21. ICHTHYOLITH EVIDENCE FOR THE AGE OF REFLECTOR A^u, DEEP SEA DRILLING PROJECT SITE 603[1]

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ABSTRACT

Reflector A^u is extensively developed along the western margin of the North Atlantic Ocean. Evidence from ichthyoliths (fish skeletal debris) would suggest that the sediments immediately overlying the prominent hiatus are of early Miocene age.

INTRODUCTION

A^u is an important seismic reflector that is extensively developed along the western margin of the North Atlantic Ocean (Tucholke and Mountain, 1979). This reflector marks an erosional unconformity beneath the North American continental margin, where it truncates a number of deeper reflectors. Presumably it was formed by a southerly-flowing, westward-intensified abyssal boundary current that was a precursor to the modern Western Boundary Undercurrent (Heezen et al., 1966). The timing of this event has, however, proved difficult to determine (Tucholke and Mountain, 1979), for various geological and geophysical reasons. Most DSDP boreholes that have penetrated the reflector were drilled in areas where substantial parts of the succession are missing or where core recovery was too sparse to allow accurate assessment of the age of A^u.

One of the objectives of Leg 93 was to calibrate the seismic reflection stratigraphy, and in Hole 603B (Fig. 1) Reflector A^u was penetrated enroute to the Mesozoic of the lower continental rise of the western North Atlantic Ocean. The succession recovered from the critical level is very nearly complete, but unfortunately is barren of several groups of stratigraphically diagnostic microfossils. Leg 95 returned to Site 603 for a renewed attempt on the Jurassic basement following loss of the drill string on Leg 93. In this later attempt (in August 1983), with no reentry capability, it was necessary to drill the complete hole with a single bit. To save wear on the bit, few cores were taken in the upper part of the succession. Because of the interest in A^u, one core was taken just above its predicted depth in Hole 603E. Recovery was poor, with only 60 cm of sediment obtained (Core 603E-1; 936.4–937.0 m). This material proved barren of radiolarians, foraminifers, and nannofossils, but contained abundant ichthyoliths. Material from Hole 603B was also studied and the positions of the samples are shown in Figure 2.

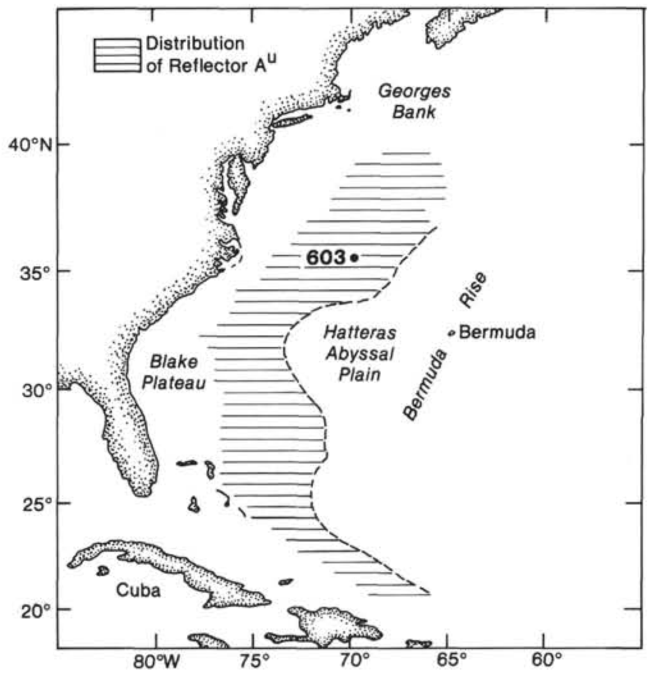

Figure 1. Location of DSDP Site 603 and the distribution of Reflector A^u in the western North Atlantic Ocean.

METHODS

Unlike most of the previous ichthyolith work, which used radiolarian preparation techniques, the present investigation was done as part of a study of the Foraminifera. Samples were, therefore, disaggregated using very dilute hydrogen peroxide, wet-sieved on a 75 μm mesh, and then dried. The dried samples were then sieved in a nest of sieves (500 μm, 250 μm, 125 μm, and 90 μm), after which they were hand-picked onto assemblage slides. They were then mounted and photographed in transmitted light. The Foraminifera recovered from Cores 603B-14 and 603B-15 are all arenaceous, and include an interesting range of deep-sea taxa (Hart, unpublished material).

ICHTHYOLITHS FROM HOLES 603B AND 603E

Ichthyoliths, or fish skeletal debris, were first described from DSDP material by Helms and Riedel (1971). Since

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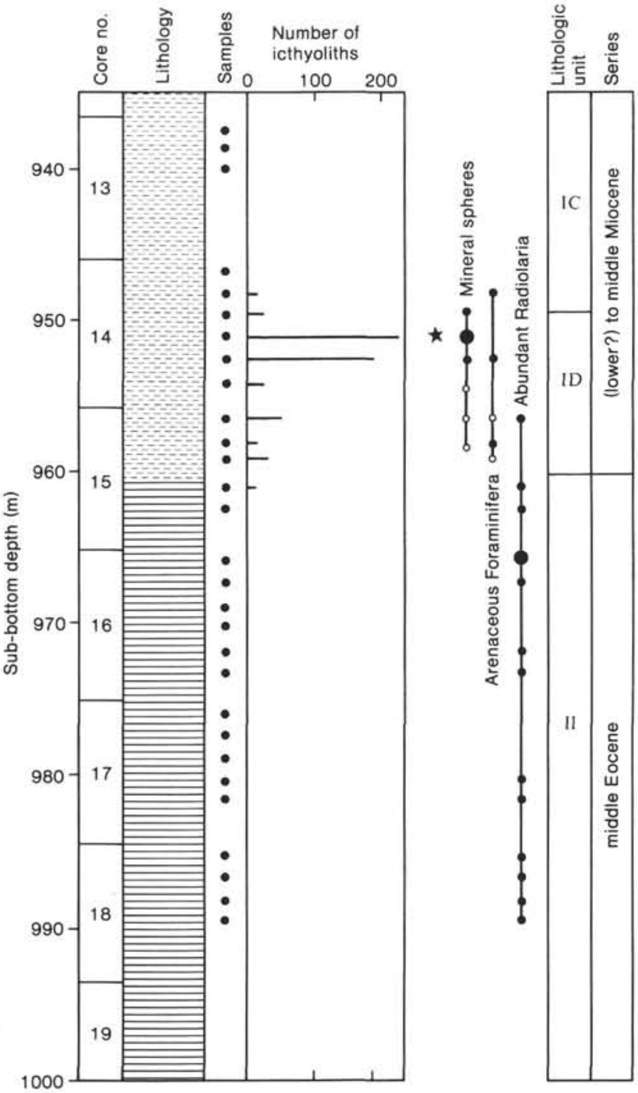

Figure 2. The succession in part of Hole 603B showing the location of the samples studied and the number of ichthyoliths in each 30 cm^3 sample. The star marks the probable equivalent horizon of material recovered on Leg 95 (603E-1,CC). Small open circles represent rare, solid circles common, and large solid circles abundant ichthyolith occurrences "Mineral spheres" are small, crystalline spheres of sugary-looking mineral, possibly dolomite. The lithological boundary between the lower, green radiolarian claystone (solid lines) and the overlying yellow brown silt-rich claystone (dashed lines) is located at 603B-15-4, 46 cm.

then a new subject, "stratignathy," has been developed by Riedel, Doyle, and their coworkers (Doyle et al., 1974, 1977, 1978; Dunsworth et al., 1975; Doyle and Riedel, 1979, a, b, 1980, 1981; Edgerton et al., 1977; Kaneps et al., 1981; Gottfried et al., 1984 a, b; and other papers currently in press).

These publications have developed and refined an identification scheme for ichthyoliths. This is based on an identification key with a straightforward coded system, coupled with the use of informal names. We have not attempted to further develop that scheme, but have simply used the identification key and known ranges for dating the succession under discussion. Several of the "taxa" observed and figured appear to be new and they are therefore left as undescribed.

Sample 603E-1,CC and the material from Hole 603B have all yielded the same range of forms. It was impossible to determine any differences between Cores 603B-14 and 603B-15. The samples from lithologic Subunit IC (603B-14-1, 73–76 cm; 603B-14-2, 64–67 cm; 603B-14-3, 65–68 cm) contained few ichthyoliths, and on the basis of existing evidence it is impossible to differentiate that fauna from the underlying Subunit ID. The bulk of the fauna investigated comes from three samples (603E-1,CC; 603B-14-4, 74–77 cm; 603B-14-5, 64–67 cm). The majority of the forms identified by their informal names (see Fig. 3) are long-ranging. Diagnostic forms are as follows:

1. *Rectangular saw-toothed* (Plate 1, Figs. 2, 3): these forms have a recorded range from early Oligocene through Quaternary.
2. *Small triangle long striations* (Plate 3, Fig 11): this is a Neogene form that is most common in late Miocene and younger assemblages.
3. *Triangle pointed margin ends* (Plate 3, Fig. 6): this is a very rare form in our material. It has a recorded range of Paleocene through Quaternary, although occurrences are sporadic and uncommon above the base of the Miocene.
4. *Skewed with transverse lines* (Plate 1, Fig. 4): this form has a recorded range of middle Miocene, and although the single specimen recorded here is very close to that figured by Doyle et al. (1974, pl. 1A, Fig. 3) the transverse lines are very faint. Another specimen, too broken to illustrate, is close to *Three similar peaks*. It definitely does not possess the transverse lines.
5. *Type a3/b1* (Plate 3, Fig. 22): only two specimens of this distinctive form have been found. The specimens are close to that figured by Doyle et al. (1974, pl. 3, fig. 6) from the early Miocene.
6. *Type a2/b2* (Plate 3, Fig. 21): this is a single specimen close to another unnamed type figured by Doyle et al. (1974, pl. 3, fig. 2) from the middle Miocene.
7. (?) *Kite-shaped elongate prominence* (nôt figured): this single, broken specimen may not be correctly identified, although it definitely belongs in the "kite-shaped" group. Doyle et al. (1974) indicate that this form only extends as far as the late Oligocene, and its occurrence here would appear to conflict with some of the ranges quoted above.

Most of the above data implies an early or middle Miocene age for the material. This depends on (1) the precision of the known ranges, and (2) our identification of the limited number of stratigraphically diagnostic forms (4, 5, and 6 above). The radiolarian data (Nishimura, this volume) indicates that samples from Section 603B-13-2 and 603B-13,CC contain faunas indicative of the *Calocycletta costata* Zone of early Miocene age. Core 14 is reportedly barren, as is the sample from Section 603B-15-2. A sample from Section 603B-15-4 contains *Spongodiscus phrix, Dictyoprora amphora*, and *Theocotyle ficus* and has been tentatively assigned to the *Phormocyrtis striata striata* Zone of early Eocene age. Sample 603B-15,CC through Section 603B-17-3 are definite-

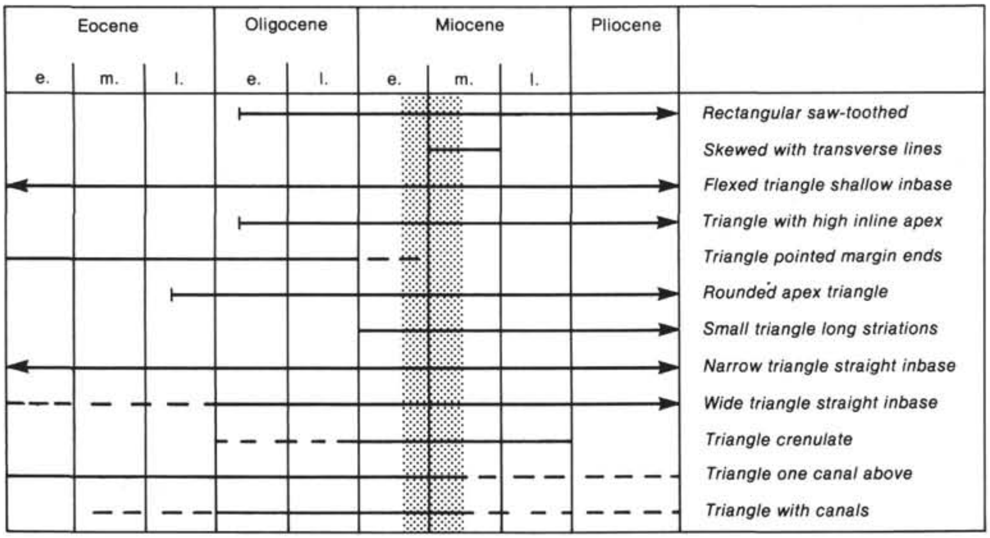

Figure 3. Ranges of previously described ichthyolith taxa, with the probable age of the Legs 93 and 95 material indicated by shading.

ly assigned to the *P. striata striata* Zone. The lithological break identified by a color and textural change at 603B-15-4, 46 cm (Fig. 4) is, therefore, regarded as the chronostratigraphic break between radiolarian claystones of early Eocene age and the overlying silt-rich claystones of early Miocene age.

PALEOCEANOGRAPHIC IMPLICATIONS

Determining the precise age for the erosional event that formed Reflector A^u along the North American continental margin continues to be an elusive paleoceanographic goal. On the basis of radiolarian and planktonic foraminiferal assemblages, previous drill sites that penetrated the reflector (Tucholke and Mountain, 1979) along the lower continental rise constrained the event to between late Eocene and early? middle? Miocene (Figs. 5, 6), leaving a gap of at least 14 Ma between the late Eocene and early Miocene during which one or more erosional events occurred.

It was proposed (Miller and Tucholke, 1983) that a deep-sea erosional event formed Reflector R4 in the northern North Atlantic, and planktonic Foraminifera have been used to determine that it occurred very near the Eocene/Oligocene boundary. Like Reflector A^u, R4 is best recognized along the likely flow path of a westward-intensified bottom current. Because of the similarities in paleogeographic location, seismic character, and stratigraphic position of these two reflectors, Miller and Tucholke (1983) suggested that A^u and R4 were formed at the same time by the same geostrophic current. Evidently, either nondepositional conditions or multiple erosional events along the North American margin produced the especially long hiatus that has been documented by drilling.

On the basis of the seismic character of the strata resting directly above Reflector A^u in the vicinity of Site 603, Tucholke and Laine (1983) proposed that these sediments comprise a lower fan deposit that emanated from the vicinity of the modern Hudson Canyon (Fig. 7). Mountain and Tucholke (1985) took a modified view based on the distribution of thickness patterns in these post-A^u strata; they proposed that the resumption of deposition following the Eocene/Oligocene "A^u event" was in part a result of increased sediment supply from the North American continent in the early Miocene as well as a result of waning bottom currents. They concluded that submarine fan processes rapidly delivered sediment to the lower rise, but that prevailing current redistributed it into current-controlled deposits.

There is little sedimentological evidence in support of fan deposition in the strata immediately above A^u at Sites 603B or 603E. Primary structures such as discrete turbidites or facies associations such as fining- and thinning-upward sequences (Mutti and Ricci Lucchi, 1972) are not seen. Futhermore, there are no reports of mineralogical or paleoecological indicators of shallow-water environments in these sediments. To the contrary, the paucity of fossil remains other than ichthyoliths supports the argument that these strata represent a condensed section that accumulated very slowly while the current that had formed Reflector A^u was dropping to below erosional velocities.

ACKNOWLEDGMENTS

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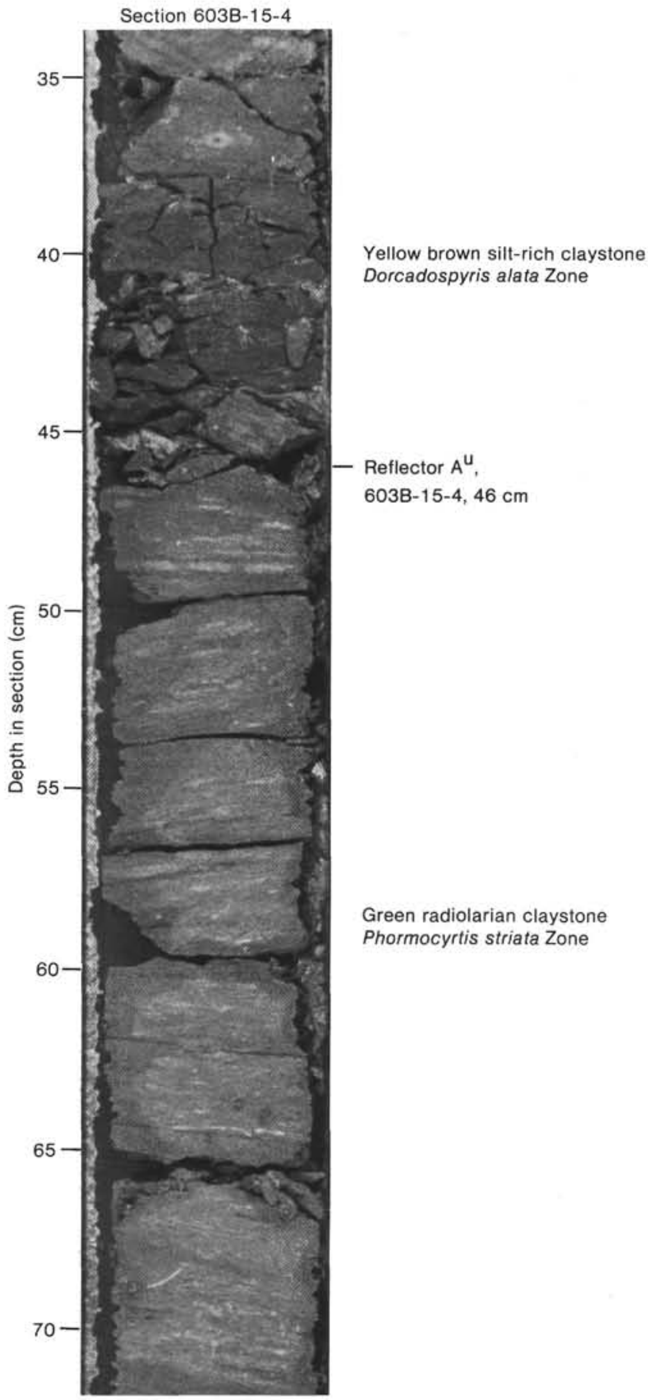

Figure 4. Sample 603B-15-4, 34-72 cm, showing the position of Reflector A^u, the lithology, and radiolarian zones.

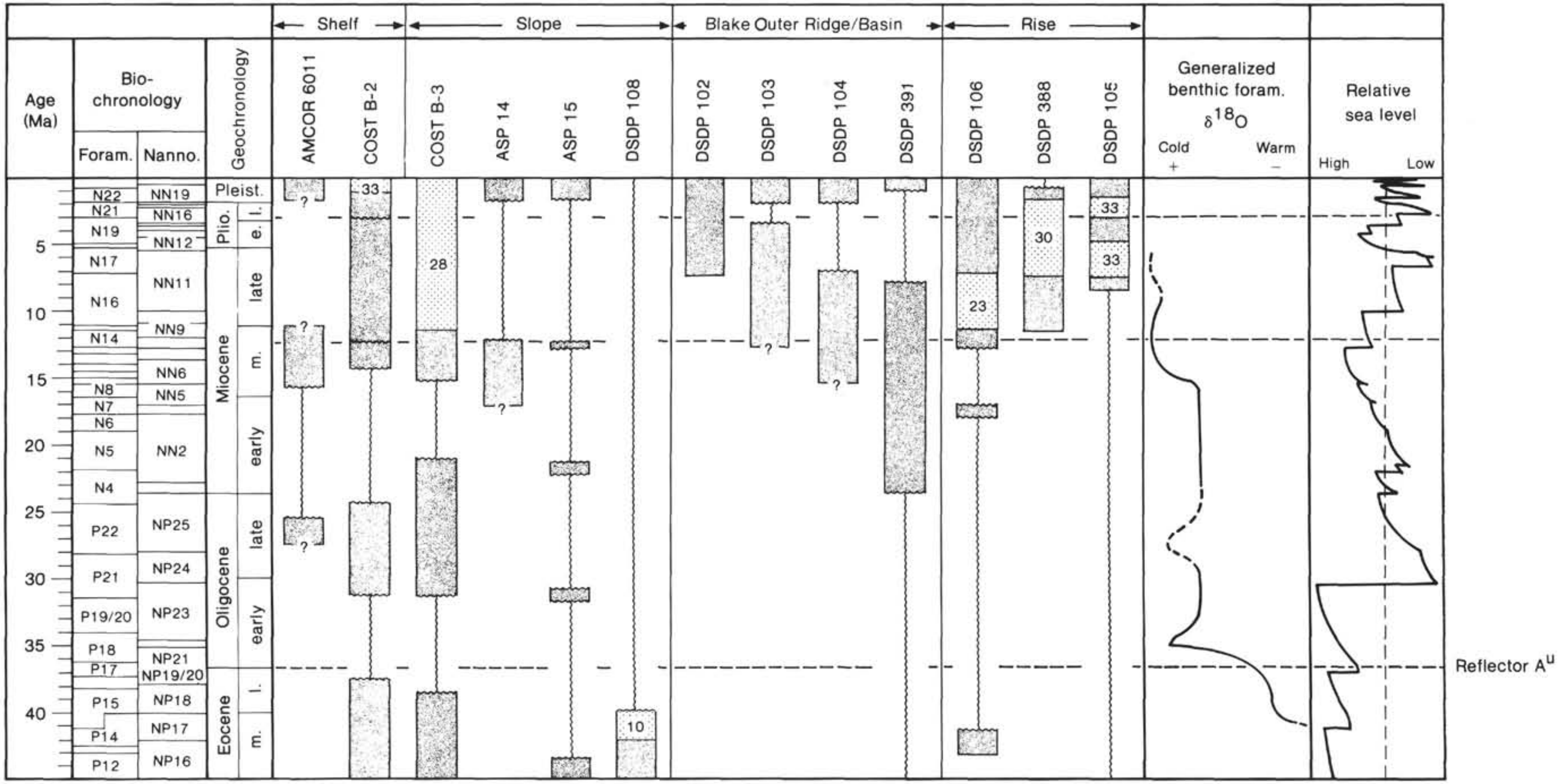

Figure 5. Correlation chart of the Eocene to Pleistocene interval, borehole material, relative sea level, generalized oxygen isotope values, and Reflector A^u along the U.S. continental margin. The numbers and associated lightly stippled patterns in the stratigraphic columns are average accumulation rates between dated samples; values less than 3 m/Ma are shown as a hiatus. Taken from Mountain and Tucholke (1985), in which full data sheets and references can be found.

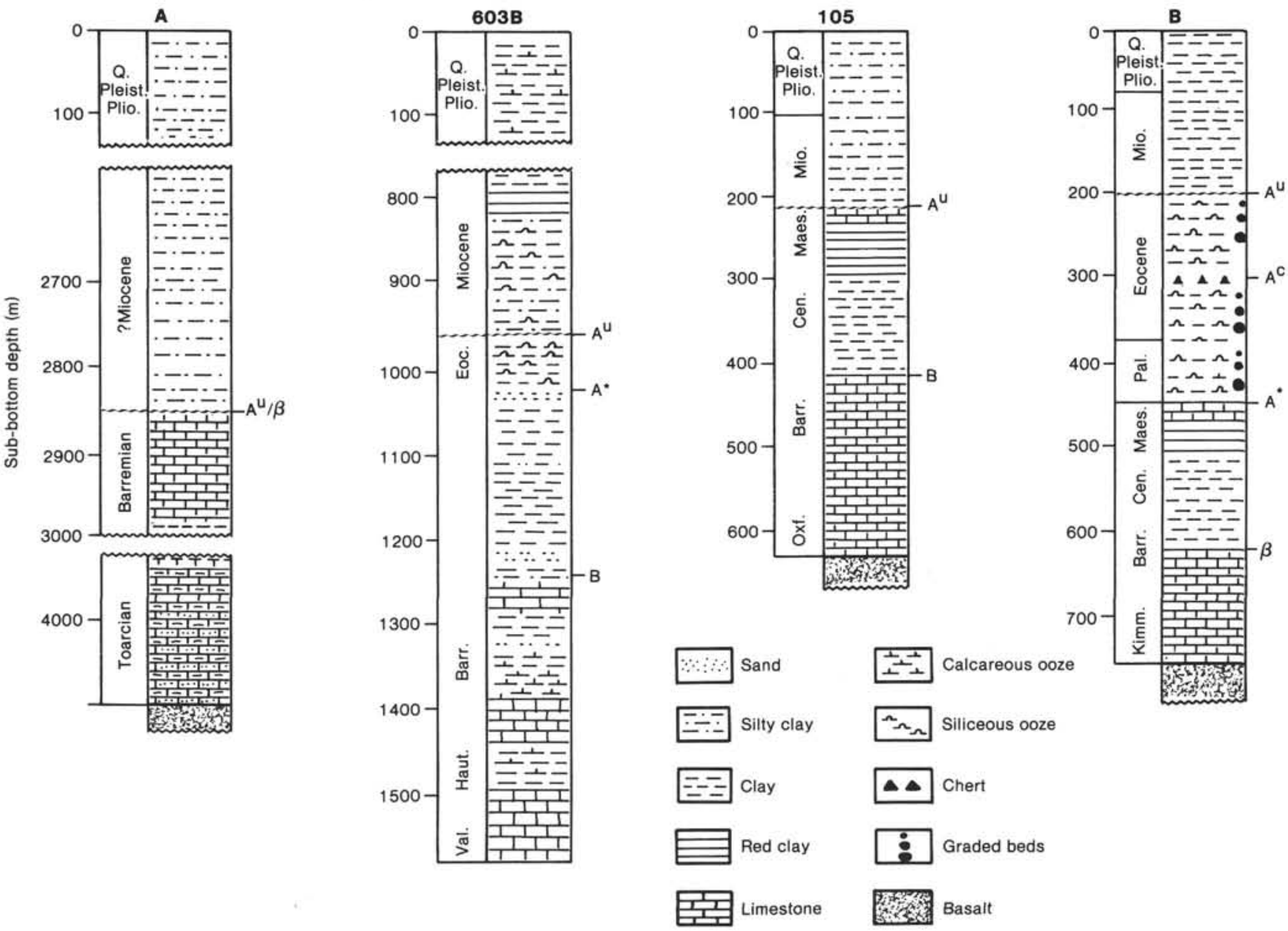

Figure 6. The location and age of seismic Reflectors β, A^u, A^*, A^c along the North Atlantic continental margin. The figure is modified from data presented by Tucholke and Mountain (1979). Hole 603B is the present data, whereas A (beneath landward edge of Blake Outer Ridge), B (vicinity of DSDP Site 8) and 105 represent previously published information, slightly generalized for the present purpose.

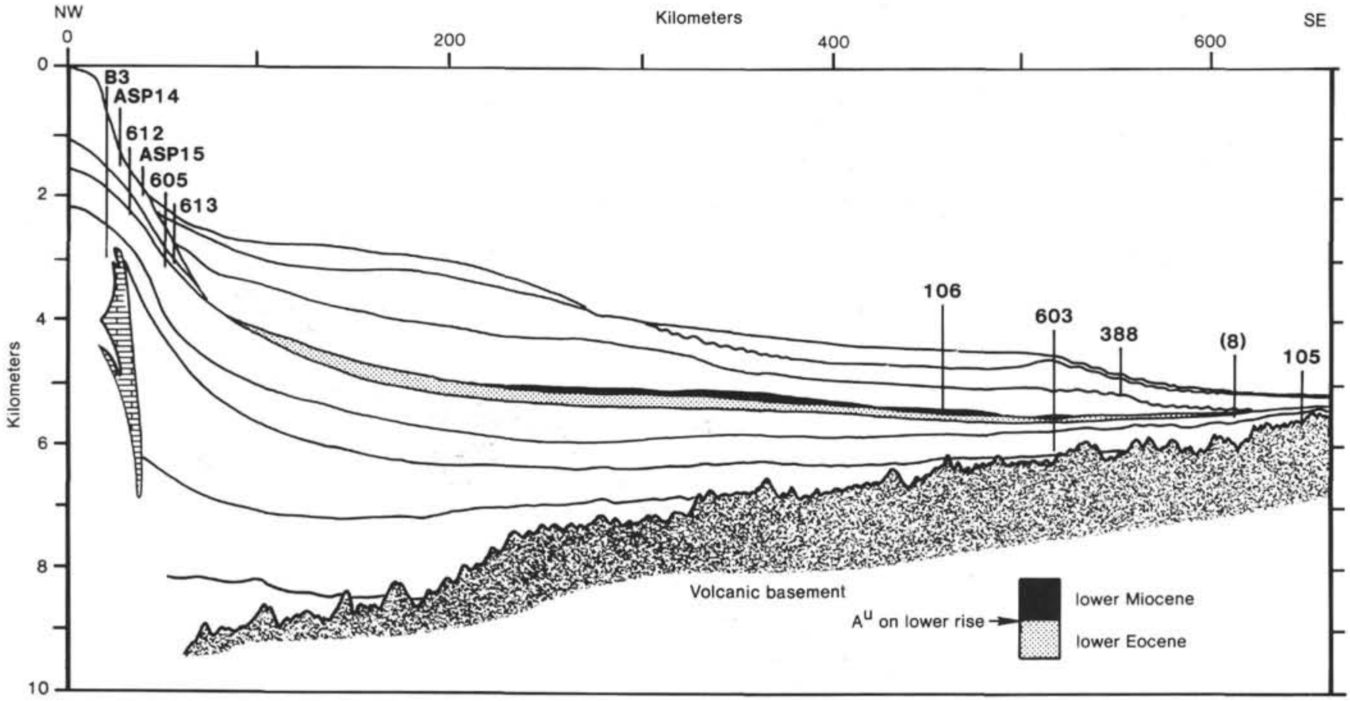

Figure 7. Simplified depth section of composite multichannel profiles from New Jersey continental shelf to the lower continental rise. All the drill sites shown are located on this line except DSDP Site 8, which is projected from its true location 200 km to the northeast. B3 is the Continental Offshore Stratigraphic Test (COST) -B3 well, and the ASP wells are part of the Atlantic Slope Project. The block symbol at the left-hand margin of the figure is a "supposed" reef structure, shown on most profiles of this area.

APPENDIX
Samples Studied

603E-1,CC	603B-14-1, 73–76
	603B-14-2, 64–67
603B-8-1, 70–73	603B-14-3, 65–68
603B-8-2, 70–73	603B-14-4, 74–77
603B-8-3, 76–79	603B-14-5, 64–67
603B-8-4, 76–79	603B-14-6, 74–77
603B-8-5, 67–70	
603B-8-6, 72–75	603B-15-1, 70–73
	603B-15-2, 80–83
603B-9-1, 48–51	603B-15-3, 70–73
	603B-15-4, 63–66
603B-10-1, 72–75	603B-15-5, 60–63
603B-10-2, 70–73	
603B-10-3, 70–73	603B-16-1, 72–75
603B-10-4, 70–73	603B-16-2, 74–77
603B-10-5, 69–72	603B-16-3, 90–93
	603B-16-4, 68–71
603B-11-1, 57–60	603B-16-5, 69–72
603B-11-2, 57–60	603B-16-6, 59–62
603B-11-3, 80–83	
603B-11-4, 80–83	603B-17-1, 79–82
603B-11-5, 70–73	603B-17-2, 74–77
603B-11-6, 71–74	603B-17-3, 76–79
	603B-17-4, 74–77
603B-12-1, 68–71	603B-17-5, 42–45
603B-12-2, 57–60	
603B-12-3, 65–68	603B-18-1, 72–75
603B-12-4, 66–69	603B-18-2, 63–66
603B-12-5, 60–63	603B-18-3, 68–71
	603B-18-4, 43–46
603B-13-1, 71–74	
603B-13-2, 68–71	
603B-13-3, 66–69	

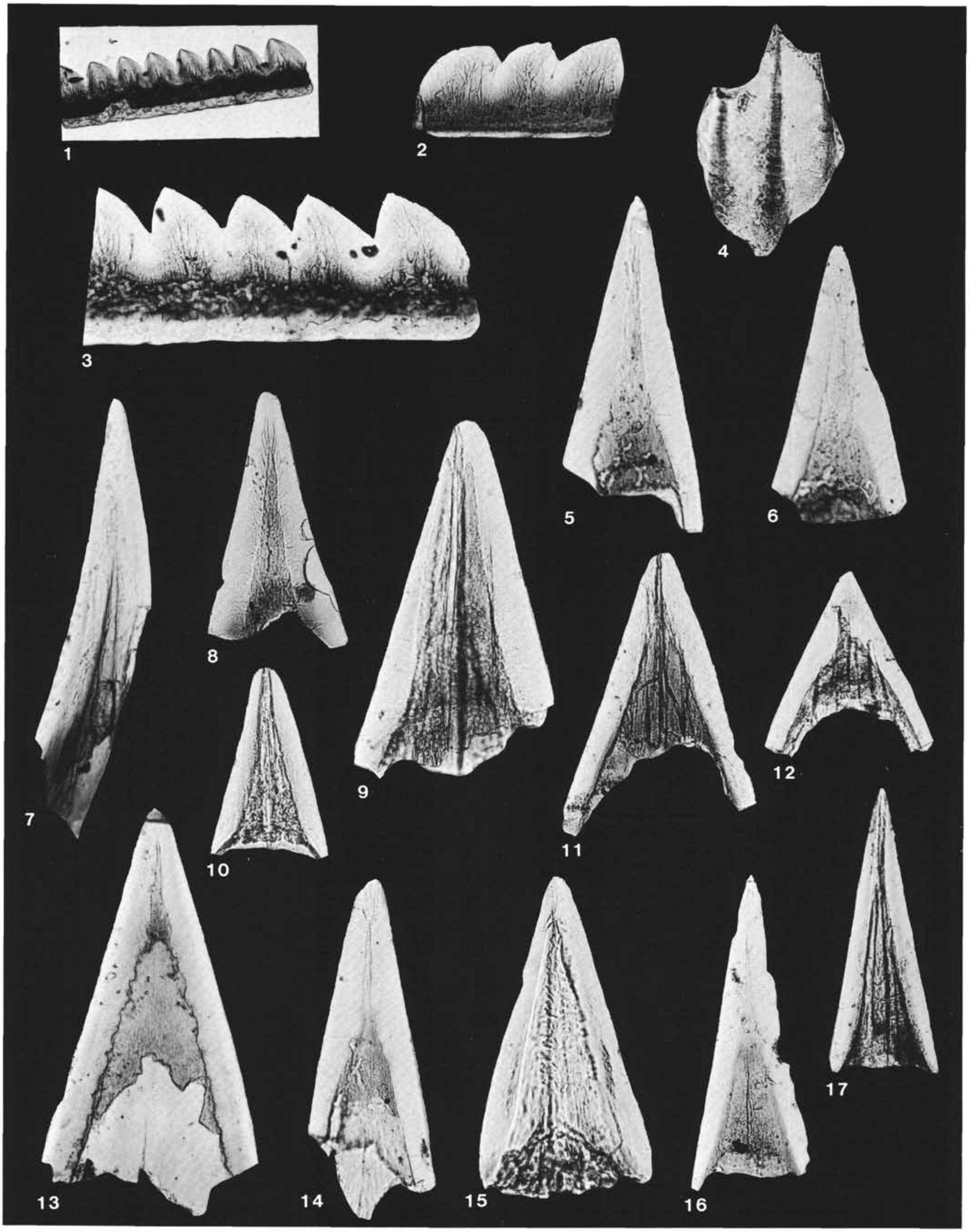

Plate 1. Ichthyoliths in Sample 603E-1,CC.(All ×75 except Fig. 1, which is ×50.) **1.** *Rectangular irregularly saw-toothed*, Doyle and Riedel, 1979b. **2, 3.** *Rectangular saw-toothed*, Doyle and Riedel, 1979b. **4.** *Skewed with transverse lines*, Doyle et al., 1974. **5.** *Flexed triangle 102–112*, Doyle et al., 1974. **6, 8–17.** Undescribed form of *a9/b1*. **7.** (?)*Triangle medium wing*, Doyle and Riedel, 1979b.

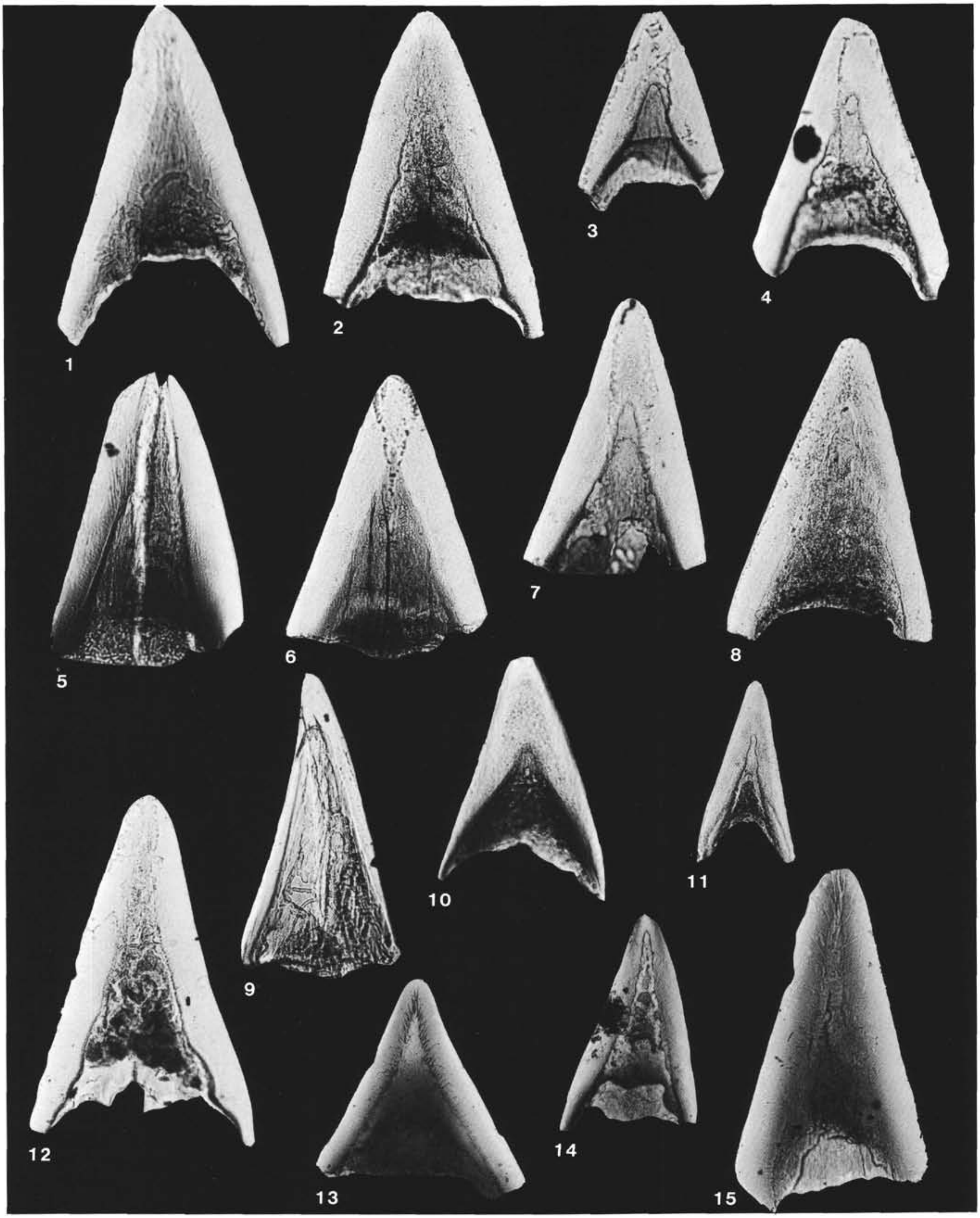

Plate 2. Ichthyoliths in Sample 603E-1,CC. (×75.) **1-11, 13-15.** Undescribed forms of *a9/b1*. **12.** *Triangle sinuous inline,* Gottfried et al., 1984a.

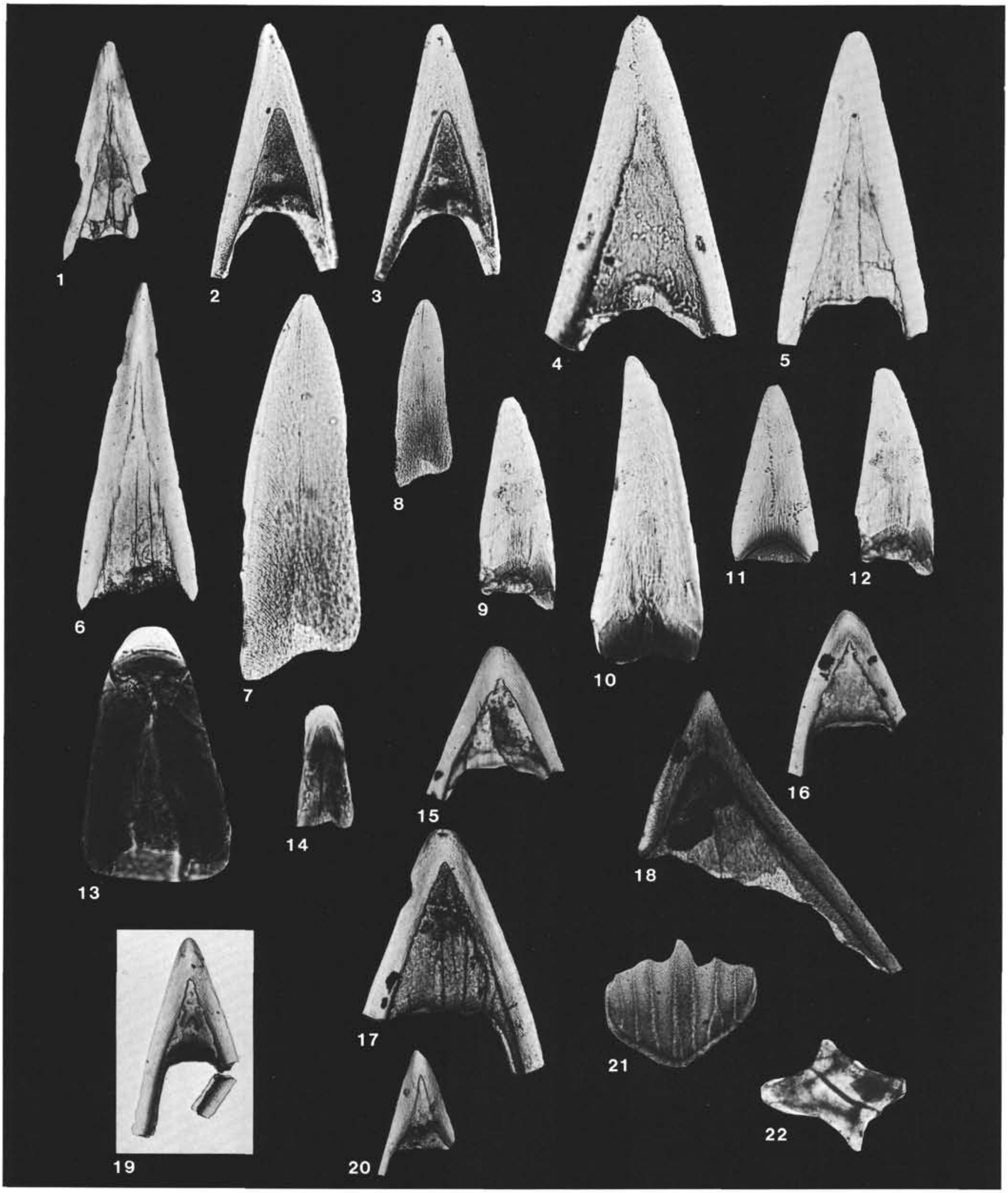

Plate 3. Ichthyoliths in Sample 603E-1,CC (×70.5) **1-4** .Forms similar to *Narrow triangle straight inbase,*. **5.** *Narrow triangle straight inbase,* Doyle and Reidel, 1979b. **6.** *Triangle pointed margin ends,* Doyle and Riedel, 1979b. **7-10, 12.** Forms similar to *Small triangle long striations.* **11.** *Small triangle long striations,* Doyle and Riedel, 1979b. **13.** Undescribed form of *a9/b5.* **14.** *Rounded open triangle,* Doyle et al., 1974. **15-17.** Forms of *a9/b1* similar to *Wide triangle straight inbase.* **18.** Form of *a9/b1* similar to *Curved fibrous triangle,* Tway et al., in press. **19, 20.** *Wide triangle straight inbase,* Doyle and Riedel, 1979b. **21.** *Many peaks transverse lines,* Tway et al., in press. **22.** Form of *a3/b1.*

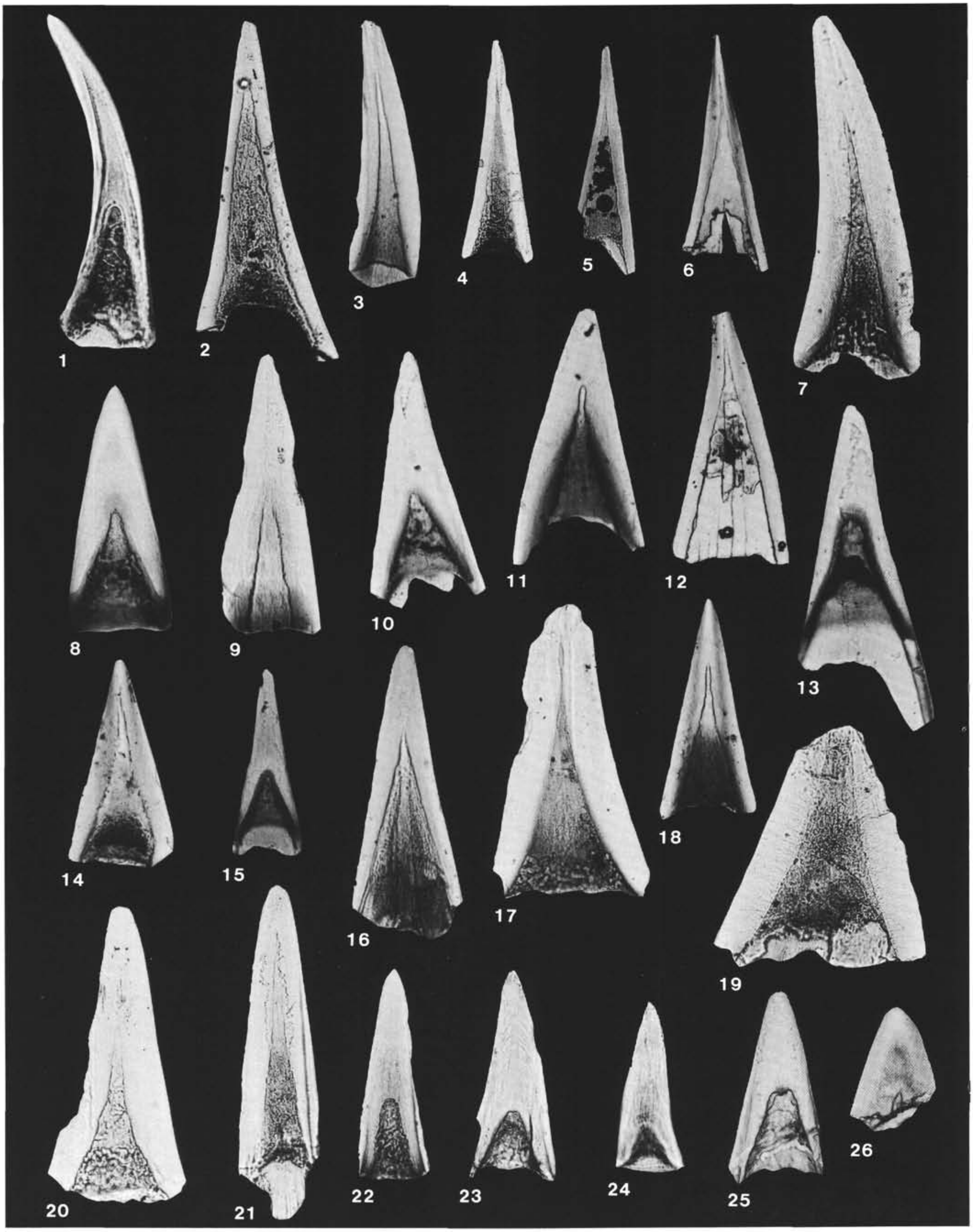

Plate 4. Ichthyoliths in Sample 603E-1,CC (×75.) **1, 3–26.** Undescribed forms of *a8,9/b1,5*. **2.** *Triangle double flex,* Dunsworth et al., 1975.

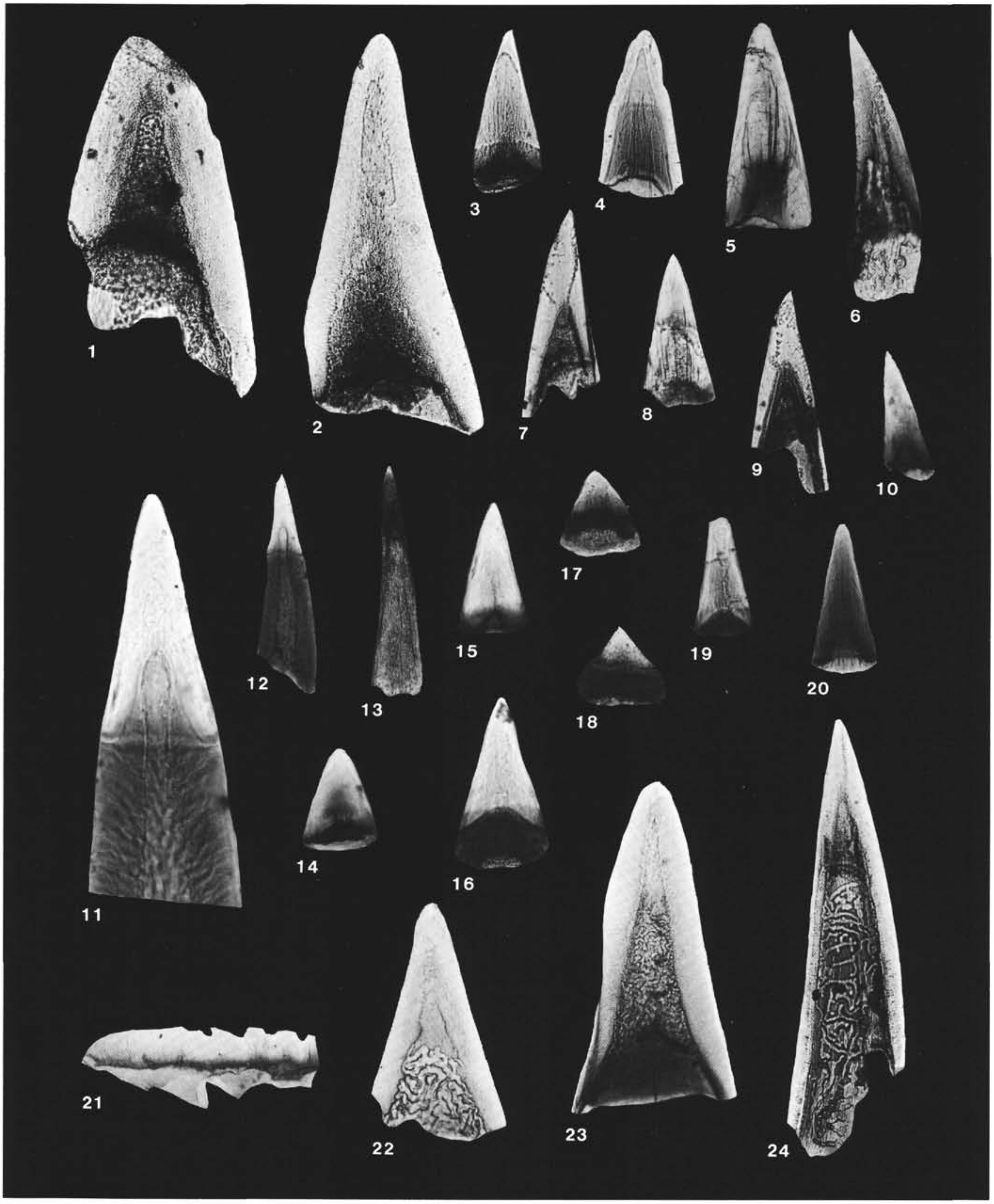

Plate 5. Ichthyoliths in Sample 603E-1,CC (×70.5) **1-10, 13-20, 22-24.** Undescribed forms of *a9/b1, 5;* **11, 12.** Specimens similar to *Curved triangle inline constricted,* Doyle and Riedel, 1979b, which differ in being straight, not curved. **21.** (?)Fragment of *Triangle crenulate,* Doyle and Riedel, 1979b.