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2. ICHTHYOLITH BIOSTRATIGRAPHY OF DEEP-SEA CLAYS FROM THE SOUTHWESTERN HAWAIIAN ARCH[1]

John V. Firth[2] and Donna Meyerhoff Hull[3]

ABSTRACT

Sixty-nine ichthyolith taxa have been identified in otherwise unfossiliferous red clays from Cores 136-842B-3H, -4H, and -5H at Ocean Drilling Program Site 842 on the Hawaiian Arch. Based on correlation with previous studies of ichthyoliths, these assemblages indicate that sediments from 21.53 to 31.10 mbsf are of early Miocene age. Ichthyolith-bearing sediments below this interval, from 31.10 to 35.57 mbsf, are Oligocene to early Miocene in age, whereas overlying clays from 21.53 to 19.05 mbsf are early to middle Miocene in age. Reworked ichthyoliths of Cretaceous to Eocene age are present in the cores, suggesting an exposed source of sediments of these ages during the early Miocene.

INTRODUCTION

The major objective of Leg 136 of the Ocean Drilling Program (ODP) was to drill a test site for developing ocean bottom seismometers that would eventually be placed around the Earth's oceans as the Ocean Seismographic Network. Secondary objectives were to recover the deep sea sediments and ocean crust at this site, located about 100 miles southwest of Hawaii (Fig. 1), and to study the nature and history of the crust through which the nearby Hawaiian volcanic chain emerged. The sediments consist of about 35 m of clays and silty clays with variable amounts of ash, radiolarians, and sponge spicules, overlying about 200 m of claystones and chert with some intercalated nannofossil ooze. The base of the sedimentary sequence, just overlying basaltic basement, consists of limestone (Dziewonski, Wilkens, Firth, et al., 1992). In Hole 842B, the middle and lower parts of Core 136-842B-3H, and Cores 136-842B-4H and -5H (from 19.05 to 35.57 meters below seafloor [mbsf]) contain dark reddish brown clays with altered volcanic ash layers. These sediments were barren of all microfossils except for ichthyoliths. A preliminary ichthyolith age determination of the cores based on two core-catcher samples was made on ship (Dziewonski, Wilkens, Firth, et al., 1992). This paper presents a more detailed analysis of the ichthyolith assemblages recovered from these cores and their significance for determining the age of the ash-bearing clays.

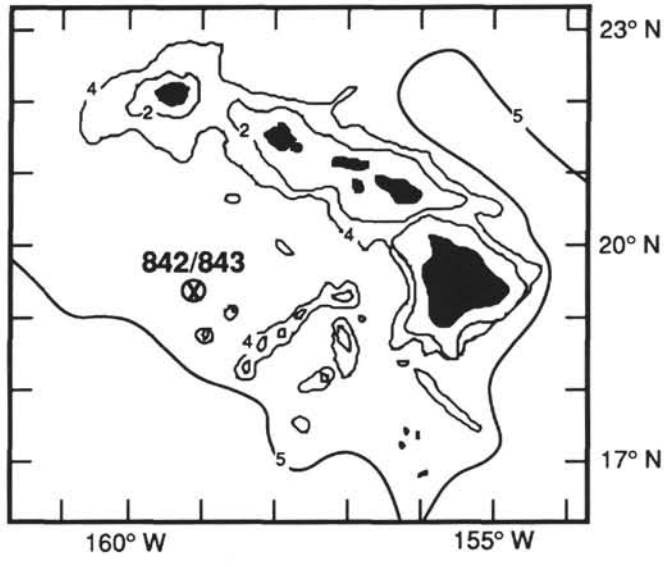


Figure 1. Location map showing Sites 842 and 843 drilled southwest of Hawaii on the Hawaiian Arch. Bathymetry in thousands of meters.

METHODS

Samples of 10–15 cm^3 were disaggregated by boiling for 2–4 min in a 50:50 mixture of water and hydrogen peroxide, with Calgon added as a clay-dispersant. After boiling, samples were sieved and gently washed through 60, 100, and 230 mesh stainless steel sieves. Residues from each sieve were collected into filter paper and dried in a laboratory oven. Ichthyoliths were picked from the residues and mounted on glass slides, with cover slips fastened with Norland Optical Adhesive. The slides were studied using transmission light microscopy at 50× magnification.

Samples were not weighed before processing; therefore, we could not determine absolute abundances of the different taxa. In some samples, ichthyoliths were too abundant to pick all of them. Therefore, we concentrated on collecting just the presence/absence data for all previously described taxa found in each sample, as well as for a few unnamed forms. After producing an initial range chart, the sample residues were reexamined to fill in and double check the ranges of identified forms, especially of taxa whose published stratigraphic ranges are useful for determining the age of these sediments.

The system of nomenclature developed by Doyle et al. (1974) and modified by Dunsworth et al. (1975), Ramsey et al. (1976), Doyle et al. (1978), Doyle and Riedel (1979b), Tway (1979), Gottfried et al. (1984a), Doyle and Riedel (1985b), Tway et al. (1985), and Winfrey et al. (1987) was followed in this paper.

RESULTS

The ranges of 69 taxa of ichthyoliths in Cores 842B-3H, -4H, and -5H are documented in Table 1. Of these, 5 taxa are considered to be reworked, whereas several other taxa may be either reworked or have extensions of their previously reported ranges. Five undescribed taxa are also documented. Many undescribed forms are not included in the results discussed in this paper. In fact, a large fraction of the assemblages in residue is composed of undescribed forms. Of the previously

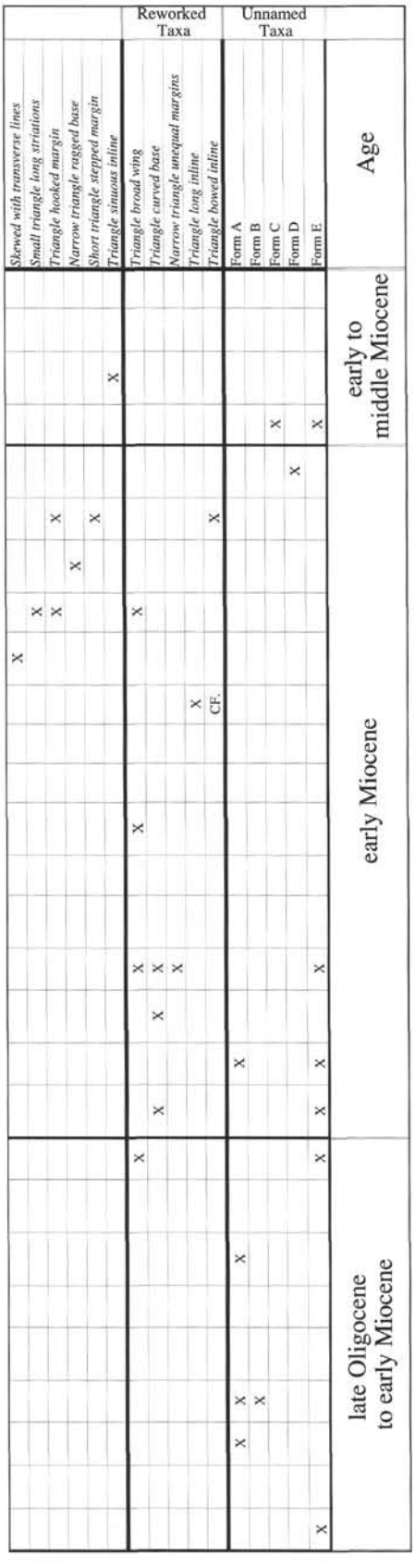
[1] Wilkens, R.H., Firth, J., Bender, J., et al., 1993. *Proc. ODP, Sci. Results,* 136: College Station, TX (Ocean Drilling Program).
[2] Ocean Drilling Program, Texas A&M University Research Park, 1000 Discovery Drive, College Station, TX 77845-9547, U.S.A.
[3] Program in Geosciences, The University of Texas at Dallas, P.O. Box 830688, Richardson, TX 75083-0688, U.S.A.

Table 1. Range chart showing presence/absence of selected ichthyolith taxa from Hole 842B.

5H-CC	5H-CC	4H-CC	4H-7	4H-6	4H-6	4H-5	4H-5	4H-5	4H-4	4H-4	4H-3	4H-3	4H-2	4H-2	4H-1	4H-1	3H-7	3H-7	3H-6	3H-6	3H-5	3H-5	3H-4	3H-4	3H-3	3H-3	3H-3	Sample (Core - Section)	Ichthyolith Taxa
12-14	9-11		20-22	129-131	19-21	129-131	109-112	22-24	129-131	19-21	130-132	19-21	131-133	19-21	130-132	19-21	64-66	4-6	124-126	27-29	122-124	27-29	122-124	25-27	123-125	79-81	24-26	Interval	
35.56	35.53	34.75	34.5	34.09	32.99	32.59	32.39	31.52	31.09	29.99	29.6	28.49	28.11	26.99	26.60	25.49	25.28	24.84	24.54	23.57	23.02	22.07	21.52	20.55	20.03	19.59	19.04	Depth (mbsf - top)	
35.58	35.55	34.8	34.52	34.11	33.01	32.61	32.42	31.54	31.11	30.01	29.62	28.51	28.13	27.01	26.62	25.51	25.30	24.86	24.56	23.59	23.04	22.09	21.54	20.57	20.05	19.61	19.06	Depth (mbsf - bottom)	
X	X	X										X	X					X				X						*Kite shaped longitudinal line*	
X																	X	X							CF.			*Triangle inward angle*	
X														X							X	X	X					*Flexed narrow triangle 120-128*	
X		X	X	X		X		X	X	X	X		X	X		X										X		*Triangle pointed margin ends*	
X		X						X			X			X	X			X		X	X		X		X			*cf. Triangle with pointed margin ends*	
X		X	X	X	X	X	X	X				CF.						X			X								*Plain and lined lanceolate*	
X		X	X	X		X		X				X			X				X	X				X					*Rectangular triangular toothed*	
X						X			X	X	X	X	X	CF.	CF.		X			X	CF.			X					*Triangle medium wing*	
X		X							X								X				X								*Triangle short wing*	
	CF.								X							CF.													*Two triangles*	
	X	X				X		X	X		X					X						CF.				X			*Triangle concave base*	
	X	X			X				X	X	X	X	X		X				X			X							*Triangle with canals*	
	X	X	X	X	X	X		X		X	X	X	X	X	X	X		X	X			X							*Triangle transverse line across*	
	X	X	X		X	X							X	X	X			X	X	X			CF.						*Polygonal cavity long rays*	
	X	X				X			X				X					X		X			X		X				*Polygonal cavity*	
	X	X		X							X		X	X		X	X			X	X	X	X						*Skewed 4 or 5 peaks*	
	X				X																								*Curved triangle pointed inline*	
	X									X				X			X					X	X						*Flexed triangle shallow inbase*	
	X																						X		X				*Rectangular sawtoothed*	
		X			X	X																							*Ogee lanceolate*	
		X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						*Triangle with triangular projection*	
		X							X						X			X					X						*Narrow triangle cross-hatchured*	
		X	X										CF.					X		X		X	X	X		X	X	*Triangle with high inline apex*	
		X											X	X				X		X									*Seven peaks*	
		X	X							X		X			X	X	X		X					X					*Wide triangle straight inbase*	
			X									X																	*Triangle double wing*	
			X		X					X																			*cf. Five peaks flared base*	
			X	X						X	X			X		X	X	X		X									*Flexed triangle shallow inbase ≥ 120*	
				X	X																	X	X	X					*Narrow triangle straight inbase*	
					X																								*Kite shaped irregular network*	
					X							X			X			X											*Asymmetrical peak wide depression*	
					X			X				X																	*Many peaks transverse lines*	
					X																								*Short kite shaped*	
					X	X		CF.				X			X										X				*Tanged triangle*	
					X	X		X				X	X								X								*Five peaks flared base*	
						X		X																					*cf. Pointed triangle short inline*	
									X																				*Kite shaped elongate prominence*	
									X						X	X				X	X								*Long triangle thin wall*	
									CF.									X											*Triangle with base angle*	
										X	X	X	X	X	X			X	X	X									*Rectangular irregularly sawtoothed*	
										X					X											X			*Large fibrous triangle*	
											X					X													*Three equal peaks flared base*	
												X																	*Elliptical with line across*	
													X							X	X		X						*Pointed triangle long margins*	
													X		X														*Small triangle crenate margin*	
														X									X						*Small dendritic many radiating lines*	
															X	X	X									X			*Curved triangle pointed margin*	
															X														*Asymmetrical peaks narrow depression*	
															X														*Triangle crenulate*	
															X														*Stippled triangle*	
															CF.		CF.								X		X		*Flexed triangle 102-112*	
																X													*cf. Triangle inline halfway*	
																X				X									*Triangle sigmoid*	

Notes: "X" indicates presence; "CF" indicates the presence of a comparable form to the listed taxon. Bold boxes mark where taxa have 5 or more specimens in a particular sample. Maximum previously reported age ranges of each named taxa are listed in Table 2, along with references used.

Table 1 (continued).



described taxa identified in our samples, only a few forms appear to be common, whereas the rest of the taxa are represented by less than 5 specimens per sample, and typically only one or two specimens per sample. Of the more common forms, *Triangle with triangular projection* is the most common, with 5 or more specimens per sample in 8 samples. Other forms that have 5 or more specimens per sample are *Polygonal cavity, Triangle transverse line across,* and *Triangle pointed margin ends.* The samples in which these forms are common are indicated on Table 1 by bold boxes around their occurrences. The following samples have poor preservation and/or few (<100) total specimens found in the residues: 136-842B-4H-6, 129–131 cm; -4H-5, 109–112 cm; -3H-3, 123–125 cm; -3H-3, 79–81 cm; and -3H-3, 24–26 cm. All other samples have several hundred specimens, and have good preservation.

Because of the presence of reworked forms in the cores, only first occurrences of index taxa are considered reliable for age determinations. Most ichthyolith taxa are long-ranging, and because of the absence of other microfossil groups, only broad age assignments can be established for these cores. Age determinations were based on the cumulative age ranges of each taxa published in the extensive DSDP/ODP and journal literature (Table 2).

Based on the successive first occurrences of *Two triangles* (sensu Doyle et al., 1974), *Stippled triangle, Small triangle long striations, Narrow triangle ragged base,* and *Short triangle stepped margin,* the interval from Sample 842B-4H-4, 129–131 cm (31.10 mbsf), to Sample 136-842B-3H-4, 122–124 cm (21.53 mbsf), is of early Miocene age (Fig. 2).

The interval from Section 136-842B-5H-CC to Sample 136-842B-4H-5, 109–112 cm (32.40 mbsf), lacks taxa that are exclusively indicative of Miocene or younger age. One specimen referred to herein as cf. *Two triangles* Doyle et al. (1974) occurs in Sample 136-842B-5H-CC, 9–11 cm (35.54 mbsf). This specimen possesses two closely spaced triangular projections with a well-developed inline that closely parallels the outer margin. The original description (Doyle et al., 1974, p. 845) describes this form as "two simply triangular projections, widely spaced, arising from a short, stubby base." No reference to the character of the inline is mentioned, and all illustrated specimens in Doyle et al. (1974) and Doyle and Riedel (1985a) either lack an inline or possess an inline in only one triangular projection. If we consider our specimen to fit within the original definition of this taxon, the interval from Sample 136-842B-5H-CC, 9–11 cm, to Sample 136-842B-4H-5, 22–24 cm, may be assigned to the lower Miocene (based on range reported in Doyle and Riedel, 1985a). Two other possibilities exist: (1) the range of *Two triangles* may be extended into the Oligocene, or (2) this specimen does not fall within the morphotypic range of *Two triangles.* In either case, the age of Sample 136-842B-5H-CC, 9–11 cm, and of the lower part of Core 136-842B-4H may be restricted to the late Oligocene or younger based on the occurrences of *Skewed 4 or 5 peaks* and *Asymmetrical peak wide depression* (Tables 1 and 2). Based on the occurrence of *Flexed triangle 120–128,* the age of Sample 136-842B-5H-CC, 12–14 cm, may be early Oligocene or younger (Doyle and Riedel, 1985a), or late Eocene or younger (Kozarek and Orr, 1979).

The last occurrences of *Skewed 4 or 5 peaks* and *Triangle short wing* in Sections 136-842B-3H-5 and -3H-4 may indicate an age of middle Miocene above this level (based on reported ranges from Kozarek and Orr, 1979, and Doyle and Riedel, 1985a, respectively). Because of scattered occurrences of these taxa throughout the cores, and because of reworking evident by the presence of older forms, these last occurrences may not be reliable. Therefore, the interval from Samples 136-842B-3H-4, 25–27 cm (20.56 mbsf), to -3H-3, 24–26 cm (19.05 mbsf) is assigned an early to middle Miocene age.

The following taxa are reworked: *Triangle broad wing, Triangle curved base, Narrow triangle unequal margins, Triangle long inline* and *Triangle bowed inline.* These forms range in age from Upper Cretaceous to Eocene (Table 2), which indicates the exposure of older

Table 2. List of taxa and their previously reported age ranges and references.

Ichthyolith Taxa	Age range	References
Kite shaped longitudinal line	late Eocene–early Oligocene	Doyle et al., 1974
Triangle inward angle	middle Eocene–early middle Miocene	Gottfried et al., 1984a
Flexed narrow triangle 120–128	early Oligocene–Holocene	Doyle and Riedel, 1985a
Triangle pointed margin ends	Paleocene–early middle Miocene	Doyle and Riedel, 1985a
Plain and lined lanceolate	Cretaceous–middle Miocene	Winfrey et al., 1987 and Kozarek and Orr, 1979
Rectangular triangular toothed	Cretaceous–Pliocene	Kozarek and Orr, 1979
Triangle medium wing	early Paleocene–middle Miocene	Doyle and Riedel, 1985a
Triangle short wing	middle Paleocene–early middle Miocene	Doyle and Riedel, 1985a
Two triangles	early Miocene–Holocence	Doyle and Riedel, 1985a
Triangle concave base	Paleocene/early Eocene–middle Miocene	Kozarek and Orr, 1979
Triangle with canals	Cretaceous–Pliocene	Kozarek and Orr, 1979
Triangle transverse line across	Cretaceous–Pliocene	Kozarek and Orr, 1979
Polygonal cavity long rays	late Eocene–early Miocene	Kozarek and Orr, 1979
Polygonal cavity	Cretaceous?–early Miocene	Kozarek and Orr, 1979
Skewed 4 or 5 peaks	late Oligocene–early Miocene	Kozarek and Orr, 1979
Curved triangle pointed inline	early Eocene–late Pliocene	Tway et al., 1985
Flexed triangle shallow inbase	Cretaceous–Holocene	Kozarek and Orr, 1979
Rectangular sawtoothed	Oligocene–Holocene	Doyle and Riedel, 1985a
Ogee lanceolate	early Eocene–middle Miocene	Tway et al., 1985
Triangle with triangular projection	Cretaceous–Holocene	Kozarek and Orr, 1979
Narrow triangle cross-hachured	earliest Paleocene–middle Miocene	Kozarek and Orr, 1979
Triangle with high inline apex	early Oligocene–Holocene	Doyle and Riedel, 1985a
Seven peaks	late Eocene–latest Oligocene	Kozarek and Orr, 1979
Wide triangle straight inbase	early Eocene–Holocene	Kozarek and Orr, 1979
Triangle double wing	latest Eocene–middle Miocene	Kozarek and Orr, 1979
cf. *Five peaks flared base*	early Eocene–early Oligocene	Doyle et al., 1974
Flexed triangle shallow inbase ≥ 120	early Oligocene–late Miocene	Doyle and Riedel, 1985a
Narrow triangle straight inbase	early middle Eocene–Holocene	Kozarek and Orr, 1979
Kite shaped irregular network	early Eocene–Oligocene	Kozarek and Orr, 1979
Asymmetrical peak wide depression	early Oligocene–middle Miocene	Kozarek and Orr, 1979
Many peaks transverse lines	middle Eocene–Pliocene	Tway et al., 1985
Short kite shaped	middle Eocene–late Oligocene	Doyle et al., 1974
Tanged triangle	Paleocene–early Miocene	Gottfried et al., 1984a, b
Five peaks flared base	early Eocene–middle Miocene	Kozarek and Orr, 1979
cf. *Pointed triangle short inline*	early Eocene–middle Miocene	Gottfried et al., 1984a
Kite shaped elongate prominence	early Eocene–late Oligocene ?Paleocene	Doyle et al., 1974; Kozarek and Orr, 1979 Winfrey et al., 1987
Long triangle thin wall	early Eocene–late Oligocene	Kozarek and Orr, 1979
Triangle with base angle	late Eocene–Holocene	Doyle and Riedel, 1985a
Rectangular irregularly sawtoothed	Paleocene?/Eocene–Holocene	Doyle et al., 1979a, Gottfried et al., 1984b.
Large fibrous triangle	middle Paleocene–middle Miocene	Tway et al., 1985
Three equal peaks flared base	middle Eocene–early Oligocene	Kozarek and Orr, 1979
Elliptical with line across	middle Miocene–Holocene	Doyle and Riedel, 1985a
Pointed triangle long margins	middle Eocene–Pliocene	Gottfried et al., 1984a; Doyle and Riedel, 1985b
Small triangle crenate margin	early Eocene–early Oligocene	Doyle and Riedel, 1985a
Small dendritic many radiating lines	early Oligocene–Holocene	Doyle and Riedel, 1985a
Curved triangle pointed margin	middle Eocene–Holocene	Doyle and Riedel, 1985a
Asymmetrical peaks narrow depression	early Eocene–middle Miocene	Doyle et al., 1974
Triangle crenulate	late Eocene–Pliocene	Kozarek and Orr, 1979
Stippled triangle	Oligocene/Miocene boundary–Holocene	Doyle and Riedel, 1985a
Flexed triangle 102–112	late Oligocene–Pliocene	Doyle and Riedel, 1985a
cf. *Triangle inline halfway*	early Eocene–middle Miocene	Kozarek and Orr, 1979
Triangle sigmoid	early Eocene–Pliocene	Kozarek and Orr, 1979
Skewed with transverse lines	Oligocene–Miocene	Winfrey et al., 1987
Small triangle long striations	Oligocene/Miocene boundary–Holocene	Doyle and Riedel, 1985a
Triangle hooked margin	early Eocene–Holocene	Doyle and Riedel, 1985a
Narrow triangle ragged base	early Miocene–Holocene	Doyle and Riedel, 1985a
Short triangle stepped margin	Oligocene/Miocene boundary–Holocene	Doyle and Riedel, 1985a
Triangle sinuous inline	Oligocene/Miocene boundary–Holocene	Gottfried et al., 1984a
Triangle broad wing	middle Paleocene–middle Eocene	Doyle and Riedel, 1985a
Triangle curved base	early Paleocene–early Eocene	Doyle and Riedel, 1985a
Narrow triangle unequal margins	Paleocene	Doyle and Riedel, 1985b
Triangle long inline	Cretaceous–early Paleocene	Doyle et al., 1978
Triangle bowed inline	Cretaceous	Ramsey et al., 1976

sediments in the region. *Three equal peaks flared base* and *Small triangle crenate margin* have reported ranges of middle and upper Eocene to lower Oligocene, whereas *Seven peaks* and *Long triangle thin wall* have reported ranges into the upper Oligocene (Table 2). It is uncertain whether their occurrences in Hole 842B represent reworking or extensions of previously reported ranges.

The source and extent of exposed older sediments is unknown, but they indicate the occurrence of some form of lateral transport on the seafloor during the deposition of pelagic clays in the early Miocene. Early to middle Eocene radiolarians have been observed within ash layers in Core 842A-1H (Hull, this volume). The sediments in Core 842A-1H are of Quaternary age (Dziewonski, Wilkens, Firth et al., 1992). Similar mixtures of Eocene and Quaternary radiolarians have been reported at DSDP Sites 67 (Winterer, Riedel, et al., 1971) and 68 (Tracey, Sutton, et al., 1972), near the Hawaiian Arch. Similar processes of reworking and deposition are suggested during both the early Miocene and Quaternary at Site 842.

CONCLUSIONS

Ichthyolith biostratigraphy of deep-sea red clays recovered at Site 842 on the southwest Hawaiian Arch indicates an age of early Miocene between 31.10 and 21.53 mbsf. Sediments below this interval, down to 35.57 mbsf, are of Oligocene to early Miocene age. The interval between 21.53 and 19.05 mbsf is of early to middle Miocene age. Sediments immediately overlying and underlying the studied intervals are barren of all microfossils, and their ages are unknown.

Reworked ichthyoliths are evident in the studied intervals and indicate sources of Cretaceous to Eocene age exposed on the seafloor during the early Miocene.

SYSTEMATIC TAXONOMY

The system of nomenclature developed by Doyle et al. (1974), and subsequently modified by Dunsworth et al. (1975), Ramsey et al. (1976) (Mesozoic forms, presumably reworked in these samples), Doyle et al. (1978), Doyle and Riedel (1979b), Tway (1979), Gottfried et al. (1984a), Doyle and Riedel (1985b), Tway et al. (1985), and Winfrey et al. (1987), was followed in this paper. Some undescribed forms are described and discussed herein, but are not formally named.

Skewed 4 or 5 peaks Doyle et al., 1974 (Pl. 2, Fig. 1)
a2/b2/c3/d2,3/e1/f1/g1,2/h4/i1,2/j1

Skewed with transverse lines Doyle et al., 1974 (Pl. 2, Fig. 7)
a2/b2/c3/d1/e2/f2/g1/h1,2/i1/j2,(2+3)

Three equal peaks flared base Doyle et al., 1974 (Pl. 2, Fig. 6)
a2/b2/c3/d2,3/e1/f1/g1,2/h4/i1,2/j1

Five peaks flared base Doyle et al., 1974 (Pl. 2, Fig. 3)
a2/b2/c5/d3/e1/f1/g1/h4/i1/j1,2

cf. *Five peaks flared base* Doyle et al., 1974 (Pl. 2, Fig. 4)
a2/b2/c5/d3/e1/f1/g1/h4/i1/j1,2
Remarks: U-shaped depressions present between peaks on *Five peaks flared base* are shallow to absent on the form illustrated herein.

Many peaks transverse lines Tway et al., 1985 (Pl. 2, Figs. 8, 11)
a2/b2/c5,6,7/d0.89—1.09/e1,2/f3/g1,2/h1,3/i1/j2+3/k2

Seven peaks Kozarek and Orr, 1979 (Pl. 2, Figs. 9, 10)
a2/b2/c7/d1/e1/f1/g2/h1/i1/j1/k2

Short kite-shaped Doyle et al., 1974 (Pl. 1, Fig. 6)
a3/b1/c3/d1,3/e1/f1,(2+3)/g1+2
Remarks: This form appears to be equivalent to *Lined lanceolate differentiated margin* of Tway et al. (1985). *Short kite-shaped* is retained as the name of this form by priority.

Kite-shaped irregular network Doyle et al., 1974 (Pl. 1, Fig. 1)
a3/b1/c3/d4/e2/f2/g1+4

Polygonal cavity long rays Kozarek and Orr, 1979 (Pl. 1, Fig. 5)
a3/b1/c4/d5/e1/f1/g1+2

Polygonal cavity Kozarek and Orr, 1979 (Pl. 1, Figs. 2–4)
a3/b1/c5/d5/e1/f1/g1+2

Kite-shaped elongate prominence Doyle et al., 1974 (Pl. 1, Fig. 8)
a3/b1/c3/d3,4/e2,3,4/f2+3/g1+8

Kite-shaped longitudinal line Doyle et al., 1974 (Pl. 1, Fig. 7)
a3/b1/c3/d2/e2/f2+3/g1+2

Plain and lined lanceolate Doyle et al., 1974 (emend. Winfrey et al., 1987) (Pl. 2, Fig. 2)
a4/b1,2/c2/d1,4/e2/f2+3/g1+2/h1

Ogee lanceolate Tway et al., 1985 (Pl. 3, Figs. 1, 2)
a4/b1/c2/d6/e1,2/f2+3/g1+2/h3

Small dendritic many radiating lines Doyle et al., 1974 (Pl. 3, Fig. 6)
a5,6/b3/c2/d2/e1,2

Elliptical with line across Doyle et al., 1974 (Pl. 3, Fig. 4)
a6/b4/c2

Rectangular sawtoothed Doyle et al., 1974 (Pl. 3, Fig. 10)
a7/b1/c2/d3/e6

Rectangular irregularly sawtoothed Doyle and Riedel, 1979b (Pl. 3, Fig. 9)
a7/b1/c2/d3/e7,8,9

Rectangular triangular toothed Kozarek and Orr, 1979 (Pl. 3, Fig. 5)
a7/b1,5/c1/d3/e5

Two triangles Doyle et al., 1974 (Pl. 3, Fig. 4)
a7/b1/c1/d4/e4

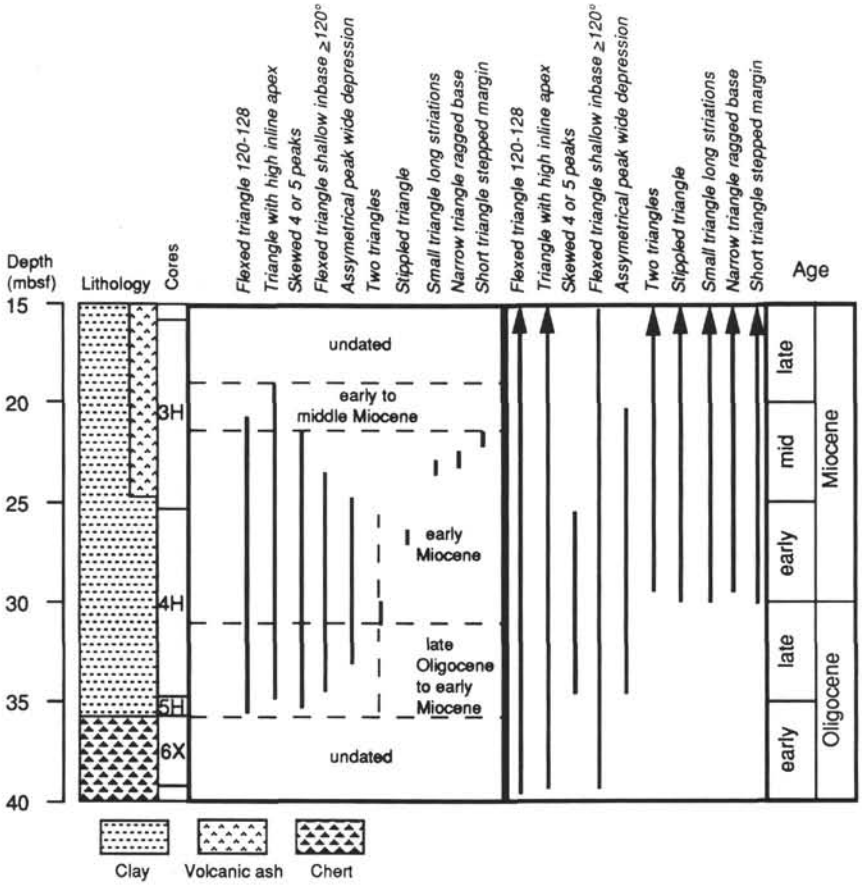


Figure 2. Ranges of selected ichthyolith taxa in Hole 842B on the left, and their corresponding reported age ranges in Doyle and Riedel (1985a) on the right (except for *Skewed 4 or 5 peaks* and *Asymmetrical peak wide depression,* the ranges of which are listed in Table 2). Dashed lines show range of forms comparable to (cf.) the indicated taxon.

cf. *Two triangles* Doyle et al., 1974 (Pl. 3, Fig. 8)
Remarks: This form is characterized by two triangles that are closely adjacent and appear to have a well-developed inline that follows the outline of the tooth.

Asymmetrical peak wide depression Doyle et al., 1974 (Pl. 3, Fig. 7)
a7/b6/c1

Asymmetrical peaks narrow depression Doyle et al., 1974 (Pl. 3, Fig. 11)
a7/b6/c3

Flexed triangle shallow inbase Doyle et al., 1974 (Pl. 4, Figs. 2, 3)
a8/b1,5/c1/d2/e80—140/f26-36

Flexed triangle shallow inbase ≥ 120 Dunsworth et al., 1975 (Pl. 4, Figs. 6,7)
a8/b1,5/c1/d2,3/e≥120/f≤25+a9/b1/c13/d1/e1/f4+(1,8)/g1/h2,3,4,5/i2/j2/k4,8/m0.25—0.45/n2.00—3.00/p0/q2,3,4,6,7/r2/s1/t1

Flexed triangle 102-112 Doyle et al., 1974 (Pl. 4, Fig. 4)
a8/b1,5/c1/d1/e102—112/f26-36

Flexed narrow triangle 120-128 Doyle et al., 1974 (Pl. 4, Fig. 5)
a8/b1,5/c1/d1/e120—128/f20-26

Triangle short wing Doyle et al., 1974 (Pl. 5, Figs. 6,7)
a9/b1/c5/d1/e1/f4+5/g1/h2,3,4,5/i2,3/j6/k8/m<0.4/n1.50—2.00/p2.00—4.00/q1,9/r1/s1,2/t1

Triangle medium wing Doyle et al., 1974 (Pl. 5, Fig. 5)
a9/b1/c6,7/d1/e1/f4+5/g1/h2,3,4,5/i2,3/j6/k8/m<0.40/n1.50—2.00/p2.00—4.00/q1,9/r1/s1,2/t1

Triangle broad wing Doyle et al., 1974 (Pl. 5, Fig. 8)
a9/b1/c6/d1/e1/f1,4/g1/h3,4,5/i2/j2,6/k8/m>0.15/n<1.40/p2.00—3.00/q9/r1/s1,2/t1

Triangle double wing Kozarek and Orr, 1979 (Pl. 5, Fig. 4)
a9/b1/c6/d6,7/e1/f1/g1/h5/i2,6/j2/k8/l0.2—0.5/m2.2—3.0/n2/01/p2,3

Triangle pointed margin ends Doyle et al., 1974 (Pl. 6, Fig. 2)
a9/b1,5/c13/d13/e1/f4/g1/h0,5/i2/j2/k3,8/m<0.60/n2.00—3.00/p2.0—3.00/q0,3/r0,3/s1,2/t4/z11/cc1/dd1/ee1/ff1/gg1/hh0.50—3.00/jj2/kk2/mm0/nn0

cf. *Triangle pointed margin ends* Doyle et al., 1974 (Pl. 6, Figs. 1, 3)
Remarks: Forms described as cf. *Triangle pointed margin ends* include specimens that have less angular margins at the base, length to width ratios greater than 2.0–3.0, and inlines that are at the same level or slightly below the margin ends at the base of the specimen.

Triangle transverse line across Doyle et al., 1974 (Pl. 7, Fig. 3)
a9/b1,5/c1/d1/e1,2/f4/g1/h0,5/i4/j4/k3,8/m0.20—0.40/n1.50—2.50/p1.50—2.60/q6,7,8/r4/s1/t1/z4/cc1/dd1/ee2/ff1/gg1/hh0/jj1,2,3/kk1,2,3/mm0/nn0

Triangle with canals Doyle et al., 1974 (Pl. 7, Figs. 1, 5)
a9/b5/c1/d1/e1/f1/g1,2/h2/i1,4/j1/k2/l2/m2/n2/o5,6/p3/q0.2—0.5/r1—1.5/s0/t1

Triangle with triangular projection Doyle et al., 1974 (Pl. 7, Fig. 4)
a9/b5/c1/d1/e1/f1,8/g1/h0/i2,7/j2,3/k0,5,7/m0/n>1.00/p0/q0/r0/s2/t1/z2/cc3/dd1/ee1/ff1/gg1/hh>3.00/jj2,4/kk3/mm1.40—4.50/nn0

Narrow triangle cross-hachured Doyle et al., 1974 (Pl. 7, Fig. 7)
a9/b5/c1,4/d1/e1/f1,16,18/g1/h0/i2,7/j2/k0,5,8/m0/n>0.50/p0/q0/r0/s2/t1/z2/cc1,3/dd1/ee1/ff1/gg2/hh>3.00/jj2,4/kk2,3/mm1.70—4.50/nn0

Short triangle stepped margin Doyle et al., 1974 (Pl. 8, Fig. 5)
a9/b5/c1/d1/e1/f(1,3)+(1,16,18)/g1/h0/i2,6/j3/k0,7,8/m>0.25/n<2.00/p0/q0/r0/s2/t1/z3/cc1/dd1/ee1/ff1/gg1/hh>1.00/jj2,4/kk3/mm1.20—1.60/nn0

Triangle with high inline apex Doyle et al., 1974 (Pl. 7, Fig. 2)
a9/b1/c1/d1/e1/f1,4,8,21/g1/h2,3,4,5/i2,6,8/j2,3/k3,8/m<0.20/n1.50—2.00/p1.50—2.00/q3,4,5/r1/s1/t1

Narrow triangle straight inbase Doyle et al., 1974 (Pl. 9, Fig. 1)
a9/b1/c1/d1/e1,2/f1/g1/h1,2/i2/j2/k2/l0.2—0.4/m1.6—2.0/n4,5/o1/p1,3

Wide triangle straight inbase Doyle et al., 1974 (Pl. 9, Fig. 3)
a9/b1/c1/d1/e1/f1/g1/h1,2,3/i2,3/j2,3/k2/l0.25—0.45/m1—1.5/n4,5/o1/p3

Pointed triangle long margins Gottfried et al., 1984a (Pl. 9, Figs. 4, 5)
a9/b1/c1/d1/e1/f4+17/g1/h2,5/i2,4/j2,4/k5,8/m0.45—0.80/n1.15—1.50/p1.10—1.85/q1,8,9/r1/s2/t1

Tanged triangle Gottfried et al., 1984a (Pl. 5, Fig. 1)
a9/b1/c1/d1/e1/f4/g1/h0/i2/j2/k0,4,7/m0.55—1.00/n1.75—1.95/p0/q10/r1/s1/t1

Triangle concave base Doyle et al., 1978 (Pl. 10, Figs. 2, 3)
a9/b1/c1/d1/e1/f1/g1/h2,4,5/i2,6/j2/k8/l0.2—0.3/m1.9—2.5/n6,7,8/o1,3/p1,2/q1

cf. *Pointed triangle short inline* Gottfried et al., 1984a (Pl. 6, Fig. 7)
a9/b1/c1/d1/e1/f(1,14)+4/g1/h5/i2/j2/k5,7/m0.70—0.90/n2.10—3.20/p0/q2,6,7/r1,5/s2/t1

Stippled triangle Dunsworth et al., 1975 (Pl. 10, Fig. 4)
a9/b5/c1/d1/e1/f1/g1/h0/i2/j2/k0/m0/n0/p0/q0/r0/s1,2/t1/z2,3/cc2/dd1,2/ee2/ff1/gg4/hh>2.00/jj4,6/kk1,3/mm0/nn0

Triangle curved base Doyle et al., 1978 (Pl. 5, Fig. 3)
a9/b1,5/c1/d1/e1,2/f4/g1/h0,5/i2,3/j2,3/k3,7/m0.50—0.70/n1.50—2.30/p1.50—2.50/q0,6,7/r0,1,3,4/s1/t1/z4/cc1/dd1/ee2/ff1/gg1/hh0/jj1,2/kk1,2/mm1.00—1.15/nn0

Triangle with base angle Dunsworth et al., 1975 (Pl. 4, Fig. 1)
a9/b1,5/c9,13/d1/e1/f4+8/g1/h0,4/i2/j2/k7,8/m0.20—0.60/n1.60—2.80/p0/q0,2/r0,1,2/s1/t1/z9/cc1/dd1/ee1/ff1/gg1/hh0/jj2/kk2/mm0/nn0

Large fibrous triangle Tway et al., 1985 (Pl. 6, Figs. 8, 9)
a9/b1/c1/d1/e1/f1/g4/h2,3,4,5/i2,7,8/j2/k4,9/m0.23—0.5/n1.67—2.36/p1.67—2.36/q9,10/r1/s2/t1/z0

Narrow triangle unequal margins Doyle and Riedel, 1985b (Pl. 9, Fig. 6)
a9/b1,5/c13/d1,13/e1/f1/g1/h0,3,4/i2,3/j6/k8/m0.1—0.4/n1.8—2.5/p2.2—2.6/q0,6/r0,1,2,3/s1,2/t1/z9/cc0/dd0/ee0/ff0/gg0/hh0/jj0/kk0/mm0/nn0

Long triangle thin wall Dunsworth et al., 1975 (Pl. 10, Fig. 7)
a9/b5/c1/d1/e1/f1/g1/h1/i1/j1/k2,6/l2,3/m2,4/n2,3/o2/p2,3,7/q0/r1.5—2.5/s≥4.0/t2/u3

Curved triangle pointed margin Doyle et al., 1974 (Pl. 9, Fig. 2)
a9/b1/c1/d1/e1/f2/g1/h1,2,3/i6/j4/k2,4/l0.2—0.4/m1—2/n3,4,5/o2/p1

Curved triangle pointed inline Tway et al., 1985 (Pl. 9, Fig. 7)
a9/b1/c1/d1/e1/f4/g1/h3,4,5/i6/j2,3/k3,4/m0.30—0.63/n0.93—1.46/p0.90—1.46/q6/r1,3/s2/t4/z0

Small triangle crenate margin Dunsworth et al., 1975 (Pl. 5, Fig. 2)
a9/b1,5/c15,17/e1,2/f1,17/g1/h0,5/i2,3/j2,3/k7,9/m0.25—0.50/n0.50—1.50/p0.70—1.60/q0,6,7,9/r0,1/s1,2/t1/z4/cc1/dd1/ee1,2/ff1/gg1/hh1.00—2.75/jj1,2,3/kk1,2,3/mm0/nn0

Triangle crenulate Doyle et al., 1974 (Pl. 8, Fig. 4)
a9/b1/c3/d1,3/e1,2/f1,2/g1/h1,2,3/i2,6/j2,3,6/k2/l<0.3/m1—2/n4,5/o1/p1,3

cf. *Triangle inline halfway* Doyle et al., 1974 (Pl. 7, Fig. 8)
a9/b1/c1/d1/e1/f4/g1/h1/i2/j2/k2/l0.45—0.55/m2.5—3.5/n2/o1,5/p2

Triangle sigmoid Dunsworth et al., 1975 (Pl. 10, Fig. 6)
a9/b1/c1/d1/e1/f1,3/g1/h5/i9/j9/k8/l0.75-0.95/m≥2.75/n2/o1/p2+a9/b5/c1/d1/e1/f1/g1/h1/i1/j1/k9/l9/m1,4/n1,3/o9/p3/q0.75—0.95/r≥2.75/s0/t2/u1

Triangle inward angle Gottfried et al., 1984a (Pl. 6, Fig. 5)
a9/b1/c20/d1/e1/f1,4/g1/h4/i6/j2/k3,12+14/m0.15—0.30/n2.25—2.50/p0/q3,6,9,10/r1/s1,2/t1

Triangle long inline Doyle et al., 1978 (Pl. 10, Fig. 8)
a9/b1/c1/d1/e1/f1,4/g1/h5/i2,6/j2,3/k7,12/m0.05—0.40/n2.50—4.99/p0/q2/r1/s1,2/t4

Small triangle long striations Dunsworth et al., 1975 (Pl. 8, Fig. 7)
a9/b1,5/c1,13/d1/e1/f(9,10)+13+14+18/g1/h0,5/i2/j2/k0,3,5/m0.75—1.00/n1.30—2.00/p0/q2/r1/s1,3/t1/z2/cc1/dd1/ee1/ff1/gg1/hh0/jj4/kk3/mm0/nn0

Triangle hooked margin Doyle et al., 1974 (Pl. 10, Fig. 5)
a9/b1,5/c14/d1/e1/f5+8/g1/h0,2/i4,10/j2,3/k8/m0.10—0.40/n1.00— 2.00/p0/q0,1/r0,1/s1,2/t1/z10/cc1/dd1/ee1/ff1/gg1/hh0/jj2/kk3/mm0/nn0

Narrow triangle ragged base Dunsworth et al., 1975 (Pl. 7, Fig. 6)
a9/b1/c1/d1/e1/f1/g1/h3,4,5/i6/j3,5/k9/m0.20—0.70/n≥4.00/p≥4.00/q9/r1/s1,3/t1

Triangle sinuous line Gottfried et al., 1984a (Pl. 10, Fig. 1)
a9/b1/c1/d1/e1/f(1,4)+21/g1/h0/i2/j2/k(4,8)+13/m0.10—0.20/n1.25—1.60/p0/q4,9/r1/s1/t1

Triangle bowed inline Ramsay et al., 1976 (Pl. 8, Figs. 8, 9)
a9/b1/c1/d1/e1/f1,4/g1/h5/i2/j2/k3,9/l0.4—0.6/m1.4—2.8/u2,6/o1/p1,3/q4

cf. *Triangle bowed inline* Ramsay et al., 1976 (Pl. 8, Fig. 10)
Remarks: The inline of the specimen illustrated herein is of greater length and possesses a base that extends below the margin ends of the tooth.

Unnamed form A (Pl. 8, Figs. 1–3)
Remarks: Undescribed form of a9/b1,5.

Unnamed form B (Pl. 2, Fig. 5)
a4/b2/c2/d4/e1/f5/g3/h1
Remarks: System of nomenclature modified by Tway (1979) is utilized to describe this form, which is characterized by the presence of a small platform at the base of the blade. This form differs from *Three equal peaks flared base* by having no depressions between the peaks.

Unnamed form C (Pl. 6, Fig. 4)
Remarks: Undescribed form of a9/b1,5.

Unnamed form D (Pl. 8, Fig. 6)
Remarks: Undescribed form of a9/b1,5.
Unnamed form E (Pl. 6, Fig. 6)
Remarks: Undescribed form of a9/b1,5.

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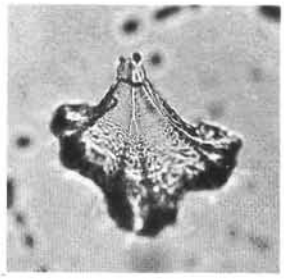

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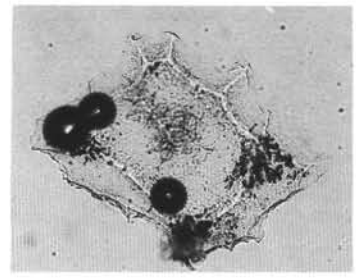

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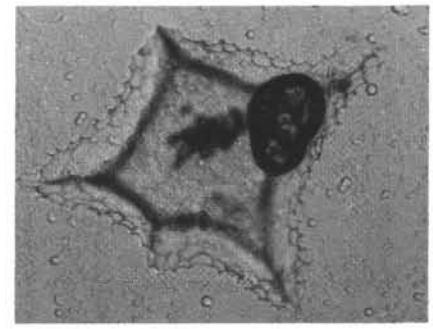

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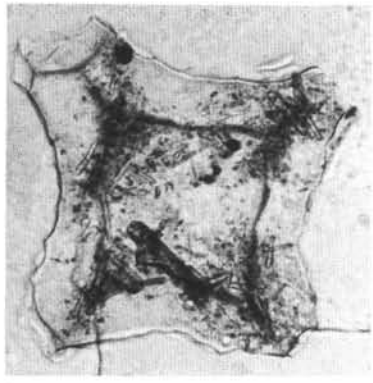

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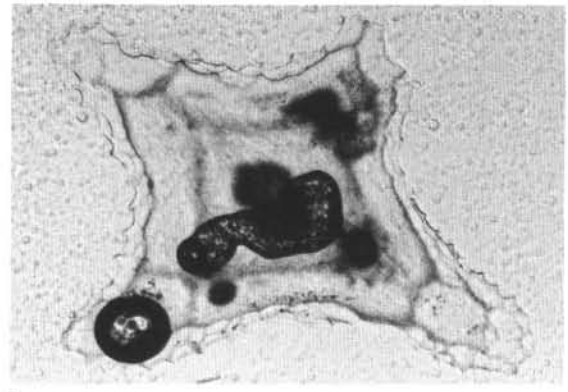

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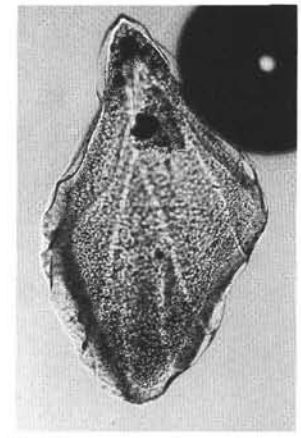

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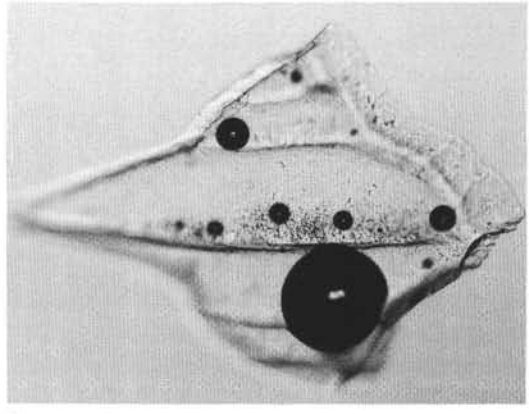

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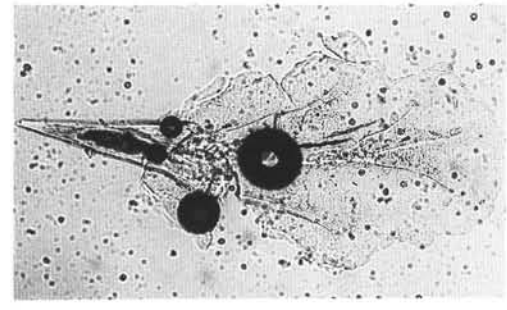

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Plate 1. **1.** *Kite-shaped irregular network,* Sample 842B-4H-6, 19–21 cm, 105×. **2, 3, 4.** *Polygonal cavity,* Sample 842B-4H-5, 129–131 cm, 105×; Sample 842B-3H-4, 122–124 cm, 216×; Sample 842B-3H-7, 4–6 cm, 210×. **5.** *Polygonal cavity long rays,* Sample 842B-3H-6, 27–29 cm, 202×. **6.** *Short kite-shaped,* Sample 842B-4H-6, 19–21 cm, 105×. **7.** *Kite-shaped longitudinal line,* Sample 842B-5H-CC, 105×. **8.** *Kite-shaped elongate prominence,* Sample 842B-4H-4, 129–131 cm, 105×.

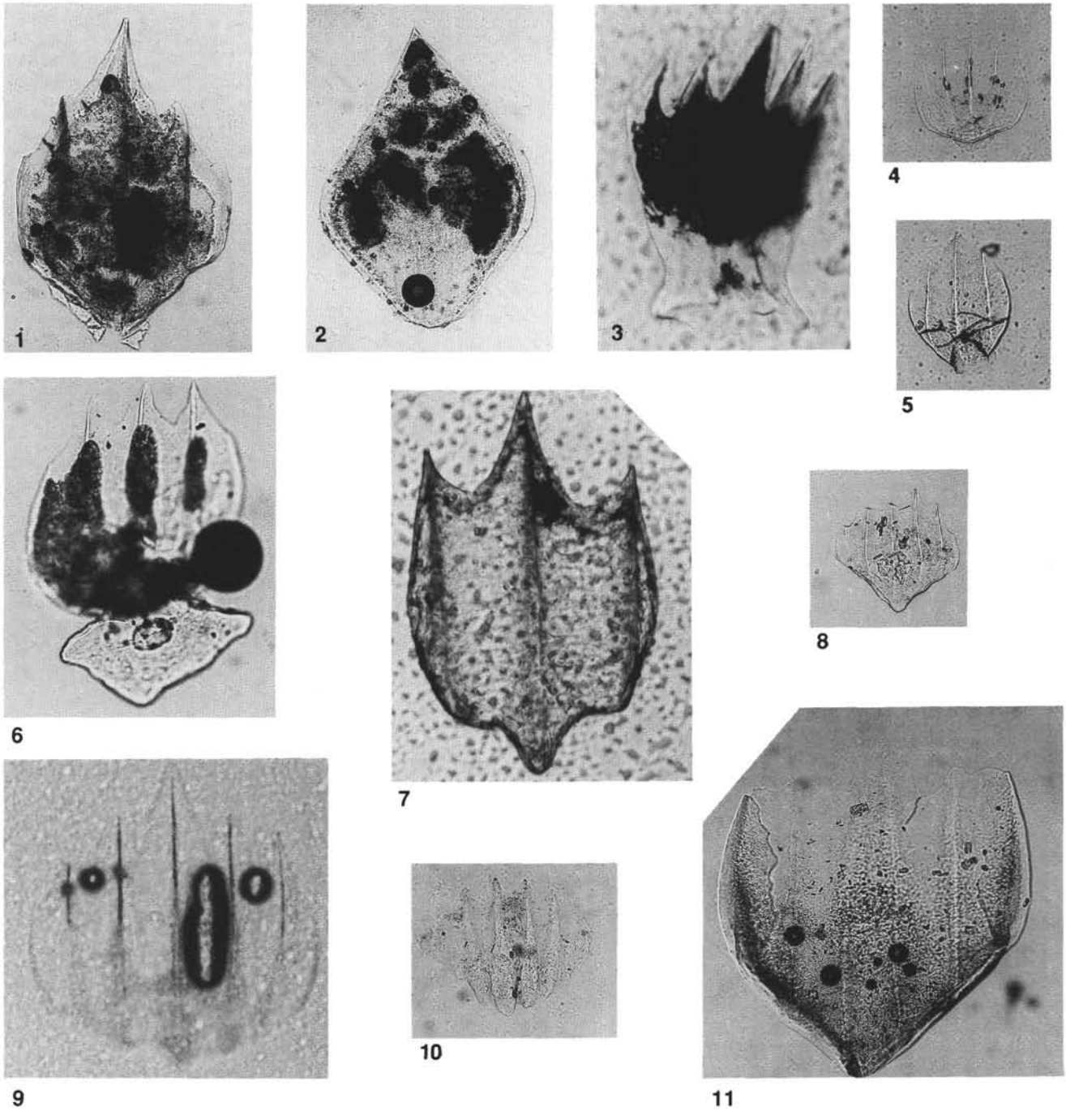

Plate 2. **1.** *Skewed 4 or 5 peaks,* Sample 842B-4H-CC, 105×. **2.** *Plain and lined lanceolate,* Sample 842B-4H-CC, 105×. **3.** *Five peaks flared base,* Sample 842B-3H-6, 27–29 cm, 192×. **4.** cf. *Five peaks flared base,* Sample 842B-4H-7, 20–22 cm, 105×. **5.** Unnamed form B, Sample 842B-4H-7, 20–22 cm, 105×. **6.** *Three equal peaks flared base,* Sample 842B-4H-3, 130–132 cm, 105×. **7.** *Skewed with transverse lines,* Sample 842B-3H-6, 124–126 cm, 207×. **8, 11.** *Many peaks transverse lines,* Sample 842B-4H-3, 19–21 cm, 105×; Sample 842B-4H-6, 19–21 cm, 105×. **9, 10.** *Seven peaks,* Sample 842B-4H-2, 19–21 cm, 104×; Sample 842B-4H-CC, 105×.

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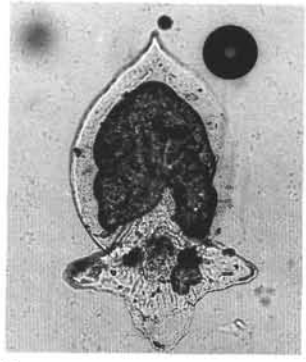

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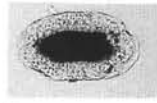

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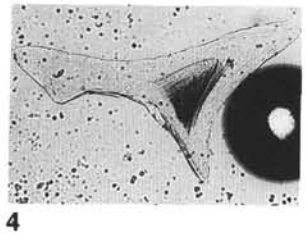

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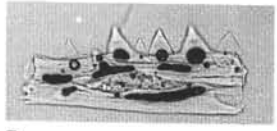

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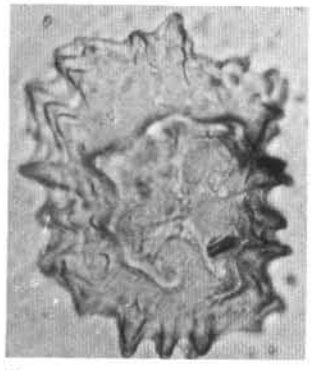

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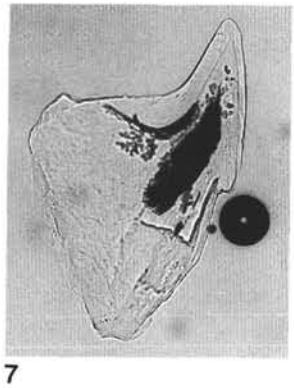

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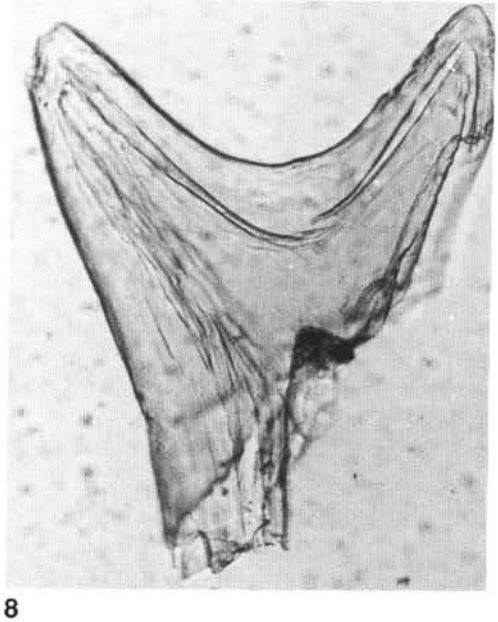

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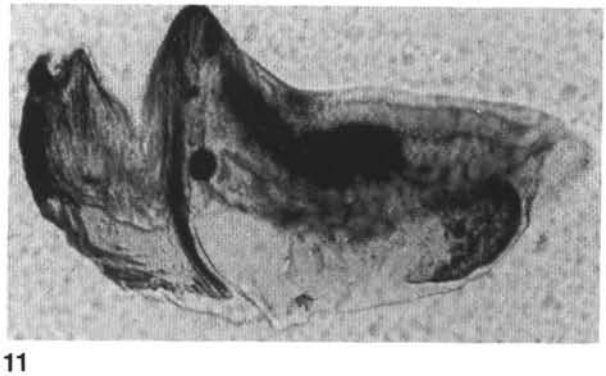

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Plate 3. **1, 2.** *Ogee lanceolate,* Sample 842B-4H-6, 19–21 cm, 105×; Sample 842B-4H-CC, 105×. **3.** *Elliptical with line across,* Sample 842B-4H-3, 19–21 cm, 105×. **4.** *Two triangles,* Sample 842B-4H-4, 129–131 cm, 105×. **5.** *Rectangular triangular toothed,* Sample 842B-4H-3, 19–21 cm, 105×. **6.** *Small dendritic many radiating lines,* Sample 842B-4H-2, 19–21 cm, 210×. **7.** *Asymmetrical peak wide depression,* Sample 842B-4H-6, 19–21 cm, 105×. **8.** cf. *Two triangles,* Sample 842B-4H-1, 19–21 cm, 188×. **9.** *Rectangular irregularly sawtoothed,* Sample 842B-4H-3, 19–21 cm, 105×. **10.** *Rectangular sawtoothed,* Sample 842B-3H-3, 123–125 cm, 210×. **11.** *Asymmetrical peaks narrow depression,* Sample 842B-4H-1, 130–132 cm, 210×.

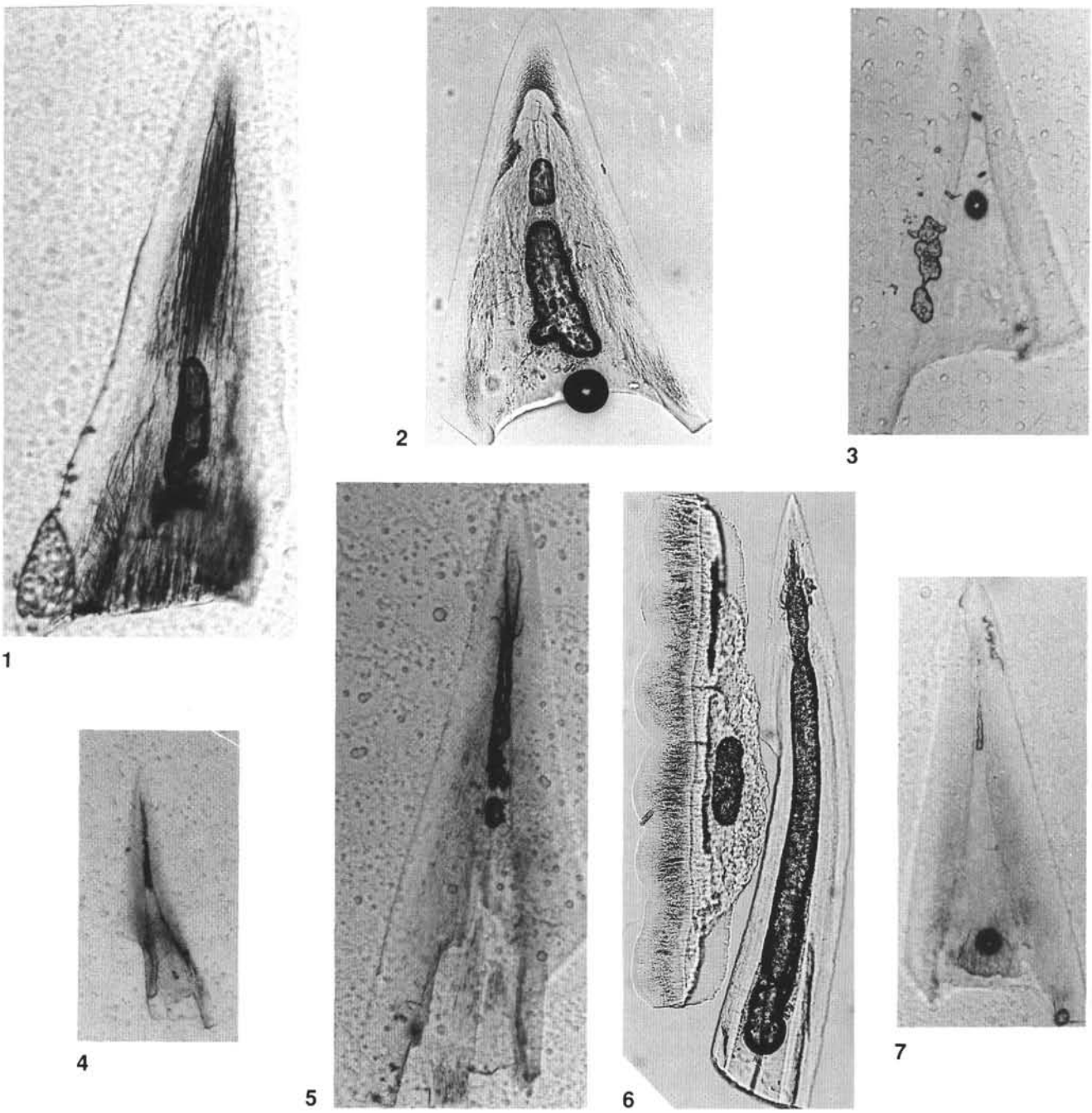
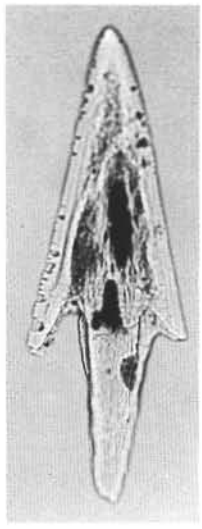


Plate 4. **1.** *Triangle with base angle,* Sample 842B-3H-7, 4–6 cm, 206×. **2, 3.** *Flexed triangle shallow inbase,* Sample 842B-4H-4, 19–21 cm, 210×; Sample 842B-3H-5, 27–29 cm, 210×. **4.** *Flexed triangle 102–112,* Sample 842B-3H-3, 24–26 cm, 83×. **5.** *Flexed triangle 120–128,* Sample 842B-3H-5, 122–124 cm, 165×. **6.** *Flexed triangle shallow inbase ≥ 120* (with base attached) and *Rectangular irregularly sawtoothed,* Sample 842B-4H-3, 130–132 cm, 105×. **7.** *Flexed triangle shallow inbase ≥ 120,* Sample 842B-4H-1, 19–21 cm, 210×.



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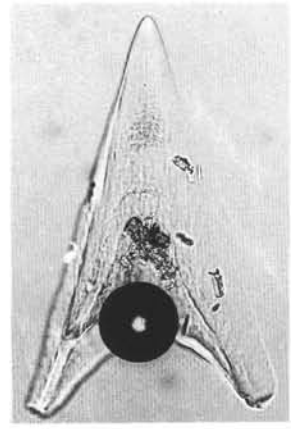

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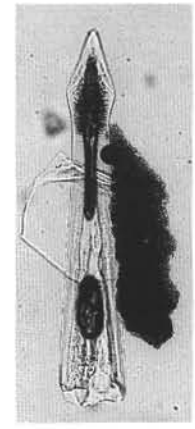

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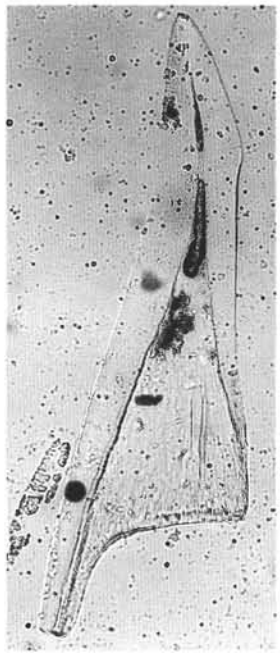

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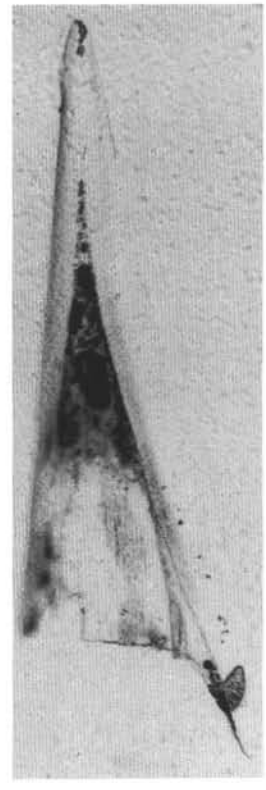

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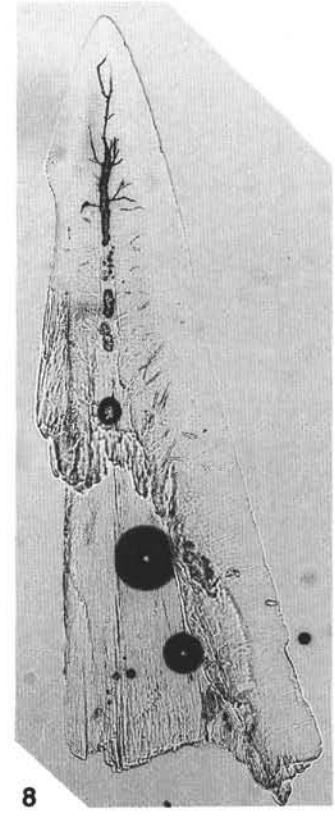

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Plate 5. **1.** *Tanged triangle,* Sample 842B-4H-6, 19–21 cm, 105×. **2.** *Small triangle crenate margin,* Sample 842B-4H-1, 130–132 cm, 152×. **3.** *Triangle curved base,* Sample 842B-4H-4, 129–131 cm, 210×. **4.** *Triangle double wing,* Sample 842B-4H-7, 20–22 cm, 105×. **5.** *Triangle medium wing,* Sample 842B-4H-4, 129–131 cm, 105×. **6, 7.** *Triangle short wing,* Sample 842B-4H-CC, 105×; Sample 842B-3H-5, 122–124 cm, 80×. **8.** *Triangle broad wing,* Sample 842B-4H-3, 19–21 cm, 105×.

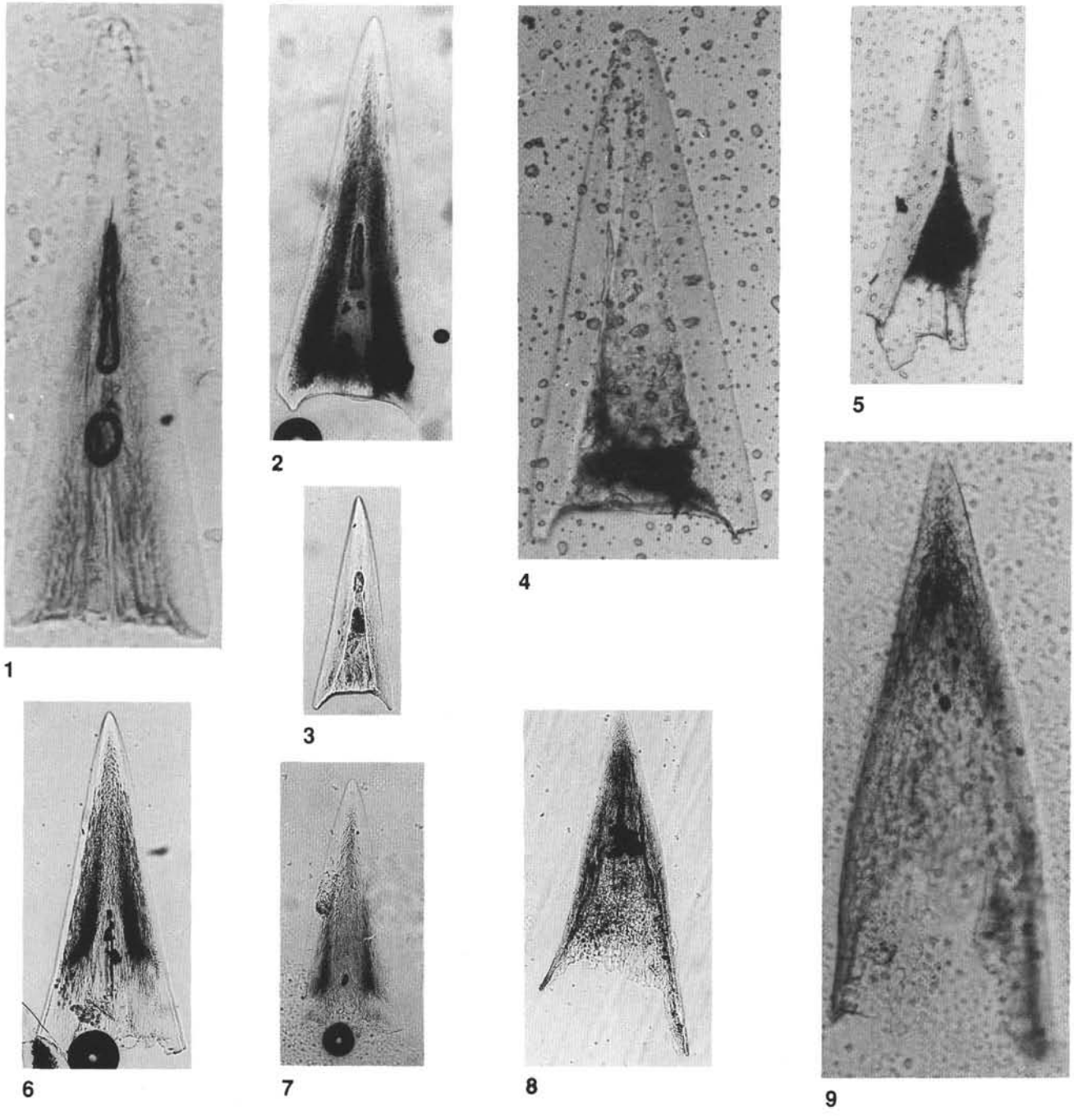


Plate 6. **1, 3.** cf. *Triangle pointed margin ends,* Sample 842B-4H-1, 130–132 cm, 196×; Sample 842B-4H-3, 19–21 cm, 105×. **2.** *Triangle pointed margin ends,* Sample 842B-4H-CC, 105×. **4.** Unnamed form C, Sample 842B-3H-4, 25–27 cm, 202×. **5.** *Triangle inward angle,* Sample 842B-3H-7, 4–6 cm, 74×. **6.** Unnamed form E, Sample 842B-4H-4, 19–21 cm, 105×. **7.** cf. *Pointed triangle short inline,* Sample 842B-4H-5, 22–24 cm, 105×. **8, 9.** *Large fibrous triangle,* Sample 842B-4H-4, 19–21 cm, 105×; Sample 842B-3H-3, 79–81 cm, 195×.

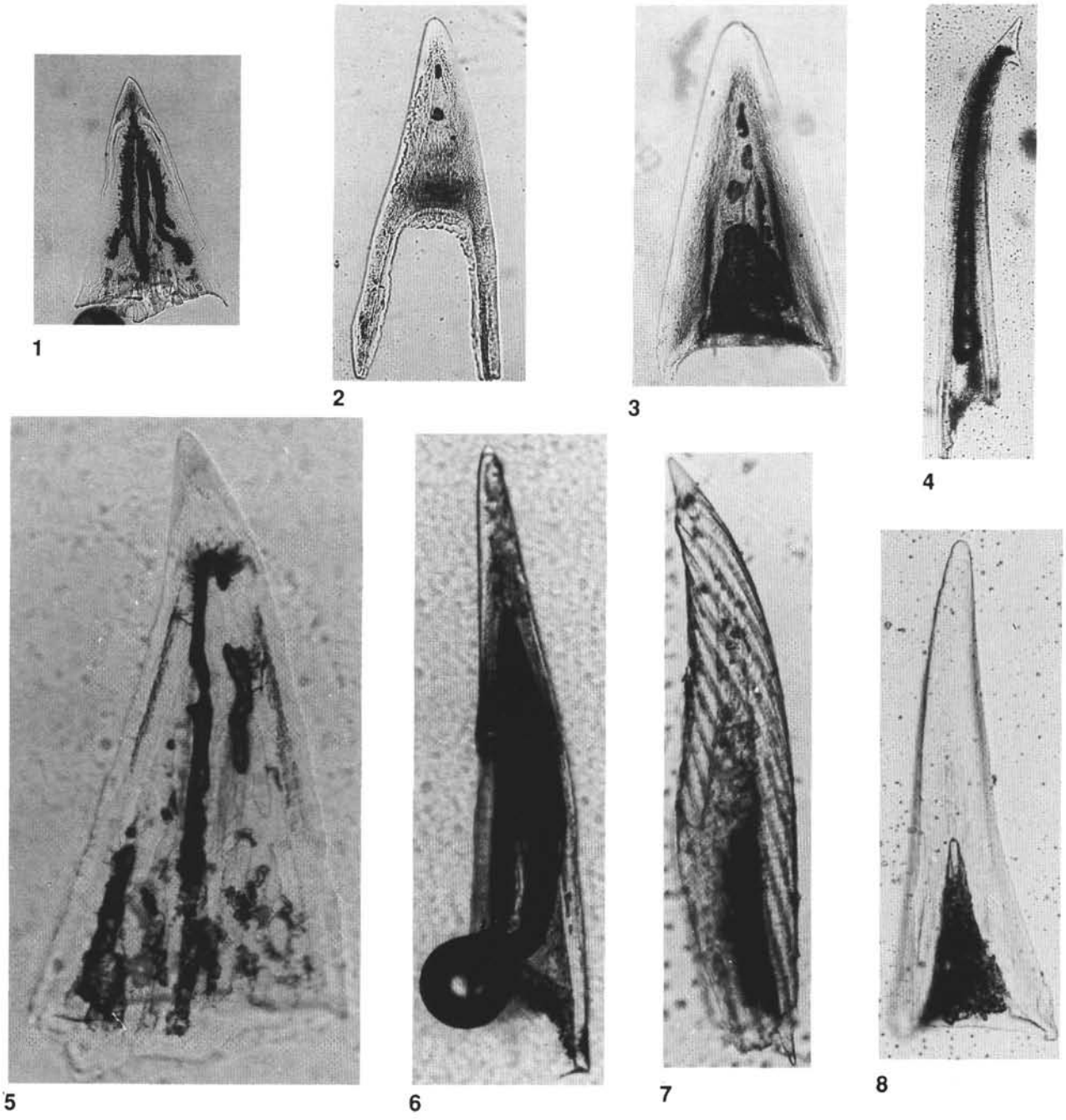


Plate 7. **1, 5.** *Triangle with canals,* Sample 842B-4H-6, 19–21 cm, 105×; Sample 842B-4H-1, 130–132 cm, 216×. **2.** *Triangle with high inline apex,* Sample 842B-4H-7, 20–22 cm, 105×. **3.** *Triangle transverse line across,* Sample 842B-3H-7, 4–6 cm, 87×; Sample 842B-4H-CC, 105×. **4.** *Triangle with triangular projection,* Sample 842B-4H-CC, 105×. **6.** *Narrow triangle ragged base,* Sample 842B-3H-5, 122–124 cm, 208×. **7.** *Narrow triangle cross-hachured,* Sample 842B-3H-7, 4–6 cm, 202×. **8**. cf. *Triangle inline halfway,* Sample 842B-4H-1, 19–21 cm, 186×.

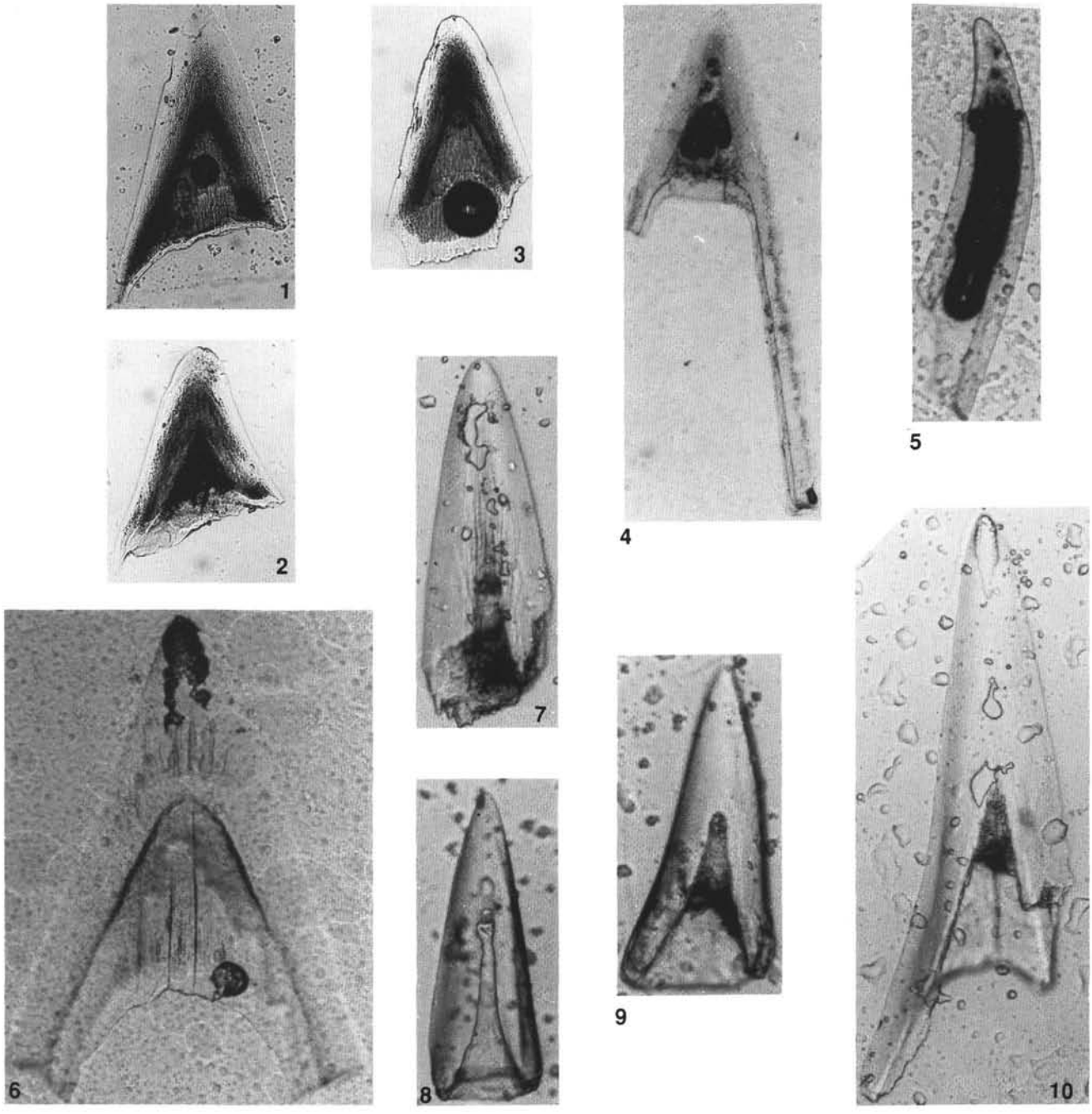
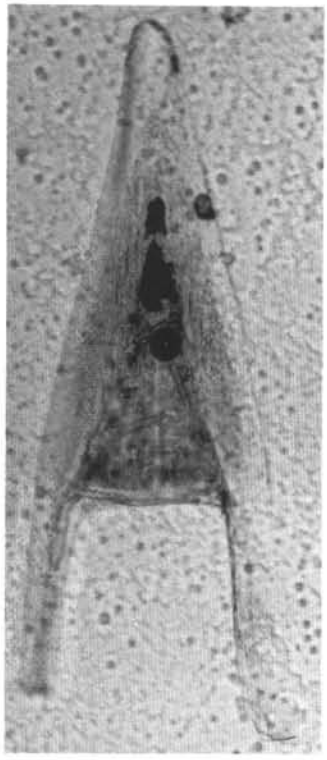


Plate 8. **1–3.** Unnamed form A, Sample 842B-4H-7, 20–22 cm, 105×; Sample 842B-4H-4, 19–21 cm, 105×; Sample 842B-4H-5, 129–131 cm, 105×. **4.** *Triangle crenulate,* Sample 842B-4H-1, 130–132 cm, 86×. **5.** *Short triangle stepped margin,* Sample 842B-3H-5, 27–29 cm, 206×. **6.** Unnamed form D, Sample 842B-3H-4, 122–124 cm, 205×. **7.** *Small triangle long striations,* Sample 842B-3H-5, 122–124 cm, 220×. **8, 9.** *Triangle bowed inline,* Sample 842B-3H-5, 27–29 cm, 208×; Sample 842B-3H-5, 27–29 cm, 212×. **10.** cf. *Triangle bowed inline,* Sample 842B-3H-7, 4–6 cm, 202×.



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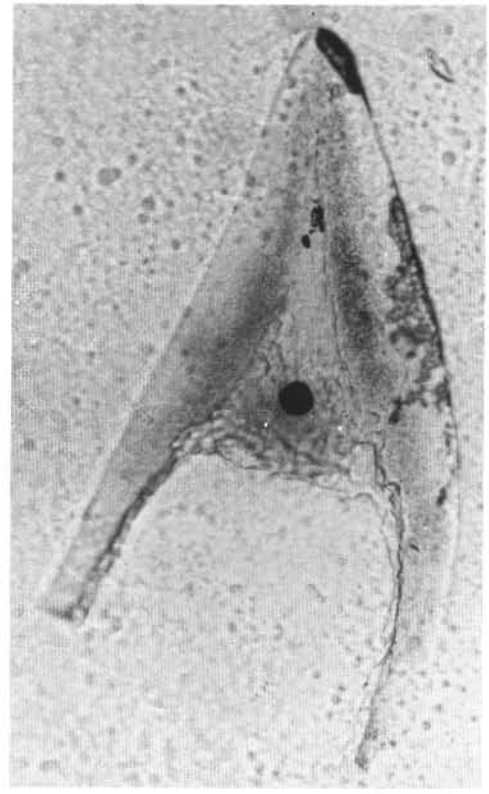

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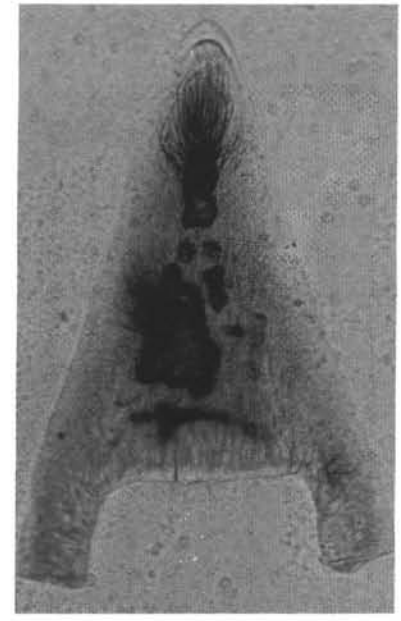

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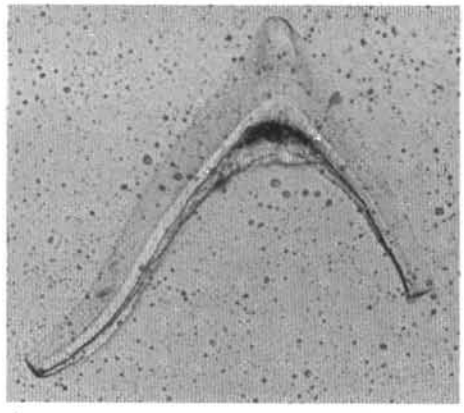

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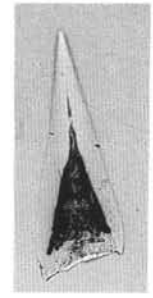

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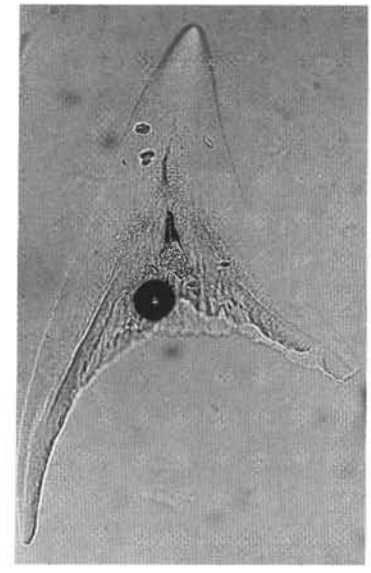

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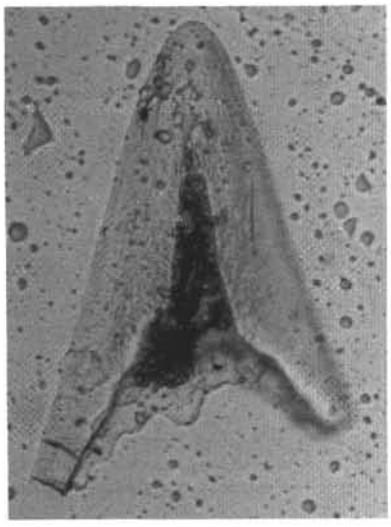
Plate 9. **1.** *Narrow triangle straight inbase,* Sample 842B-3H-4, 122–124 cm, 65× and 204×. **2.** *Curved triangle pointed margin,* Sample 842B-4H-1, 19–21 cm, 188×. **3.** *Wide triangle straight inbase,* Sample 842B-4H-1, 130–132 cm, 210×. **4, 5.** *Pointed triangle long margins,* Sample 842B-4H-1, 130–132 cm, 200× (note: pointed apex is broken off); Sample 842B-3H-4, 122–124 cm, 82×. **6.** *Narrow triangle unequal margins,* Sample 842B-4H-3, 19–21 cm, 105×. **7.** *Curved triangle pointed inline,* Sample 842B-4H-6, 19–21 cm, 105×.



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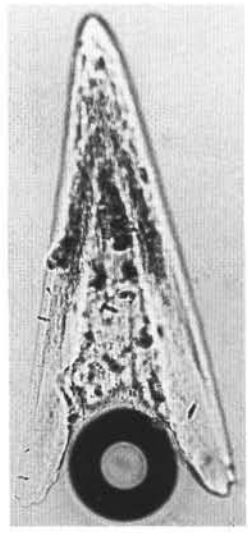

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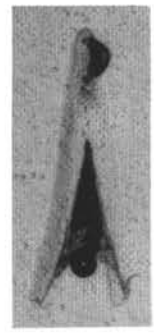

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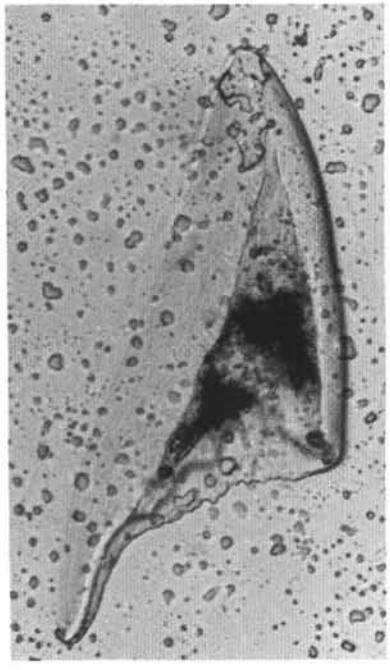

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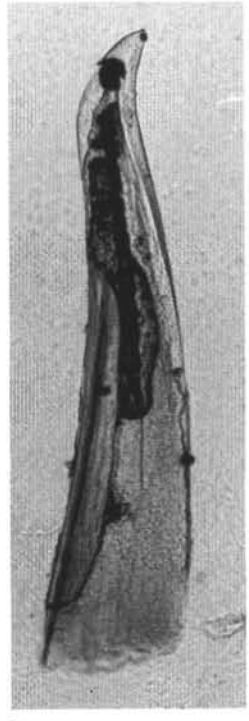

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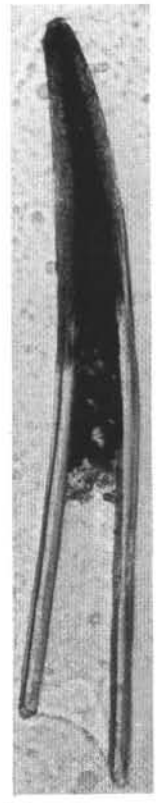

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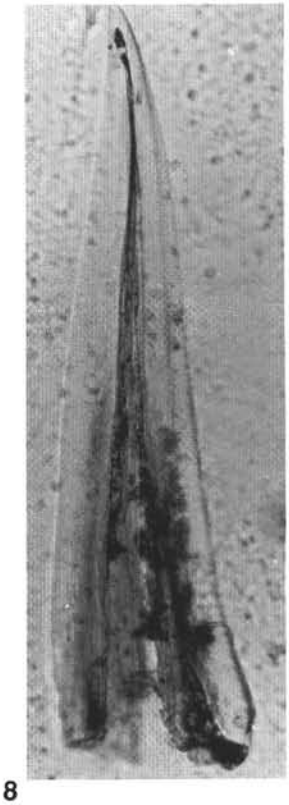

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Plate 10. **1.** *Triangle sinuous inline,* Sample 842B-3H-3, 123–125 cm, 206×. **2, 3.** *Triangle concave base,* Sample 842B-4H-4, 129–131 cm, 210×; Sample 842B-3H-3, 79–81 cm, 64×. **4.** *Stippled triangle,* Sample 842B-4H-1, 130–132 cm, 210×. **5.** *Triangle hooked margin,* Sample 842B-3H-6, 27–29 cm, 230×. **6.** *Triangle sigmoid,* Sample 842B-3H-6, 27–29 cm, 215×. **7.** *Long triangle thin wall,* Sample 842B-4H-1, 19–21 cm, 188×. **8.** *Triangle long inline,* Sample 842B-3H-7, 4–6 cm, 148×.