

23. LOWER CRETACEOUS NANNOFOSSIL BIOSTRATIGRAPHY OF ODP LEG 113 HOLES 692B AND 693A, CONTINENTAL SLOPE OFF EAST ANTARCTICA, WEDDELL SEA¹

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ABSTRACT

Organic-rich, moderately to sparsely nannofossiliferous Lower Cretaceous claystones ("black shales") were cored at two Ocean Drilling Program Leg 113 sites on the continental slope of East Antarctica off Dronning Maud Land. A 39 m section at Site 692 yielded a Neocomian assemblage of limited diversity with rare *Cyclagelosphaera deflandrei*, *Didorhombus rectus*, and *Crucellipsis cuvillieri*, and is probably Valanginian in age. A 70-m section at Site 693 is assigned to the *Rhagodiscus angustus* Zone (late Aptian–early Albian in age). The latter zone is represented at DSDP sites on the Falkland Plateau, but equivalents to the Neocomian section are absent there, probably due to a disconformity. *Watznaueria barnesae* is the dominant species at both ODP sites, but it shares dominance with *Repagulum parvidentatum* at Site 693, where they total 70%–90% of the assemblage; their dominance is attributed to a paleogeographic setting within a restricted basin rather than to postdepositional dissolution of other species. The evolutionary development of this restricted basin and its eventual ventilation in early Albian times is discussed in terms of the regional stratigraphy and the breakup and dispersal of southwestern Gondwanaland. One new species, *Corolithion covingtonii*, is described.

INTRODUCTION

A major but totally unexpected discovery during ODP Leg 113 was the recovery of organic-rich Lower Cretaceous "black shales" on the continental slope of East Antarctica at Sites 692 and 693 (Fig. 1). The principal goal of drilling Sites 691 and 692 was to decipher the Cenozoic history of glacial climates, with a secondary aim of dating the seaward-dipping basement reflectors of the "Explora Wedge" in the vicinity of Wegener Canyon off Dronning Maud Land (Fig. 2). At Site 692, however, 40 m of Lower Cretaceous (probably Valanginian) carbonaceous (or sapropelic) claystones (lithostratigraphic Unit III) was penetrated beneath a cover of only 52 m of coarse Neogene glacio-marine sediments (Fig. 3). These generally massive, often laminated claystones exhibit moderate to no bioturbation and have an exceptionally high total organic carbon content (TOC averaged 8.6%, maximum 18.41%; Shipboard Scientific Party, 1988a, table 7). The organic matter was largely derived from phytoplankton sources and was deposited under anaerobic to dysaerobic bottom conditions (Mohr, this volume, chapter 29; Thompson and Dow, this volume). The kerogens are Type II hydrocarbons with a low oxygen index, thus the unit is considered to be a petroleum source rock of high quality (Thompson and Dow, this volume). Hole conditions at Site 692, however, were relatively unstable, drilling was difficult, and the site was abandoned. After relocation upslope from the axis of the canyon, Site 693 was cored through 397.8 m of Holocene to lower Oligocene sediment before a lower Albian radiolarian diatomite (lithostratigraphic Unit VI) and another organic-rich Lower Cretaceous (upper Aptian–lower Albian) claystone (lithostratigraphic Unit VII) were encountered beneath a disconformity (Fig. 4). The TOC of these Unit VII claystones averaged 2.56% (Shipboard Scientific Party, 1988b), and although largely algal-derived, the low Rock-Eval hydrocarbon responses of this immature kerogen (an oxidized Type II hydrocarbon) indicate deposi-

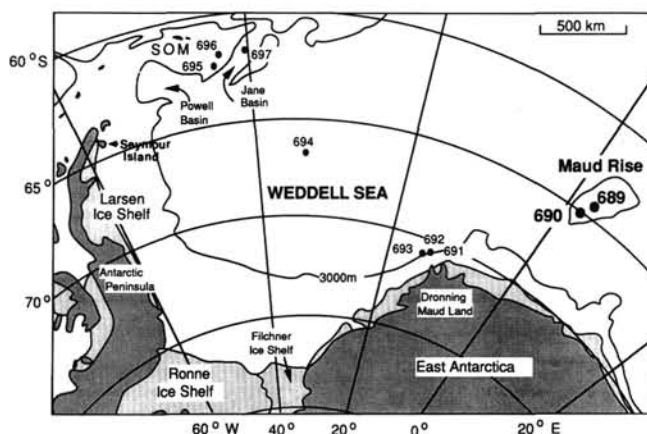


Figure 1. Location of ODP Sites 692 and 693 in relation to other Leg 113 sites. SOM = South Orkney microcontinent.

tion in an environment with relatively more oxygenated bottom waters than for the Cretaceous material at Site 692 (Thompson and Dow, this volume).

Seismic stratigraphic correlations suggest that nearly 450 m of Lower Cretaceous sediments lie between the Albian-Aptian and Valanginian intervals sampled in the two holes; most of the sequence was probably deposited under similar, intermittently anoxic conditions (Shipboard Scientific Party, 1988b), becoming, however, more oxygenated toward the top (Thompson, pers. comm., 1989). Analyses of benthic foraminiferal assemblages from the two sites suggest deposition at water depths of about 500 m (Shipboard Scientific Party, 1988a, b; Thomas, this volume), and the low percentage of organic terrestrial debris places the sites well offshore (≥ 100 km; Mohr, this volume, chapter 29).

We have examined the Cretaceous calcareous nannofossils sampled at Sites 692 and 693 to help determine the ages of these sequences and their paleoenvironments of deposition. Next we compare the assemblages with others recovered in this part of the world, particularly from the Falkland Plateau, and we conclude with a discussion of the timing of the cessation of restricted depositional conditions within the Weddell Sea region.

¹ Barker, P. F., Kennett, J. P., et al., 1990. *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program).

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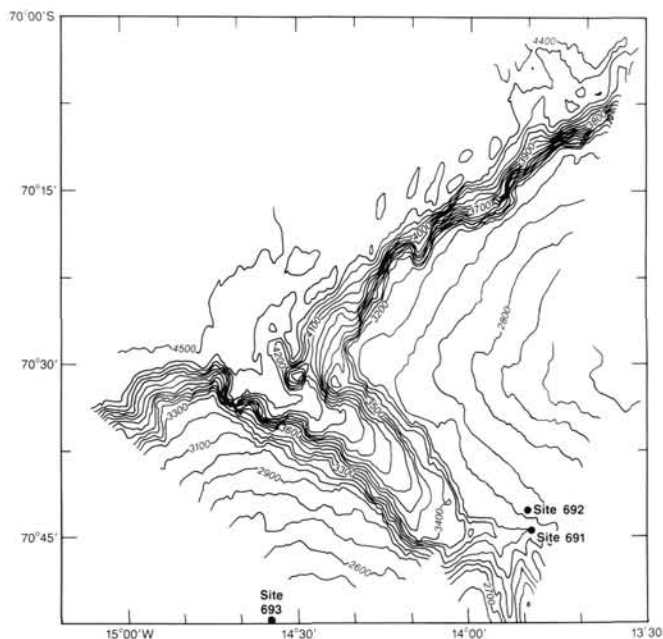


Figure 2. Sea Beam bathymetric map of Wegener Canyon on Dronning Maud Land (DML) margin showing the locations of Sites 691, 692, and 693. Contours in uncorrected meters; contour interval is 100 m (from Shipboard Scientific Party, 1988b, fig. 1).

METHODS

Simple smear slide preparations were examined under the light microscope. For each sample at least 300 specimens or all specimens in at least 200 fields of view were counted, using a magnification of $1500\times$.

The abundances of each coccolith species were tabulated on the range chart by giving the counts for each species/sample. From these abundances the ratios I/F (individuals/field) and I/mm (individuals/millimeter) were calculated. Letters used on the range chart in order to describe the abundance of coccoliths are linked to the 10 log as follows:

A = abundant	(10.1–100 specimens/field)
C = common	(1.1–10 specimens/field)
F = few	(1 specimen/1.1–10 fields)
R = rare	(1 specimen/10.1–100 fields)
EB = essentially barren	(1 specimen/more than 100 fields).

Preservation is indicated by the following: E1 (slightly etched), E2 (moderately etched), and E3 (heavily etched). Taxa considered in this report are listed in the Appendix. Most bibliographic references for these taxa are given in Perch-Nielsen (1985); any not included therein are given in the references.

BIOSTRATIGRAPHY

Site 692 (Table 1)

Hole 692B (70°43.43'S, 13°49.20'W; water depth = 2875 m) is located about 20 km north of the coast of Dronning Maud Land (East Antarctic). Some 97 m of sediment was penetrated, of which about 39 m was assigned a Neocomian age (probably Valanginian according to our data; see below). Aside from the age given in the present chapter, see also Mohr (this volume, chapter 29) and Doyle et al., (this volume). Core 113-692B-7R to Section 692B-13R, CC yielded Lower Cretaceous nannofossils, but the base of the Cretaceous section was not reached, and

it may coincide with the position of the prominent seismic reflector U6 estimated to lie 60 m beneath the base of Hole 692B. Up to 1000 m of presumed Middle to Upper Jurassic sediments may lie beneath this reflector (Shipboard Scientific Party, 1988a).

Preservation and abundances of nannofossils are shown in Table 1. Only a few poorly preserved specimens of *Watznaueria barnesae* and *Rhagodiscus* have been observed in Core 113-692C-7R, so its assignment to the Lower Cretaceous assumes close stratigraphic continuity with the underlying sequence; the above taxa range throughout the Cretaceous. Cores 113-692B-8R to -13R also yielded nannofossil assemblages dominated by *W. barnesae*, which makes up between 57% and 96% of the total assemblage (Samples 113-692B-11R-2, 96–97 cm, and 113-692B-12R-1, 22–23 cm, respectively). Other common and generally well preserved species include *Rhagodiscus asper*, *Biscutum constans*, *Cyclagelosphaera magerelii*, *Watznaueria ovata*, *Crucibiscutum salebrosum*, and *Zeughrabdotus* spp.

Entire specimens of *Micrantholithus hoshulzii* and *M. obtus* and numerous fragments were observed as high as Sample 113-692B-9R, 31–32 cm; fragments continue upsection to Sample 113-692B-8R-3, 60 cm. Less common are *Cretarhabdus angustifloratus*, *Cretarhabdus conicus*, *Cretarhabdus crenulatus*, *Glaukolithus diplogrammus*, *Zeughrabdotus embergeri*, *Sollasites horticus*, *Vekshinella stradneri*, and *Ethmorhabdus hauterivianus*.

The critical taxa for dating this section are rare *Cyclagelosphaera deflandrei*, *Diadorhombus rectus*, and *Crucellipsis cuvillieri*, all of which occur at or near the base of the hole in Core 113-692B-12R. In Tethyan sections from the North Atlantic, Roth (1983) and Applegate et al. (1989) found *Crucellipsis cuvillieri* from the Berriasian to just below the top of the Hauterivian. Roth (1983) observed *Cyclagelosphaera deflandrei* from the Middle Jurassic to the top of the Valanginian, but Covington and Wise (1987) cautioned that the identification of this species could be influenced by its state of preservation and that it is difficult to detect in carbonate-poor sections. Nevertheless, one of us (JM) observed the taxon restricted to the Tithonian(?), Berriasian-Valanginian at Site 766 off Australia; it does not occur above the interval dated as Valanginian-Hauterivian (Gradstein, Ludden, et al., 1990).

Thierstein (1976) and Roth (1978) originally believed that *Diadorhombus rectus* was confined to the Valanginian, where it is well developed, and suggested that it was an excellent marker for that interval. It has since been reported in rare occurrences from the Hauterivian and upper Barremian of northwest Germany (Crux, 1989; Mutterlose and Harding, 1987, respectively) and from the Barremian of the western North Atlantic (Roth, 1983; Covington and Wise, 1987). Crux (1989) considers all such specimens above the Valanginian to be reworked; nevertheless, the biostratigraphic utility of *D. rectus* may be questioned by some. However, as the ranges of *C. deflandrei* and *D. rectus* do overlap in the Valanginian of the Tethyan region, these taxa can be taken together to date the Cretaceous section at Site 692 as Valanginian (nannofossil Zone NC3 of Roth, 1983). This assumes that the section drilled represents a reasonably short interval of time with high sedimentation rates (as indicated by escape burrows of trace fossils; Shipboard Scientific Party, 1988a) and that the apparent absence of *D. rectus* above the base of the hole can be attributed to its general scarcity and the generally carbonate-poor nature of the section. On the other hand, the section above Core 113-692B-12R could be younger than the last occurrence of *D. rectus*, perhaps even Hauterivian in age.

The generally low carbonate content (average 17%; Thompson and Dow, this volume) and perhaps the restricted environment of deposition might also explain the absence of other generally scarce but important Valanginian index taxa one might expect to see in mid- to high-latitude sections, such as *Calcica-*

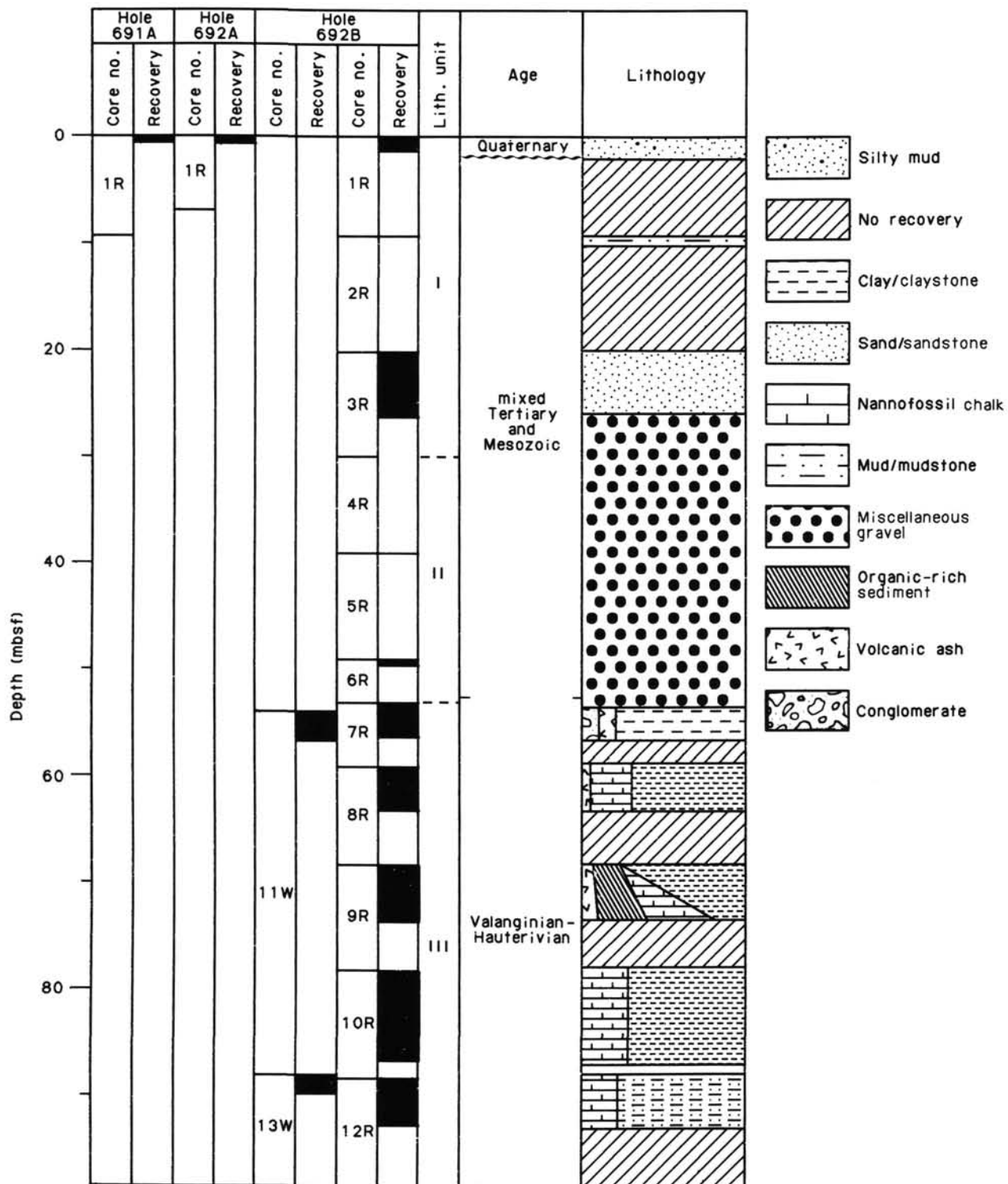


Figure 3. Lithostratigraphic summary of Hole 692B.

lathina oblongata. It may be possible, however, that forms such as *Tubodiscus verena* are present, as rare specimens of *Tubodiscus* sp. were observed in Core 113-692B-12R (Pl. 3, Fig. 1).

The approximate Valanginian age for this sequence deduced from the calcareous nannofossil assemblage agrees reasonably well with the ages assigned by studies of the palynology and macrofauna. Mohr (this volume, chapter 29) suggests a ?Valan-

ginian-Hauterivian age based on palynology, whereas Doyle et al. (this volume) suggest a Tithonian-Berriasian age based primarily on a spiticeratid ammonite in Core 113-692B-10R. Although some differences exist, as one might expect for a restricted environmental setting in a little-studied frontier area, a probable Valanginian age appears to be the best compromise among the three data sets.

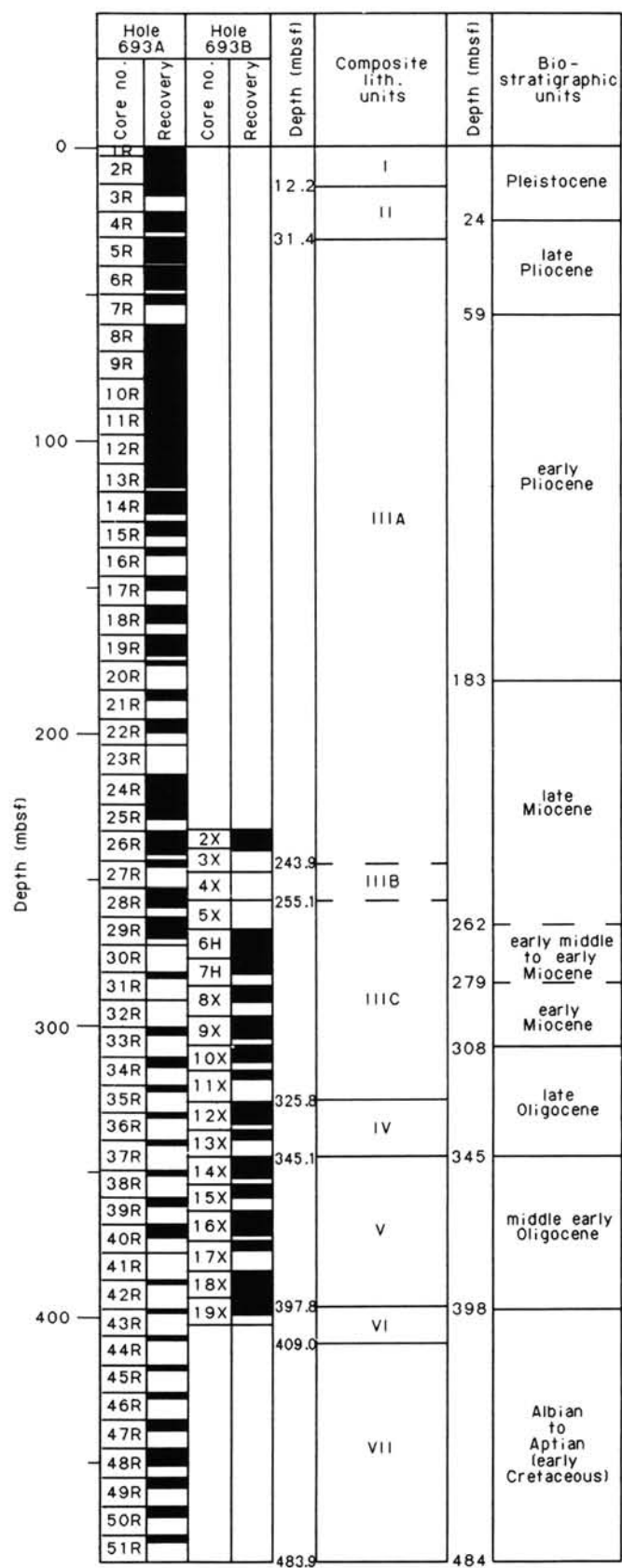


Figure 4. Lithostratigraphic summary of Site 693.

Table 1. Distribution of Lower Cretaceous calcareous nannofossils, Hole 692B. Abundance is characterized by A (abundant) = 10–100 specimens/field; C (common) = 1–10 specimens/field; F (few) = 1 specimen/1.1–10 fields; R (rare) = 1 specimen/10.1–100 fields; EB (essentially barren) = 1 specimen/more than 100 fields; B (barren). Preservation: E1 = slightly etched; E2 = moderately etched; E3 = heavily etched. Species marked with an asterisk have only been observed under the SEM.

Litho-stratigraphic unit	Age	Core, section, interval (cm)	Depth (mbsf)	Preservation	Abundance	Number of species	Individuals (I)	Fields (F)	I/F	I/mm	<i>Axopodorhabdus dietzmannii</i>	<i>Bidiscus rotatorius</i>	<i>Biscutum constans</i>	<i>Chiastocyclus</i> sp.	<i>Corollithion silvradion</i>	<i>Cretarhabdus angustifuratus</i>	<i>Cretarhabdus conicus</i>	<i>Cretarhabdus crenulatus</i>	<i>Cretarhabdus</i> sp. cf. <i>schizobrachiatius</i>	<i>Crucibiscutum salebrosum</i>
VII	Valanginian (–Hauterivian?)	7R-1, 44	53.6	E3	R	2	20	230	.	.	.	.	.	.	.	.	.	.	.	.
		7R-1, 80	54.0	.	B	.	.	200	.	.	.	.	.	.	.	.	.	.	.	.
		7R-1, 124	54.4	.	B	.	.	220	.	.	.	.	.	.	.	.	.	.	.	.
		7R-2, 30	55.0	.	B	.	.	215	.	.	.	.	.	.	.	.	.	.	.	.
		8R-1, 30	59.6	E3	C	9	343	110	3.1	22.3	.	.	.	.	.	.	.	.	.	2
		8R-2, 30	61.1	E3	F	5	90	260	0.3	2.5	.	.	.	.	.	.	.	.	.	1
		8R-3, 60	63.9	E1	A	22	346	10	34.6	247	.	.	15	.	.	1	2	1	.	41
		8R-3, 65	64.0	E1	A	19	347	7	49.6	354	.	.	12	.	.	3	.	1	.	32
		9R-1, 34–35	69.1	E1	A	14	331	6	55.2	394	1	.	1	.	.	1	.	1	.	7
		9R-2, 31–34	70.6	E1	A	18	360	7	51.4	367	.	.	2	.	.	2	1	2	.	7
		9R-2, 91–92	71.2	E2	A	16	327	22	14.9	106.2	.	.	6	2	.	4	2	1	.	9
		9R-2, 96	71.2	E2	A	16	348	14	24.9	177.6	.	.	5	.	.	4	.	1	.	8
		9R-2, 137–138	71.6	E1	A	14	327	14	23.4	166.8	.	.	.	1	.	3	1	1	.	2
		9R-3, 62–63	72.3	E1	A	14	312	6	52	371.4	.	.	1	.	.	1	1	1	.	12
		9R-3, 104–105	72.7	E1	A	14	364	5	72.8	520	.	.	.	1	.	3	1	1	.	8
		9R-3, 110	72.8	E1	A	18	319	6	53.2	379.8	.	.	2	.	.	2	2	.	.	5
		9R-3, 129	73.0	E1	A	15	337	6	56.2	401.2	.	.	2	.	.	2	1	2	.	11
		9R-3, 138–139	73.1	E1	A	16	371	9	41.2	294.4	.	.	9	1	.	1	1	1	.	15
		9R, CC	78.5	E1	A	9	352	6	58.7	419	.	.	4	.	.	1	1	.	.	5
		10R-1, 42–43	78.9	E1	A	9	322	29	11.1	79.3	.	.	1	.	.	1	1	1	.	27
		10R-1, 45	78.9	E1	A	13	353	10	35.3	252	.	.	8	.	.	1	1	1	.	28
		10R-1, 82–85	79.3	E1	C	15	322	55	5.9	41.8	.	9	31	.	.	1	.	.	.	59
		10R-1, 110.5	79.6	E1	A	20	333	11	30.2	216	.	1	12	.	.	1	1	.	.	28
		10R-1, 110–113	79.6	E1	A	19	324	23	14.1	100.6	.	12	15	.	.	1	1	.	.	92
		10R-2, 103–106	80.9	E1	A	27	327	14	23.4	166.8	1	6	20	.	P	2	1	1	.	47
		10R-3, 20–22	81.4	E1	A	16	332	16	20.8	148.2	.	1	3	.	.	1	.	2	.	85
		10R-3, 121–124	82.4	E1	A	18	337	7	48.1	343.9	1	1	8	.	.	1	3	1	.	14
		10R-4, 1–4	82.5	E1	A	13	319	24	13.3	94.9	.	2	.	.	.	1	1	.	.	60
		10R-4, 68–71	83.2	E1	A	20	353	15	22.5	168	.	5	38	.	.	3	1	2	.	48
		10R-4, 114–116	83.7	E1	C	14	318	32	9.9	71	.	1	8	.	.	2	1	.	.	53
		10R-5, 1–4	83.8	E1	A	13	302	16	18.9	143.8	.	.	8	.	.	1	1	.	.	32
		10R-5, 82–84	84.6	E1	C	26	333	35	9.5	68	1	2	47	.	.	1	1	1	.	17
		11R-1, 70–72	85.5	E1	A	13	316	8	39.5	282	.	.	12	.	.	2	1	3	.	8
		11R-2, 9–11	86.4	E1	A	17	327	10	32.7	233.6	.	3	23	.	.	.	1	.	1	32
		11R-2, 96–97	87.2	E1	A	15	326	17	19.2	137	.	.	23	.	.	1	2	1	.	89
		11R-2, 123–125	87.5	E1	A	19	337	28	12	86	1	3	6	.	.	.	1	1	.	50
		11R, CC	88.2	E1	A	22	347	12	28.9	206.5	.	1	.	.	.	1	2	1	.	5
		12R-1, 22–23	88.4	E1	A	8	303	21	14.4	103.1	.	.	.	.	.	.	.	.	.	6
		12R-1, 75–77	88.9	E2	C	23	325	63	5.2	36.9	1	.	18	.	.	2	1	2	.	21
		12R-2, 10–12	89.9	E2	F	6	63	260	0.2	1.7	.	1	.	.	.	1	.	.	.	6
		12R-2, 101–103	90.7	E2	C	15	316	37	8.5	61	.	.	8	.	.	.	.	.	.	9
	Valanginian (Zone NC3)	12R-3, 50–52	91.7	E1	A	28	345	16	21.6	154	1	.	10	.	.	.	1	1	.	10
		12R-3, 99–100	92.2	E1	A	18	337	30	11.2	80.2	1	1	1	.	.	.	.	.	.	8
		12R, CC	92.4	E1	A	28	347	10	34.7	247.9	.	.	1	1	.	.	.	1	.	4
		13R, CC	89.9	E1	A	18	297	12	24.8	176.8	.	.	10	.	.	3	1	.	.	20

One especially abundant taxon throughout the section below Core 113-692B-7R is *Crucibiscutum salebrosum* (Pl. 1, Figs. 7–9; Pl. 2, Figs. 1–3). This form is quite abundant in sediments dated as Barremian to early Aptian on the Falkland Plateau (Wise, 1983). In the North Sea region, it ranges as high as the upper Barremian (Crux, 1989), but its abundance peaks are in the Ryazanian, Valanginian, and Hauterivian (Jakubowski, 1987; Crux, 1989). Therefore, attempts to use this form as a stratigraphic datum (Sissingh, 1977), even for provincial correlations (Wise, 1983), have been largely unsuccessful (Perch-Nielsen, 1985; see also "Paleoenvironment and ecology" below).

The drilling difficulties mentioned previously resulted in the acquisition of two repetitive "wash" cores. Core 113-692B-1W is a wash core taken after the pipe was raised about 30 m to remove knobby joints. The interval then had to be redrilled through cavings and should have bottomed at the same depth as Core 113-692A-10R (88.2 mbsf). Nevertheless, about 2.8 m of a coherent Cretaceous claystone sequence was recovered, and the assemblage closely resembles portions of Core 113-692B-10R although the assemblages from the core catchers of these two cores appeared rather different (Shipboard Scientific Party, 1988a, p. 309).

Table 1 (continued).

Litho- stratigraphic unit	Age	Core, section, interval (cm)	<i>Crucellipsis</i> <i>cuvillieri</i>	<i>Cyclagelosphaera</i> <i>de/landrei</i>	<i>Cyclagelosphaera</i> <i>margerelii</i>	<i>Diadorhombus</i> <i>rectus</i>	<i>Diazomatolithus</i> <i>lehmannii</i>	<i>Ethmorhabdus</i> <i>hauterivianus</i>	<i>Glaucolithus</i> <i>diplogrammus</i>	<i>Glaucolithus</i> sp. aff. <i>diplogrammus</i>	<i>Grantarhabdus</i> <i>meddii</i>	<i>Manivitella</i> <i>pemmatoides</i>	<i>Micrantholithus</i> <i>herschulzii</i>	<i>Micrantholithus</i> <i>obtusius</i>	<i>Micrantholithus</i> sp. (frags.)	<i>Microstaurus</i> <i>chastius</i>	<i>Polypodorhabdus</i> <i>madingleyensis</i>	<i>Reinhardtites</i> <i>fenestratus</i>	<i>Rhagodiscus</i> <i>asper</i>	<i>Rhagodiscus</i> sp. aff. <i>asper</i>	<i>Rhagodiscus</i> sp. cf. <i>angustus</i>	<i>Rotelapillus</i> <i>laffittei</i>
VII	Valanginian (-Hauterivian?)	7R-1, 44	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
		7R-1, 80	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		7R-1, 124	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		7R-2, 30	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		8R-1, 30	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.	.
		8R-2, 30	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		8R-3, 60	.	.	.	.	1	.	2	1	2	2	.	.	5	.	.	.	3	.	.	1
		8R-3, 65	.	.	.	.	3	.	.	.	2	1	.	.	4	.	.	.	1	.	.	1
		9R-1, 34-35	.	.	.	.	.	.	.	1	.	1	.	.	3	.	.	.	.	.	.	.
		9R-2, 31-34	.	1	3	.	.	1	.	.	1	.	.	1	7	.	.	.	.	.	.	1
		9R-2, 91-92	.	.	.	.	.	1	1	4	.	.	.	.	2	1	.	.	1	.	.	.
		9R-2, 96	.	.	.	.	.	2	.	3	.	.	.	.	.	.	.	.	2	.	4	.
		9R-2, 137-138	.	.	1	.	.	.	2	3	.	.	.	.	2	.	1	.	1	.	.	.
		9R-3, 62-63	.	1	1	.	.	1	.	.	.	.	.	.	1	.	2	.	.	.	.	.
		9R-3, 104-105	.	.	.	.	.	1	1	1	.	.	.	.	1	.	1	.	1	.	.	.
		9R-3, 110	.	.	.	.	.	.	.	3	1	1	.	.	1	.	.	.	1	.	1	.
		9R-3, 129	.	1	.	.	.	.	1	3	.	.	.	.	.	.	.	.	.	.	3	.
		9R-3, 138-139	.	.	.	.	.	1	1	.	.	.	.	.	1	.	1	.	1	.	.	.
		9R, CC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
		10R-1, 42-43	.	.	.	.	.	.	.	2	.	.	.	.	1	.	.	.	1	.	.	.
		10R-1, 45	.	.	1	.	.	.	.	2	.	.	.	.	.	.	.	.	1	.	.	.
		10R-1, 82-85	.	.	2	.	.	.	.	2	.	.	.	.	6	1	.	.	2	.	.	.
		10R-1, 110.5	.	.	2	.	.	.	.	1	.	1	.	.	3	.	.	.	1	.	3	.
		10R-1, 110-113	.	.	1	.	.	.	1	1	.	.	.	.	2	.	1	.	1	.	.	.
		10R-2, 103-106	.	1	21	.	.	1	.	2	1	.	.	1	1	.	.	.	4	.	.	2
		10R-3, 20-22	.	.	1	.	.	.	1	1	.	.	.	.	2	.	1	.	4	.	.	.
		10R-3, 121-124	.	.	2	.	.	2	.	1	1	.	.	.	.	.	.	.	2	.	1	.
		10R-4, 1-4	.	.	.	.	.	.	.	1	.	1	.	.	1	.	1	.	5	.	.	.
		10R-4, 68-71	.	1	5	.	.	.	.	5	.	.	.	.	2	.	.	.	5	.	2	1
		10R-4, 114-116	.	.	2	.	.	.	1	.	.	.	.	.	2	.	.	.	12	.	.	.
		10R-5, 1-4	.	1	2	.	.	.	2	.	.	.	.	.	.	.	.	.	6	.	.	.
		10R-5, 82-84	.	1	25	.	1	.	.	1	3	.	.	.	1	1	.	.	2	.	.	1
		11R-1, 70-72	.	.	.	.	.	.	.	1	.	.	.	.	3	.	1	.	.	.	.	.
		11R-2, 9-11	.	1	2	.	.	.	.	.	.	.	.	.	6	.	1	.	5	.	.	.
		11R-2, 96-97	.	.	.	.	.	1	.	4	.	.	.	.	.	.	2	.	2	.	.	.
		11R-2, 123-125	.	.	1	.	.	.	1	.	.	.	1	.	1	.	1	.	1	.	.	.
		11R, CC	.	1	11	.	.	.	.	2	.	.	.	.	.	.	1	.	.	.	1	.
		12R-1, 22-23	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
		12R-1, 75-77	.	1	2	.	.	.	.	2	1	1	.	.	.	.	.	.	5	.	.	.
		12R-2, 10-12	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		12R-2, 101-103	.	2	3	.	2	.	.	.	.	.	.	.	1	.	.	.	1	.	.	1
	Valanginian (Zone NC3)	12R-3, 50-52	.	.	8	3	2	1	.	.	1	2	.	.	1	.	1	.	1	.	.	1
		12R-3, 99-100	.	.	2	1	10	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
		12R, CC	1	1	2	.	2	1	.	1	1	.	.	.	.	.	.	1	1	1	3	1
		13R, CC	.	.	.	.	2	.	.	3	1	.	.	.	.	.	1	.	3	4	.	.

The last core taken, Core 113-692B-13W, was a wash core taken to clean cavings from the hole down to the depth reached by Core 113-692B-12R (97.2 mbsf). It recovered 1.57 m of drill cuttings and "pebbles" of Lower Cretaceous claystone rounded by drilling. Several of the latter were examined, and all contained uphole nannofossil assemblages similar to those from Core 113-693B-10R. Although we were successful in cleaning the hole of cuttings, the decision was made to abandon the hole after this core was retrieved.

Site 693 (Table 2)

Hole 693A (70°49.89'S, 14°34.41'W; water depth = 2359 m) is situated 26 km southwest of Site 692 on a midslope bench off

the coast of Dronning Maud Land of East Antarctica (Fig. 2). This hole penetrated about 477 m sediment, of which the lowermost 70 m yielded a nannoflora of Early Cretaceous age. Whereas Core 113-693A-45R-1, 3-5 cm, yielded only rare *Coccolithus pelagicus*, indicating Tertiary (probably downhole contamination), Sample 113-693A-45R-1, 67-69 cm contained a rare but distinguishable Cretaceous flora. Cores 113-693A-46R-1 to 113-693A-51R-2 are characterized by nannofossil assemblages low in both numbers of specimens and diversity. Many samples are barren or nearly so.

In contrast to those in Hole 692B, the assemblages of the present site are not always dominated by *Watznaueria barnesae*, which nonetheless is common throughout the sequence. The

Table 1 (continued).

<i>Sollasites horticus</i>	<i>Tegumentum striatus</i>	<i>Tegumentum tenuis</i>	<i>Tetrapodorhabdus decorus</i>	<i>Tranolithus gabalus</i>	<i>Tubodiscus</i> sp.	<i>Vekshinella quadriarculla</i>	<i>Vekshinella stradneri</i> sp. 1	<i>Watznaueria barnesae</i>	<i>Watznaueria biporia</i>	<i>Watznaueria britannica</i>	<i>Watznaueria ovata</i>	<i>Watznaueria</i> sp.	<i>Watznaueria supracretacea</i>	<i>Zeughabdotus choffatii</i>	<i>Zeughabdotus embergeri</i>	<i>Zeughabdotus erectus</i>	<i>Zeughabdotus</i> sp.	<i>?Bidiscus rotatorius</i>	<i>?Conusphaera mexicana</i>	<i>?Crucibiscutum salebrosum</i>	<i>?Dizomatolithus lehmannii</i>	<i>?Manivitella pemmatoides</i>	<i>?Watznaueria britannica</i>
.	19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.
.	4	300	.	30	1	.	.	.	1	3	.	.	.	.	.	.	.
2	1	81	.	6	.	.	.	.	1	.	.	.	.	.	.	.	.
.	2	252	1	5	2	.	1	.	3	1	.	.	.	.	.	.	.
1	.	.	1	.	.	1	1	275	1	1	2	.	.	1	2	2	.	.	.	1	.	.	.
.	1	.	295	1	4	8	.	.	.	6	.	.	.	.	.	.	.	.
2	3	.	.	.	.	1	.	312	.	2	7	.	.	.	7	.	.	.	.	.	.	.	.
1	.	.	1	.	.	.	1	290	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.
2	1	.	304	.	2	1	.	.	3	3	.	.	.	.	.	.	.	.
1	.	.	1	.	.	.	1	303	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.
.	280	.	.	7	.	.	.	.	.	.	.	.	1	.	.	.
.	7	.	.	.	.	1	1	340	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.
2	1	.	285	.	1	2	.	.	.	2	.	.	.	.	1	.	.	.
.	1	1	305	.	1	2	.	.	.	.	.	.	?	1	.	.	.	.
.	1	.	.	.	.	.	.	330	.	.	4	.	.	2	.	.	.	.	.	.	.	.	.
.	335	1	.	3	.	.	.	.	.	.	.	.	.	.	.	.
.	285	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
.	1	.	.	.	.	.	.	305	.	1	2	.	.	.	.	1	.	.	.	.	.	.	.
.	.	.	.	1	.	2	2	200	.	1	2	.	.	.	1	.	.	.	.	.	.	.	.
.	.	.	.	1	.	2	1	270	.	2	1	.	.	.	.	2	.	1	?	1	.	.	.
3	.	.	1	1	.	.	1	187	.	1	1	.	.	1	3	.	.	.	.	.	.	.	.
2	1	4	199	1	.	3	.	1	1	1	1	.	.	.	.	.	.	.
.	2	222	.	.	3	.	.	.	1	.	.	.	.	.	.	.	.
1	3	288	.	.	6	.	1	.	1	.	.	.	.	.	.	.	.
3	1	242	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.
.	.	.	1	.	.	.	1	225	.	.	2	.	.	2	1	.	.	.	.	.	.	.	.
.	1	1	227	.	.	3	.	.	4	.	.	.	.	.	.	.	.	.
.	.	.	1	.	.	1	.	240	.	.	4	.	.	3	.	.	.	.	.	.	.	.	.
1	.	.	1	.	.	1	7	204	1	2	2	.	.	3	5	.	.	.	.	.	.	.	.
.	2	.	.	278	.	1	3	.	.	.	1	.	.	.	.	.	.	.	.
.	1	1	245	.	1	1	.	.	2	1	.	1	.	.	.	.	.	.
7	1	1	187	.	1	4	.	.	.	.	.	.	.	.	.	.	.	.
2	.	.	1	.	.	.	2	256	.	1	1	.	.	1	4	.	.	.	.	1	.	.	.
1	.	.	2	.	.	2	1	304	.	1	3	1	.	1	2	.	.	.	.	.	1	.	1
.	1	290	.	2	1	.	.	1	.	.	.	.	.	.	.	.	.
1	.	.	2	.	.	1	1	235	.	15	7	.	1	3	1	.	.	.	.	.	.	.	.
.	52	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	1	.	.	.	.	270	.	11	3	.	2	.	1	1	.	.	.	.	.	.	.
1	.	1	6	.	1	1	5	258	1	12	9	.	1	.	2	.	3	.	.	.	.	.	.
.	.	1	.	.	.	1	2	297	.	3	.	.	3	.	1	.	1	.	.	.	.	.	.
.	.	1	.	.	1	2	1	299	.	5	6	.	1	.	3	.	.	.	.	1	1	.	4
1	1	1	1	240	.	.	3	.	.	.	1	.	.	.	1	.	.	.	.

abundance of *Repagulum parvidentatum* varies between 1% (Sample 113-693A-48R-2, 1–2 cm) and 83% (Sample 113-693A-50R-2, 93–95 cm), while *W. barnesae* makes up 85.4% and 16.4% in these samples, respectively. In other samples the abundance of *W. barnesae* varies between 12% (Sample 113-693A-47R-1, 60 cm) and 95% (Sample 113-693A-48R-2, 33–35 cm). Other species present in the section are indicated on the distribution chart in Table 2. The taxon labeled *Vagalapilla matalosa* is synonymous with *Acaenolithus* sp. in Wise (1983).

Critical for dating the section is *Eprolithus apertior* (Sample 113-693A-49-1, 144–147 cm), which has its first occurrence in the upper Aptian, where it marks the base of the *Rhagodiscus angustus* Zone. Absent in these cores are *Prediscosphaera col-*

umnata, *Tranolithus orionatus*, and *Eiffellithus turriseiffelii*, the index taxa for the three next younger zones on the Falkland Plateau (Wise, 1988), and *Sollasites falklandensis*, a middle Albian subzonal marker on the Falkland Plateau. Based on the presence or absence of these respective taxa, the interval in question is assigned to the upper Aptian to lower Albian *Rhagodiscus angustus* Zone.

The only apparent contradiction to the above assignment is the presence of a single specimen of *Gartnerago* sp. cf. *G. confossus*, which is present in Sample 113-693A-48R-2, 70 cm. On the Falkland Plateau, *Gartnerago* has only been observed in the upper Albian and younger Cretaceous sediments, and we know of no reports of this genus below the middle Albian. At present,

Table 2. Distribution of Lower Cretaceous calcareous nannofossils, ODP Hole 693A. Abundance is characterized by A (abundant) = 10–100 specimens/field; C (common) = 1–10 specimens/field; F (few) = 1 specimen/1.1–10 fields; R (rare) = 1 specimen/10.1–100 fields; EB (essentially barren) = 1 specimen/more than 100 fields; B (barren). Preservation: E1 = slightly etched; E2 = moderately etched; E3 = heavily etched. Species marked with an asterisk have only been observed under the SEM.

Litho- stratigraphic unit	Age	Zone	Core, section, interval (cm)	Depth (mbsf)	Preservation	Abundance	Number of species	Individuals (I)	Fields (F)	I/F	I/mm	<i>Axopodorhabdus dietzmannii</i>	<i>Bidiscus rotatorius</i>	<i>Biscutum constans</i>	<i>Biscutum</i> sp.	<i>Biscutum</i> sp. (cross)	<i>Chiasiozygus literarius</i>	<i>Chiasiozygus</i> sp.	<i>Coccolithus pelagicus</i>
III	? <																		

we cannot explain this discrepancy, but we discount this observation as far as dating this section is concerned. The upper Aptian–lower Albian assignment given this sequence is in good agreement with age estimates based on palynomorphs (Mohr, this volume, chapter 29) and planktonic foraminifers (Leckie, this volume). Mohr (this volume, chapter 29) suggests that Cores 113-693A-44R and -45R are most likely Albian in age, whereas the sequence below is late Aptian in age. Leckie (this volume) dates Cores 113-693A-47R and -48R as late Aptian; he did not report on cores higher in the section.

On the Falkland Plateau, *Seribiscutum primitivum* is present only down to the middle Albian. At Site 693, however, this taxon is common in Core 113-693A-46R and present down to Core 113-693A-49R, and elsewhere in the world it ranges down into the upper Aptian (Perch-Nielsen, 1985). Its absence in Aptian sediments on the Falkland Plateau may be due to the restricted environment of deposition that prevailed there during the Aptian. The mid- to high-latitude, bipolar distribution of

this taxon is shown in Figure 5 (see Table 3 for abundance and citations), and its occurrence at Site 693 falls well within its known biogeographic range.

PALEOENVIRONMENT AND ECOLOGY

Most samples from Hole 692B yielded nannofloras dominated by *Watznaueria barnesae*, which makes up at least 57% of the assemblages and in most cases 70%–90%. These nearly monospecific assemblages might suggest a selection due to dissolution, an inference supported by the generally low calcium carbonate content of the cores (Shipboard Scientific Party, 1988a, table 6) and the “black shale” lithology. According to Roth and Krumbach (1986, p. 243), *W. barnesae* dominated assemblages are indicators of dissolution, as this species is ranked highest for dissolution resistance. However, our SEM investigations show a rather well preserved nannoflora with delicate species such as *Corollithion geometricum*, *Rotelapillus laffittei*, *Sollasites horiticus*, and *Zeugrhabdotus* sp. This indicates that the composi-

Table 2 (continued).

<i>Corollithion geometricum</i>	<i>Cretarhabdus angustifloratus</i>	<i>Cretarhabdus</i> sp. cf. <i>schizobrachiatus</i>	<i>Cretarhabdus conicus</i>	<i>Cretarhabdus crenulatus</i>	<i>Cretarhabdus</i> sp.	<i>Crucibiscutum salebrosum</i>	<i>Cyclagelosphaera margerelii</i>	<i>Diazomatolithus lehmannii</i>	<i>Eprolithus apertior</i>	<i>Gartnerago</i> sp. cf. <i>confossus</i>	<i>Glaucolithus diplogrammus</i>	<i>Grantarhabdus coronadventis</i>	<i>Lithraphidites carniolensis</i>	<i>Nannoconus globulus</i>	<i>Nannoconus</i> sp.	<i>Nannoconus truitii</i>	<i>Polypodorhabdus madingleyensis</i>	<i>Repagulum parvidentatum</i>	<i>Rhagodiscus achylostaurion</i>	<i>Rhagodiscus</i> sp. aff. <i>asper</i>	<i>Rhagodiscus asper</i>	<i>Rhagodiscus</i> sp. cf. <i>angustus</i>	<i>Rotelapillus laffitei</i>	<i>Seribiscutum primitivum</i>	<i>Sollasites horticus</i>	<i>Tegumentum stradneri</i>	<i>Tetrapodorhabdus decorus</i>	
.	?
1	2	.	.	1	.	1	.	.	.	.	8	.	.	.	.	1	1	225	.	.	3	3	2	1	.	.	1
4	1	.	1	.	.	2	.	.	.	.	3	.	1	.	1	1	1	456	1	1	1	2	1	48	1	1	
4	1	.	1	.	.	.	.	.	.	.	10	.	2	.	.	.	1	228	1	1	5	.	1	14	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	375	2	4	4	.	2	71	2	.	3
1	1	.	.	1	.	.	.	1	.	1	3	1	.	1	.	1	1	.	.	2	1	.	1	.	.	.	2	
.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	1	1	1	1	1	.	5	1	.	.	.
.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	8	.	1	1	.	.	.	.	.	1
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	10	.	.	1	.	.	.	.	.	.
1	.	.	1	.	.	.	.	.	.	.	1	1	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.
2	1	1	1	1	.	.	.	.	1	.	.	1	.	.	.	1	1	194	.	.	.	2	1	1	.	.	1
2	2	.	1	.	.	.	.	.	.	.	.	.	.	.	.	1	1	345	.	.	1	1	.	.	.	.	1
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	244	.	.	.	2	.	.	.	.	.
.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	51	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	245	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13	.	.	.	.	.	.	.	.	.
.	1	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	1	35	.	1	.	.	.	.	.	.	1
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	247	.	1	4	1	.	.	.	.	1
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	214	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	288	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	49	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	185	.	.	1	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.	.	.	.	.	.
.	
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	15	.	.	.	.	.	.	.	.	.

tions of the assemblages were controlled by factors other than dissolution, although this may have played a role. Appreciable dissolution, however, seems unlikely, particularly since the estimated paleodepth for the site of deposition is relatively shallow, "probably upper bathyal (500–1000 m) with the shallower value more probable" (Shipboard Scientific Party, 1988a, p. 308; see also Thomas, this volume).

Similar observations have been made by Parker et al. (1983, p. 1060) for the black shales of Falkland Plateau Site 511, which yielded a well-preserved nannoflora. Thus *Watznaueria barnesae* not only was dissolution resistant but also seems to have been an ecologically robust form that could tolerate a wide range of extreme biotopes. Extremely high abundances of *W. barnesae* have been observed in other restricted, shallow-water settings such as the Valanginian and upper Aptian of northwest Germany (Mutterlose, 1989), where samples show a high abundance/low diversity nannoflora consisting almost entirely of *W. barnesae*. The high abundance of *W. barnesae* at Hole 692B is

best explained, therefore, by a paleogeographical setting in a restricted basin.

The diversity (species per sample), which is highest in the lowermost part of the section (Samples 113–692B–12R, CC, and 113–692B–12R–3, 50–52 cm), is comparable to that known elsewhere. The overall composition of the nannoflora closely resembles those known from the Valanginian of northwest Europe. Cosmopolitan species (*Watznaueria barnesae*, *Biscutum constans*, *Rhagodiscus asper*, *Cyclagelosphaera margerelii*, *Vekshinella stradneri*) form the bulk of the Valanginian assemblages. Rarer species like *Tegumentum striatum* and *Corollithion silvaradion* occur in both areas as well. On the other hand, there are a few taxa which occur in both the low latitudes and in the Boreal realm that are nonetheless missing at Site 692. These include *Lithraphidites carniolensis*, *Speetonia colligata*, and *Nannoconus* spp. In the Tethyan section of the hypostratotype of Angles, *L. carniolensis* and *S. colligata* are rare to common and *Nannoconus* spp. is even abundant (Manivit, 1979). All three

Table 2 (continued).

Litho-stratigraphic unit	Age	Zone	Core, section, interval (cm)	<i>Tranolithus gabalus</i>	<i>Tubodiscus</i> sp.	<i>Vagalapilla matalosa</i>	<i>Vekshinella dibrachiata</i>	<i>Vekshinella quadriarculla</i>	<i>Vekshinella stradneri</i>	<i>Watznaueria barnesae</i>	<i>Watznaueria biporta</i>	<i>Watznaueria briannica</i>	<i>Watznaueria ovata</i>	<i>Watznaueria supracretacea</i>	<i>Zeughabdotus embergeri</i>	<i>Zeughabdotus erectus</i>	<i>Zeughabdotus salitum</i>	<i>Zeughabdotus</i> sp. 1	<i>Zeughabdotus</i> sp. 2	? <i>Esgia junior</i>	? <i>Vekshinella quadriarculla</i>
III	early Albian/late Aptian	<i>Rhagodiscus angustus</i>	45R-1, 3-5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			45R-1, 67-69	.	.	.	.	.	.	25	.	.	.	.	.	.	.	.	.	.	.
			46R-1, 10-12	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			46R-1, 41-43	.	.	6	.	.	4	132	.	2	.	.	.	.	.	.	.	.	.
			46R-1, 110-112	.	.	3	.	.	4	157	1	.	1	.	.	.	.	4	.	.	.
			47R-1, 60	.	.	5	.	1	2	39	.	.	3	.	.	.	.	2	.	.	.
			47R-1, 59-61	.	.	10	.	2	7	174	.	.	2	.	1	.	.	13	.	.	1
			48R-1, 148-150	.	2	.	.	.	1	184	.	.	1	1	.	.	.	1	.	.	.
			48R-2, 33-35	.	.	.	.	1	.	142	.	.	1	.	.	.	.	1	.	.	.
			48R-2, 70-72	1	.	5	1	1	6	133	.	.	.	.	1	.	1	2	.	.	.
			48R-3, 1-2	.	.	.	.	.	.	103	.	.	1	.	.	1	.	1	.	.	.
			48R-3, 35-37	.	.	1	.	.	1	38	.	.	.	1	.	.	.	1	.	.	.
			48R-3, 148-150	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	.	.	.
			48R-4, 78-80	.	.	2	.	.	.	105	.	.	.	.	.	.	.	2	.	.	.
			49R-1, 7-9	.	.	.	.	.	1	16	.	.	.	.	.	.	.	.	.	.	.
			49R-1, 51-54	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
			49R-1, 92-95	.	.	1	.	.	1	85	.	.	1	.	1	.	.	1	2	.	.
			49R-1, 144-147	.	.	2	.	.	1	123	.	.	.	1	.	.	.	1	2	1	.
			49R-2, 7-9	.	.	2	.	.	1	115	.	.	2	1	.	.	.	1	1	.	.
			49R-2, 51-54	.	.	.	1	.	1	92	.	.	1	.	.	.	.	.	.	.	.
			49R-2, 92-95	.	.	.	.	.	.	69	.	.	1	.	.	.	.	1	.	.	.
			49R-2, 144-147	.	.	.	.	1	1	91	.	.	1	.	.	.	.	1	.	.	.
			50R-1, 81-83	.	.	.	.	.	.	15	.	.	.	.	.	.	.	.	.	.	.
			50R-1, 90-92	.	.	1	.	.	1	91	.	.	.	.	.	.	.	.	.	.	.
			50R-1, 140-142	.	.	1	.	.	2	117	.	.	2	.	1	.	.	1	.	.	.
			50R-2, 7-8	.	.	.	.	.	.	125	.	.	2	.	.	.	.	2	.	.	.
			50R-2, 93-95	.	.	.	.	.	.	57	.	.	1	.	.	.	.	.	.	.	.
			51R-1, 48-50	.	1	.	.	.	.	32	.	.	.	.	.	.	.	.	.	.	.
			51R-1, 54	.	.	1	.	.	1	117	.	.	1	.	.	.	.	2	.	.	.
			51R-1, 91-93	.	.	.	.	.	.	21	.	.	.	.	.	.	.	.	.	.	.
			51R-1, 104-106	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
			51R-1, 134-136	.	.	.	.	.	.	21	.	.	1	.	.	.	.	.	.	.	.
			51R-2, 7-9	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.
			51R-2, 28-30	.	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.
			51R-2, 60-62	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
			51R-2, 82-83	.	.	.	.	.	.	48	.	.	.	.	.	.	.	.	.	.	.

taxa are present in northwestern Europe, although *S. colligata* is very rare (Mutterlose, 1988; Crux, 1989). These different distribution patterns might be explained by the high-latitude position of Site 692.

The abundance of *Watznaueria barnesae* in Hole 693A is less pronounced, because *Repagulum parvidentatum* partially displaces *W. barnesae* as the dominant taxon. Both species together, however, make up between 70% and 90% of the assemblages, while the remainder of the species may be less than 10% (compare Table 4). Figure 6 shows the correlation between *W. barnesae* and *R. parvidentatum* for 23 samples of Hole 693A; only those samples in which more than 30 specimens/200 fields were counted were considered. The high negative correlation between the two species (the correlation factor is highly significant; $R = 0.97$) is easy to explain by the closed sum phenomenon. As all the populations consist mainly of the two species discussed here, a decrease of *W. barnesae* necessarily involves an increase of *R. parvidentatum* and vice versa.

Nevertheless this correlation shows very clearly that both species have a similar distribution pattern, reflecting a similar re-

sistance to dissolution and possibly a similar tolerance of extreme environmental settings. Further work is necessary to show whether the first occurrence of this "*barnesae-parvidentatum*" assemblage is of stratigraphic value. Neither *Watznaueria barnesae* nor *Repagulum parvidentatum* shows any significant correlation with either the nannofossil abundance/mm or with the diversity. If dissolution was the controlling factor, a negative correlation between either one of the two species would be expected.

The composition of the floras of Hole 693 differs from those derived from sites further to the north by the absence of *Braarudospaera*, *Corollithion achylosum*, *Eprolithus varolii*, and *Flabellites biforaminis* and the isolated occurrence of *E. apertior* and *Lithraphidites carniolensis*. In particular the absence of *Eprolithus* spp., which is quite common in the Aptian and Albian of northwest Europe, is striking.

REGIONAL CORRELATIONS

Dark organic-rich claystones characterize the pre-Albian Cretaceous sediments at a number of DSDP/ODP drill sites in or

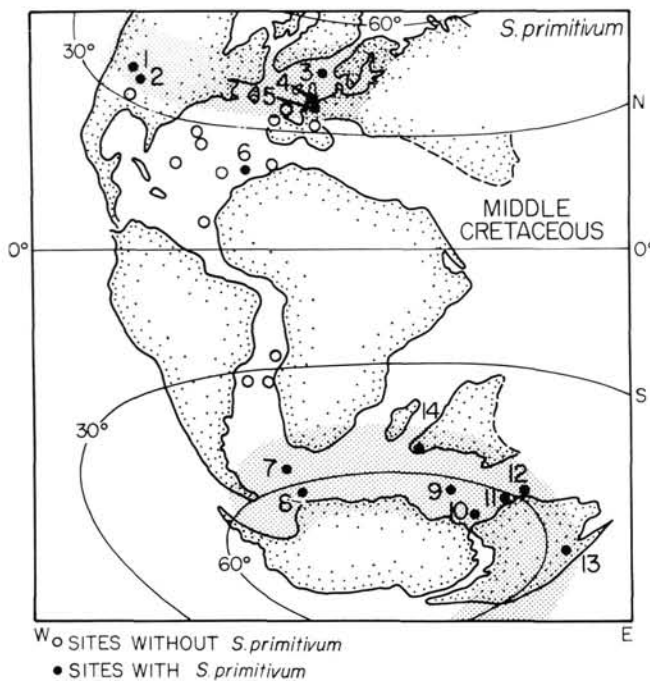


Figure 5. Bipolar distribution of *Seribiscutum primitivum* during the middle Cretaceous; areas where this taxon is most likely to be found indicated by stipple pattern (updated from Wise (1988) and Roth and Krumbach (1986, fig. 13)). Sites that contain *S. primitivum* are numbered on the map and are listed in Table 3 along with abundances (where known), stratigraphic interval, and references.

Table 3. Localities at which *Seribiscutum primitivum* has been reported (see Fig. 5 for localities keyed to reference number).

Locality	Abundance	Time interval ^a	Reference
1. Utah, Wyoming, USA	present	Cenomanian	Roth and Krumbach (1986)
2. Kansas, USA	rare	Santonian	Covington (1985)
3. Moray Firth	abundant	NC9/NC10 base	Jakubowski (1987)
4. Southern England	0.7% 0.3%	NC8/NC9 NC10/NC11	Roth and Krumbach (1986)
5. Normandy Coast; Paris Basin	present present	Cenomanian Albian	Amedeo et al. (1978)
6. DSDP Site 369	0.2%	NC8/NC9	Manivit (1979) Roth and Krumbach (1986)
7. DSDP Site 327	3.8%	NC8/NC9	Roth and Krumbach (1986)
DSDP Site 330	24.5% 1.6%	NC10/NC11 NC8/NC9	Roth and Krumbach (1986) Roth and Krumbach (1986)
8. ODP Site 693	9.9%	NC7/NC8	This volume
9. Kerguelen Plateau	present	Cenomanian-Turonian	Thierstein (1977)
10. DSDP Site 258	30.0% 15.0%	NC8/NC9 NC10/NC11	Roth and Krumbach (1986)
11. DSDP Site 259	2.6%	NC8/NC9	Roth and Krumbach (1986)
12. ODP Site 766	rare	NC10	Gradstein, Ludden, et al. (in press)
13. Queensland, Australia	abundant	NC8/NC9	Shafik (1985)
14. Cauvery Basin	common	NC9	Kale and Phansalkar (1989)

^a Nannofossil zones (NC) are from Roth (1978).

adjacent to the South Atlantic sector of the Southern Ocean (Figs. 7, 8). The most extensive of these sections are on the Falkland Plateau.

In addition to its occurrence at Hole 693A, the *Rhagodiscus angustus* Zone was cored at Holes 327A and 511 on the Falkland Plateau (Wise and Wind, 1977; Wise, 1983). Due to the restricted paleoenvironment, nannofossils were common in only half or less than half of the samples examined. Only Hole 511 was continuously cored, but the nannofossil assemblage there compares well with that from Hole 693A. *Nannoconus truittii* and the zonal marker *Eprolithus apertior* (stratigraphically equivalent to *Eprolithus* (= *Lithastrinus*) *floralis*), are few to common where nannofossils as a group are generally common. *Repagulum parvidentatum* and *Vagalapilla matalosa* (listed as *Acaenolithus* sp. by Wise, 1983) are common to abundant. As mentioned above, *Seribiscutum primitivum* is not present, which is perhaps the only major difference between the assemblages at these two localities.

At Site 511, Jeletzky (1983) and Mutterlose (1989) draw the Aptian/Albian boundary within the *Rhagodiscus angustus* Zone at 500 m and 500–503 m, respectively. This is just at or slightly below the Lithostratigraphic Unit 5/6 boundary, at which point the section changes transitionally from "black shales" to well-oxygenated chalks.

A correlation between the Neocomian of Site 692 and the Falkland Plateau is more difficult to make in that no Berriasian to Hauterivian sediments have been positively identified on the Falkland Plateau. This is generally attributed to a disconformity between Jurassic and Barremian–Aptian sediments thought to have formed during uplift associated with the early stages of opening of the South Atlantic Basin (Barker, Dalziel, et al., 1977; Wise et al., 1980).

Despite continuous coring at Site 511, the exact boundary between the Jurassic and Cretaceous is difficult to delineate for several reasons. The "black shale" lithologies are similar across the presumed contact, the section is barren of macrofossils and nannofossils in the vicinity of the boundary, and there has apparently been reworking of Jurassic nannofossils above the boundary. Nevertheless, the Neocomian section is clearly thinner and probably truncated at Sites 327, 330, and 511 on the Falkland Plateau. As no assemblages containing the important Neocomian index taxa *Crucellipsis cuvillieri*, *Diadorhombus rectus*, and *Ethmorhabdus hauterivianus* have been found there, we assume that strata equivalent to that cored in Hole 692B are missing at these sites.

An assemblage containing abundant *Crucibiscutum salebrosum* and numerous fragments of *Micrantholithus hoschulzii* is present at Site 511, but this assemblage is characterized by abundant *Corollithion silvaradion* and lies within strata dated as Aptian–Barremian by foraminifers and mollusks. This assemblage, therefore, is younger than the sequence at Site 692B.

Organic-rich claystones also characterize the *Rhagodiscus angustus* Zone at Site 361 in the Cape Basin off South Africa (lithologic Unit 7; Bolli, Ryan, et al., 1978). The Aptian/Albian boundary is tentatively placed below the top of the carbonaceous (sapropelic) claystones near the top of this zone by Proto Decima et al. (1978, table 7), who assign the lower portion of the section to the lower Aptian *Chiastozygus litterarius* Zone. Organic-rich claystones also occur within a sequence at Site 249 on the Mozambique Ridge, which is assigned to the *Chiastozygus litterarius* Zone by Bukry (1974). The organic content diminished toward the top of this sequence, which is capped by a disconformity.

Table 4. Relative abundance of the major nannofossil groups in the Lower Cretaceous of ODP Hole 693A. The samples and data correspond to those shown in Figure 6. Note: Data compiled from 23 samples, which yielded more than 30 specimens/200 fields of view. Samples containing less have been omitted.

Hole 693A core, section, interval (cm)	Individuals	Diversity	l/mm	<i>Repagulum</i> <i>parvidentatum</i> (%)	<i>Watznaueria</i> <i>barnesae</i> (%)	Other species (%)
46R-1, 41-43	383	14	12.8	58.6	34.4	2
46R-1, 110-112	723	24	36.2	63	21.7	3
47R-1, 60	323	25	60.7	70.6	12.1	4
47R-1, 59-62	718	26	37.8	52.1	24.2	5
48R-1, 148-150	198	12	5.7	0	92.5	7.5
48R-2, 33-35	149	7	4.3	0	95.3	4.7
48R-2, 70-72	187	26	5.3	4.8	71.1	24.1
48R-3, 1-2	113	11	3.2	0.9	91.1	8
48R-3, 35-37	56	12	1.6	14.3	67.9	17.8
48R-4, 78-81	123	8	3.5	8.1	85.4	6.5
49R-1, 92-95	407	22	32.3	73.7	20.9	5.4
49R-1, 144-147	342	21	18.5	56.7	36	7.3
49R-2, 7-9	483	20	26.7	71.6	23.9	4.5
49R-2, 51-54	343	8	10.2	71.1	26.8	2.1
49R-2, 92-95	122	4	3.5	41.8	56.6	1.6
49R-2, 144-147	343	9	19	71.4	26.5	2.1
50R-1, 90-92	129	5	3.7	27.1	70.5	2.4
50R-1, 140-142	383	16	10.9	64.5	30.5	5
50R-2, 7-8	347	7	43.5	61.7	36.0	2.3
50R-2, 93-95	347	4	23.2	83	16.4	0.6
51R-1, 48-50	82	3	2.3	59.8	39.0	1.2
51R-1, 54	311	10	47.3	59.5	37.6	2.9
51R-2, 82-83	64	3	1.6	23.4	75.0	1.6

TERMINATION OF "BLACK SHALE" DEPOSITION IN THE WEDDELL BASIN

An important implication of the age dates provided by this and other biostratigraphic studies in this volume as well as in the literature cited above is the timing of the end of "black shale" deposition in the Weddell Basin and adjacent areas. At Site 693 the transition from the accumulation of organic-rich claystones (lithostratigraphic Unit VII) to a glauconitic radiolarian diatomite (lithostratigraphic Unit VI) is recorded in core Section 113-693A-44R-1 where dark olive claystone at the base gives way to a lighter, more greenish diatomite at the top; the diatomite was also recovered in core Section 113-693B-19X-4 (see Barker, Kennett, et al., 1988, p. 426 and 447, respectively; O'Connell, this volume, chapter 55).

As stated previously, core Section 113-693A-44R-1 is dated by palynomorphs as early Albian in age (Mohr, this volume, chapter 29), whereas Cores 113-693A-47R and -48R are dated as late Aptian-early Albian by calcareous nannofossils (this study) and more specifically as late Aptian by planktonic foraminifers (Leckie, this volume). It appears, therefore, that the Aptian/Albian boundary lies near the base of Core 113-693A-45R.

The transition from predominantly anoxic to truly oxic depositional conditions in the sediment as well as in the water column at Site 693, therefore, appears to have occurred close to or slightly after the Aptian/Albian boundary, remarkably close to the time of that transition at Site 511 on the Falkland Plateau and at Site 361 in the Cape Basin (see "Regional Correlations," above). At all of these sites the transition occurred near the top of the calcareous nannofossil *Rhagodiscus angustus* Zone.

On the Falkland Plateau, the actual transition from anoxic to oxic conditions is best recorded over several nearly complete cores taken at DSDP Site 511 on the Falkland Plateau. As depicted in the frontispiece for the Leg 71 volume (Ludwig, Krasheninnikov, et al., 1983), the replacement of "black shale" by nannofossil chalk was not an instantaneous event; it occurred through a series of progressively longer pulses of carbonate deposition. The transition was apparently accompanied by the in-

flux of warmer surface waters that introduced Tethyan elements such as *Nannoconus truitii* (Mutterlose, 1989), and the transition may have been modulated by rising eustatic sea levels (Wise, 1988; Mutterlose, 1989). Nevertheless, the transition occurred over a geologically short period of time and there was no subsequent return to anoxic conditions at this site.

Nannoconus truitii was also recovered at Site 693 but in lesser numbers than at Site 511; however, part of the sequence leading up to the transition from predominantly anoxic to oxic conditions at Site 693 was lost due to poor core recovery. The transition from dark claystones to radiolarian diatomite, however, signifies overturn, upwelling, and increasing productivity, all indications of the development of a reasonably strong oceanic circulation system within the basin.

In Figure 8 bottom-water conditions at the Southern Ocean and neighboring drill sites are compared with Cretaceous sequences from throughout the Atlantic basins depicted mostly by Krasheninnikov and Basov (1985). Three features stand out in this comparison. First, essentially anoxic depositional conditions characterize the pre-Albian Cretaceous sequences on the Falkland Plateau and off the Antarctic margin. This is in contrast to equivalent sequences in the Atlantic basins where carbonaceous claystones are interbedded within red or green claystones or cyclic bioturbated and laminated limestones deposited under dominantly oxic or suboxic bottom water conditions. Drilling through a deep-sea fan complex close to the continental margin at Site 603 in the eastern North Atlantic Basin confirmed earlier suggestions that many of the carbonaceous claystones were probably emplaced as mud turbidites from sediments originally accumulated on the continental slopes and outer shelves within the oxygen minimum zone (van Hinte, Wise, et al., 1987; see also discussion by Thompson and Dow, this volume). The lack of sands and turbidite units in the sequences on the Falkland Plateau and Antarctic margin, however, precludes such an origin there. These sequences clearly accumulated adjacent to or within a predominantly anoxic basin, and the basin was in that condition throughout the Neocomian and apparently back into the Jurassic. The Jurassic and Neocomian sedi-

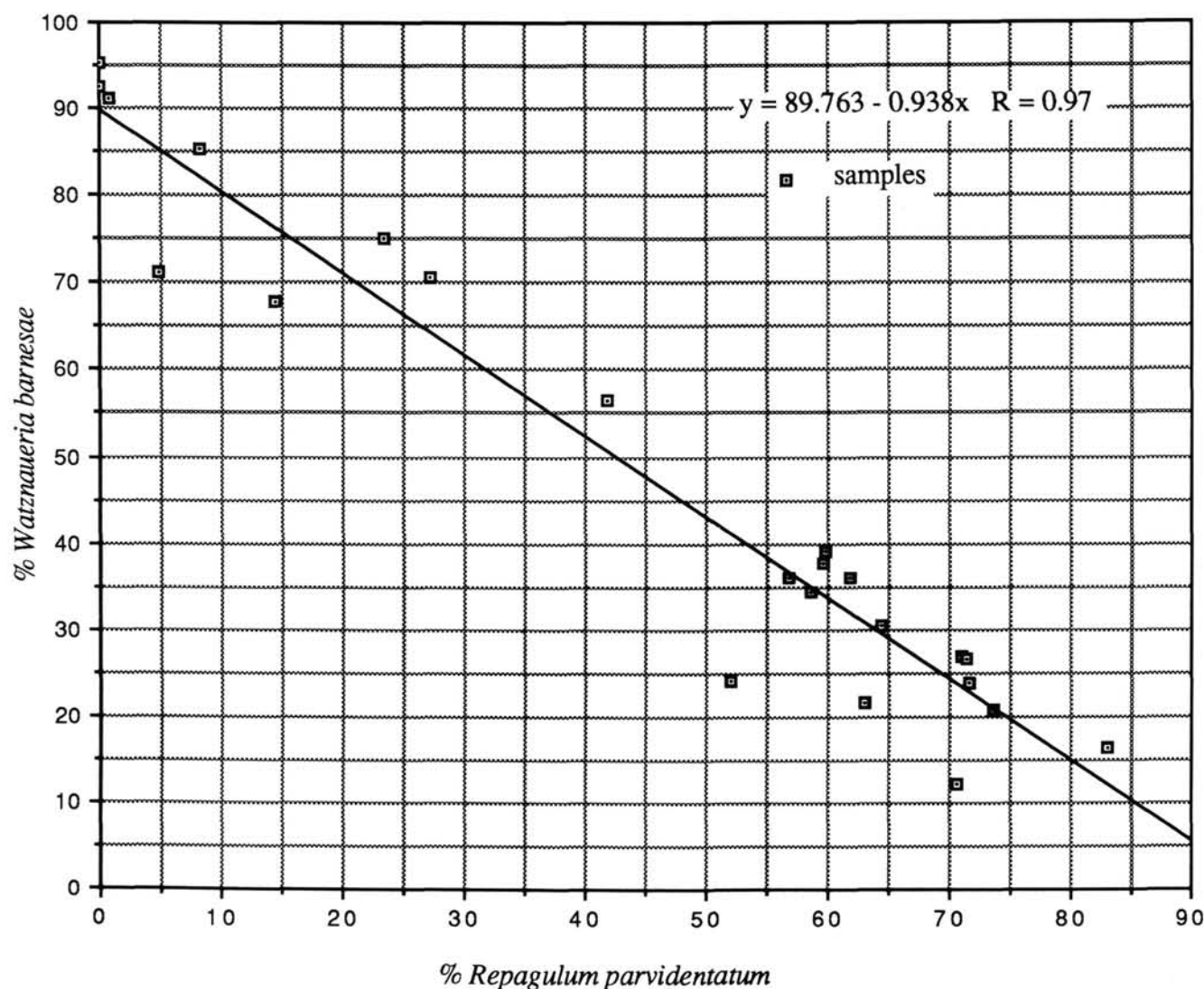


Figure 6. Correlation of *Watznaueria barnesae* and *Repagulum parvidentatum* for the Lower Cretaceous of Hole 693A. Diversity = number of species/sample. Data compiled from 23 samples, which yielded more than 30 specimens/200 fields of view. Samples containing less have been neglected. R = correlation factor.

ments on the Falkland Plateau and at Site 692 are massive, and show no alternations with nannofossil chalks. The Rock-Eval data for Sites 692 and 693, however, do indicate that the dissolved oxygen content of the bottom waters was rising gradually from Valanginian to Aptian times (Thompson and Dow, this volume).

Second, as pointed out previously, the change from anoxic to oxic conditions occurs at about the same time at all of the Southern Ocean sites. There is a suggestion from Figure 8 that the change is manifested first at the Indian Ocean Site 249 on the Mozambique Ridge and that it progresses sequentially westward across the Weddell Sea and finally north into the South Atlantic Basin. Such a progression from the Falkland Plateau northward was postulated by Barker et al. (1977), Thompson (1977), and Natland (1978). Third, it appears from the record on the Falkland Plateau that once the change to oxic conditions occurred in the Southern Ocean during the Albian, there was no reversion back to suboxic or anoxic environments. Such was not the case at many sites in the Atlantic basins, particularly along the upper continental margins, where an expanded oxygen minimum layer and in some areas bottom water anoxia in the deep

basins developed during the Cenomanian-Turonian (Jackson and Schlanger, 1976) and later. Minor organic-rich claystones even punctuate this part of the section at Site 361 in the Cape Basin (Fig. 8; Davey, 1978; Kendrick et al., 1978).

Following the conclusion of DSDP drilling on the Falkland Plateau, Farquharson (1983), Krasheninnikov and Basov (1985), and Zimmerman et al. (1987) each postulated the existence of a triangular-shaped anoxic basin south of the Falkland Plateau more or less bounded on the west by the Antarctic Peninsula and to the southeast and east by East Antarctica and Madagascar respectively. To explain the anoxic conditions, Farquharson (1983) suggested a productivity-driven, expanded oxygen minimum zone for the Weddell Basin probably coupled with a barred basin model for the South Atlantic basins as suggested earlier by Barker et al. (1977), Thompson (1977), Natland (1978), and others. Zimmerman et al. (1987) favored a silled basin "preservational" model for preserving organic carbon in sediments of the incipient Weddell and South Atlantic basins.

The combination model suggested by Farquharson (1983) to explain bottom anoxia in the Weddell Basin and those to the north is highly attractive. On the other hand, the simplest way

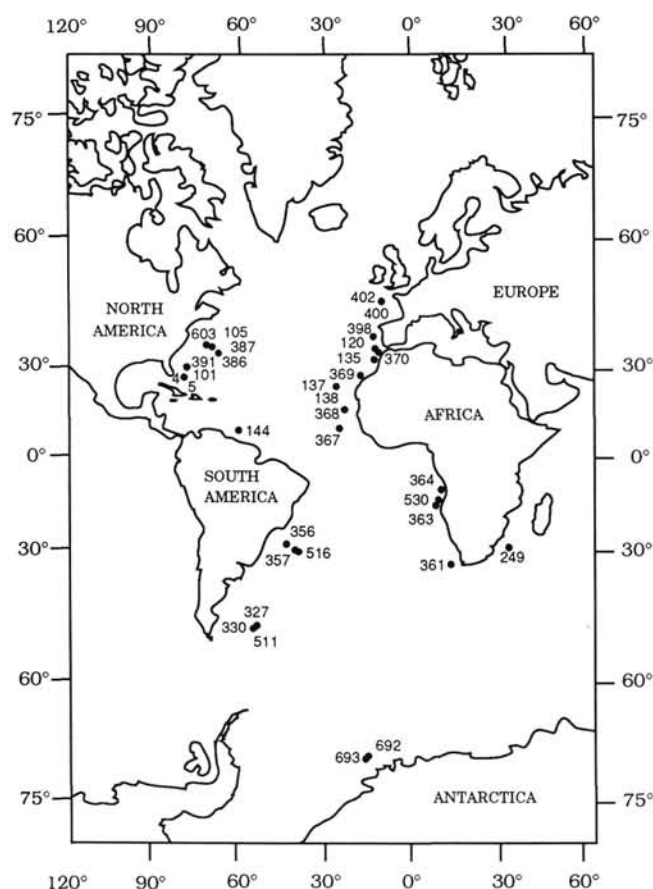


Figure 7. Locations of DSDP/ODP drill sites in the Atlantic, Southern Ocean, and southwest Indian Oceans that contain Cretaceous organic-rich sediments.

to account for the Albian ventilation of the Weddell Basin is through continued seafloor spreading and the gradual widening of the basin in concert with the breakup of this portion of Gondwanaland (Thompson, 1977; Farquharson, 1983). By this mechanism, shallow sills or other physical barriers that had previously restricted deep oceanic circulation into the basin would be breached. Flushing of the basins with better oxygenated waters from the world ocean would have broken down stratification that may have existed within the water column, thereby destroying the "preservational" mechanism for preserving organic carbon in sediments as postulated by Zimmerman et al. (1987).

Plate reconstructions (Figs. 9–12) of Lawver et al. (in press) permit one to visualize how this might have been achieved. As indicated in Figures 9 and 10, the incipient, tectonically isolated and restricted Weddell (WB) and Mozambique (MB) Basins opened through shear along the Mozambique and Explora escarpments (ME and EE, respectively, in Fig. 10). At 140 Ma (Fig. 10), euxinic sediments were accumulating on the Falkland Plateau (F) and possibly along the Antarctic margin off Dronning Maud Land (D).

By Valanginian time (Fig. 11), Madagascar would still serve as the major obstruction to deep-water circulation into the incipient anoxic basins from the Tethyan region to the northeast, and the Mozambique Ridge would stand as a sill between them. The position and configuration of the Antarctic Peninsula is still a major uncertainty in all such reconstructions, and it is entirely possible that surface water connections existed over or

through the Peninsula (arrows) as suggested by Farquharson (1983).

By Aptian time (Fig. 12), the major components of southern Gondwanaland were being sundered, leaving only partial sills restricting the Weddell Basin, although the juxtaposition of the Mozambique Plateau, Maud Rise, and Astrid Ridge (AR in Fig. 10) may have achieved a temporary blockage to deep-water flow into the Weddell Sea from the east through the Madagascar Channel (arrow). The increased oxygenation of the bottom waters of that basin noted by Rock-Eval analyses (Thompson and Dow, this volume), however, indicate that the sills restricting the basin were becoming increasingly fragmented and ineffective as barriers at this point. Major gaps probably existed through the Antarctic Peninsula as well (arrows). During the early Albian, the final ventilation of the Weddell Basin was taking place and sufficiently strong flow was being established to cause upwelling and the accumulation of diatom ooze in a reasonably well oxygenated environment at Site 693. By middle Albian time, the Falkland Plateau was clearing the southern tip of Africa, and the progressive ventilation of the South Atlantic Basin would have proceeded as suggested by Barker et al. (1977), Thompson (1977), Natland (1978), and others.

SYSTEMATIC PALEONTOLOGY

Genus *COROLLITHION* Stradner, 1961

Corollithion covingtonii, n. sp.

(Pl. 4, Figs. 5, 6)

Diagnosis. Oval species of *Corollithion* with vertical wall elements and a central area largely filled by four broad x-shaped bars that splay out against the wall to leave four rounded holes roughly aligned along the major and minor axes. Bars are composed of long, thin, mostly parallel laths and support a short central spine.

Description. The wall is composed of about 30 elements; the length/width ratio of the oval is about 1.3. The bar elements are aligned parallel to the bar lengths except where they splay outward at the juncture with the wall to inscribe the roughly circular holes. The bars are not strictly symmetrical about the major and minor axes, thus the holes are offset about 15° counterclockwise from the minor axis in distal view.

Remarks. A broad concept of the genus is employed here (see Wise, 1983, p. 507); otherwise this species might be placed in the genus *Stoverius* Perch-Nielsen. The fibrous central area bars are reminiscent of those of the upper Jurassic *Corollithion helotatus* Wind and Wise in Wise and Wind (1977) and the closely related *Stephanolithion bigotii brevispinus* Wind and Wise in Wise (1983), from which the present form may have been derived.

Named in honor of J. Mitchener Covington for his contributions to studies of Cretaceous nannofossils.

Occurrence. Rare in the Valanginian(?) of ODP Site 692 on the continental slope off East Antarctica, Weddell Sea.

Size. 5–5.5 μ m.

Holotype. Plate 4, Figure 6.

Isotype. Plate 4, Figure 5.

Type locality. ODP Sample 113-692B-10R-2, 103–106 cm.

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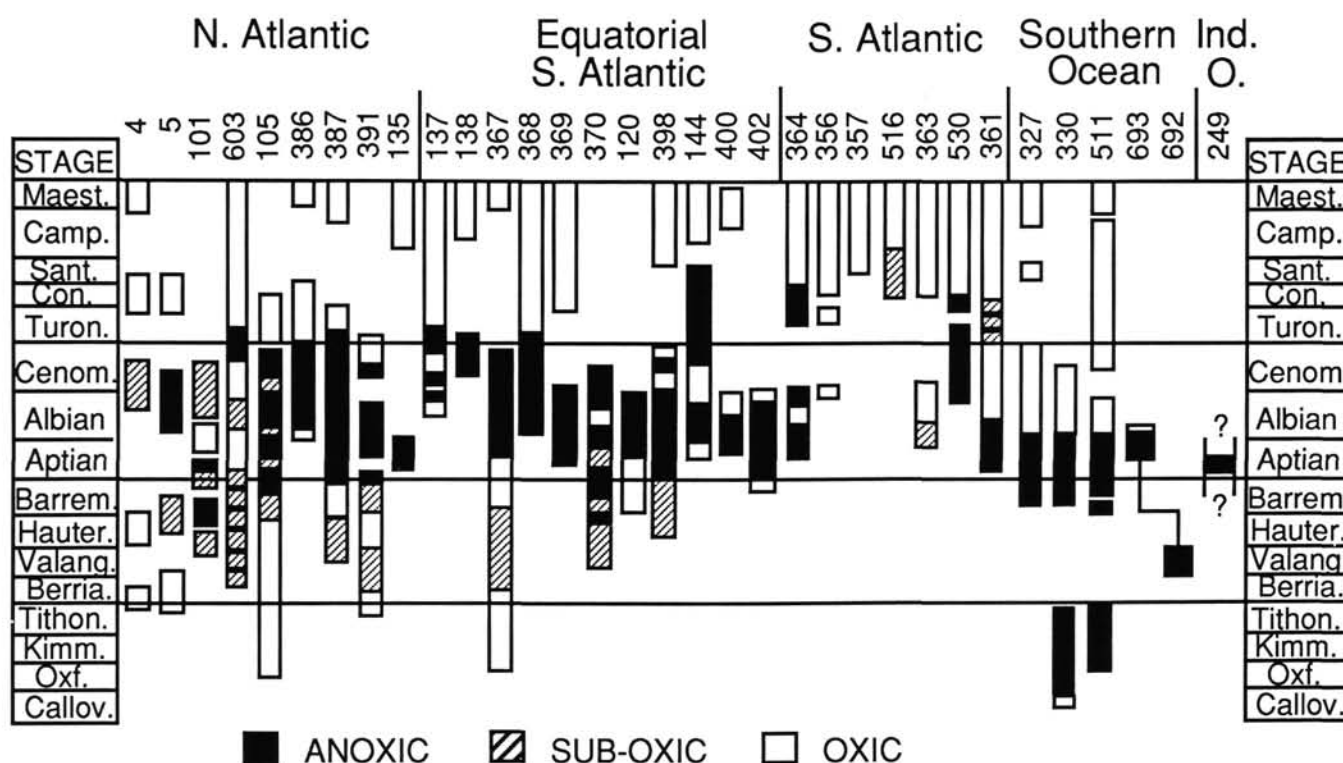


Figure 8. Distribution of anoxic, sub-oxic and oxic conditions in bottom waters of the Atlantic, Southern Ocean, and southwest Indian Oceans interpreted from organic carbon content, sedimentary, and paleontologic features of the sediments (modified and updated from Krashennikov and Basso, 1985; see also Hay, 1988).

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REFERENCES

- Amedeo, F., Damotte, R., Manivit, H., Robaszynski, F., and Somay, J., 1978. Echelles biostratigraphiques dans le Cénomanien de Boulonnais (Macro-micro-nanno fossiles). *Géol. Méditerranée*, 5:5-18.
- Applegate, J. L., Bergen, J. A., Covington, J. M., and Wise, S. W., 1989. Lower Cretaceous calcareous nannofossils from continental margin drill sites off North Carolina (DSDP Leg 93) and Portugal (ODP Leg 103): a comparison. In Crux, J. A., and van Heck, S. E. (Eds.), *Nannofossils and their Applications*: Chichester (Ellis Horwood), 212-222.
- Barker, P. F., Dalziel, I. W. D., et al., 1977. *Init. Repts. DSDP*, 36: Washington (U.S. Govt. Printing Office).
- Barker, P. F., Dalziel, I. W. D., Dinkelman, M. G., Elliot, D. H., Gombos, A. M., Lonardi, A., Plafker, G., Tarney, J., Thompson, R. W., Tjalsma, R. C., von der Borch, C. C., and Wise, S. W., 1977. Evolution of the southwestern Atlantic Ocean Basin: results of Leg 36, Deep Sea Drilling Project. In Barker, P. F., Dalziel, I. W. D., et al., *Init. Repts. DSDP*, 36: Washington (U.S. Govt. Printing Office), 993-1014.
- Barker, P. F., Kennett, J. P., et al., 1988. *Proc. ODP Init. Repts.*, 113: College Station, TX (Ocean Drilling Program).
- Bolli, H. M., Ryan, W. B. F., et al., 1978. *Init. Repts. DSDP*, 40: Washington (U.S. Govt. Printing Office).
- Bukry, D., 1974. Phytoplankton stratigraphy, offshore east Africa, Deep Sea Drilling Project Leg 25. In Simpson, E. S. W., Schilich, R., et al., *Init. Repts. DSDP*, 25: Washington (U.S. Govt. Printing Office), 635-646.
- Covington, J. M., 1985. New morphologic information on Cretaceous nannofossils from the Niobrara Formation (Upper Cretaceous) of Kansas. *Geology*, 13:683-686.
- Covington, J. M., and Wise, S. W., 1987. Calcareous nannofossil biostratigraphy of a Lower Cretaceous deep-sea fan: Deep Sea Drilling Project Leg 93 Site 603, lower continental rise off Cape Hatteras. In van Hinte, J. E., Wise, S. W., et al., *Init. Repts. DSDP*, 93: Washington (U.S. Govt. Printing Office), 617-660.
- Crux, J. A., 1989. Biostratigraphy and palaeogeographical applications of Lower Cretaceous nannofossils from north-western Europe. In Crux, J. A., and van Heck, S. E. (Eds.), *Nannofossils and their applications*: Chichester (Ellis Horwood), 143-211.
- Davey, R. J., 1978. Marine Cretaceous palynology of Site 361, DSDP Leg 40, off southwestern Africa. In Bolli, H. M., Ryan, W. B. F., et al., *Init. Repts. DSDP*, 40: Washington (U.S. Govt. Printing Office), 883-913.
- Farquharson, G. W., 1983. The Nordenskjöld Formation of the northern Antarctic Peninsula: an upper Jurassic radiolarian mudstone and tuff sequence. *Br. Antarct. Surv. Bull.*, 60: 1-22.
- Gradstein, F., Ludden, J., et al., 1990. Site 766. *Proc. ODP Init. Repts.*, 123: College Station, TX (Ocean Drilling Program).
- Hay, W. W., 1988. Paleooceanography: a review for the GSA Centennial. *Geol. Soc. Am. Bull.*, 100:1934-1956.
- Jackson, E. D., and Schlanger, S. O., 1976. Regional syntheses, Line Islands Chain, Tuamoth Island Chain, and Manihiki Plateau, Central Pacific Ocean. In Schlanger, S. O., Jackson, E. D., et al., *Init. Repts. DSDP*, 33: Washington (U.S. Govt. Printing Office), 915-927.
- Jakubowski, M., 1986. New calcareous nannofossil taxa from the Lower Cretaceous of the North Sea. *INA Newsletter*, 8:35-42.
- , 1987. A proposed Lower Cretaceous calcareous nannofossil zonation scheme for the Moray Firth area of the North Sea. *Abh. Geol. B.-A.*, 39:99-119.
- Jeletzky, J. A., 1983. Macroinvertebrate paleontology, biochronology, and paleoenvironments of Lower Cretaceous and Upper Jurassic rocks, Deep Sea Drilling Hole 511, eastern Falkland Plateau. In Ludwig, W. J., Krashennikov, V. A., et al., *Init. Repts. DSDP*, 7: Washington (U.S. Govt. Printing Office), 951-975.
- Kale, A. S., and Phansalkar, V. G., 1989. Black Shale facies from Albian of Cretaceous of South India. *Abstracts, 28th International Geological Congress*, 2:149-150.

- Kendrick, J. W., Hood, A., and Castaño, J. R., 1978. Petroleum-generating potential of sediments from Leg 40, Deep Sea Drilling Project. In Bolli, H. M., Ryan, W.B.F., et al., *Init. Repts. DSDP*, 40 (Supplement): Washington (U.S. Govt. Printing Office), 671-686.
- Krashennnikov, V. A., and Basov, I. A., 1985. *Stratigrafiya mela Yuzhnogo Okeana*: Moscow (Izdatelstvo "Nauka").
- Lawver, L. A., Royer, J.-Y., Sandwell, D. T., and Scotese, C. R., in press. Evolution of the Antarctic continental margins. In Thompson, M.R.A., Crame, J. A., and Thompson, J. W. (Eds.), *Geological Evolution of Antarctica*: Cambridge (Cambridge Univ. Press).
- Ludwig, W. J., Krashennnikov, V. A., et al., 1983, *Init. Repts. DSDP*, 71: Washington (U.S. Govt. Printing Office).
- Manivit, H., 1979. Le nannoplancton du stratotype de l'Albien: biozation, systématique, nannofaciès, paléocologie. In Rat, P. (Ed.), *L'Albien de l'Aube. Les Stratotypes Français*. Paris (C.N.R.S.), 307-340.
- Mutterlose, J., 1988. Das kalkige Nannoplankton des NW-deutscher Valangin und seine palaeozanographische Deutung. *Berliner geowiss. Abh.*, A44:175-209.
- , 1989. Temperature-controlled migration of calcareous nannofloras of the north-west European Aptian. In Crux, J. A., and van Heck, S. E. (Eds.), *Nannofossils and their applications*: Chichester (Ellis Horwood), 122-142.
- Mutterlose, J., and Harding, I., 1987. Phytoplankton from the anoxic sediments of the Barremian (Lower Cretaceous) of north-west Germany. *Abh. Geol. B.-A.*, 39:177-215.
- Natland, J. H., 1978. Composition, provenance and diagenesis of Cretaceous clastic sediments drilled on the Atlantic continental rise off southern Africa, DSDP Site 361—implications for the early circulation of the South Atlantic. In Bolli, H. M., Ryan, W.B.F., et al., *Init. Repts. DSDP*, 40: Washington (U.S. Govt. Printing Office), 1025-1061.
- Parker, M. E., Arthur, M. A., Wise, S. W., and Wenkam, C. R., 1983. Carbonate and organic carbon cycles in Aptian-Albian black shales at Deep Sea Drilling Project Site 511, Falkland Plateau. In Ludwig, W. J., Krashennnikov, V. A., et al., *Init. Repts. DSDP*, 71: Washington (U.S. Govt. Printing Office), 1051-1070.
- Perch-Nielsen, K., 1985. Mesozoic calcareous nannofossils. In Bolli, H. M., Saunders, J. B., and Perch-Nielsen, K. (Eds.), *Plankton stratigraphy*: Cambridge University Press, 329-426.
- Proto Decima, F., Medizza, F., and Todesco, L., 1978. Southeastern Atlantic Leg 40 calcareous nannofossils. In Bolli, H. M., Ryan, W.B.F., et al., *Init. Repts. DSDP*, 40: Washington (U.S. Govt. Printing Office), 571-634.
- Roth, P. H., 1978. Cretaceous nannoplankton biostratigraphy and oceanography of the northwestern Atlantic Ocean. In Benson, W. E., Sheridan, R. E., et al., *Init. Repts. DSDP*, 44: Washington (U.S. Govt. Printing Office), 731-760.
- , 1983. Jurassic and Lower Cretaceous calcareous nannofossils in the western North Atlantic (Site 534): biostratigraphy, preservation, and some observations on biogeography and paleoceanography. In Sheridan, R. E., Gradstein, F. M., et al., *Init. Repts. DSDP*, 76: Washington (U.S. Govt. Printing Office), 587-621.
- Roth, P. H., and Krumbach, K. R., 1986. Middle Cretaceous calcareous nannofossil biogeography and preservation in the Atlantic and Indian Ocean: Implications for paleoceanography. *Mar. Micropaleontol.*, 10:235-266.
- Shafik, S., 1985. Calcareous nannofossils from the Toolebuc Formation, Eromanga Basin, Australia. *BMR J. Australian Geol. Geophys.*, 9:171-181.
- Shipboard Scientific Party, 1988a. Sites 691 and 692. In Barker, P. F., Kennett, J. P., et al., *Proc. ODP, Init. Repts.*, 113: College Station, TX (Ocean Drilling Program), 293-328.
- , 1988b. Site 693. In Barker, P. F., Kennett, J. P., et al., *Proc. ODP, Init. Repts.*, 113: College Station, TX (Ocean Drilling Program), 329-447.
- Sissingh, W., 1977. Biostratigraphy of Cretaceous calcareous nannoplankton. *Geol. Mijnbouw*, 56:37-65.
- Thierstein, H. R., 1976. Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. *Mar. Micropaleontol.*, 1:325-362.
- , 1977. Mesozoic calcareous nannofossils from the Indian Ocean, DSDP Legs 22 to 27. In Heitzler, J. R., Bolli, H. M., Davies, T. A., Saunders, J. B., and Sclater, J. (Eds.), *Indian Ocean Geology and Biostratigraphy*: Washington, D. C. (Am. Geophys. Union), 339-351.
- Thompson, R. W., 1977. Mesozoic sedimentation on the eastern Falkland Plateau. In Barker, P. F., Dalziel, I.W.D., et al., *Init. Repts. DSDP*, 36: Washington (U.S. Govt. Printing Office), 877-891.
- van Hinte, J. E., Wise, S. W., Jr., et al., 1987. *Init. Repts. DSDP*, 93: Washington (U.S. Govt. Printing Office).
- Wise, S. W., 1983. Mesozoic and Cenozoic calcareous nannofossils recovered by Deep Sea Drilling Project Leg 71 in the Falkland Plateau Region, Southwest Antarctic Ocean. In Ludwig, W. J., Krashennnikov, V. A., et al., *Init. Repts. DSDP*, 71: Washington (U.S. Govt. Printing Office), 481-550.
- , 1988. Mesozoic-Cenozoic history of calcareous nannofossils in the region of the Southern Ocean. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 67:157-178.
- Wise, S. W., Jr., Ciesielski, P. F., MacKenzie, D. T., Wind, F. H., Busen, K. E., Gombos, A. M., Haq, B. U., Lohmann, G. P., Tjalsma, R. C., Harris, W. K., Hedlund, R. W., Beju, D. N., Jones, D. L., Plafker, G., and Sliter, W., 1980. Paleontologic and paleoenvironmental synthesis for the Southwest Atlantic Ocean basin based on Jurassic to Holocene faunas and floras from the Falkland Plateau. In Craddock, C. (Ed.), *Antarctic Geoscience*: Madison (Univ. Wisconsin Press), 155-163.
- Wise, S. W., and Wind, F. H., 1977. Mesozoic and Cenozoic calcareous nannofossils recovered by DSDP Leg 36 drilling on the Falkland Plateau, Southwest Atlantic sector of the southern ocean. In Barker, P. F., Dalziel, I.W.D., et al., *Init. Repts. DSDP*, 36: Washington (U.S. Govt. Printing Office), 269-491.
- Zimmerman, H. B., Boersma, A., and McCoy, F. W., 1987. Carbonaceous sediments and paleoenvironment of the Cretaceous South Atlantic Ocean. In Brooks, J., and Fleet, A. J. (Eds.), *Marine Petroleum Source Rocks*: Oxford (Blackwell Scientific Publications, Ltd.), Geol. Soc. London., Spec. Publ., 26:271-286.

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APPENDIX

List of species mentioned in the text, arranged in alphabetical order by generic epithets.

- Axopodorhabdus dietzmannii* (Reinhardt, 1965) Wind and Wise (1983)
- Bidiscus rotatorius* Bukry (1969)
- Biscutum constans* (Gorka, 1957) Black in Black and Barnes (1959)
- Calcicalathina oblongata* (Worsley, 1971) Thierstein (1971)
- Chiastozygus litterarius* (Gorka, 1957) Manivit (1971)
- Coccolithus pelagicus* (Wallich, 1877) Schiller (1930)
- Conusphaera mexicana* Trejo (1969)
- Corolithion achylosum* (Stover, 1966) Thierstein (1971)
- Corolithion covingtonii*, Mutterlose and Wise, n. sp.
- Corolithion helotatus* Wind and Wise in Wise and Wind (1977)
- Corolithion geometricum* (Gorka, 1957) Manivit (1971)
- Corolithion silvaradion* Filewicz, Wind and Wise in Wise and Wind (1977)
- Cretarhabdus angustiforatus* (Black, 1971) Bukry (1973)
- Cretarhabdus conicus* Bramlette and Martini (1964)
- Cretarhabdus crenulatus* Bramlette and Martini (1964)
- Cretarhabdus loriei* Gartner (1968)
- Cretarhabdus schizobrachiatus* (Gartner, 1968) Bukry, 1969
- Crucibiscutum salebrosum* (Black, 1971) Jakubowski (1986)
- Crucellipsius cuvillieri* (Manivit, 1966) Thierstein (1971)
- Cyclagelosphaera deflandrei* (Manivit, 1966)
- Cyclagelosphaera margerelii* Noël (1965)
- Diadorhombus rectus* Worsley (1971)
- Diazomatolithus lehmannii* Noël (1965)
- Eiffelithus turrisseiffelii* (Deflandre in Deflandre and Fert, 1954) Reinhardt (1965)
- Eprolithus apertior* Black (1973)
- Eprolithus varolii* Jakubowski (1986)
- Esgia junior* Worsley (1971)
- Ethmorhabdus gallicus* (Black, 1971) Applegate et al. in Covington and Wise (1987)
- Flabellites biforaminis* Thierstein (1973)
- Gartnerago confossus* (Noël, 1969) Noël (1972)
- Glaukolithus diplogrammus* (Deflandre and Fert, 1954) Reinhardt (1964)

- Grantarhabdus coronadventis* (Reinhardt, 1966) Grün in Grün and Al-
lemann (1975)
- Grantarhabdus meddii* Black (1971)
- Lithraphidites carniolensis* Deflandre (1963)
- Manivitella pemmatoidea* (Reinhardt, 1966) Thierstein (1977)
- Micrantholithus hoschulzii* (Reinhardt, 1966) Thierstein (1971)
- Micrantholithus obtusus* Stradner (1963)
- Microstaurus chiastius* (Worsley, 1971) Grün in Grün and Allemann
(1975)
- Nannoconus globulus* Brönnimann (1955)
- Nannoconus truitii* Brönnimann (1955)
- Polypodorhabdus madingleyensis* Black (1968)
- Reinhardtites fenestratus* (Worsley, 1971) Thierstein in Roth and Thier-
stein (1972)
- Repagulum parvidentatum* (Deflandre and Fert, 1954) Forchheimer (1972)
- Rhagodiscus achylostaurion* (Hill, 1976) Crux (1981)
- Rhagodiscus angustus* (Stradner, 1963) Reinhardt (1971)
- Rhagodiscus asper* (Stradner, 1963) Reinhardt (1967)
- Rotelapillus laffittei* (Nöel, 1957) Nöel (1973)
- Seribiscutum primitivum* (Thierstein, 1974) Filewicz, Wind and Wise in
Wise and Wind (1983)
- Sollasites falklandensis* Filewicz, Wind and Wise in Wise and Wind
(1977)
- Sollasites horticus* (Stradner, Adamiker and Maresch, 1966) Cepek and
Hay (1969)
- Speetonia colligata* Black (1971)
- Stephanolithion bigotii brevispinus* Wind and Wise in Wise (1983)
- Tegumentum stradneri* Thierstein in Roth and Thierstein (1972)
- Tegumentum striatum* (Black, 1971) Crux (1989)
- Tegumentum tenuis* (Black, 1971) Crux (1989)
- Tetrapodorhabdus decorus* (Deflandre and Fert, 1954) Wind and Wise
in Wise and Wind (1977)
- Tranolithus gabalus* Stover (1966)
- Tranolithus orionatus* Reinhardt (1966) Perch-Nielsen (1968)
- Tubodiscus verena* Thierstein (1973)
- Vagalapilla matalosa* (Stover, 1966) Thierstein (1973)
- Vekshinella dibrachiata* Gartner (1968)
- Vekshinella quadriarculla* Nöel, 1965) Rood, Hay, and Barnard (1971)
- Vekshinella stradneri* Rood, Hay, and Barnard (1971)
- Watznaueria barnesae* (Black in Black and Barnes, 1959) Perch-Nielsen
(1968)
- Watznaueria biporta* Bukry (1969)
- Watznaueria britannica* (Stradner, 1963) Reinhardt (1964)
- Watznaueria ovata* Bukry (1969)
- Watznaueria supracretacea* (Reinhardt, 1965) Wind and Wise in Wise
and Wind (1977)
- Zeugrhabdotus choffati* Rood, Hay, and Barnard (1973)
- Zeugrhabdotus embergeri* (Nöel, 1958) Perch-Nielsen (1985)
- Zeugrhabdotus erectus* (Deflandre, 1954) Reinhardt (1965)
- Zeugrhabdotus salillum* (Nöel, 1965) Rood, Hay, and Barnard (1971)

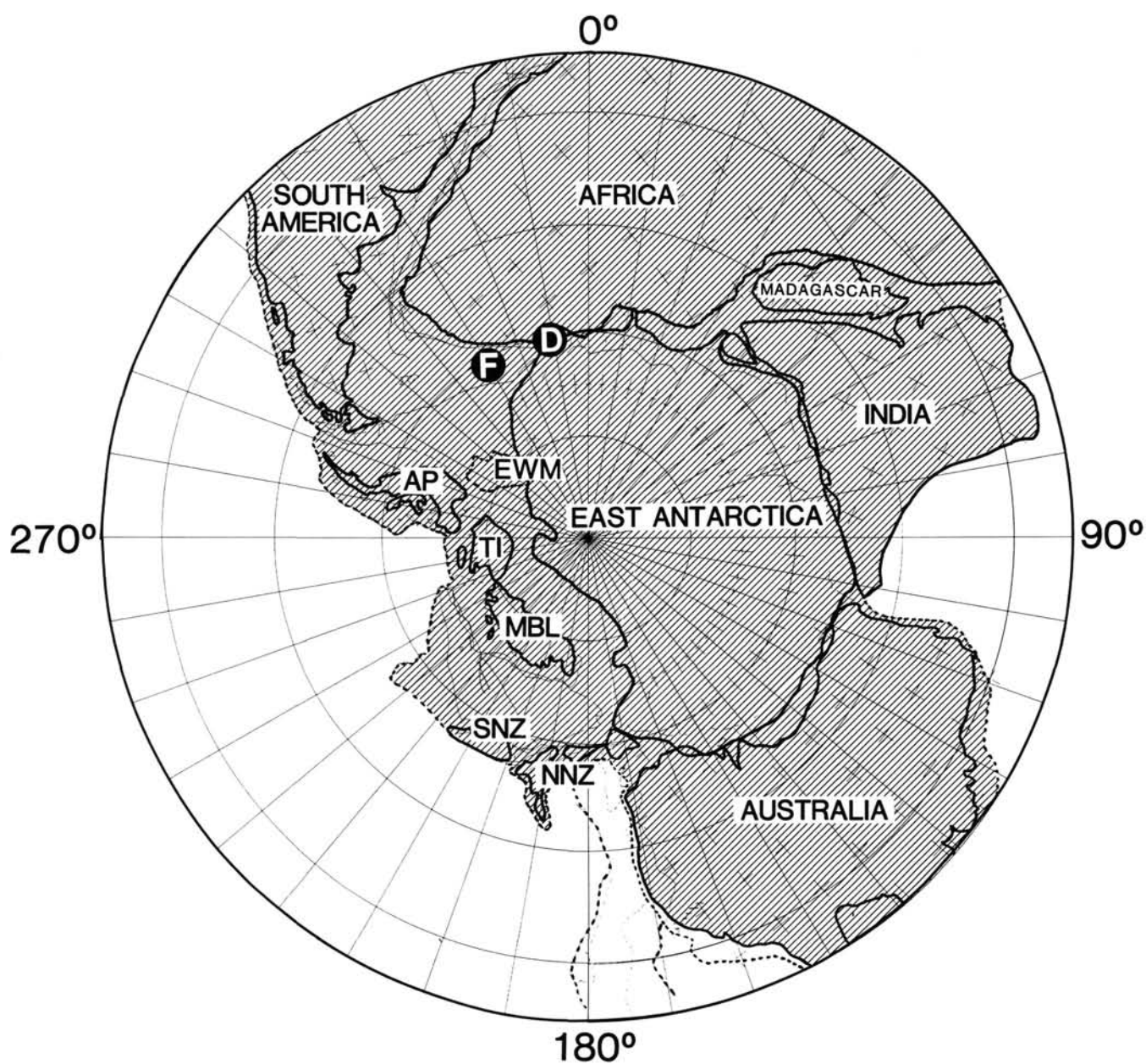


Figure 9. Early Mesozoic "tight" reconstruction of Gondwanaland (from Lawver et al., in press). F = eventual location of DSDP Sites 327, 330, and 511 drilled on the Falkland Plateau, D = eventual locations of ODP Sites 692 and 693 drilled off Dronning Maud Land of Antarctica. AP = Antarctic Peninsula, MBL = Marie Byrd Land, SNZ = South New Zealand, NNZ = North New Zealand. Continental blocks are shaded and are reconstructed to a fixed East Antarctica.

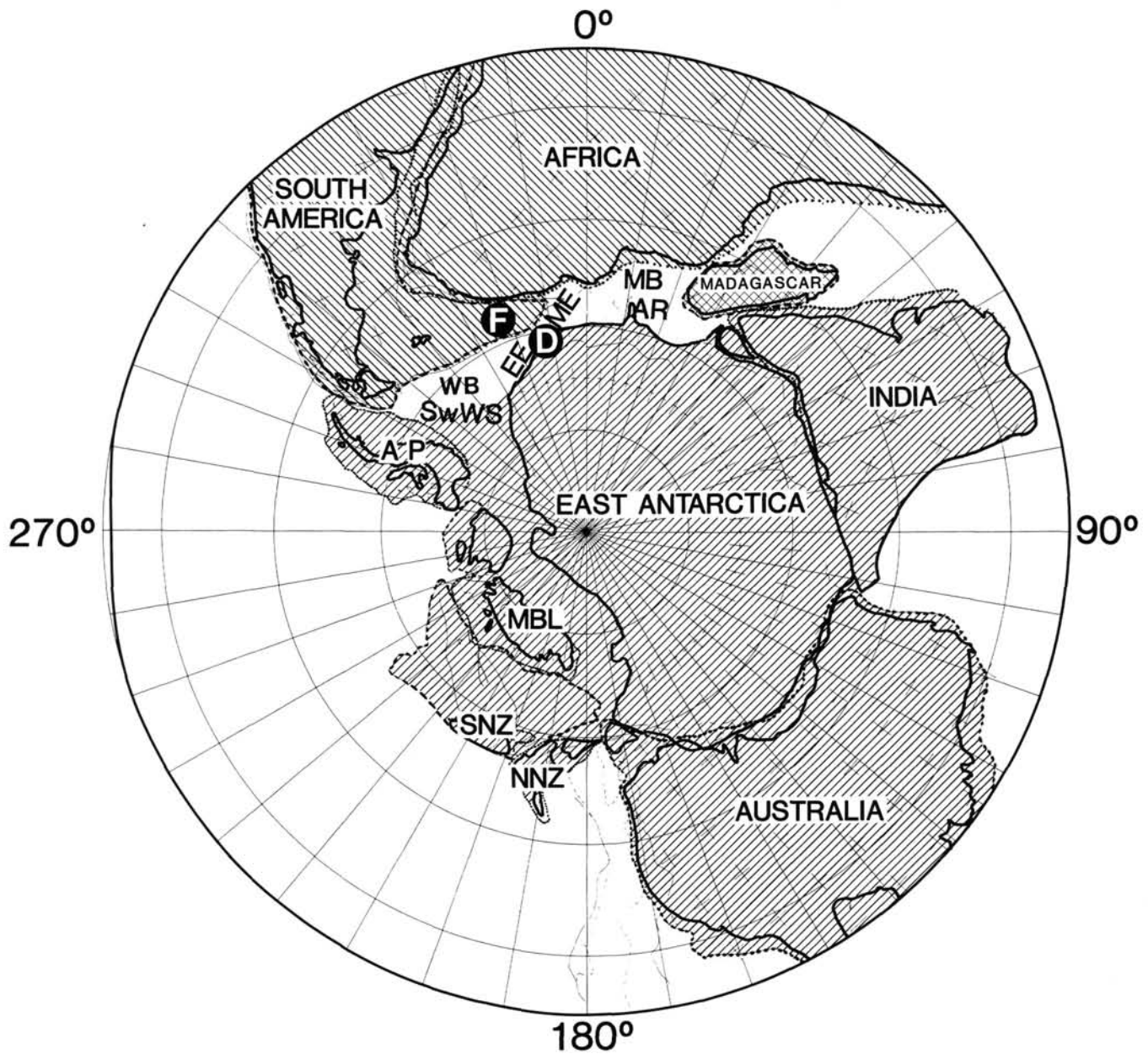


Figure 10. Magnetic anomaly M15 time (140 Ma; Late Jurassic) reconstruction of West Gondwanaland (from Lawver et al., in press) showing opening of the tectonically restricted Weddell and Mozambique Basins (WB and MB, respectively). A sheared transform margin has developed along the Explora Escarpment (EE). F = location of DSDP Sites 330 and 511, which recovered Jurassic sediment on the Falkland Plateau; D = position of ODP Sites 692 and 693, which apparently overlie Jurassic sediments; SwWS = Southwestern Weddell Sea, AR = Astrid Ridge (labels are not necessarily repeated on subsequent figures).

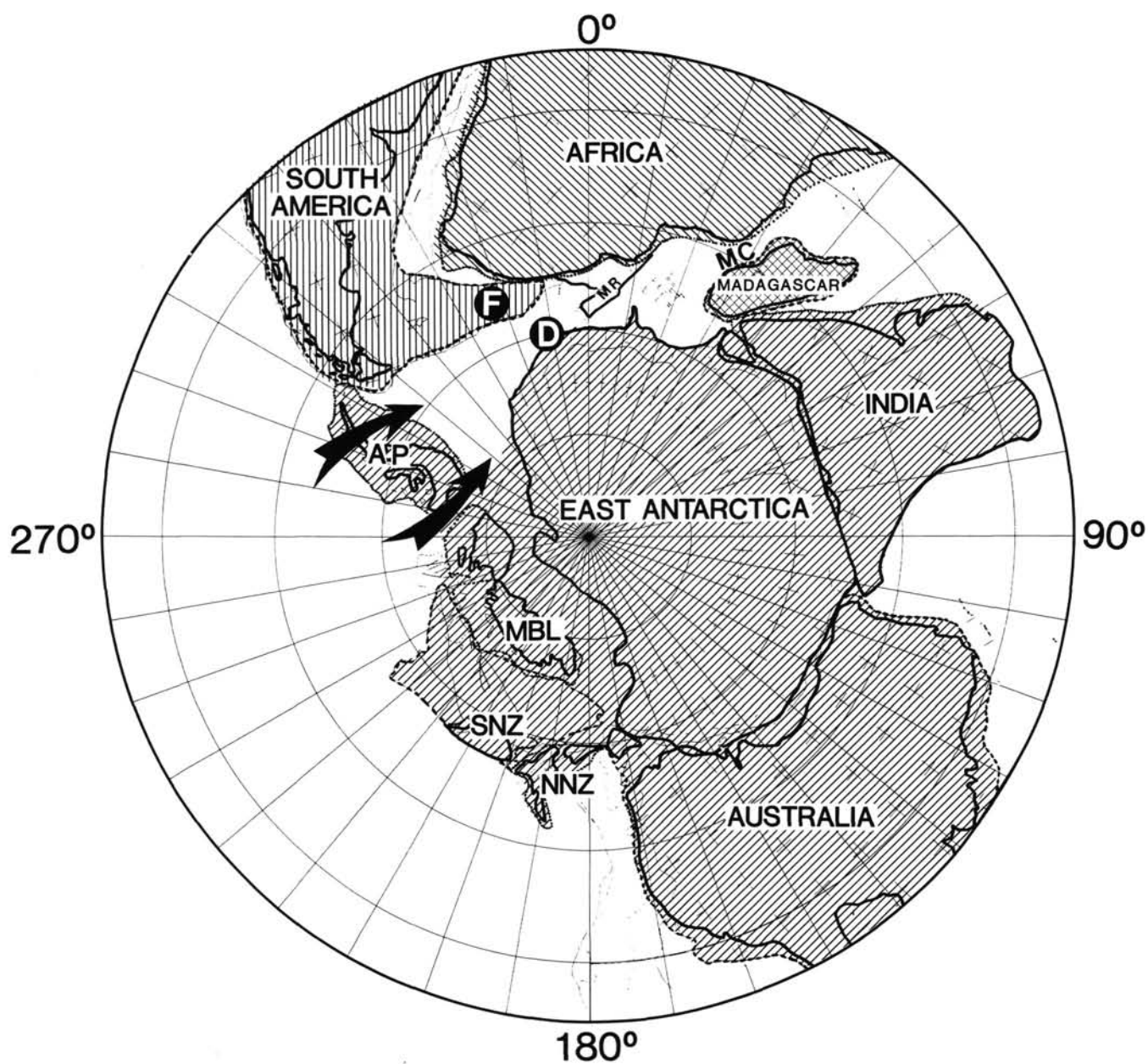


Figure 11. Magnetic anomaly M10 time (130 Ma; Valanginian) reconstruction of Gondwanaland (after Lawver et al., in press) showing initial opening of the Madagascar Channel (MC) and possible surface or deeper water connections to the Pacific through the Antarctic Peninsula (arrows). The Mozambique Ridge (MR) separates the Weddell and Mozambique Basins.

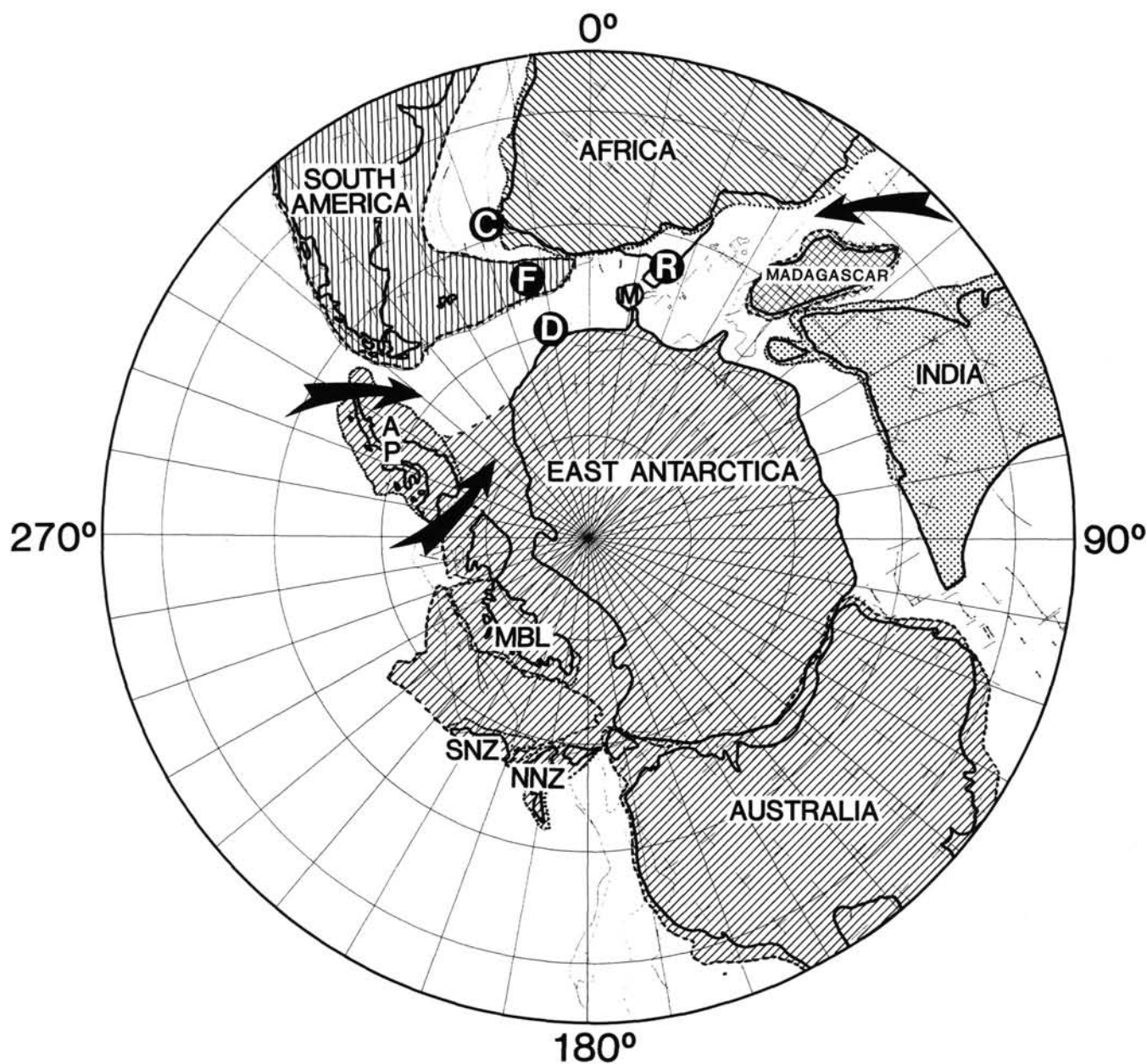


Figure 12. Magnetic anomaly MO time (118 Ma; Aptian) showing further opening of a moderately deep passage through the Madagascar Channel, separation between South America and the Antarctic Peninsula, and probable surface or deep water breaches through the Antarctic Peninsula (arrows). The juxtaposition of the Mozambique Ridge, Maud Rise (M), and Astrid Ridge serves to temporarily separate the Weddell and Mozambique Basins. C = Cape Basin DSDP Site 361, R = Mozambique Ridge DSDP Site 249.

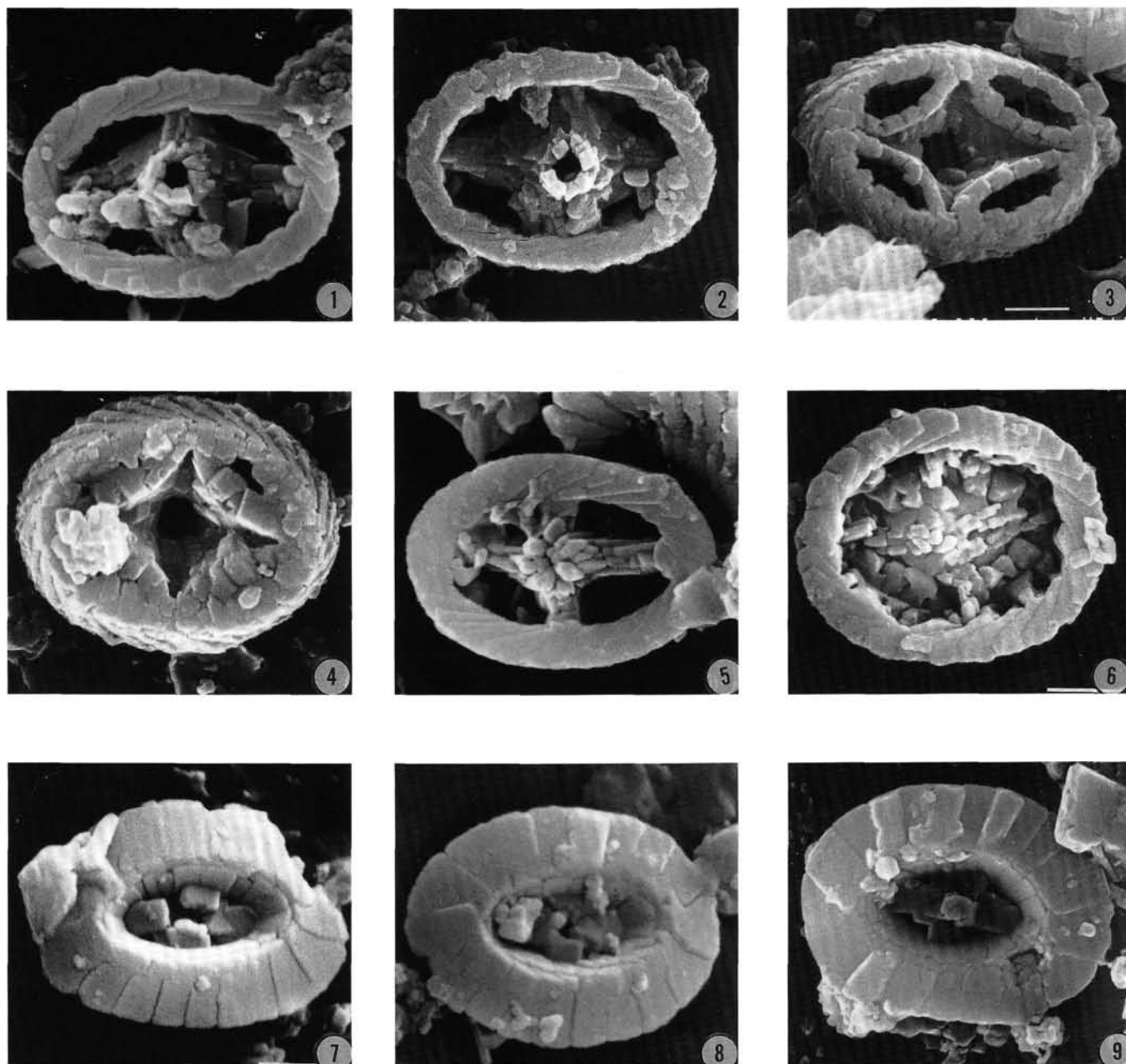


Plate 1. Note: All illustrations on the plates are scanning electron micrographs unless noted otherwise in the captions. P, D, and L denote proximal, distal, and lateral views, respectively. Abbreviations LM, TL, POL, and PH denote light micrograph, plain transmitted light, cross-polarized light, and phase contrast light micrograph, respectively. Ahmuellerellaceae and Biscutaceae from Hole 113-692B. 1-4. *Vekshinella quadriarculla* (Nöel) Rood et al. (1) D, $\times 12,000$, Sample 113-692B-10R-2, 103-106 cm. (2) D, $\times 11,500$, Sample 113-692B-10R-2, 103-106 cm. (3-4) P, $\times 10,500$, Sample 113-692B-12R-3, 50-52 cm. 5-6. *Vekshinella stradneri* Rood et al. (5) D, $\times 12,000$, Sample 113-692B-10R-2, 103-106 cm. (6) *Vekshinella* sp., D, $\times 12,250$, Sample 113-692B-10R-2, 103-106 cm. 7-9. *Crucibiscutum salebrosum* (Black) Jakubowski, D, Sample 113-692B-10R-2, 103-106 cm, (7) $\times 15,500$, (8) $\times 17,000$, (9) $\times 10,000$.

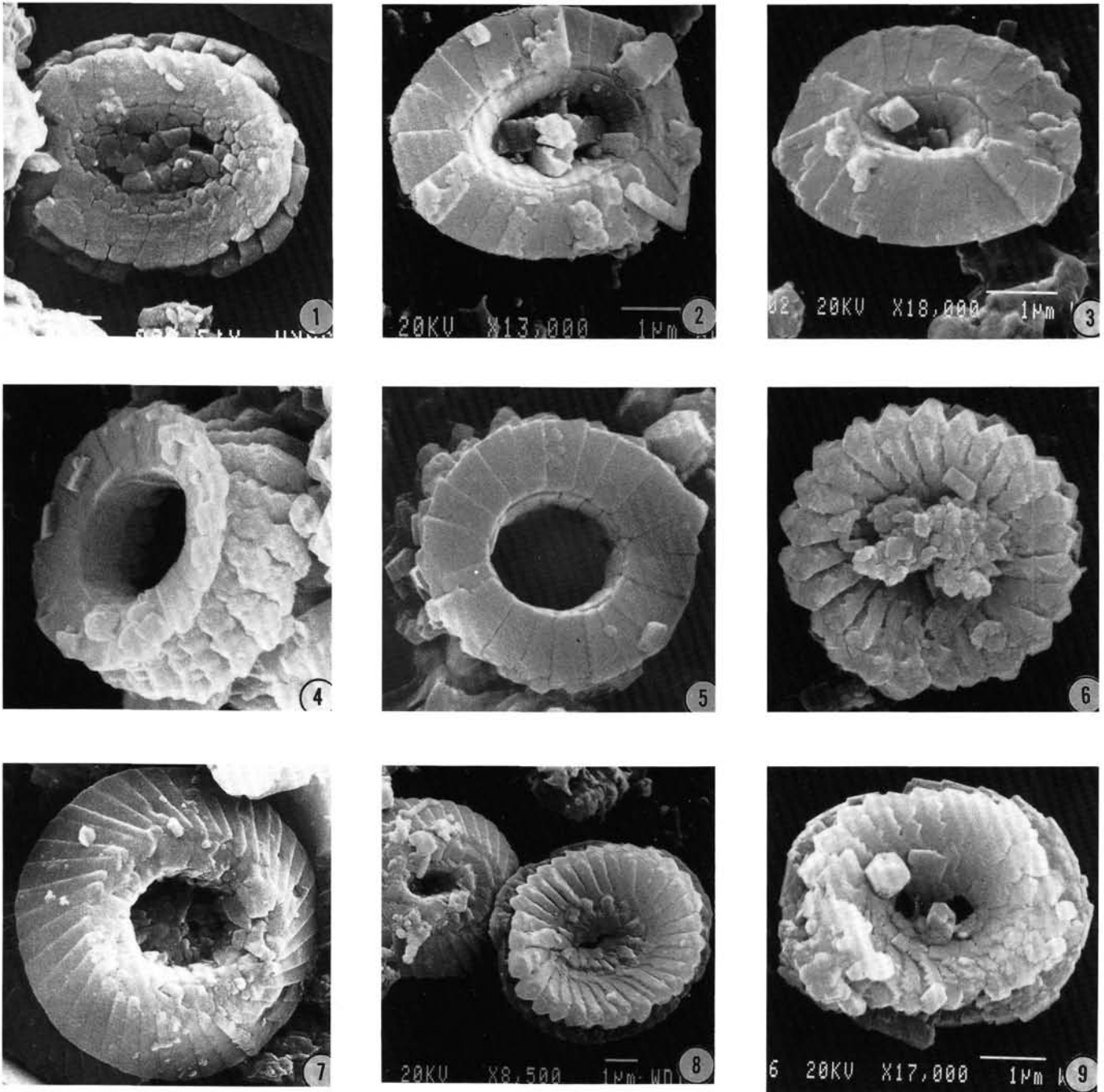


Plate 2. Biscutaceae, Crepidolithaceae, and Ellipsagelosphaeraceae from Hole 113-692B. 1-3. *Crucibiscutum salebrosum* (Black) Jakubowski; (1) P, $\times 10,000$, Sample 113-692B-10R-2, 103-106 cm; (2) D, $\times 9,250$, Sample 113-692B-10R-5, 82-84 cm; (3) D, $\times 11,500$, Sample 113-692B-12R-3, 50-52 cm. 4-5. *Diazomatolithus lehmanii* Noël; (4) L, $\times 11,500$, Sample 113-692B-12R-3, 50-52 cm; (5) P, $\times 15,000$, Sample 113-692B-12R-3, 50-52 cm. 6. *Cyclagelosphaera margerelii* Noël, P, $\times 10,500$, Sample 113-692B-10R-2, 103-106 cm. 7. *Cyclagelosphaera* sp., D, $\times 7,000$, Sample 113-692B-10R-2, 103-106 cm. 8. *Watznaueria barnesae* (Black in Black and Barnes) Perch-Nielsen, P and D, $\times 4,500$, Sample 113-692B-10R-5, 82-84 cm. 9. *Watznaueria britannica* (Stradner) Reinhardt, P, $\times 11,000$, Sample 113-692B-12R-3, 50-52 cm.

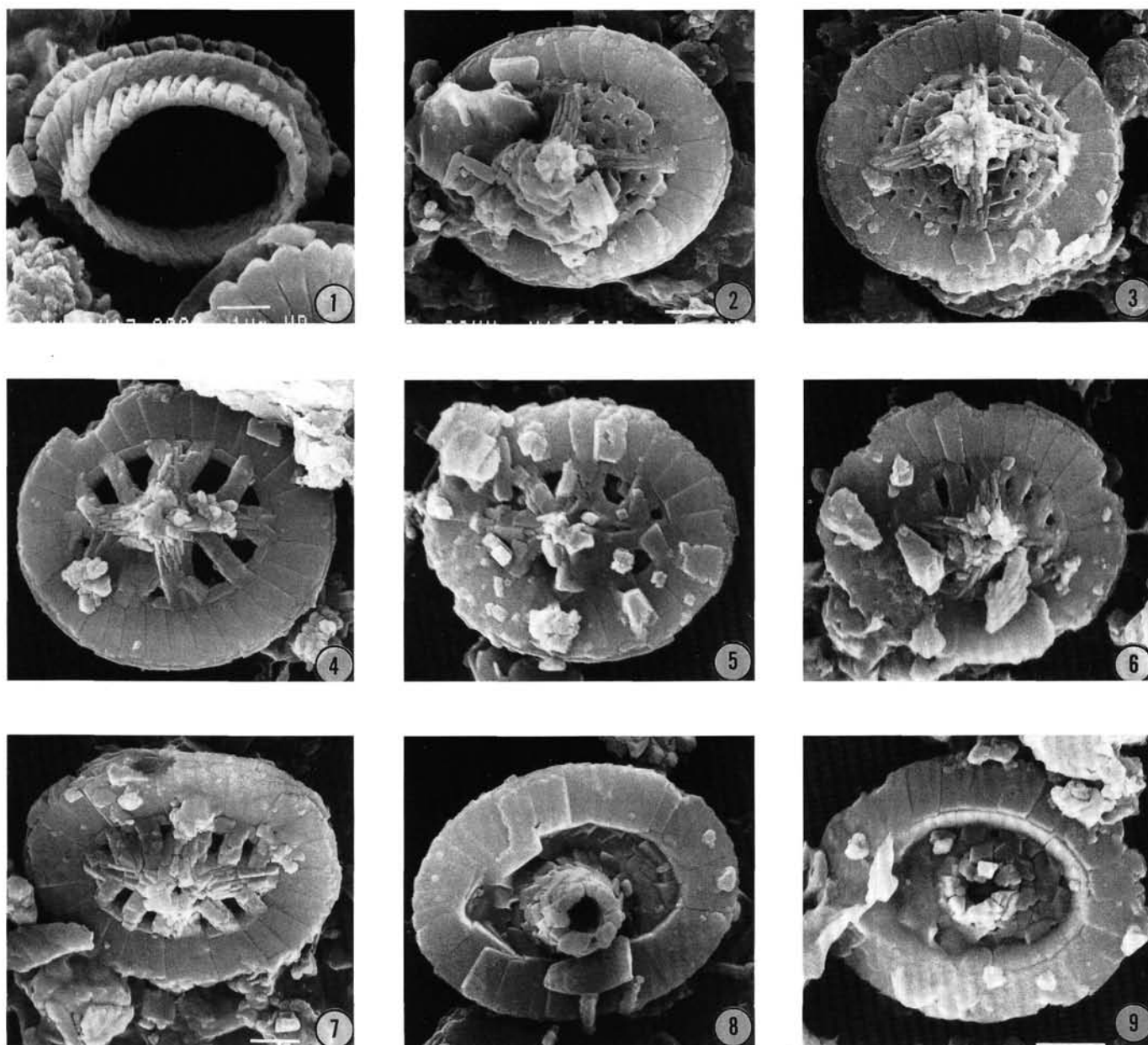


Plate 3. Ellipsagelosphaeraceae and Podorhabdaceae from Hole 113-692B. 1. *Tubodiscus* sp. cf. *T. verenae* Thierstein, D, $\times 9,500$, Sample 113-692B-10R-2, 103–106 cm. 2, 3. *Cretarhabdus conicus* Bramlette and Martini; (2) D, $\times 7,500$, Sample 113-692B-10R-2, 103–106 cm; (3) D, $\times 7,000$, Sample 113-692B-12R-3, 50–52 cm. 4, 5. *Cretarhabdus angustiforatus* Black, D, (4) $\times 7,500$, (5) $\times 8,500$, Sample 113-692B-10R-2, 103–106 cm. 6, 7. *Cretarhabdus crenulatus* (Bramlette and Martini) Grün in Grün and Allemann (1975), D, $\times 8,000$, Sample 113-692B-12R-3, 50–52 cm. 8, 9. *Perissocyclus*? sp., distal view; (8) $\times 10,000$, Sample 113-692B-10R-2, 103–106 cm; (9) $\times 11,000$, Sample 113-692B-12R-3, 50–52 cm.

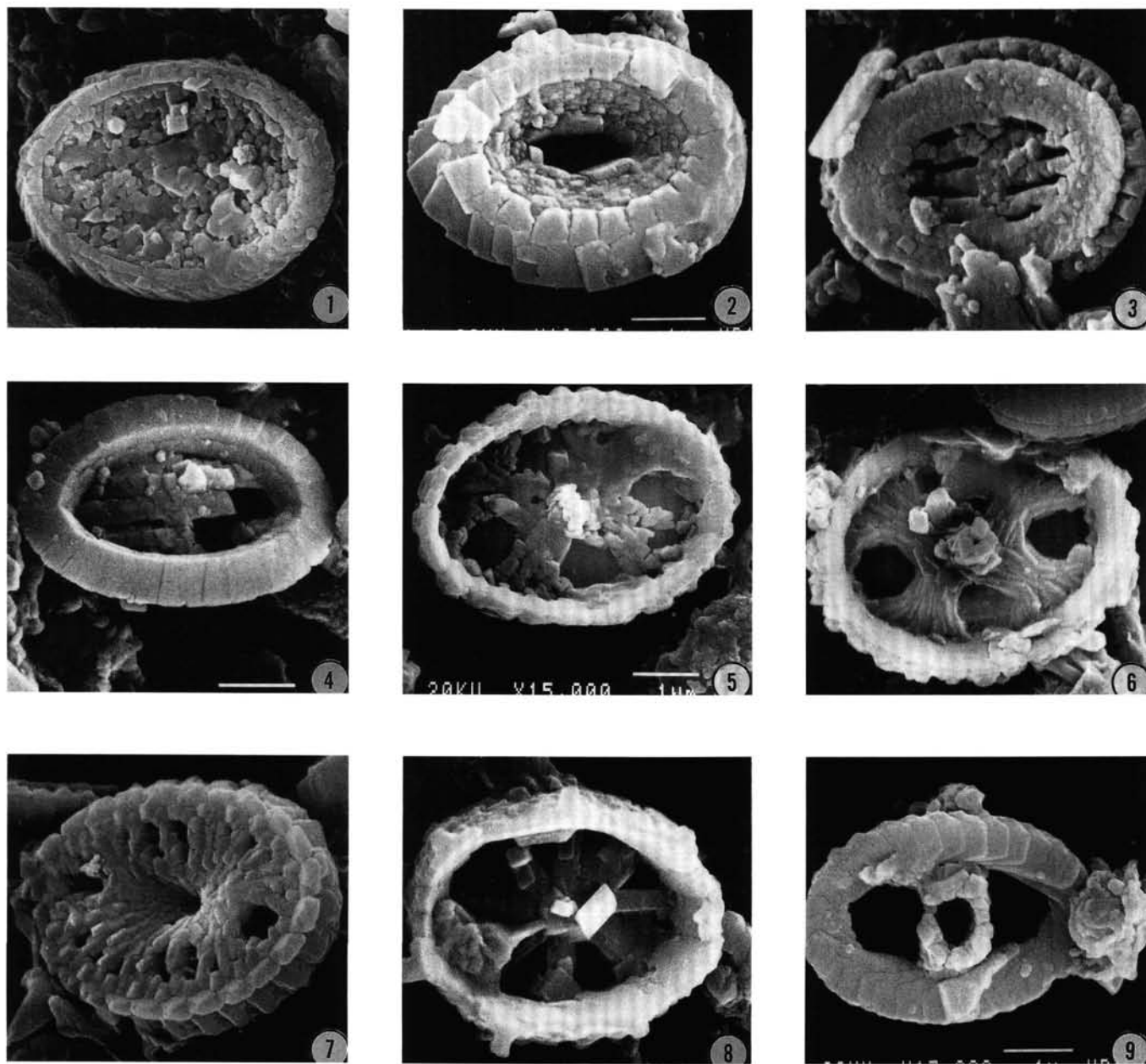


Plate 4. Rhagodiscaceae, Sollasitaceae, Stephanolithiaceae, and Zygodiscaceae of Holes 113-692B and 113-693A. 1. *Rhagodiscus asper* (Stradner) Reinhardt, P, $\times 8,000$, Sample 113-692B-10R-2, 103–106 cm. 2. *Watznaueria?* sp., $\times 11,500$, Sample 113-692-10R, 103–106 cm. 3, 4. *Sollasites horticus* (Stradner, Adamiker, and Maresch) Cepek and Hay; (3) P, $\times 11,000$, Sample 113-692B-10R-5, 82–84 cm; (4) D, $\times 12,000$, Sample 113-692B-12R-3, 50–52 cm. 5, 6. *Corollithion covingtonii* n. sp., D, Sample 113-692B-10R-2, 103–106 cm. (5) Isotype, $\times 10,400$ (6) holotype, $\times 9500$. 7. *Corollithion silvaradion* Filewicz, Wind and Wise in Wise and Wind, P, $\times 11,000$, Sample 113-692B-10R-2, 103–106 cm. 8. *Rotelapillus laffittei* Noël, D, $\times 12,000$, Sample 113-692B-12R-3, 50–52 cm. 9. *Zeughrabdotus choffatii* Rood, Hay, and Barnard, D, $\times 13,500$, Sample 113-692B-10R-2, 103–106 cm.

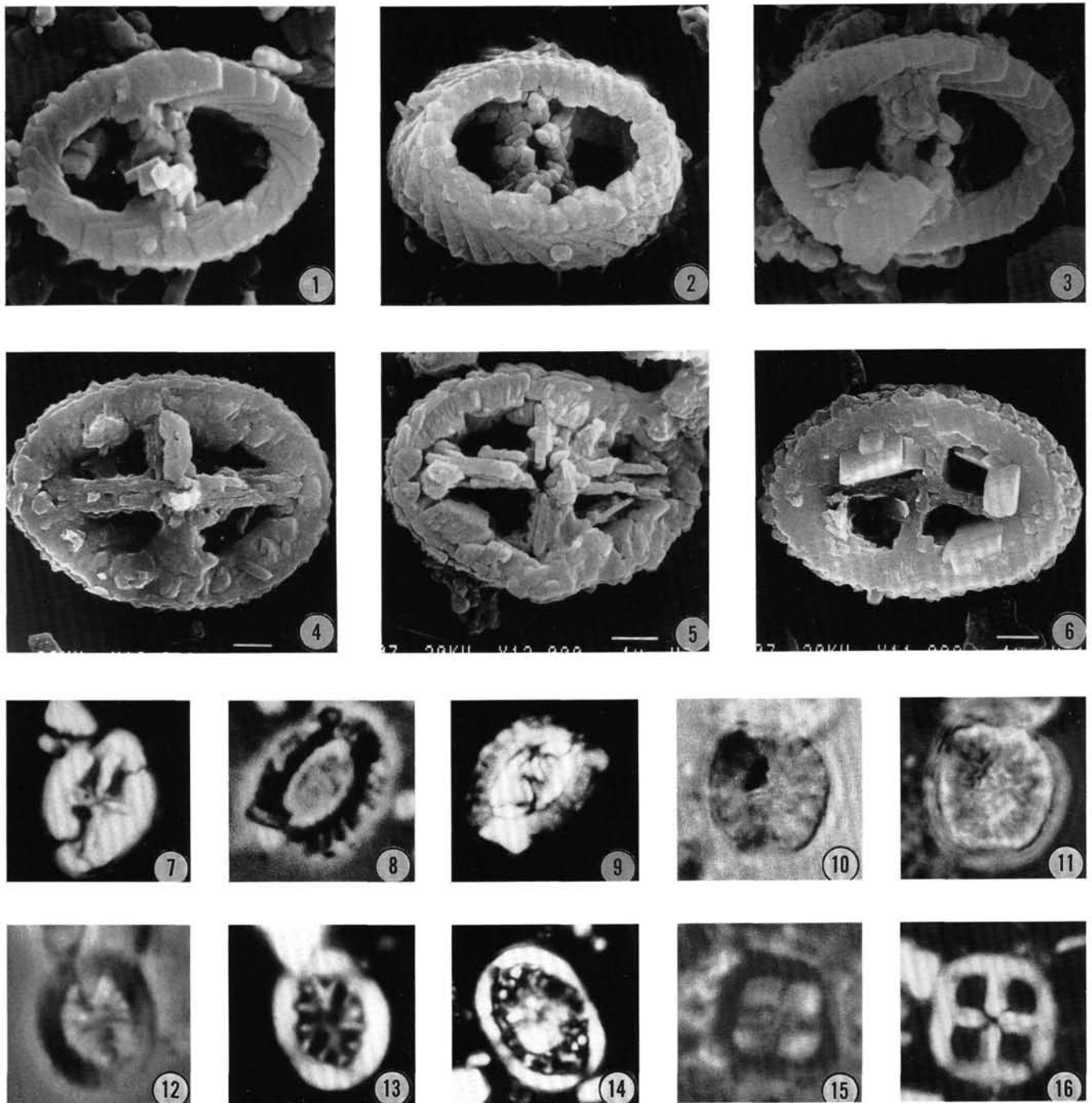


Plate 5. Zygodiscaceae of Hole 113-692B, Ahmuellerellaceae of Hole 113-693A, and light micrographs. 1. *Zeugrhabdotus* sp. $\times 14,500$, Sample 113-692B-10R-2, 103-106 cm. 2. *Zeugrhabdotus* sp., P, $\times 12,000$, Sample 113-692B-10R-2, 103-106 cm. 3. *Zeugrhabdotus* sp. cf. *Z. erectus* (Deflandre) Reinhardt, $\times 12,000$, Sample 113-692B-12R-3, 50-52 cm. 4-7. *Vagalapilla matalosa* (Stover) Thierstein; (4) D, $\times 6,500$, Sample 113-693A-46R-1, 110-112 cm; (5) D, $\times 7,500$, Sample 113-693A-49R-2, 7-9 cm; (6) P, $\times 7,200$, Sample 113-693A-46R-1, 110-112 cm; (7) LM, $\times 3,200$, Sample 113-693A-46R-1, 110-112 cm. 8, 9. *Crucibiscutum salebrosum* (Black) Jakubowski, LM; (8) PH, $\times 3,700$, (9) POL, $\times 4,000$, Sample 113-692B-9-2, 91-92 cm. 10, 11. *Nannoconus truitii* Brönnimann, LM; (10) TL, $\times 2,300$, (11) PH, $\times 2,300$, Sample 113-693A-47R-1, 60 cm. 12, 13. *Cretarhabdus angustiforatus* Black, LM; (12) PH, $\times 3,850$, (13) POL, $\times 3,850$, Sample 113-693A-47R-1, 59-62 cm. 14. *Rhagodiscus* sp. aff. *R. asper* LM POL, $\times 2,800$, Sample 693A-47R-1, 60 cm. 15, 16. *Diadorhombus rectus* Worsley (1971), LM; (15) PH, $\times 4,550$, (16) POL, $\times 4,800$, Sample 113-692B-12R-3, 50-52 cm.

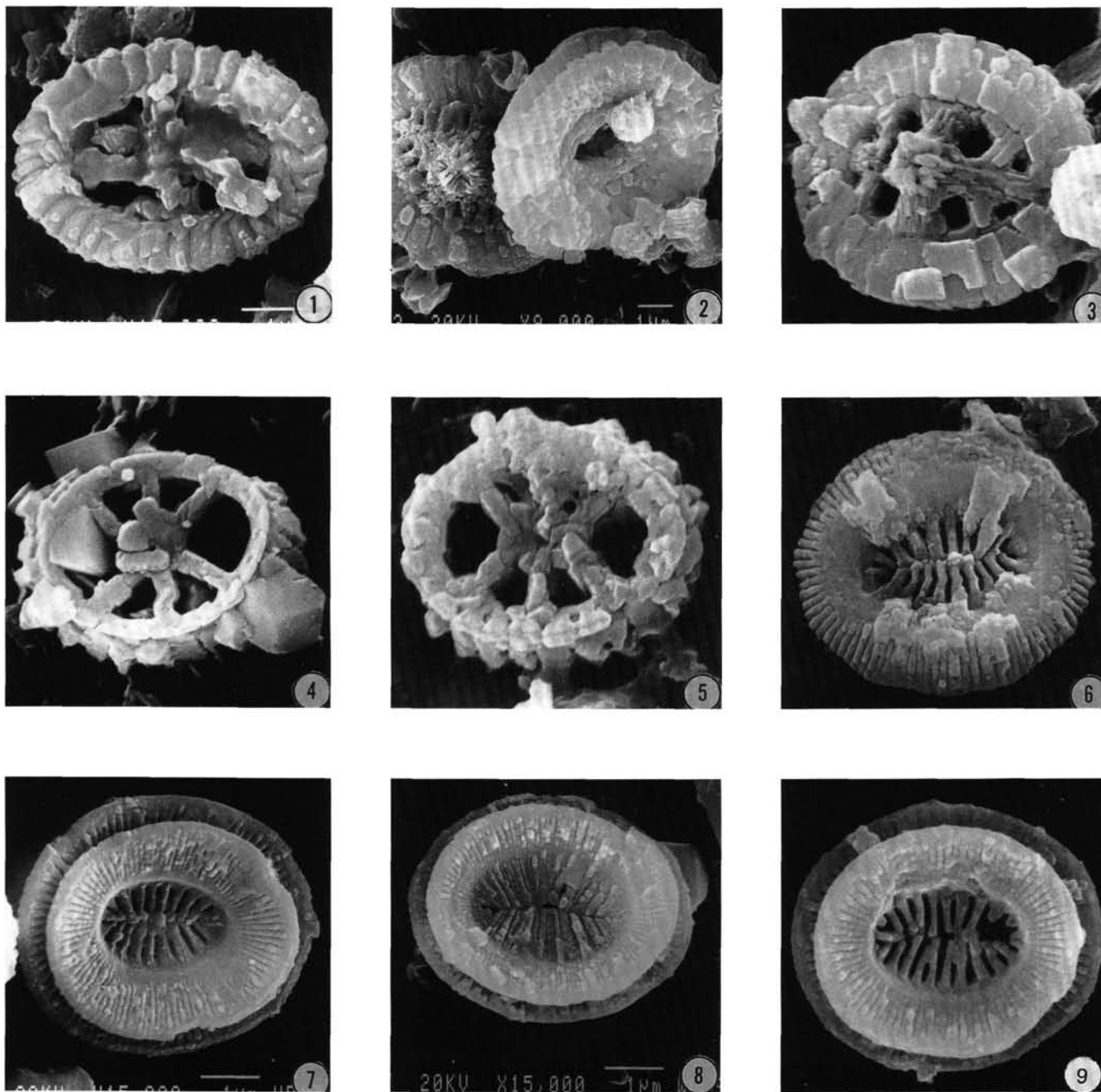


Plate 6. Ahmuellerellaceae, Podorhabdaceae, Stephanolithiaceae, and species *incertae sedis* of Hole 113-693A. 1. *Vekshinella* sp. D $\times 16,000$, Sample 113-693A-46-1, 110–112 cm. 2. *Polypodorhabdus madingleyensis* Black, D, $\times 10,500$, Sample 113-693A-46-1, 110–112 cm. 3. *Cretarhabdus angustiforatus* Black, D, $\times 11,500$, Sample 113-693A-49-2, 7–9 cm. 4, 5. *Corollithion geometricum* (Gorka) Manivit, P, Sample 113-693A-49-2, 7–9 cm; (4) $\times 10,000$, (5) $\times 13,000$. 6–9. *Repagulum parvidentatum* (Deflandre and Fert) Forchheimer, Sample 113-693A-46-1, 110–112 cm; (6) D, $\times 13,500$; (7, 8) P, $\times 17,500$, (9) P, $\times 16,000$.