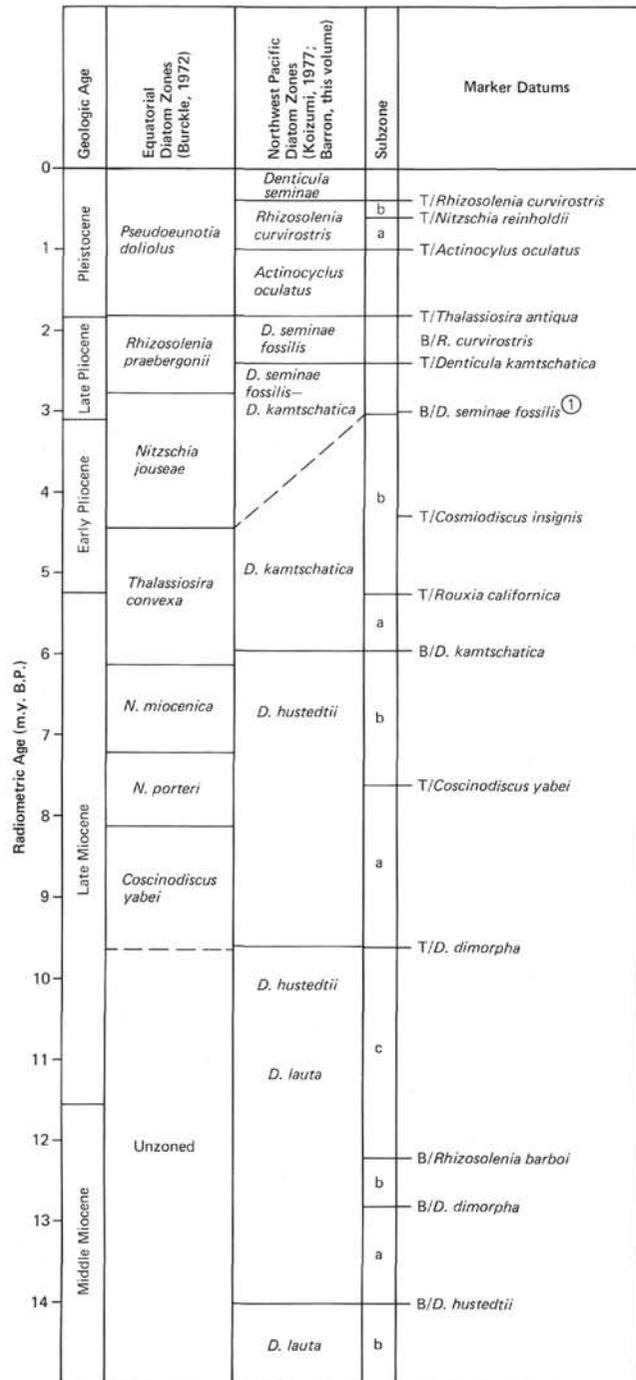


Figure 1. Pacific diatom zones. (① *D. seminae fossilis* has a diachronous first appearance, being older [4.2 m.y.] in the north and younger [~3.2 m.y.] in the mid-latitudes.)

per cent of the 637.5-meter cored interval. Figure 2 shows the datum levels and zonal assignments. Core 434-1 contains a late Pleistocene diatom assemblage correlated to the *Denticula seminae* Zone. Core 434-2, however, is late Pliocene in age, assignable to the *Denticula seminae fossilis* Zone. The *Rhizosolenia curvirostris* and *Actinocyclus oculatus* zones are missing,

TABLE 1
Taxa Used in This Chapter

<i>Actinocyclus ingens</i> Rattray	<i>Hemidiscus cuneiformis</i> Wall
<i>A. ochotensis</i> Jousé	<i>Kisseleviella carina</i> Sheshukova-Poretzkaya
<i>A. oculatus</i> Jousé	<i>Macrora stella</i> (Azpeitia) Hanna
<i>A. tsugarensis</i> Kanaya	<i>Mediaria splendida</i> Sheshukova-Poretzkaya
<i>Annellus californicus</i> Tempère	<i>Nitzschia fossilis</i> (Frenquelli) Kanaya
<i>Asterolampra acutiloba</i> Forti	<i>N. jouseae</i> Burckle
<i>Coscinodiscus insignis</i> Jousé	<i>N. miocenica</i> Burckle
<i>Coscinodiscus endoi</i> Kanaya	<i>N. praereinholdii</i> Schrader
<i>C. lewistianus</i> Greville	<i>N. reinholdii</i> Kanaya
<i>C. marginatus</i> Ehrenberg	<i>Pseudoeunotia doliohus</i> (Wall.) Grunow
<i>C. plicatus</i> Grunow	<i>Rhizosolenia barboi</i> Brun
<i>C. pustulatus</i> Mann	<i>R. curvirostris</i> Jousé
<i>C. symbolophorus</i> Grunow	<i>R. miocenica</i> Schrader
<i>C. temperei</i> Brun	<i>R. praebergonii</i> Muchina
<i>C. yabei</i> Kanaya	<i>Rouxia californica</i> Peragallo
<i>Craspedodiscus coscinodiscus</i> Ehrenberg	<i>Stephanopyxis horridus</i> Koizumi
<i>Custia paleacea</i> (Grunow) Schrader	<i>Synedra jouseana</i> Sheshukova-Poretzkaya
<i>C. tatsunokuchienis</i> (Koizumi) Schrader	<i>Thalassiosira antiqua</i> (Grunow) Cleve-Euler
<i>Denticula hustedtii</i> Simonsen and Kanaya	<i>T. burckliana</i> Schrader
<i>D. kamtschatica</i> Zabelina	<i>T. convexa</i> Muchina
<i>D. lauta</i> Bailey	<i>T. miocenica</i> Schrader
<i>D. punctata</i> Schrader	<i>T. nidulus</i> (Tempère and Brun) Jousé
<i>D. seminae</i> Simonsen and Kanaya	<i>T. ostrupii</i> (Osten.) Proskina-Lavrenko
<i>D. seminae fossilis</i> Schrader	<i>T. usatchevii</i> Jousé
<i>Goniothecium tenue</i> Brun	<i>T. zabelinae</i> Jousé

Note: Taxonomy of these taxa may be found in Koizumi (1973, 1975a, 1975b) and Schrader (1973, 1974a, 1974b).

indicating a hiatus of about 1.5 m.y. I found the top occurrence of *D. kamtschatica* in Core 434-4, and the concurrent range of *D. kamtschatica* and *D. seminae fossilis* extends continuously in the samples I examined through 434-6, CC. Below this level and through Sample 434-33-3, 72 cm, I found several repetitions of the typical *D. seminae fossilis*-*D. kamtschatica* and the *D. kamtschatica* zonal taxa. These are shown in Table 2. The definitions of the two zones are based on the concurrent range of *D. seminae fossilis* and *D. kamtschatica* for that zone and the nonconcurrent range of *D. kamtschatica*, respectively.

Taxa which Koizumi (1975b) associated with the *D. seminae fossilis*-*D. kamtschatica* Zone or younger zones are *Rhizosolenia praebergonii* and *A. oculatus*. Taxa which he associated with the *D. kamtschatica* Zone or older zones are *Coscinodiscus insignis*, *Coscinodiscus symbolophorus*, *C. temperei*, *Rouxia californica*, and *Goniothecium tenue*. There are two types of data in Table 2, as discussed earlier. Table 2 shows an assemblage difference between the samples with *D. seminae fossilis* and *D. kamtschatica* and the samples with only *D. kamtschatica*. *A. oculatus* and *R. praebergonii* occur only with *D. seminae fossilis*, and *Coscinodiscus insignis* and *R. californica* occur with *D. kamtschatica* alone.

Samples 434-28-2, 82cm, and 434-28, CC, although low in diatom abundance and poor preservationally, contain specimens of the late to middle Miocene species *D. lauta*, *A. ingens*, *G. tenue* and *D. punctata*, with *D. kamtschatica* and *D. seminae fossilis* absent. In the next sample down, 434-39, CC, I find *D. seminae fossilis* and *D. kamtschatica* again. In Hole 434B, from Samples 2, CC to 17, CC, I find the *D. kamtschatica* assemblage and place the top of the *D. hustedtii* Zone at Sample 434B-18, CC, although preservation and diatom abundance become very poor, several samples within Hole 434B being barren (25, CC; 33, CC; 34, CC; 37, CC) and core recovery very bad. The tops of *C. insignis* and *R. californica* are tentatively placed in Core 434B-7 and

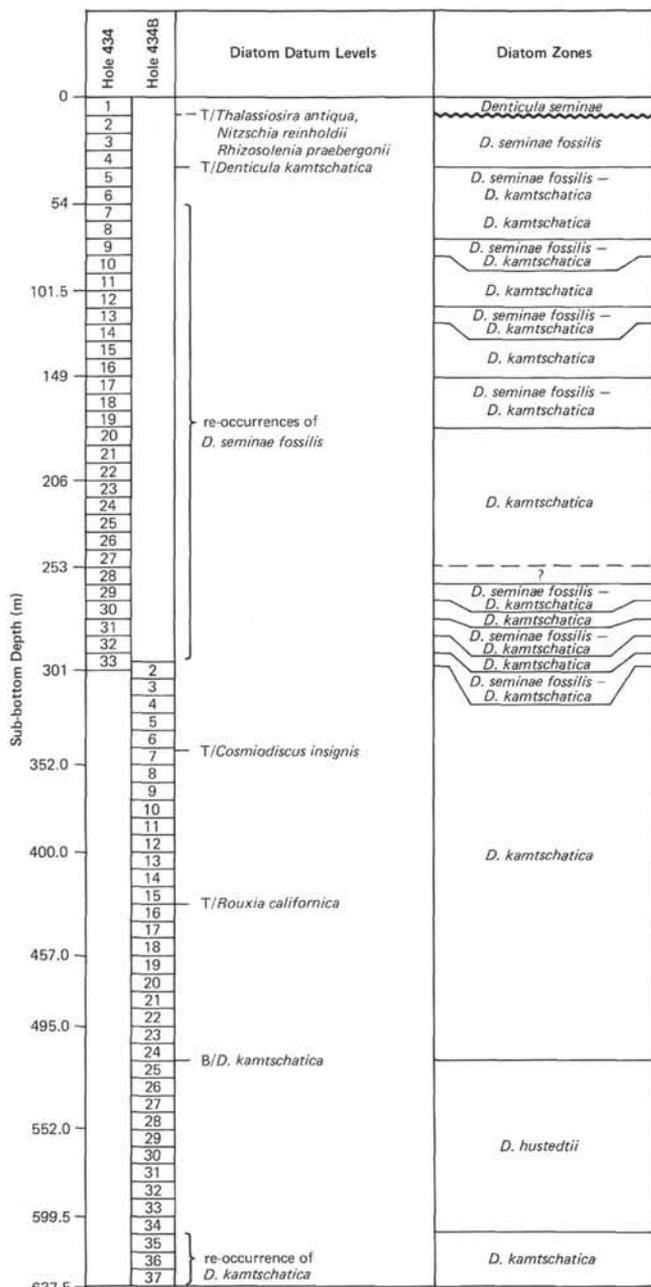


Figure 2. Placement of datum levels at Site 434. (T/ = top occurrence, B/ = base occurrence.)

Core 434B-15, respectively, although both species appear higher in the section within the confused interval of Hole 434.

The abundances of *Coscinodiscus marginatus* are recorded in Table 2 to show the relation between its abundance and the preservational state of a sample. Samples with only moderate or poor preservation represent most of the *D. kamtschatica* Zone samples, whereas the *D. seminae fossilis*–*D. kamtschatica* Zone generally contains samples with good preservation. Whether this is due to differential diagenesis of the samples because of differing ages or to tectonic forces or differences in the ecological conditions during deposition is not evident.

Probable causes for the repetitions of the diatom zonal assemblages in Hole 434 are limited. The simplest is to explain the occurrences of *D. seminae fossilis* below Sample 434-6, CC as the result of downhole contamination. This conclusion is generally supported by 1) the fact that except for Sample 434-9-1, 70 cm, all assemblage breaks occur at core boundaries; 2) the drilling difficulty and poor core recovery of this section; 3) the last occurrence of *D. seminae fossilis* is at the basal part of Hole 434, and Hole 434B, which was drilled from the sediment surface to 295.5 meters, does not contain any of the younger assemblages. If this conclusion is correct, the basal appearance of *D. seminae fossilis* is at a sub-bottom depth of about 54.0 meters. The total thickness of the *D. seminae fossilis*–*D. kamtschatica* Zone is 20 meters and that of *D. kamtschatica* Zone at about 400 meters.

Another explanation is that repetition of zonal sequence is caused by faulting. Although the general tectonic setting of the area supports this thesis, it is unlikely for so many faults, with as little as 20 meters between them, to occur.

A third cause for the repetitions is slumping — that is, a downslope movement of essentially *D. kamtschatica* zonal sediments during the regular pelagic deposition of *D. seminae fossilis* zonal taxa. This explanation too is supported by the tectonic setting and by the missing Pleistocene section. If it is correct, the *D. seminae fossilis*–*D. kamtschatica* Zone occurs from about 35 meters to 300 meters sub-bottom and the *D. kamtschatica* Zone from 300 to 457 meters sub-bottom.

The last probable explanation is climatic fluctuations during the time range of the *D. seminae fossilis*–*D. kamtschatica* Zone. Hole 434 is located near the high and low latitude diatom provincial boundaries and near the convergence of the northern Oyashio and southern Kuroshio currents. Small changes in the circulation patterns could cause major changes in the diatom assemblages deposited in this area. This explanation would produce the same zonal boundaries as the slumping hypothesis.

Unfortunately, other evidence such as sediment character, sedimentary structures, and foraminifer and radiolarian assemblages have not given conclusive support to any of the foregoing hypotheses. For example, the sediment accumulation rates implied by the downhole contamination and those implied by slumping or climate are quite different (Figure 3).

Site 435

We drilled Holes 435 and 435A on the upper slope of the landward side of the Japan Trench. Figure 4 shows the placement of the diatom datum levels and the zonal assignments. Because I used the shipboard slides for this site, the data are less detailed than for Sites 436 and 434. The sequence of North Pacific zonal markers is the same as that published by Koizumi. Diatoms are abundant and well preserved in all samples except for Sample 435A-11, CC, the lowest sample, which has only moderate preservation. In examining at least one sample per core, I found no occurrence of *Denticula seminae fossilis* or its associated species below Sample 435-13, CC.

TABLE 2
Occurrence of Key Taxa in Lower Part of Hole 434

Sub-bottom Depth (m)	Sample		Distance from Top of Section (cm)	<i>Actinoecius ingens</i>	<i>A. oculatus</i>	<i>Cosmodiscus insignis</i>	<i>Coscinodiscus pustulatus</i>	<i>Cussia tatsunokuchiensis</i>	<i>Denticula hustedtii</i>	<i>D. kamtschatica</i>	<i>D. seminae</i>	<i>D. seminae fossilis</i>	<i>Nitzschia fossilis</i>	<i>N. jouseae</i>	<i>N. reinholdii</i>	<i>Rhizosolenia praeborgonii</i>	<i>Rouxia californica</i>	<i>Stephanopyxis horridus</i>	<i>Thalassiostra antiqua</i>	<i>T. convexa</i>	<i>T. nidulus</i>	<i>T. ostrupii</i>	<i>T. usatchevii + zabelinae</i>	<i>Coscinodiscus marginatus</i>	Preservation	Alternations of <i>Denticula seminae fossilis</i> - <i>D. kamtschatica</i> assemblage and <i>D. kamtschatica</i> assemblage
	Core	Section																								
44.5	5	CC		3	1				1	41			2	2					7		2			G	<i>Denticula seminae fossilis</i> - <i>D. kamtschatica</i>	
54.0	6	CC		-					-	36	15		5	3					2		8			M		
	7	1	20						9				1						1		2	82		P	<i>D. kamtschatica</i>	
	7	2	42						•				•	•	•	•	•	•	•	•	•	•		P		
63.5	7	CC					1		43				3						3	1	3	1	13	M		
	9	1	70	•	•				32		19	•	•	•	•	•	•	•	•	•	•	•	•	G	<i>D. seminae fossilis</i> - <i>D. kamtschatica</i>	
82.5	9	2	4						•															P		
92.0	10	6	15						•															P	<i>D. kamtschatica</i>	
	12	1	70						•										•	•	•	•	•	P		
111.0	12	CC							60				3						2	1	5	11		M		
120.5	13	CC		2					7	31			3	-					3	1	1	11		M	<i>D. seminae fossilis</i> - <i>D. kamtschatica</i>	
130.0	14	CC		-					59				2						-	-	1	6	27	P		<i>D. kamtschatica</i>
	15	1	110						3	16			9	-	1				4	1	-	3		M		
	15	2	60	•	•				1	20			•						•	•	•	•		G		
139.5	15	CC		-	3				4	30			1	-					2					G	<i>D. seminae fossilis</i> - <i>D. kamtschatica</i>	
	16	1	60	•					62	38			•						•	•	•	•	•	G		
149.0	16	CC							10	9			1						1	3	1	20		M		
	17	1	30	•	•				98				•	•					•	•	•	•	•	M	<i>D. kamtschatica</i>	
158.5	17	CC							83				3						1	1	2	8		M		
168.0	18	CC							40	5			2						5	3		8		M		
	19	1	70	•	•				30	10			•						•	•	•	•	•	G	<i>D. seminae fossilis</i> - <i>D. kamtschatica</i>	
177.5	19	2	20	•					27	2			•						•	•	•	•	•	G		
	19	CC		2					36	8			5	1					•	1	1	1	7	G		
	20	1	49						•				•						•	•	•	•	•	P		
	20	2	19		•				•				•						•					P		
187.0	20	CC		-	-				66				4								1	2	7	M		
196.5	21	CC			•				•				•						•	•	•	•		M	<i>D. kamtschatica</i>	
206.0	22	CC							•				•						•					M		
215.5	23	2	130				•		•				•											P		
225.0	24	CC		•					•				•											P		
234.5	25	CC							•				•						•					P		
244.0	26	CC							•				•											P		
	27	1	104	1		1			1	44			1	1					1	1	1	35		M		
253.5	27	CC		1					1	46			5						3		7	28		M		
	28	2	82	•																				P		
263.0	28	CC		•																				P	?	
272.5	29	CC							33	5			4						2	2	-	4	23	G	<i>D. seminae fossilis</i> - <i>D. kamtschatica</i>	
282.0	30	1	50						•															P		<i>D. kamtschatica</i>
291.5	31	1	28	•	•	•			11	17									•	•	•	•		G	<i>D. seminae fossilis</i> - <i>D. kamtschatica</i>	
294.5	32	1	62						•				•											P		<i>D. kamtschatica</i> ?
	33	1	72	•	•				8	2			•						•					P		
	33	2	72	•	•				3	3									•	•	•	•		G	<i>D. seminae fossilis</i> - <i>D. kamtschatica</i>	
301.0	33	CC																						P		

Note: 30 = per cent relative abundance on counted slide, ⑧ = number of specimens on scanned slide, - = <1 per cent relative abundance on counted slide, • = present on scanned slide.

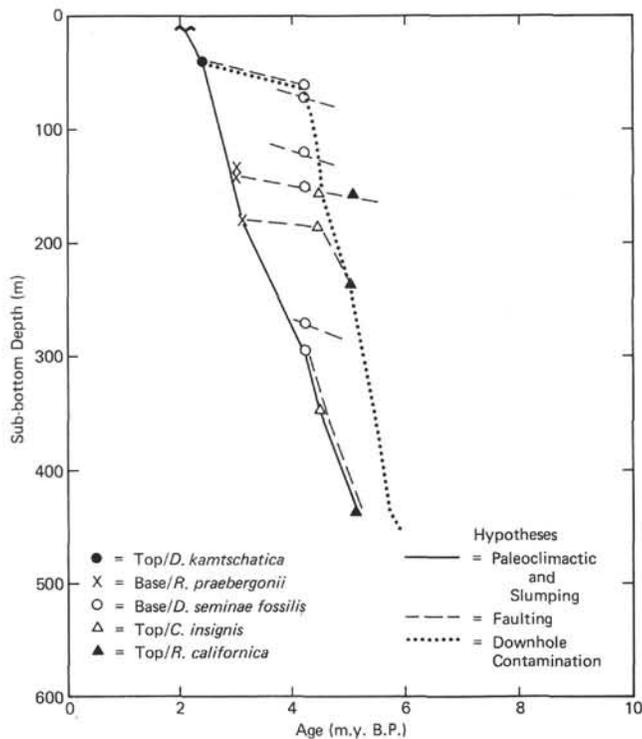


Figure 3. Sediment accumulation rates for Site 434.

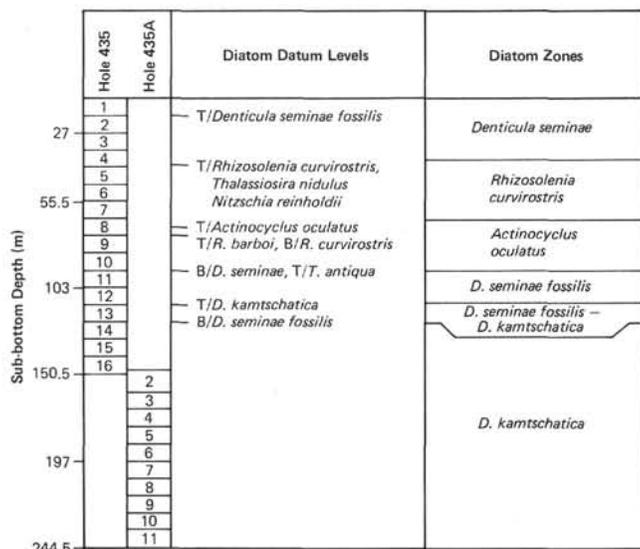


Figure 4. Placement of datum levels at Site 435. (T/ = top occurrence, B/ = base occurrence.)

Site 436

We drilled and continuously cored about 630 meters of siliceous sediment in Hole 436. Table 3 shows the occurrence of key marker taxa in the hole. Reworked specimens are present in most samples, and, going downhole, I placed more reliance on abrupt increase in abundance and on continuous occurrence in closely spaced samples than on presence or absence. From the top of the *Denticula kamtschatica* Zone downhole, I placed the

zonal boundaries based on these criteria. In the lower part of Core 436-27, the diatom preservation becomes poor and abundance is low. I find the identification of the top of the *D. hustedtii* Zone difficult. Based on the first *D. kamtschatica* and the first *Nitzschia fossilis*, I put the top between the Cores 436-28 and 436-29. *D. hustedtii*, *Actinocyclus ingens*, and *Coscinodiscus endoi* all range concurrently from Cores 30 to 35. Some taxa (*Kisseleviella carina*, *Macrora stella*) from the *D. hustedtii*-*D. lauta* Zone are sporadically present in this interval, but *D. lauta* does not appear until Core 36. I recognize a small overlap of the *D. hustedtii* and *D. lauta* in samples from Cores 36 and 37 and place these samples with the *D. hustedtii*-*D. lauta* Zone. Sample 37-5, 50 cm, is probably of middle Miocene age, from near the top of the *D. lauta* Zone. All samples below this level were barren of useful diatom remains, with only a few badly corroded fragments present.

The large amount of reworking of marker taxa in the 320 to 360 meter sub-bottom interval of Hole 436 is probably due to a decreased sedimentation rate, as reflected in the accumulation rate diagram (Figure 5) and in the change in lithology from a radiolarian-diatom mudstone downhole to a pelagic clay. The lack of diatoms in Hole 436 is not the result of silica diagenesis but of a change in diatom primary productivity.

The early Miocene and Paleogene are represented by only a 20-meter section of stiff, chocolate brown, Mn-rich abyssal clay. The hole bottomed in hard chert of Cretaceous age, the same color as the abyssal clays. In conjunction with the lithologic and biostratigraphic data from Sites 303 and 304 of Leg 32, the age of the first Tertiary development of the modern oceanic circulation and productivity pattern of this area of the North Pacific can be deduced. Figure 6 gives the back-traced positions of Sites 303, 304, and 436 based on Lancelot and Larson (1975). This reconstruction places Site 436 about 10° of latitude to the west of 303 and 304; therefore it should enter the high productivity area about 15 m.y. before either of them. Yet at all three sites the oldest Tertiary biogenic sediments are roughly late middle Miocene. This date must represent the first development of a circulation and productivity pattern equivalent to that of today.

SUMMARY

Sites 434, 435, and 436 all represent large accumulations of richly diatomaceous sediments. Site 435, from preliminary examination, has an almost 100-meter-thick continuous record of Pleistocene deposition and presents an excellent opportunity for detailed siliceous biostratigraphy. Site 436 also has an excellent section for detailed late Neogene diatom biostratigraphy. At both of these sites I found the sequence of diatom zonal datums in the same order as previously documented in the literature. Hole 434, however, represents the most interesting of Leg 56 because of the alternation of the assemblages of the *D. seminae fossilis*-*D. kamtschatica* Zone and the *D. kamtschatica* Zone. Further work on this hole is necessary.

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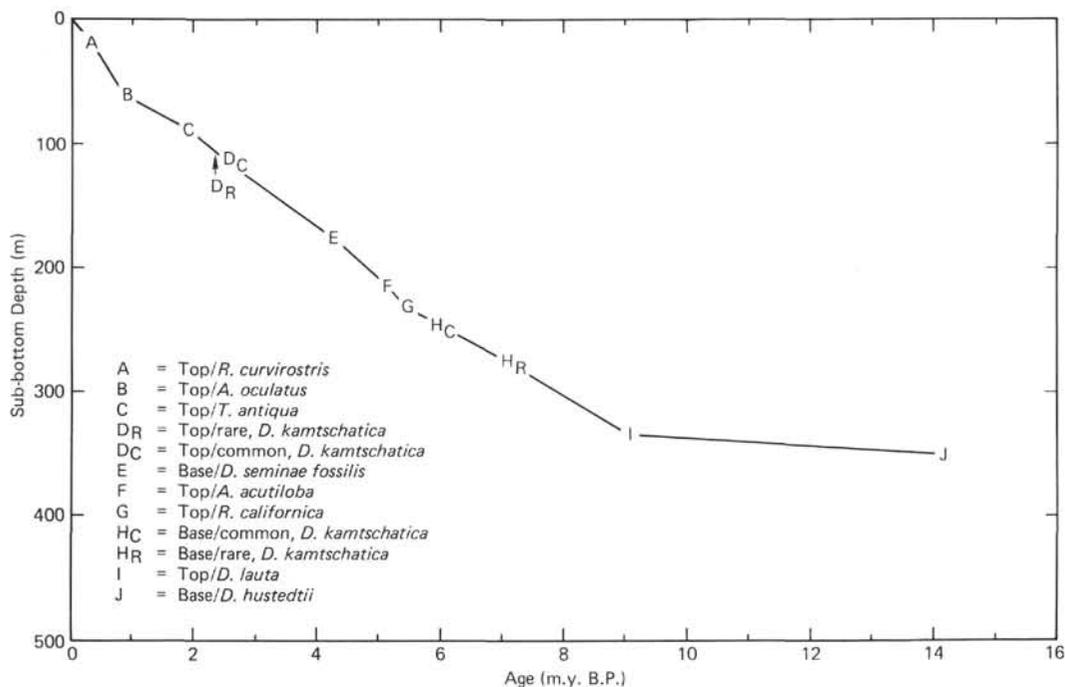


Figure 5. Accumulation rate for Site 436.

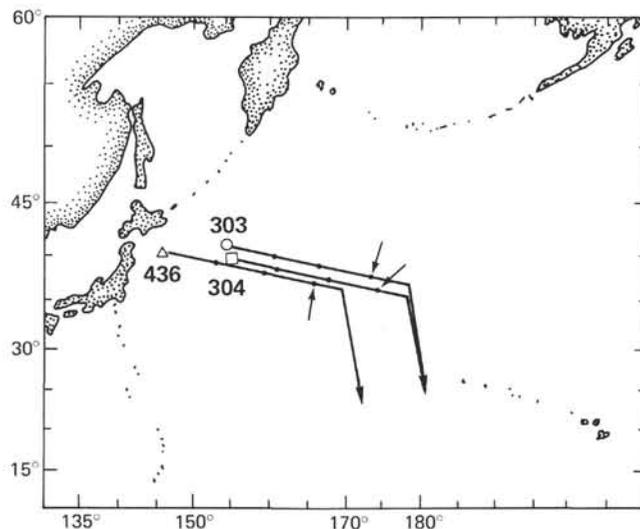


Figure 6. Back-tracked paths of Sites 303, 304, and 436 based on Lancelot and Larson (1975). (Arrows point to position of oldest Tertiary biogenic siliceous sediments.)