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COCCOLITH CORRELATION OF LATE CRETACEOUS POINT LOMA FORMATION AT LA JOLLA AND CARLSBAD, SAN DIEGO COUNTY, CALIFORNIA

BY

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OPEN-FILE REPORT 94-678

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ABSTRACT

Coccolith floras from the Late Cretaceous shale/siltstone outcrops of the San Diego County Point Loma Formation at La Jolla Bay and from trench/roadcut exposures at Carlsbad are assigned to Campanian coccolith Zone CC21, CC22 and to the Campanian or Maestrichtian Subzone CC23a. Key species *Broinsonia parca*, *Calculities obscurus*, *Quadrum trifidum*, *Reinhardtites anthophorus*, and *R. levis* indicate that the Carlsbad strata, associated with the first nodosaurid dinosaur skeleton west of the Rocky Mountains, are slightly older (CC21 and CC22) than the La Jolla sea cliff strata (CC22 and CC23a). Previous paleomagnetic studies from La Jolla strata show the Chron 33n-Chron 32r boundary occurs just above the coccolith CC22 to CC23a boundary, and thus approximates the international Campanian-Maestrichtian stage boundary, as identified by the cephalopod *Belemnella lanceolata* in Europe.

INTRODUCTION

The publication of paleomagnetic stratigraphies for the late Campanian and early Maestrichtian Point Loma Formation at La Jolla and Point Loma (Bannon and others, 1989) and the subsequent drilling of a deep corehole at Point Loma near the type section in 1991 led T. A. Deméré (San Diego Natural History Museum) to recommend the value of establishing a coccolith biostratigraphy for the La Jolla Bay section. To that end, a reconnaissance collection was made with T. A. Deméré and Annika Sanfilippo (Scripps Institution of Oceanography) along the poorly accessible sea cliff exposures at La Jolla Bay in January 1993. Although fossil radiolarians were not found (A. Sanfilippo, written communication, 1993), coccoliths were sufficiently diverse and consistently present to suggest that the Zone CC22 to Zone CC23 boundary event (last *Reinhardtites anthophorus*) occurred in the middle part of the section near the paleomagnetic boundary

between Chron 33 and Chron 32, which had been previously identified there (Bannon and others, 1989). Resampling the middle part of the section was done to detail the coccolith distribution. Because coccoliths are the common direct species link between La Jolla, Point Loma and European type sections, they could assist in correlation of local mollusks, dinosaurs, and global paleomagnetic reversals to standard stages used for transoceanic stratigraphy (Bukry, 1993).

At Carlsbad, in northern San Diego County, four short sections of the Point Loma Formation were examined for coccoliths in 1987 (D. Bukry and S. W. Starratt, unpublished data) to provide late Campanian correlation and dating for the first nodosaurid dinosaur skeleton discovered west of the Rocky Mountains (Deméré, 1988). These studies indicated the lower part of late Campanian Zone CC22 had been sampled. The Carlsbad results are included here to complete a coccolith examination for the Point Loma Formation at three key coastal localities through the county (Figure 1).

METHODS AND MATERIALS

At La Jolla Bay 44 samples were taken along a 686-foot beach traverse from the sea cliff exposures of the Point Loma Formation with bedding dipping 35° SW (Figures 2 and 3). Sampling was directed at non-sandy shale/siltstone units. Two collections were made during very low annual tides of -1.0 and -1.1 feet in January and October of 1993. A January reconnaissance collection at 10 to 30-foot intervals was supplemented by 5 to 10-foot interval collections across the key coccolith and paleomagnetic boundaries in the middle of the traverse. Sampling was done from the base of the shale/siltstone section in the sea cliff (LJ-0) south-southwestward, upsection (Plate 1), and samples were placed in sealed plastic bags to prevent contamination. Measurement was by a graduated 30-foot rope laid along Cobble Beach at the foot of the sea cliff

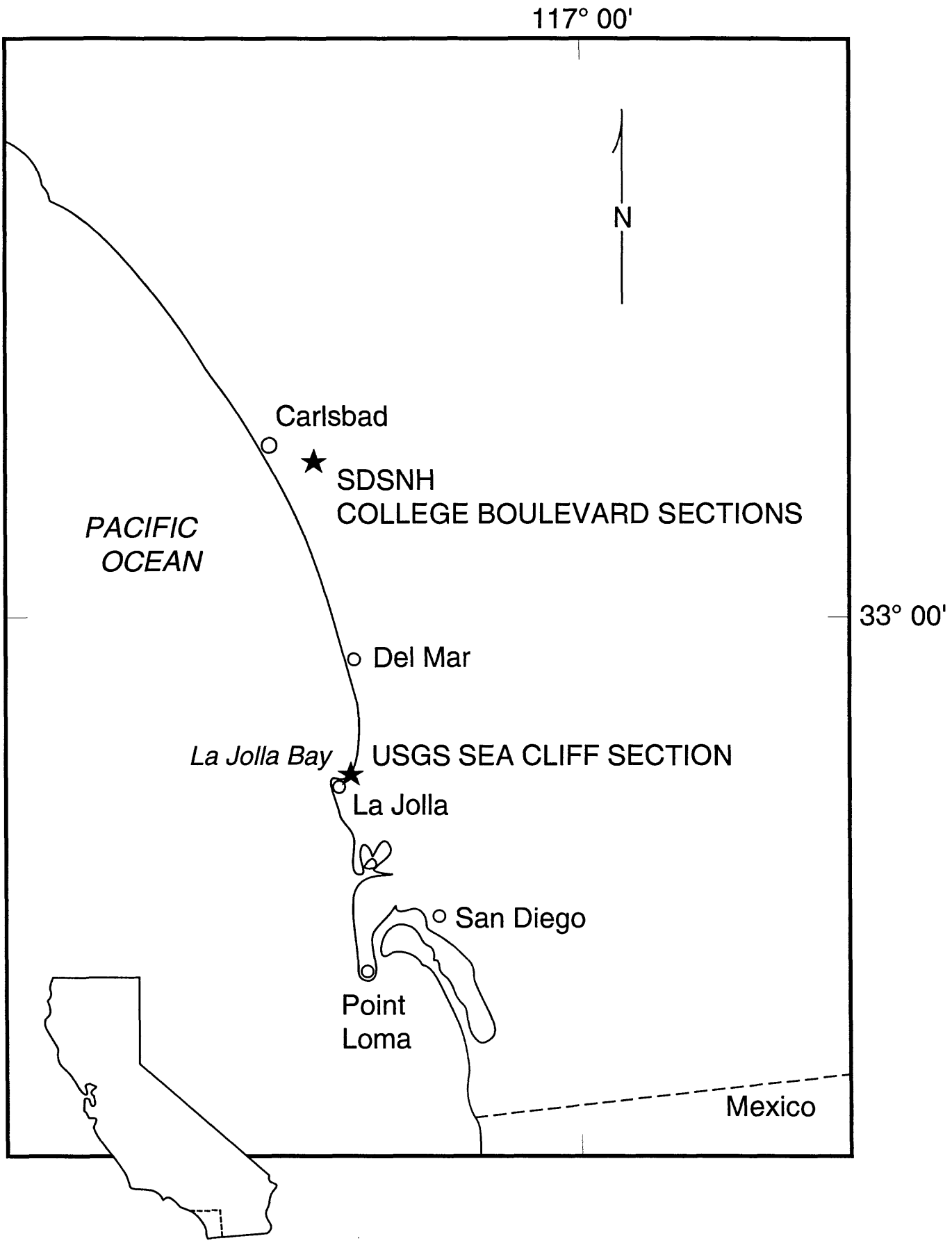


Figure 1. Location of Point Loma Formation sections studied at Carlsbad and La Jolla, San Diego County, California (after Kennedy, 1975).

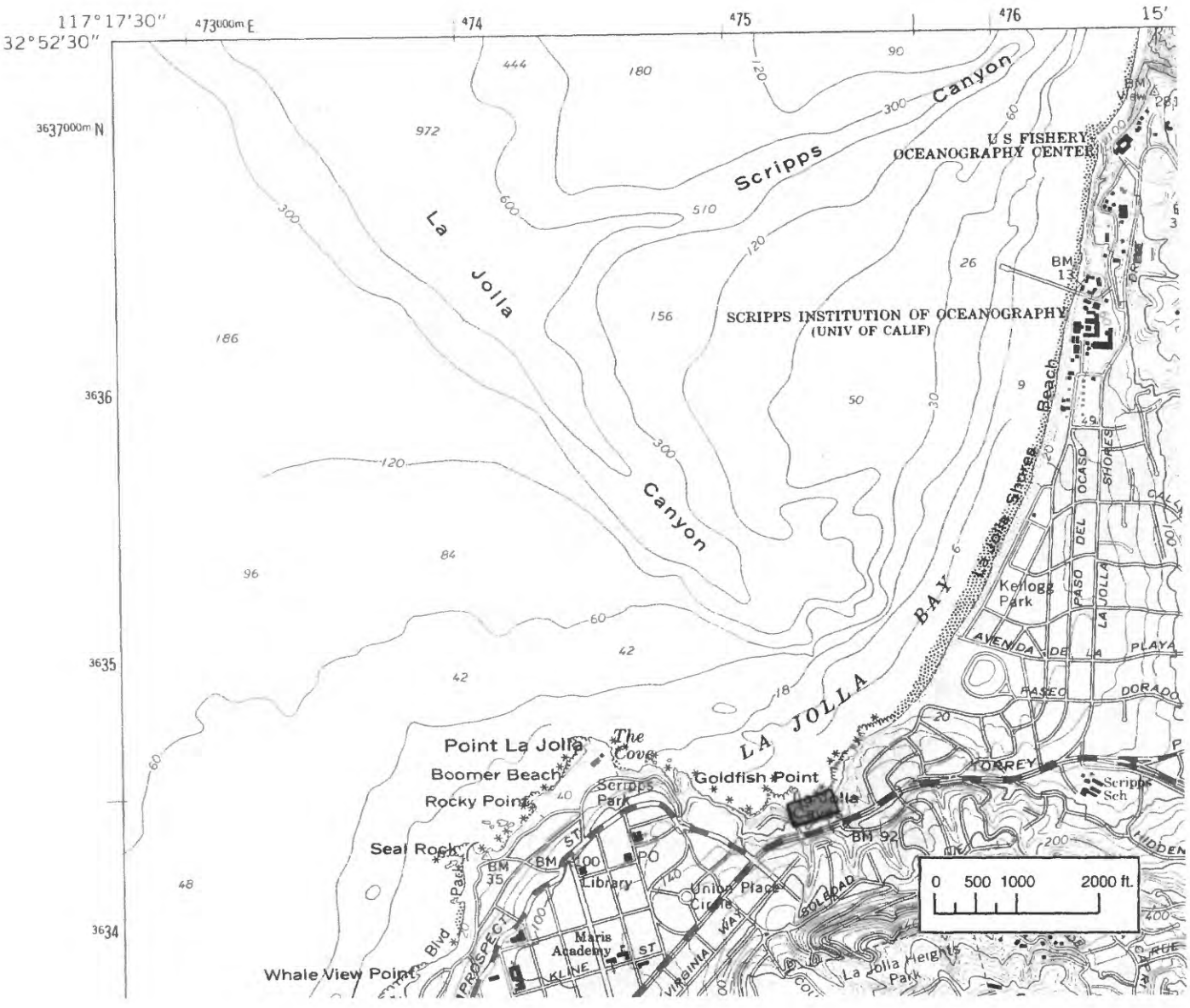


Figure 2. Location of Point Loma Formation section sampled in the seacliff along the southeast side of La Jolla Bay. Rectangle encloses the 686-foot sampling traverse at the foot of the seacliff. The map base is the U. S. Geological Survey La Jolla Quadrangle 7.5 minute topographic series of 1975.

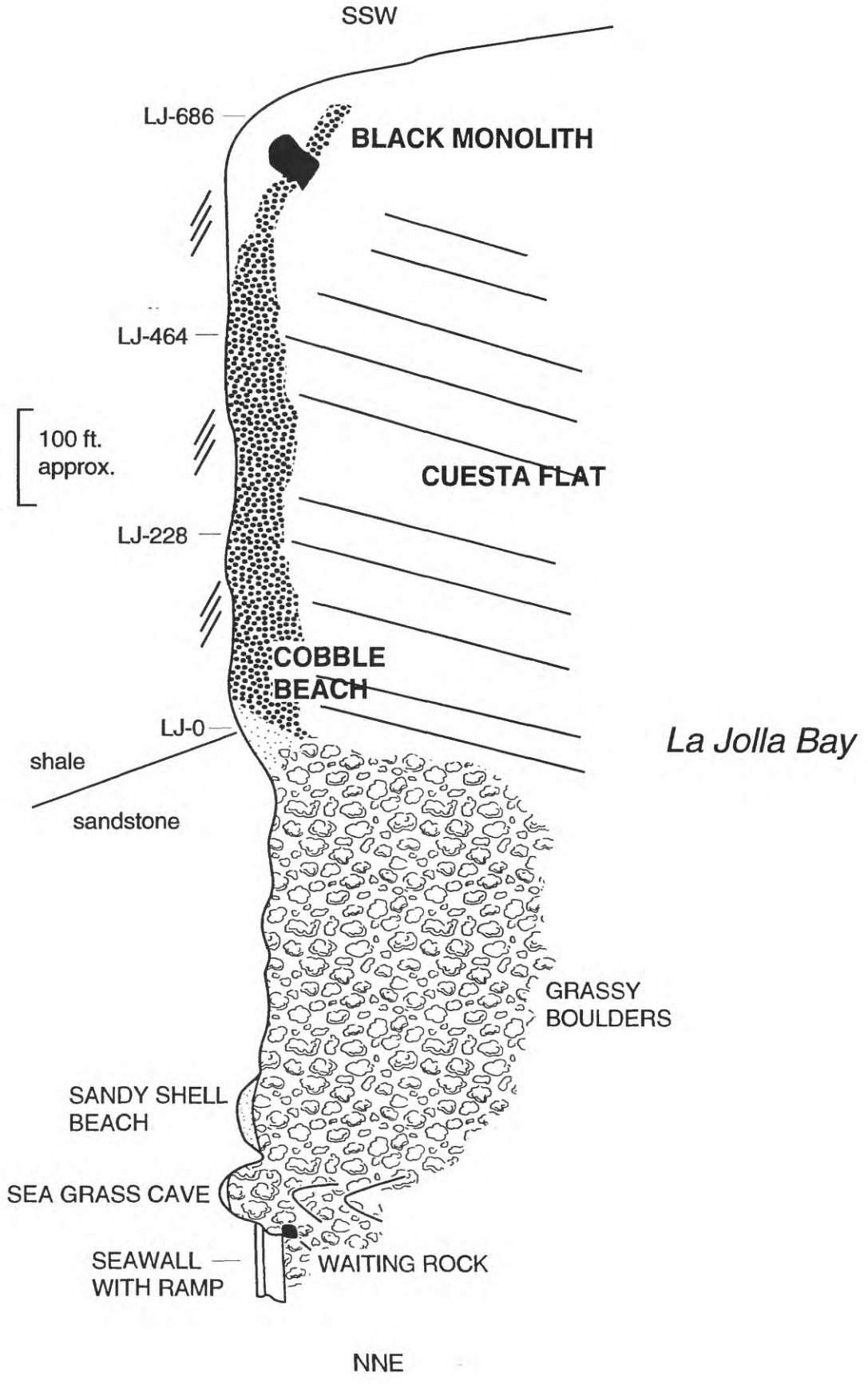


Figure 3. Sketch map of sea cliff and littoral shelf features along the NNE to SSW Point Loma Formation outcrops at La Jolla Bay. Shale bed samples were taken on a traverse from LJ-0 to LJ-686, at very low tides of -1.0 and -1.1 feet.

A.

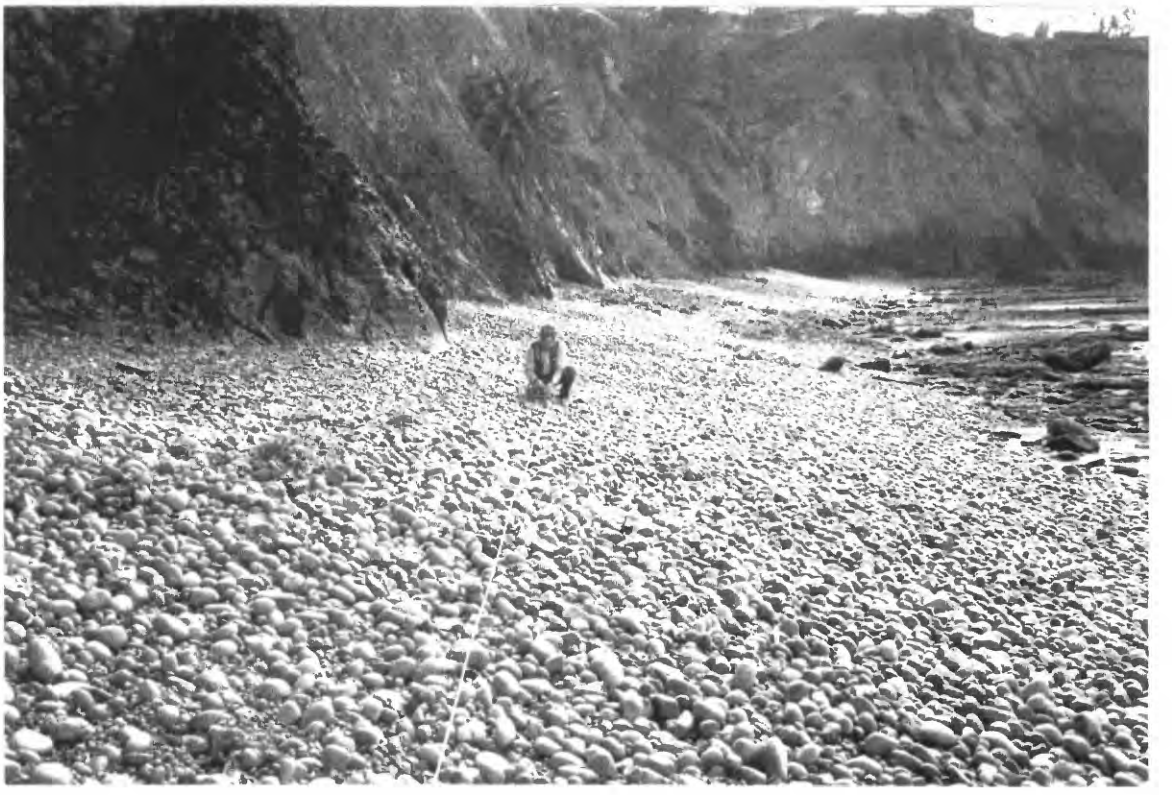
B.

Plate 1. Point Loma Formation sea cliff at La Jolla Bay, 93-10-15. A. Viewed from offshore grassy boulder area. B. Base of sampled traverse. Hand on sample LJ-0 shale bed at top of sandstone unit to left.

(Plate 2). Public access to the section from the north requires very low tides and is then obstructed by grassy boulders from Sea Grass Cave south to Cobble Beach and Cuesta Flat (Figure 3). The flat contains ridges of resistant beds of the Point Loma Formation in a littoral shelf several hundred feet wide (Plate 3).

The Carlsbad samples of the Point Loma Formation were obtained by the San Diego Natural History Museum and provided by T. A. Deméré to aid in dating the nodosaurid dinosaur skeleton discovered at the road cutting and sewer excavation for College Boulevard, just southwest of El Camino Real and north of Palomar Airport (Figure 4). According to T. A. Deméré (written communication, 1988), four sampled sections along College Boulevard "correspond to surveyed section numbers along the roadway; 1 - 98 from west to east. Each station is 100 feet from adjacent stations (i. e. Station 73 is 100 feet east of Station 72). Station 72+85 is 85 feet east of Station 72+00. Station 86 is our site 21 (the nodosaur site)." All four stations are close together. Station 86 is 1400 feet southwest of El Camino Real; Station 86 is 700 feet from Station 79 which is 450 feet from Station 74+50, which is 165 feet from Station 72+85, all along the northern end of College Boulevard. The sampled sections are short, 14 to 54 feet. Each station has a San Diego Society of Natural History (SDSNH) number : Sta. 72+85= SDSNH 3838, Sta. 74+50= SDSNH 3839; Sta. 79= SDSNH 3840; and Sta. 86=SDSNH 3405.

Light microscope smear slides of unprocessed samples were examined at 600X and 1560X magnification in cross-polarized light and bright-field illumination. Checklist occurrences are based on 5 to 20-minute examinations. Coccolith biostratigraphic zonation is based on the synthesis of Perch-Nielsen (1985). Stage and paleomagnetic stratigraphy is based on Sissingh (1977), Bannon and others (1989) and Burnett and others (1992).



A.

B.

Plate 2. La Jolla Bay section. A. Traverse measured along Cobble Beach at foot of sea cliff, looking SSW. Beginning of Cuesta Flat at right.
B. Sample LJ-686 is from the cliff at left of Black Monolith of Point Loma Formation at SW end of traverse.

A.

B.

Plate 3. Cuesta Flat, offshore from the sea cliff shale/sandstone exposures of the Point Loma Formation. Cuesta beds can be traced back to the sea cliff.

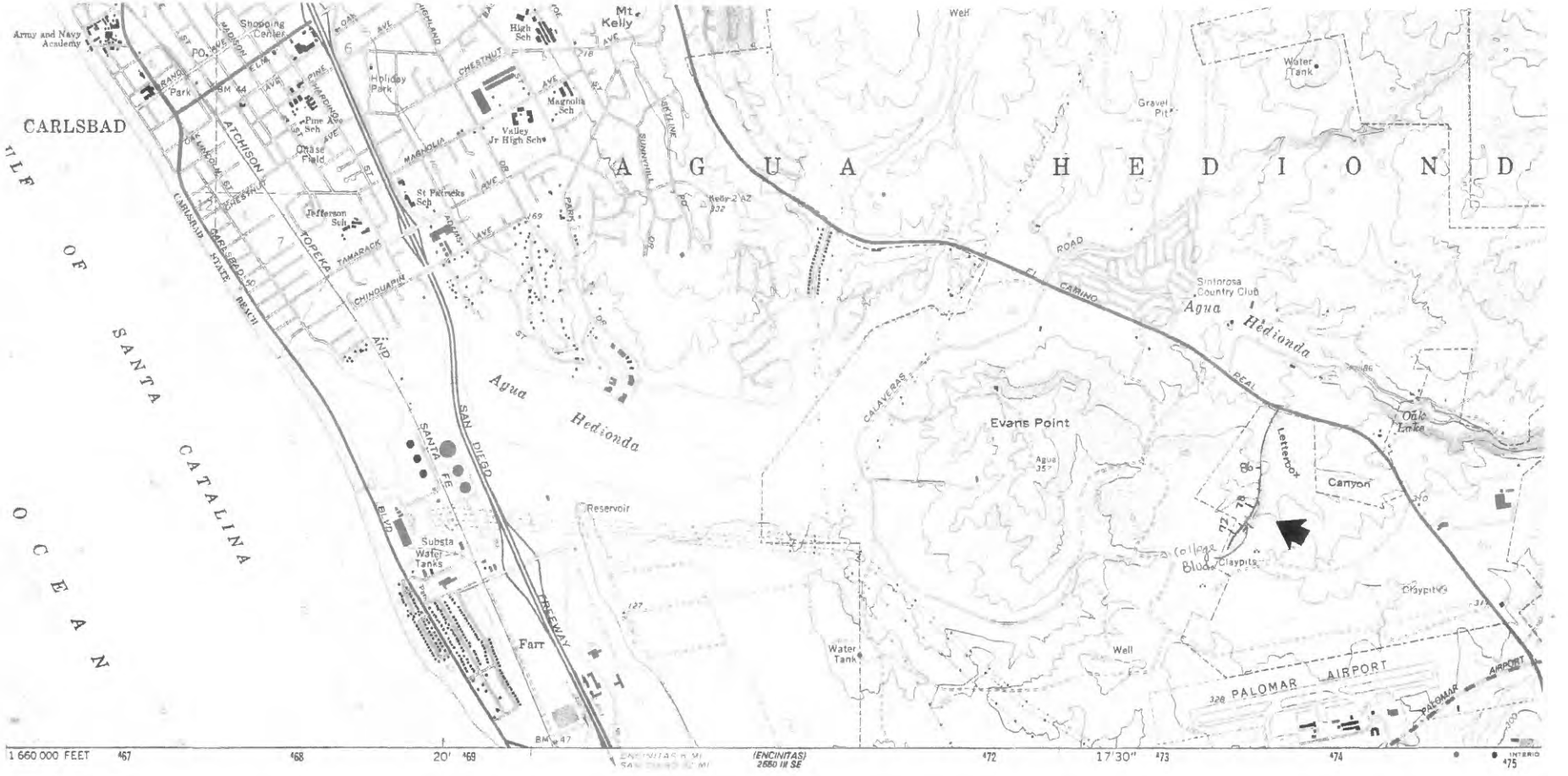


Figure 4. Location of College Boulevard sample stations (now covered by paving and landscaping). Base map is U. S. Geological Survey San Luis Rey Quadrangle 7.5 minute series of 1975.

COCCOLITH RESULTS

At La Jolla Bay coccolith floras are sparse to abundant with only four barren samples among the 44 examined. Most floras show minor to moderate etching and fragmentation. Coccolith zonal identifications of Subzones CC22b and CC23a in the section are based on the occurrence of both *Reinhardtites anthophorus* and *R. levis* in the lower samples LJ-0 to LJ-280. The last occurrence of *R. anthophorus* is used to mark the top of CC22b. *R. levis* occurs through the upper section, LJ-290 to LJ-686, without *R. anthrophorus*. *Quadrum trifidum*, another zonal guide taxon, is consistently present in the upper part of the section, but is intermittent in the lower part of the section (Figure 5). The only specimens of *Calculites obscurus*, a mainly Campanian guide species (Perch-Nielsen, 1985), are in the lower part of the section. *Broinsonia parca*, the guide to the top of Subzone CC23a, is present in the uppermost samples from La Jolla Bay. Together, these occurrences support the identification of the zonal boundary between upper Zone CC22 and lower Zone 23 at the highest *R. anthophorus*.

Carlsbad floras are similar, but are older because of the more consistent occurrence of *Calculites obscurus* and the absence of *Quadrum trifidum* in the lower samples (Stations 79 and 86). The base of CC22 is defined by the first occurrence of *Q. trifidum* in the upper Campanian. The lowest floras at Carlsbad appear to be from shallower water than those at La Jolla because of the presence of *Braarudosphaera bigelowii* and *Lucianorhabdus cayeuxii*.

Although the four sections along College Boulevard are short (14 to 54 feet), the two thickest sections (Stations 79 and 86) probably contain the Zone CC21 to CC22 boundary; it is possibly present at Stations 72+85 and 74+50, but these sections are short and separated from the others by a fault (T. A. Deméré, verbal communication, 1994) (Figures 6, 7, 8 and 9). Unfortunately, establishment of

Age	Zone and Chron		LJ Sample	Abundance	*A. cymbiformis*	*B. parca*	*C. obscurus*	*C. aculeus*	*C. crenulatus*	*C. ehrenbergii*	*E. turriseiffeli*	*M. decoratus*	*M. decussata*	*P. cretacea*	*Q. trifidum*	*Q. sissinghii*	*R. anthophorus*	*R. levis*	*W. barnesae*	*Zygodiscus spp.*
MAESTRICHTIAN	CC23a	32n	686	C	√	√		√	√				√		√	√		√	√	√
		32r	654	A	√	√					√		√	√	√			√	√	√
			629	C	√	√					√		√		√			√	√	
			598	A	√	√			√	√	√		√		√				√	√
			565	R		√							√		√				√	
			541	A	√	?		√			√		√		√	√		√	√	
			516	A	√	√		√		√			√		√	√		√	√	
			492	A				√	√	√	√		√		√		?	√	√	
			464	R	√			√			√		√						√	√
			440	A	√	√		√	√	√	√	√		√	√		?	√	√	
			417	A	√	√							√	√	√	√			√	
			391	A	√	√							√		√	√		√	√	
			380	F		√		√					√		√	√		√	√	
			369	C	√	√							√		√				√	√
			360	C	√	√				√			√		√	√		√	√	
CAMPANIAN			350	R	√	√							√		√	√			√	
			344	F	√	√		√					√		√				√	
			335	R	√								√		√				√	
			325	C	√	√		√	√	√			√		√			√	√	√
			319	R	√								√		√	√			√	√
			305	F									√		√	√			√	
			290	F	√	√			√		√		√		√	√		√		√
			285	F	√	√		√		√		√	√		√	√			√	
	CC22b	33n	280	A	√	√		√	√		√		√		√		√		√	√
			275	F	√	√		√							√		√		√	
			270	R		√			√				√		√				√	
			265	A	√	√		√	√	√	√	√	√		√	√		√	√	√
			258	A	√	√		√	√	√	√				√	√	√	√	√	√
			228	B																
			205	C	√	√		√		√		√	√		√	√		√	√	√
			185	F	√	√		√	√	√	√	√	√	√	√	√		√	√	√
			165	A	√	√		√		√	√	√	√	√	√		√		√	√
			145	B																
			125	B																
			115	R	√	√						√	√		√	√	√		√	
			105	F	√	√				√	√	√	√	√	√	√	√	√	√	√
			95	F	√				√	√	√	√	√		√		√	√	√	√
			85	B																
			75	R		√		√		√	√	√	√	√		√		√		√
			65	F		√	√		√	√		√	√				√	√		√
			55	F		√		√		√	√		√	√	√	√		√	√	
			45	F	√	√		√	√	√	√	√	√					?		√
			35	C	√		√		√	√	√	√		√			√	√	√	√
			0	F	√	√		√	√	√	√	√	√	√			√	√	√	√

FIGURE 5. Checklist of selected coccoliths in La Jolla Bay section. Zonation from Perch-Nielsen (1985). Paleomagnetic chrons from Bannon and others (1989). Abundance after Bukry (1993).

Carlsbad 72 + 85	Zone	CC 21					CC 22					
Taxa	Sample (ft.)	226	228	229	230	231	233	234	235	238	245	250
Arkhangelskiella cymbiformis			√	√	√		√	√		√		√
Broinsonia sp.												√
Calculites obscurus											√	
C. ovalis				√								
Ceratolithoides aculeus			√	√		√		√		√		√
Chiastozygus amphipons					√			√				√
Coronocyclus sp.												√
Cretarhabdus crenulatus		√	√	√					√		√	
C. schizobrachiatus							√					
Cribrosphaera ehrenbergii		√		√		√	√	√	√	√	√	√
Eiffellithus turriseiffeli		√	√	√	√	√	√	√		√	√	√
Gartnerago concavum				√	√							
Microrhabdulus sp.						√			√		√	
Micula decussata		√	√	√	√	√	√	√	√	√	√	√
Parhabdolithus angustus												√
P. sp.				√	√				√			
Prediscosphaera cretacea cretacea		√	√	√	√	√	√		√	√	√	√
P. cretacea (large, 12 µm)								√				√
Quadrum sissinghii			√	√			√					
Q. trifidum							√		√	√	√	√
Reinhardtites anthophorus		√						√	√		√	√
R. levis			√		√	√		√			√	
Vagalapilla octoradiata								√				
V. stradneri								√				√
Watznaueria barnesae			√	√	√		√	√	√	√	√	
Zygodiscus bicrescenticus				√	√	√	√		√	√	√	
Z. deflandrei		√			√							√
Z. sp.					√		√			√	√	

FIGURE 6. Checklist of selected coccoliths in College Boulevard Station 72 + 85 at Carlsbad. Sample numbers are elevation above sea level. Coccolith zonation (CC 21 and CC 22), here and in following figures, is from Perch-Nielsen (1985).

Carlsbad 74 + 50	Zone	CC 21			CC 22						
Taxa	Sample (ft.)	230	231	233	234	235	237	239	240	243	250
Arkhangelskiella cymbiformis		√	√	√	√		√			√	
Broinsonia parca					√						
Ceratolithoides aculeus		√	√	√	√			√		√	√
Chiastozygus amphipons						√	√				
C. sp.		√				√					√
Coronocyclus sp.				√	√						
Cribrosphaera ehrenbergii		√	√	√	√	√	√			√	√
Cretarhabdus conicus											√
C. crenulatus		√	√	√	√		√	√	√		
Eiffellithus turriseiffeli		√	√	√	√	√	√	√	√	√	√
Gartnerago concavum				√		√		√			
Lithastrinus grillii				√	√						
Lucianorhabdus cayeuxii		√									√
Manivitella pemmatoidea									√		
Microrhabdulus sp.		√	√	√	√	√	√				√
Micula decussata		√	√	√	√	√	√		√		√
Parhabdolithus embergeri						√					
P. granulatus											√
Prediscosphaera cretacea cretacea			√	√	√	√	√	√		√	
P. cretacea (large, 12 µm)		√			√						
P. spinosa											√
Quadrum sissinghii				√							
Q. trifidum					√		√			√	√
Reinhardtites anthophorus		√				√	√	√			√
R. levis			√	√	√					√	
Vagalapilla sp.			√								
Watznaueria barnesae		√	√	√	√	√			√	√	√
W. biporta		√									
Zygodiscus bicrescenticus		√	√	√	√	√	√	√		√	
Z. deflandrei											√
Z. sp.					√	√			√		

FIGURE 7. Checklist of selected coccoliths in College Boulevard Station 74 + 50 at Carlsbad. Sample numbers are elevation above sea level.

Carlsbad 79 — Zone	CC 21			CC 22													
Taxa — Sample (ft.)	192	193	194	195	196	198	201	202	205	207	208	209	215	216	217	218	219
Arkhangelskiella cymbiformis	√	√				√	√	√	√			√	√	√		√	
Braarudosphaera bigelowii							√					√					
Broinsonia parca		√	√						√		√	√			√		
Calculites obscurus	√						√	√	√		√	√					√
Ceratolithoides aculeus	√				√	√	√	√		√	√		√	√		√	
Chiastozygus amphipons	√			√	√		√	√		√							√
Chiastozygus sp.																	√
Coronocyclus sp.																√	
Cretarhabdus conicus																	√
C. crenulatus					√	√	√		√	√		√				√	
Cribrosphaera ehrenbergii	√	√		√	√		√	√	√	√	√	√	√	√	√	√	√
Eiffellithus turriseiffeli	√	√	√			√	√	√	√	√	√	√	√	√	√	√	√
Gartnerago concavum													√		√		√
Lucianorhabdus cayeuxii	√								√	√		√					
L. maleformis	√																
Microrhabdulus sp.													√				√
Micula decussata	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√	√
Parhabdolithus sp.	√	√								√							
Prediscosphaera cretacea cretacea	√				√	√	√	√	√			√	√		√	√	√
P. cretacea (large, 12 µm)						√			√		√		√	√			
P. spinosa			√														
Quadrum sissinghii		√				√									√		
Q. trifidum				√		√		√		√	√	√					√
Reinhardtites anthophorus	√	√	√	√			√	√	√	√		√		√	√		√
R. levis					√	√				√	√	√	√	√			
Tetrapodorhadbus decorus						√											
Vagalapilla stradneri				√					√					√	√	√	√
Watznaueria barnesae	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√
Zygodiscus bicrescenticus			√				√		√	√				√	√		
Z. deflandrei	√									√		√					√
Z. spiralis	√		√						√								
Z. sp.			√		√					√	√	√	√				

FIGURE 8. Checklist of selected coccoliths in College Boulevard Station 79 at Carlsbad. Sample numbers are elevation above sea level.

Carlsbad 86 Zone	CC 21							CC 22																						
Taxa Sample (ft.)	156	7	8	9	160	1	2	3	4	5	6	7	8	9	170	1	2	3	4	5	6	7	8	9	180	1	2
Arkhangelskiella cymbiformis	√	√	√	√	√	√	√	√	√	√	√		√	√		√	√	√	√	√	√	√	√	√	√	√	√
Braarudosphaera bigelowii	√				√																						
Broinsonia parca		√	√		√	√	√					√	√	√	√				√		√	√	√	√	√	√	√
Calculites obscurus	√	√	√		√	√	√	√			√	√		√		√					√				√		√
Ceratolithoides aculeus		√	√	√		√	√	√	√	√		√				√			√	√	√	√	√	√	√	√	√
Chiastozygus amphipons		√		√			√		√	√										√		√		√			√
Coronocyclus sp.				√																						√	√
Cretarhabdus conicus							√													√							
C. crenulatus	√	√	√	√		√														√		√	√	√		√	
Cribrosphaera ehrenbergii	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Eiffellithus turriseiffeli	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√		√	√	√	√	√	√	√	√	√
Gartnerago concavum																				√							√
Lucianorhabdus cayeuxii	√		√		√		√																				
L. maleformis				√																							
Microrhabdulus decoratus	√		√	√	√	√		√	√	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√	√
Micula decussata	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Parhabdolithus embergeri	√						√											√			√			√	√		√
Prediscosphaera cretacea cretacea	√	√		√	√	√	√		√	√						√	√				√	√	√	√	√	√	√
P. cretacea (large, 12 µm)				√	√	√							√							√		√		√			√
Quadrum sissinghii	√	√		√	√	√	√	√			√	√											√	√		√	
Q. trifidum								√	√					√		√				√						√	√
Reinhardtites anthophorus	√	√		√		√	√	√	√	√		√		√	√		√		√	√	√	√	√	√	√	√	
R. levis					√	√				√	√			√		√		√			√	√		√	√	√	√
Tetrapodorhadbus decorus						√					√											√		√	√		√
Vagalapilla stradneri	√		√	√	√		√			√		√	√	√				√	√		√	√			√		√
Watznaueria barnesae	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Zygodiscus bicrescenticus																√	√			√		√		√	√	√	√
Z. deflandrei							√								√												
Z. spiralis	√		√								√	√										√		√			√
Z. sp.		√	√							√						√				√	√						

FIGURE 9. Checklist of selected coccoliths in College Boulevard Station 86 at Carlsbad. The nodosaurid dinosaur skeleton displayed at the San Diego Natural History Museum was excavated from the 163-foot level (T. A. Deméré, 1988, and written communication, 1987) associated with the first *Quadrum trifidum* (Zone CC 22). Sample numbers are elevation above sea level.

the first *Q. trifidum* in the lower Point Loma Formation is hindered by the spotty occurrence of the species in the lower part of the range at La Jolla Bay, Point Loma and Carlsbad. Therefore, the older and shallower-water Stations 86 and 79 at Carlsbad with *B. bigelowii*, *C. obscurus*, *L. cayeuxi* and *L. maleformis* are considered to contain the basal occurrence of *Q. trifidum*. The lower 3 to 5 feet at the other two stations could lack *Q. trifidum* because of low frequency at the lower part of the range.

Another noteworthy coccolith result at Carlsbad is the early occurrence of *Reinhardtites levis* in the samples assigned to Zone CC21 at Stations 72+85, 74+50, and 86, and in lower Zone CC22 at Station 79. The standard Late Cretaceous zonal system has used the *R. levis* first occurrence event to divide the late Campanian Zone CC22 into a lower Subzone CC22a and an upper Subzone CC22b (Perch-Nielsen, 1985). The earlier appearance of *R. levis* in San Diego strata could indicate latitudinal variation in the event. A similar early appearance for *R. levis* has been identified in Tethyan deposits in Israel by Y. Eshet and S. Moshkovitz (written communication, 1994). They report *R. levis* present as early as the *Quadrum sissinghii* Zone (CC21) at two locations, and present throughout the *Q. trifidum* Zone (CC22) -- not just limited to the upper CC22. Therefore, subdivision of CC22 by *R. levis* may not be consistently effective for middle latitude floras like those in San Diego and Israel. These results indicate that more study of correlations using *R. levis* is desirable.

CORRELATION

The long section of the Point Loma Formation exposed at La Jolla Bay contains the upper boundary of the late Campanian Zone CC22 (last *Reinhardtites anthophorus*). The best Carlsbad section of the Point Loma Formation, at Station 86, contains the lower boundary of Zone CC22 (first

Quadrum trifidum). The local distribution of *Calculites obscurus* throughout Station 86 and only in the lower part of the La Jolla Bay section, together with the spottiness of *Q. trifidum*, indicates that the Carlsbad section could correlate to the older part of the La Jolla section, but is probably an older part of CC22 at the CC21 boundary.

Paleomagnetic results that are available for the La Jolla Bay section (Bannon and others, 1989) show the Chron 33 to Chron 32 boundary was determined to be just above the Zone CC22-CC23 boundary of this report (Figure 5). A new age assignment for the top of Chron 33 of 73.619 Ma by Cande and Kent (unpublished data, 1993) represents only a slight reduction from the 74.2 Ma estimate used for previous Point Loma Formation dating (Kent and Gradstein, 1985; Bukry, 1993). Correlation between paleomagnetic chronology and coccolith zonation for La Jolla Bay supports the results reported from the deep corehole near the type section on Point Loma (Bukry, 1993) where Chron 33 was recorded up into Subzone CC23a. This matches the identification of CC23a associated with the uppermost part of the Campanian Stage from Europe based on the cephalopod *Belemnella lanceolata* boundary in standard sections (Burnett and others, 1992). Most of the Point Loma Formation (samples 103 to 597.3 of Bukry, 1993) belongs to the upper part of CC22, as shown by the consistent occurrence of *Q. trifidum* and the lack of *C. obscurus*. The local and long-range correlations of the Point Loma Formation using these coccolith results and paleomagnetic determinations help to date the nodosaurid skeleton from Carlsbad as latest Campanian.

CONCLUSION

Coccolith correlation for the Point Loma Formation shows the Carlsbad strata at College Boulevard, associated with a rare nodosaurid skeleton, to be late Campanian (Zones CC21 and CC22) and slightly older than the strata at La Jolla and Point Loma which contain CC22 and CC23. The coccolith results from La Jolla and Carlsbad combined with those for Point Loma indicate that most of the Point Loma Formation is within late Campanian Zone CC22, with the upper part of the formation at La Jolla and Point Loma in CC23a and the lower part at Carlsbad in CC21 (or possibly basal CC22).

The relative ranges of *Reinhardtites levis* and *Quadrum trifidum*, used for standard coccolith zonation, appear locally inconsistent. This makes the division of CC22 into CC22a and CC22b at the first occurrence of *R. levis* above first *Q. trifidum* not possible at the older Carlsbad stations. The occurrence pattern of *Q. trifidum* also shows some variability in San Diego County, since it is very consistently present in the upper parts of the formation at La Jolla and Point Loma, but more sporadic (less frequent) in the lower part of the sections at La Jolla and Carlsbad.

A conjunction of diverse marine and terrestrial fossil groups in the Point Loma Formation of San Diego County makes the strata potentially useful for local and regional correlation (Deméré, 1988; Bannon and others, 1989). The presence of transoceanic planktonic coccolith zonal fossils, shown by this survey, will permit direct correlation by species to standard marine sections in Europe. Combined with the paleomagnetic results, the paleontology of the Point Loma Formation can be developed into an important standard reference for correlation at the Campanian-Maestrichtian boundary.

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List of Coccolith Taxa Considered

Arkhangelskiella cymbiformis Vekshina

Braarudosphaera bigelowii (Gran and Braarud)

Broinsonia parca (Stradner)

Calculites obscurus (Deflandre)

C. ovalis (Stradner)

Ceratolithoides aculeus (Stradner)

Chiastozygus amphipons (Bramlette and Martini)

Cretarhadbus conicus Bramlette and Martini

C. crenulatus (Bramlette and Martini)

C. schizobrachiatus (Gartner)

Cribrosphaera ehrenbergii Arkhangelsky

Eiffellithus turriseiffeli (Deflandre)

Gartnerago concavum (Gartner)

Kamptnerius magnificus Deflandre

Lithastrinus grillii Stradner

Lucianorhabdus cayeuxii Deflandre

L. maleformis Reinhardt

Mannivitella pemmatoidea Deflandre

Microhabdulus angustus Stradner

Micula decussata Vekshina

Parhabdolithus angustus (Stradner)

P. embergeri (Noël)

P. granulatus Stover

Prediscosphaera cretacea (Arkhangelsky)

P. spinosa (Bramlette and Martini)

Quadrum gartneri Prins and Perch-Nielsen

Q. sissinghii Perch-Nielsen

Q. trifidum (Stradner)

Reinhardtites anthophorus (Deflandre)

R. levis Prins and Sissingh

Tetrapodorhabdus decorus (Deflandre)

Tranolithus phacelosus Stover

Vagalapilla octoradiata (Gorka)

V. stradneri (Rood, Hay and Barnard)

Watznaueria barnesae (Black)

W. biporta Bukry

Zygodiscus bicrescenticus (Stover)

Z. deflandrei Bukry

Z. spiralis Bramlette and Martini

References

Bannon, J. L., Bottjer, D. J., Lund, S. P. and Saul, L. R., 1989, Campanian/Maestrichtian stage boundary in southern California: Resolution and implications for large-scale depositional patterns: Geology, v. 17, p. 80-83.

Bukry, D., 1993, Cretaceous coccolith correlation for Point Loma Formation outfall test well, San Diego, California: U. S. Geological Survey Open-File Report 93-567, 14 p.

Burnett, J. A., Hancock, J. M., Kennedy, W. J., and Lord, A. R., 1992, Macrofossil, planktonic foraminiferal and nannofossil zonation at the Campanian/Maestrichtian boundary: Newsletters of Stratigraphy, v. 27, p. 157-172.

Deméré, T. A., 1988, An armoured dinosaur from Carlsbad: Environment Southwest, n. 539, p. 12-15.

Kennedy, M. P., 1975, Geology of the San Diego metropolitan area, California: California Division of Mines and Geology Bulletin 200, 56p.

Kent, D. V., and Gradstein, F. M., 1985, A Cretaceous and Jurassic geochronology: Geological Society of America Bulletin, v. 96, p. 1419-1427.

Perch-Nielsen, K., 1985, Mesozoic calcareous nannofossils, in Bolli, H. M., and others (editors), Plankton Stratigraphy: Cambridge, Cambridge University Press, p. 329-426.

Sissingh, W., 1977, Biostratigraphy of Cretaceous calcareous nannoplankton: Geologie en Mijnbouw, v. 56, p. 37-65.