Shorter Contributions to Paleontology, 1979

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1125-A-D

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

1879 · CENTENNIAL · 1979

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Western Hemisphere Cretaceous Itieriidae Gastropods

By HEINZ A. KOLLMANN *and* NORMAN F. SOHL

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By THOMAS M. CRONIN *and* JOSEPH E. HAZEL

Miocene Mollusks of the Topsy Formation, Lituya District, Gulf of Alaska Tertiary Province, Alaska

By LOUIE MARINCOVICH, JR.

Variability in *Trithyrodinium* Drugg 1967

By FRED E. MAY *and* DON G. BENSON, JR.

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CONTENTS

[Letters designate the chapters]

CONVERSION FACTORS

Metric unit		Inch-Pound equivalent
Length		
millimeter (mm)	= 0.03937	inch (in)
meter (m)	= 3.28	feet (ft)
kilometer (km)	= .62	mile (mi)
Area		
square meter (m^2)	= 10.76	square feet (ft^2)
square kilometer (km^2)	= .386	square mile (mi^2)
hectare (ha)	= 2.47	acres
Volume		
cubic centimeter (cm^3)	= 0.061	cubic inch (in^3)
liter (L)	= 61.03	cubic inches
cubic meter (m^3)	= 35.31	cubic feet (ft^3)
cubic meter	= .00081	acre-foot (acre-ft)
cubic hectometer (hm^3)	= 810.7	acre-feet
liter	= 2.113	pints (pt)
liter	= 1.06	quarts (qt)
liter	= .26	gallon (gal)
cubic meter	= .00026	million gallons (Mgal or 10^6 gal)
cubic meter	= 6.290	barrels (bbl) (1 bbl = 42 gal)
Weight		
gram (g)	= 0.035	ounce, avoirdupois (oz avdp)
gram	= .0022	pound, avoirdupois (lb avdp)
metric tons (t)	= 1.102	tons, short (2,000 lb)
metric tons	= 0.9842	ton, long (2,240 lb)
Specific combinations		
kilogram per square centimeter (kg/cm^2)	= 0.96	atmosphere (atm)
kilogram per square centimeter	= .98	bar (0.9869 atm)
cubic meter per second (m^3/s)	= 35.3	cubic feet per second (ft^3/s)
Specific combinations—Continued		
liter per second (L/s)	= .0353	cubic foot per second
cubic meter per second per square kilometer [$(m^3/s)/km^2$]	= 91.47	cubic feet per second per square mile [$(ft^3/s)/mi^2$]
meter per day (m/d)	= 3.28	feet per day (hydraulic conductivity) (ft/d)
meter per kilometer (m/km)	= 5.28	feet per mile (ft/mi)
kilometer per hour (km/h)	= .9113	foot per second (ft/s)
meter per second (m/s)	= 3.28	feet per second
meter squared per day (m^2/d)	= 10.764	feet squared per day (ft^2/d) (transmissivity)
cubic meter per second (m^3/s)	= 22.826	million gallons per day (Mgal/d)
cubic meter per minute (m^3/min)	= 264.2	gallons per minute (gal/min)
liter per second (L/s)	= 15.85	gallons per minute
liter per second per meter [(L/s)/m]	= 4.83	gallons per minute per foot [(gal/min)/ft]
kilometer per hour (km/h)	= .62	mile per hour (mi/h)
meter per second (m/s)	= 2.237	miles per hour
gram per cubic centimeter (g/cm^3)	= 62.43	pounds per cubic foot (lb/ft^3)
gram per square centimeter (g/cm^2)	= 2.048	pounds per square foot (lb/ft^2)
gram per square centimeter	= .0142	pound per square inch (lb/in^2)
Temperature		
degree Celsius (°C)	= 1.8	degrees Fahrenheit (°F)
degrees Celsius (temperature)	= [(1.8 × °C) + 32]	degrees Fahrenheit

Western Hemisphere Cretaceous Itieriidae Gastropods

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CONTENTS

ILLUSTRATIONS

WESTERN HEMISPHERE CRETACEOUS ITIERIIDAE GASTROPODS

By HEINZ A. KOLLMANN [1] and NORMAN F. SOHL

ABSTRACT

The presence of representatives of the itieriid (Nerinaecea) gastropod genera *Vernedia* and *Sogdianella* in Cretaceous rocks of the Western Hemisphere is reported for the first time. In addition, *Pervviella* Olsson is transferred from the Actaeonellacea because it possesses an anterior canal, thus precluding the cephalic shield characteristic of cephalaspidean Opisthobranchia. The occurrence of *Peruviella gerthi* Olsson in the area from Peru to Brazil and thence to Angola suggests a marginal Tethyan distribution pattern, whereas the other species discussed are more typically distributed through the main central Tethys biotic realm.

INTRODUCTION

Representatives of the nerineacean family Itieriidae occur widely in the shallow warm-water faunas of the Tethyan province of most areas during Middle Jurassic to Late Cretaceous time. Of all the genera assigned to the Itieriidae, only the genus *Phaneroptyxis* has previously been recognized from the Western Hemisphere. Records of this genus are rare, resting only on *Phaneroptyxis anguillana* (Castillo and Barcena) of Cserna (1956) from the Lower Cretaceous of southern Mexico and on *Phaneroptyxis? angulata* Imlay (1941) from the subsurface Smackover Formation (Jurassic) of Arkansas. Aguilera (1906) cited the additional nomen nudum *Phaneroptyxis teloloapensis* from the Cretaceous of Mexico. One major reason for the dearth of any significant record for members of this family in this hemisphere is the superficial external morphologic resemblance many species bear to members of the Actaeonellacea. Thus, a number of the species we discuss here were originally described under *Actaeonella,* a group belonging to an entirely different order, the cephalaspidean Opisthobranchia.

ACKNOWLEDGMENTS

We acknowledge the aid of Katherine Van Winkle Palmer for the loan of A. A. Olsson types from Peru housed in the collections of the Paleontological Research Institute, Ithaca, N.Y. Keith Young and Christopher Durden are due our thanks for the loan of collections from the Cretaceous of Texas housed at the Texas Memorial Museum at Austin. Annie Dhondt of the Royal Institute of Natural Sciences, Brussels, Belgium, aided in translation of pertinent Russian literature.

The following abbreviations are used for collections housed at the various institutions: USNM, National Museum of Natural History, Washington, D.C.; USGS, United States Geological Survey, Washington, D.C.; UT and UT2, University of Texas, Austin, Tex; PRI, Paleontological Research Institute, Ithaca, N.Y.

Under the sections headed "Measurements" the following symbols are used: H = Height measured parallel to the shell axis, MD = Maximum diameter measured perpendicular to the shell axis, and PA = Pleural angle.

NOTES ON PALEOBIOGEOGRAPHY

The three itieriid genera *Vernedia, Sogdianella,* and *Peruviella,* discussed here, had somewhat different patterns of distribution. In all patterns, however, they are associates of either shallow, warm-water Tethyan or marginal Tethyan faunas. The most widely spread of the genera, *Vernedia* (fig. 1) occurs from Mexico across Europe and the Middle East to India, and possibly to Borneo and Japan in a pattern closely approximating that for orbitolinid formaminifers or rudist bivalves. Within this range, however, some separation of species groups occurs that may reflect provincial separation. As discussed in the systematics part of this paper, the Mexican

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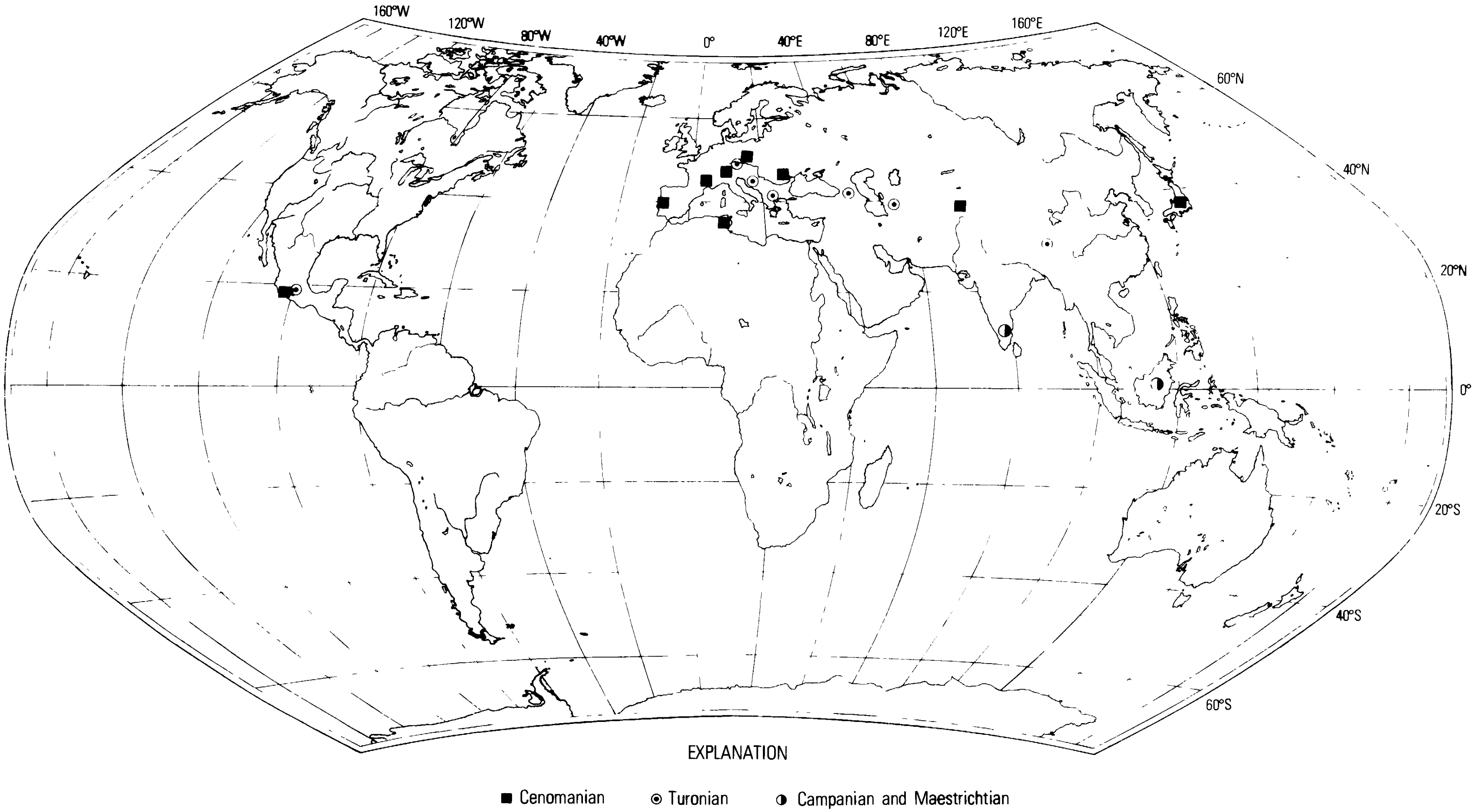


FIGURE 1.—Distribution of *Vernedia* during the Cretaceous.

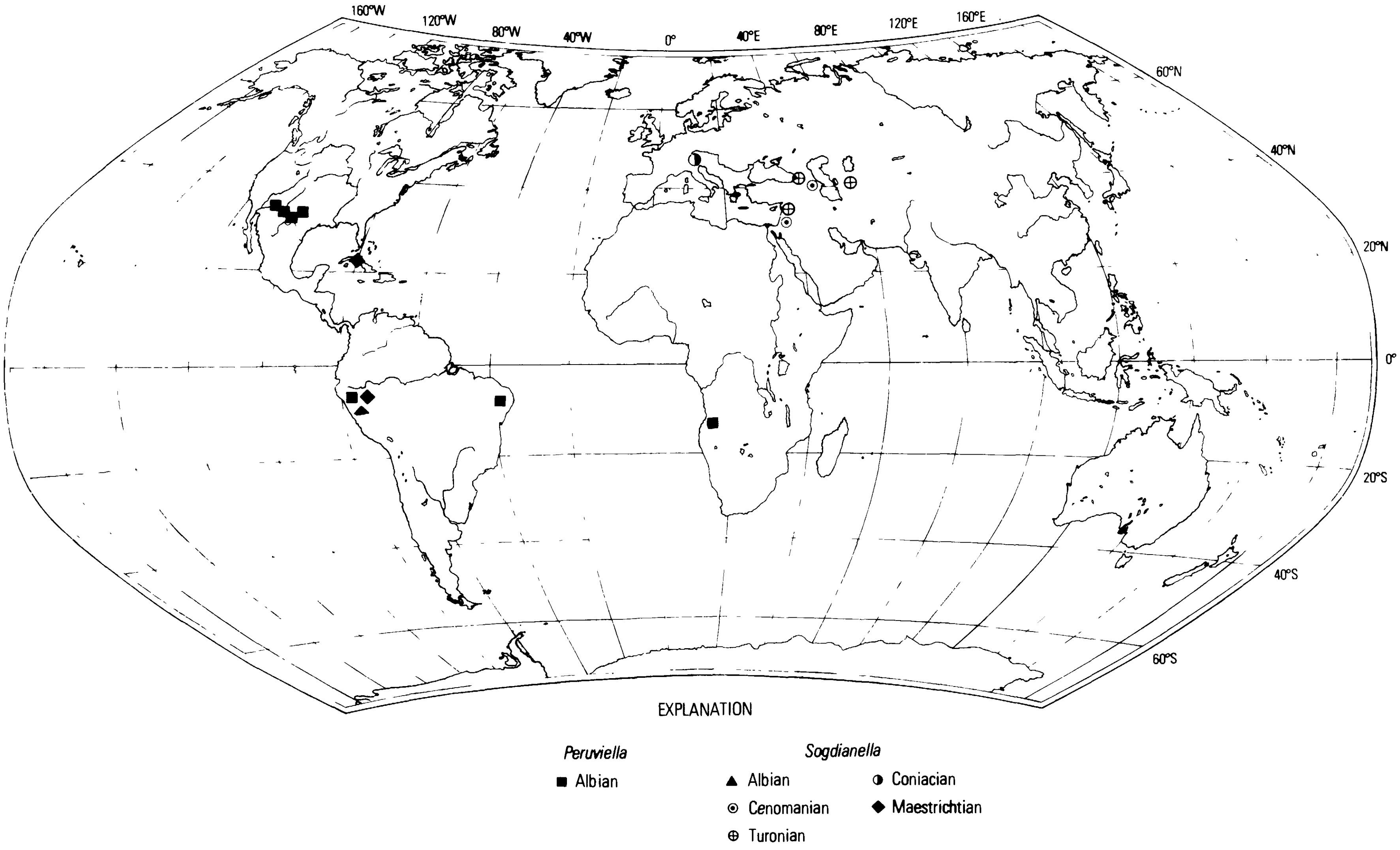


FIGURE 2.—Distribution of *Peruviella* and *Sogdianella* during the Cretaceous.

and south Indian species are morphologically closer akin to each other than to the European and Middle Eastern species. As has been pointed out by several authors, Caribbean rudist bivalves show considerable differentiation from their coeval Mediterranean relatives but are similar to forms found on Cretaceous Pacific atolls. The amount of difference in the *Vernedia* species, however, is not as great as in the rudist examples. In *Vernedia,* this is a species group level difference as opposed to the generic level difference among rudists. Although *Sogdianella* is less common and less diverse than *Vernedia,* the distribution of *Sogdianella* roughly parallels that of *Vernedia* (figs. 1 and 2).

The genus *Peruviella* shows a different distribution pattern (fig. 2). With the exception of occurrences associated with the rudist framework facies in the Albian of Texas, its presence in the Albian of Peru, Brazil, and western Africa is paralleled by other Cretaceous molluscan genera. For example, the arcoid bivalve genus *Pseudocucullaea* possessed a similar distribution (Darteville and Freneix, 1957, p. 42). This pattern of distribution may also be seen in the marginal marine or brackish-freshwater transition gastropods of the Thiariidae. The Thiariidae maintain such a dispersal pattern well into Tertiary time but later split into endemic centers. In essence, the pattern appears to be best described as southern submarginal or marginal Tethyan as opposed to the more truly Tethyan occurrence of *Vernedia* and *Sogdianella.*

SYSTEMATIC PALEONTOLOGY

Order ENTOMOTAENEATA Cossmann

Superfamily NERINAECEA

Family ITIERIIDAE Cossman, 1896

The family Itieriidae is widely represented and is diverse in the Cretaceous deposits of Europe, the Middle East, and Transcaucasia. In the Western Hemisphere, however, occurrences are sporadic. Aside from the two species of *Phaneroptyxis* noted before, only five species assigned to three genera are presently known. These are as follows:

Vernedia freisi, n. sp.
Peruviella gerthi Olsson
Peruviella dolia (Roemer)
Sogdianella peruviana (Olsson)
Sogdianella subcylindrica n. sp.

The presence of these species in rocks ranging in age from Albian to Maestrichtian and in geographic extent from Peru to Texas (figs. 1 and 2) suggests that this record reflects only minimal potential diversity. In part, it may reflect the rather poorly known or poorly represented Cenomanian to Coniacian near shore deposits, especially in the Caribbean region.

The species herein assigned to *Vernedia* would previously have been considered as belonging to *Itruvia.* The genus *Itruvia* was considered closely related to *Itieria* by Stoliczka (1868) and was later placed within the family Itieriidae by both Cossmann (1896) and Wenz (1938–44). As we indicate in the discussion of *Vernedia,* the type species of *Itruvia* appears to be a cerithiid. Both *Peruviella* and *Sogdianella* were considered as Actaeonellidae by their describers. Zilch (1959–60) followed Olsson (1934) in accepting the systematic position of *Peruviella* within the "Aceaeonellinae." The related genus *Sogdianella* was later described by Djalilov (1972). The reason these two genera are considered herein as Itieriidae is primarily the form of the whorl base. Olsson (1934) mentioned in the description of *Peruviella gerthi,* the type species, that the base of the body whorl ends in a small projecting beak. This morphologic feature is a fragile part of the shell and is usually broken off, but its shape can be deduced from the form of the whorls and columella in cut section. The columella is partly hollow, and it has a central pillar with concave sides. This pillar was originally the anterior canal of the whorls and was, at a later growth stage, filled with shell material.

The pillar is very distinct in *Peruviella* but not in *Sogdianella,* where it is short and only slightly concave at the sides. Thus, in *Sogdianella,* the columella is either solid or only slightly hollow. The description of *Sogdianella* on following pages demonstrates its close similarity to *Peruviella* and its differences from *Actaeonella,* and it is, therefore, reassigned to the Itieriidae.

Although the Cenomanian genus *Eotrochactaeon* Hacobjan, 1972, does not occur in the Western Hemisphere, its systematic placement parallels the case for *Peruviella.* Hacobjan (1972) placed *Eotrochactaeon* within the "Trochactaeonidae," but, like the genera discussed before, it possesses the hollow columella and central pillar of the Itieriidae. Unlike *Peruviella* and *Sogdianella,* however, it is not involute but has a short spire. Hacobjan (1972) defined *Eotrochactaeon* as follows: "Shell large, oval, consisting mainly of the last whorl; spire short, sometimes hardly projecting or almost invisible; whorls moderately convex, with an inclined sutural ramp in the upper portion; aperture elongate, semilunate, broad, gradually and evenly tapering towards the base; walls very thick, smooth, a little arched on top; columella with three plaits, vestiges of a narrow almost closed umbilicus."

On the basis of the characters of shell form and aperture, the Acteonellidae are considered cephalaspidian Opisthobranchia gastropods. Any shell that possesses an anterior canal would not be amenable to placement in the family, as the possession of such a feature contravenes the possession of the characteristic cephalic shield. Thus, the demonstrated presence of an anterior canal in both *Peruviella* and *Eotrochactaeon* cannot be considered an example of character homeomorphy, and it supports their exclusion from the Actaeonellidae and placement in the Itieriidae. The placement of *Sogdianella* in the Itieriidae, however, rests on the less strong basis of its similarity to *Peruviella.*

Genus Vernedia Mazeran, 1912

Type species.—Vernedia laurenti Mazeran, 1912, by original designation.

Discussion.—Douville (1921), Wenz (1940, p. 829), and subsequent workers have considered *Vernedia* Mazeran as a synonym of *Itruvia* Stoliczka (1867). Stoliczka did not designate a type species but listed several species as being representative for the genus, among them *Pyramidella canaliculata* d'Orbigny. This species was subsequently designated by Cossmann (1896) as the type species of *Itruvia.*

Mazeran (1912) proposed the generic name *Vernedia* and argued that the type species of *Itruvia,* as used by both d'Orbigny (1843) and Cossmann, comprised two different species of gastropods. The specimens from the upper Turonian of Uchaux, France, that have a smooth concave columella and no interior plication were described by Mazeran as *Vernedia canaliculata* (d'Orbigny). The other material (d'Orbigny, 1843, pl. 164, figs. 4, 5), which was described originally from the French Province of Gard, was included by Mazeran in his new species *Vernedia laurenti.* This species is characterized by both a columellar plait and a parietal plait, according to Mazeran's figures. Mazeran explicity designated *laurenti* as type species of *Vernedia.* Although Mazeran's total suppression of the name *Itruvia* is not correct in a nomenclatorial sense, we agree with him that *"Pyramidella canaliculata* d'Orbigny" included two different gastropod taxa. Thus, Mazeran's separation and description of one of these species as *Vernedia laurenti* and the type of his new genus must be viewed as valid. As Douville (1921) pointed out, even though d'Orbigny's original definition of *Pyramidella canaliculata* refers primarily to the specimens from Gard, Mazeran's discussions restrict the name to the specimens that came from Uuchaux, France. These specimens thus form the basis for understanding *P. canaliculata,* the type species of *Itruvia.* We agree with Douville that the type species, and, therefore, the genus *Itruvia* is closely related to the cerithiid genus *Campanile.* In summary, *Vernedia* cannot be considered as a junior synonym of *Itruvia.* Thus, all species from Europe and Asia that have been hitherto incorporated within *Itruvia,* except for the forms identical with *I. canaliculata* from Uchaux, should be assigned to *Vernedia.*

The oldest species of *Vernedia* occur in rocks of Cenomanian Age. The genus is most widespread and diverse in rocks of Cenomanian and Turonian Age (fig. 1), but a few are to be found as late as the Campanian and Maestrichtian deposits of Southern India (Stoliczka, 1867).

The only species of *Vernedia* known in the Western Hemisphere is *V. freisi,* described below, from Mexico. Its closest affinities are with *V. globoides* (Stoliczka) from southern India rather than with the European and Transcaucasian species discussed below.

The following species differ from *Vernedia freisi* in possessing a longer, thinner pillar, but all belong in *Vernedia* and are here transferred:

Itruvia gigantea Ptselintsev, 1953
  armenica Ptselintsev, 1953
  subornata Ptselintsev, 1953
  fergenensis Ptselintsev, 1953
  armenica ornata Ptselintsev, 1953
  caucasica Ptselintsev, 1953
  angusta Ptselintsev, 1953
  subcarinata Ptselintsev, 1953
  cycloidea Ptselintsev, 1953
  subcycloidea Ptselintsev, 1953
  dolioliformis Ptselintsev, 1953
  cerithiformis Ptselintsev, 1953
  stephanovi Ptselintsev, 1954
  ovalis Ptselintsev, 1953

The above listed species come from lower Turonian deposits of the Transcaucasia. When considering the amount of variation in proportional height of spire and resulting relative obseity of the body whorl shown by specimens of *V. freisi,* one may doubt the advisability of proposing so many species for forms from a narrow stratigraphic interval in a single region. Without having seen Ptselintsev's original material, we believe that the above listed species consist of only two groups. We feel that each group probably deserves no more than species rank. These are as follows:

1. *Vernedia cycloidea* group. Oviform to globular shells; base concave to flat; columella inclined; parietal ridge rounded and low. The group consists of the species *Itruvia cycloides, I. subcycloides, I. caucasica,* and *I. gigantea.* In addition, *Itruvia abbreviata* (Phillippi) morfa, A, B, C of Lupu, 1966, belong to the same group. Representatives of this group have also been found in Austria (Kollmann, 1968).
2. *Vernedia armenica* group. High-spired *Vernedia* with strong prosocline, transverse ribs, and rows of nodes on the upper part of the whorls; base tapering, columella high, almost vertical, with a rather weak plait; parietal ridge much stronger than in the *Vernedia cycloidea group.* The *Vernedia armenica* group consists of *I. armenica, I. subornata, I. fergenensis, I armenica ornata, I. subcanaliculata, I. angusta, I. cerithiiformis, I. stephanovi,* and *I. ovalis.*

The middle Cenomanian species that Rahman (1967) described from Hoelzelsau in Tyrol, Austria, all belong to the *V. armenica* group. The transverse ribs are dissolved or pinched into a variable number of nodes. All the forms described by Rahman were found at the same stratigraphic horizon in the same outcrop. They do not differ significantly in apertural characters or in columellar and parietal structures and probably belong, therefore, to the same species.

Vernedia abbreviata (Phillippi), 1851, is high spired and has a more or less convex last whorl. The illustration of that species provided by Lupu (1966) and Stoliczka (1868) shows that the parietal ridge is prominent and similar to the other high-spired *Vernedia* mentioned above. The outer shell surface is smooth.

Vernedia globoides (Stoliczka) (1868) from the Arrialoor group (Campanian and Maestrichtian) of Comparapolliam in the Trichinopoly district in southern India shows a remarkable similarity to *V. freisi* if figure 1, plate 14, of Stoliczka is correctly drawn. It is subcyclindrical, the columella is concave externally and twisted outwards in its lower part. As the concave part is much higher here than in the aperture, where obviously a columellar lip with a plait is present, we may conclude that the concave side of the pillar is exposed. Compared with *Vernedia freisi* from Mexico, the last whorl of the specimen of *V. globoides* figured by Stoliczka is proportionally higher, and the maximum diameter is not as high.

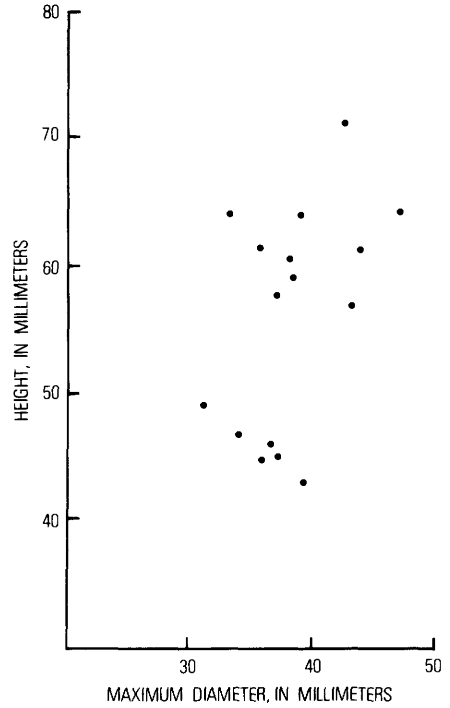


FIGURE 3.—Relationship of height and maximum diameter among specimens of *Vernedia freisi* Kollmann and Sohl.

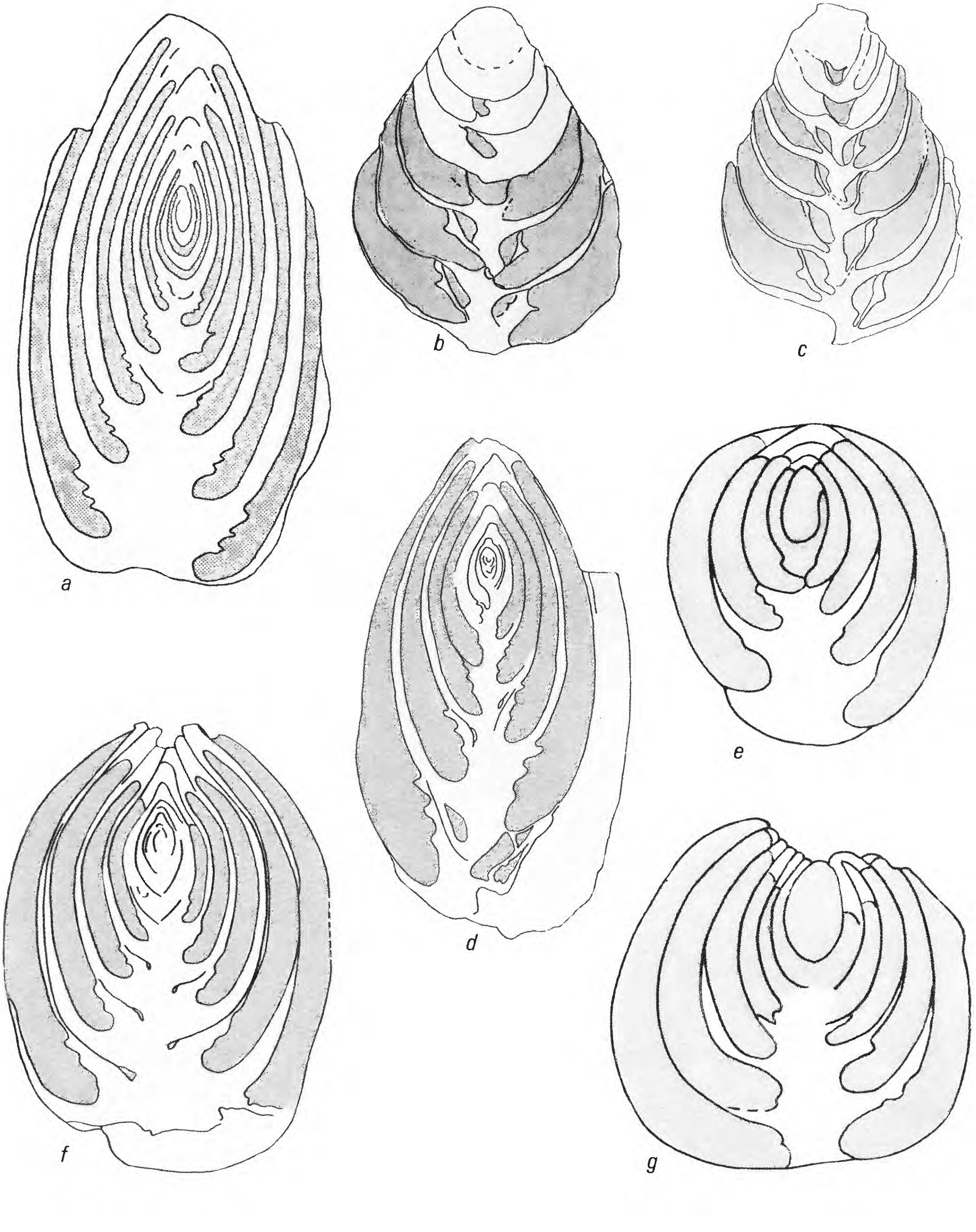
Vernedia freisi Kollmann and Sohl, n. sp.

Figures 4 *b, c,* 5 *a–e.*

Diagnosis.—A *Vernedia* with a thick, stout, columellar pillar bearing convex sides.

Description.—Globose shells of medium size; maximum diameter 60–70 percent of total height; spire high, more than eight whorls, sides concave to slightly convex; whorls with narrow inclined subsutural ramp. Body whorl convex, with a depression

FIGURE 4.—Camera lucida drawings of axial sections of:
a. *Sogdianella* aff. *S. peruviana* (Olsson) (× 2.5) from the *Actaeonella* limestone. Cerro Negro, Paita region, Peru (USGS 31452; USNM 25304).
b, c. *Vernedia freisi* Kollmann and Sohl, n. sp. (× 1.3 and 1.5), paratypes from near Armeria, State of Colima, Mexico (USGS 26391; USNM 251301 and 251300).
d. *Peruviella gerthi* Olsson (× 1.3), from Pananga Formation, Pan de Azucar, western foothills of the Amotape Mountains, near Talara, Peru (USGS 27061; USNM 251305).
e. *Peruviella dolium* (Roemer) (× 1), from the Lower Cretaceous of Texas (UT2 1030).
f. *Peruviella dolium* (Roemer) (× 1.6) from Flat Mesa 6.4 km north of Sierra Blanca, El Paso County, Tex. (USGS 1809; USNM 251307).
g. *Peruviella dolium* (Roemer) (× 1), from the Finlay Mountains, Hudspeth County, Tex. (USGS 1909; USNM 251309).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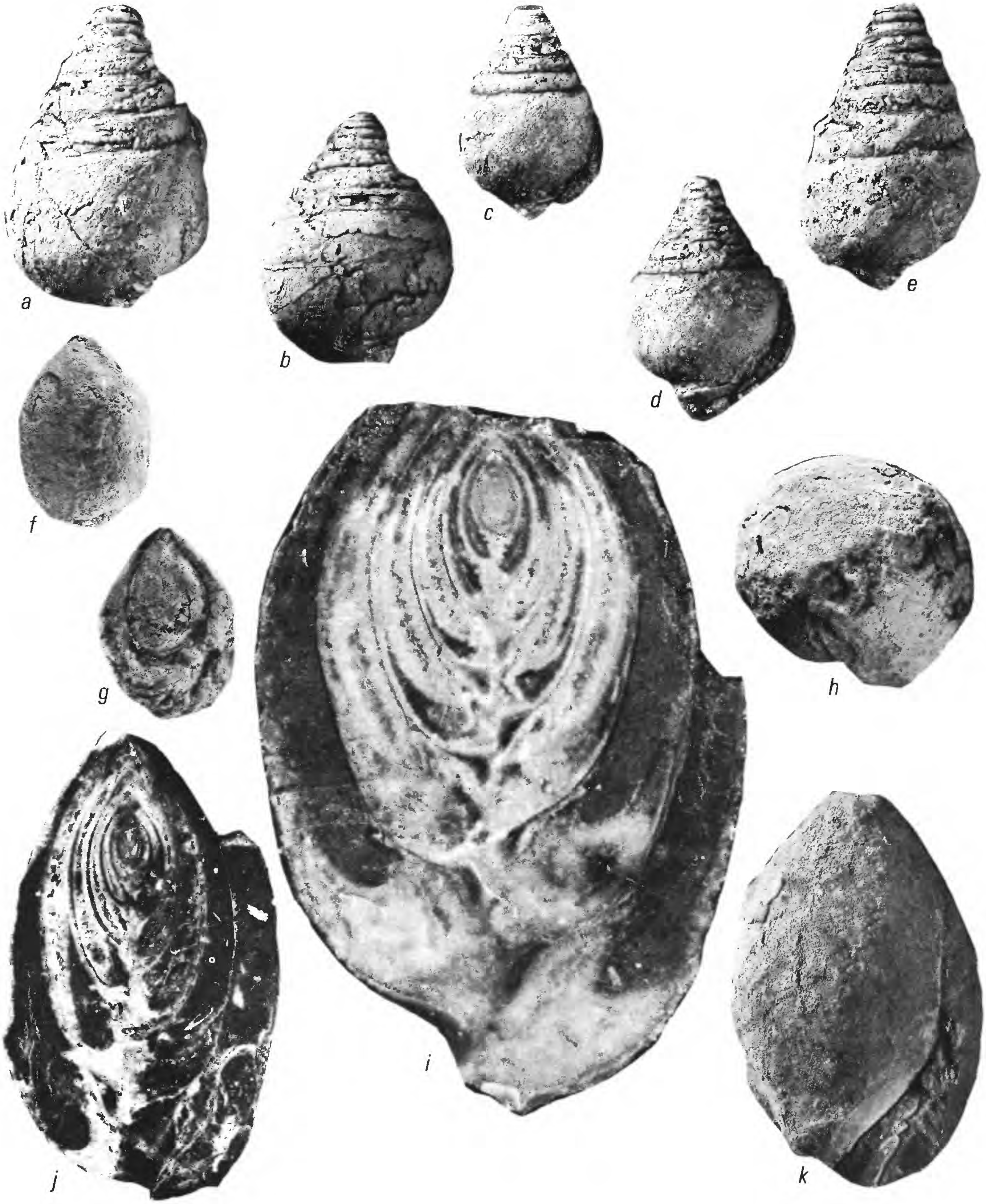
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of variable strength in the middle, and faint strongly inclined prosocline growth lines. Aperture proportionally short, scimitar shaped, lower part considerably broader than upper part. Columella short with one plait, which is obliquely bent upward; columella above and below plait concave; weak parietal thickening in middle of parietal lip is broad but flat; central pillar of columella very thick and stout, lower end broadened so that pillar has concave sides; columella between concavity of pillar and adjoining columellar lip hollow; whorl base strongly convex or rounded; columella decreases regularly in length at aperture and together with outer lip forms a beaklike process at the base.

Measurements (fig. 3).—*Holotype*—H, 44 mm; MD, 36 mm.

Paratypes—H, 39.5–58.7 mm; MD, 25.5–36.6 mm; PA, 50°–70°.

Discussion.—As indicated in the discussion of the genus, *Vernedia freisi* differs from all European species with which it could be compared by having a thick columellar pillar having convex sides. This feature indicates a dextral twisting of the apertural canal.

FIGURE 5.—*Vernedia freisi* Kollmann and Sohl and *Peruviella gerthi* Olsson.

a–e. *Vernedia freisi* Kollmann and Sohl, n. sp.

- *a.* Back view (× 1) of a paratype (USGS 26391; USNM 251298). Specimens from near Armeria, State of Colima, Mexico.
- *b.* Back view (× 1) of a paratype with an especially globose body whorl (USGS 26391; USNM 251299).
- *c.* Front view (× 1) of a paratype (USGS 26391; USNM 251297).
- *d.* Front view (× 1) of the holotype (USGS 26391; USNM 251295).
- *e.* Back view (× 1) of a paratype possessing an exceptionally high spire (USGS 26391; USNM 251296).

f–k. *Peruviella gerthi* Olsson

- *f, g.* Back and front views (× 0.8) of a paratype from the Pananga limestone, Pan de Azucar, Amotape region, Peru (Paleontological Research Institute, Ithaca, N.Y.)
- *h, k.* Apical and front views (× 1) of a specimen from the Pananga limestone, Pan de Azucar, Amotape foothills of the Amotape Mountains near Talora, Peru (USGS 27061; USNM 251306).
- *i.* Axial section (× 1.5) of a specimen from the Pananga Formation, Pan de Azucar, western foothills of the Amotape Mountains near Talara,
- *j.* Axial section (× 2) of the holotype showing whorl shape and internal features; locality same as for figures *f* and *g* (Paleontological Research Institute, Ithaca, N.Y.).

Among the 24 specimens available for study, variation in proportional shape is great. This is amply demonstrated in the plot of height against maximum diameter measurements for the best preserved specimens presented in figure 3. Equally great variation in pleural angle is seen not only between specimens but between individual specimens of changing growth stages. Some specimens, such as that illustrated in figure 4*c*, possess a convex spire profile; others (fig. 5*e*) have a rather evenly tapering spire. Similarly, the profile of the body whorl may be well rounded (fig. 5*b*) to medially flattened. All available specimens come from the same bed, and there is no reason to believe that the morphologic types present reflect more than intraspecific variation.

The species is named in honor of the original collector of the material Carl Freis, Jr., formerly of the U.S. Geological Survey.

Occurrence.—(USGS 26391).—Road cut on Colima-Manzanillo highway, at east edge of village of Armeria, lat 18°56′ N. and long 103°58′ W., State of Colima, Mexico.

Age.—late Cenomanian or early Turonian.

Types.—Holotype, USNM 251295. Paratypes, USNM 251296–251301.

Genus Sogdianella Djalilov, 1972

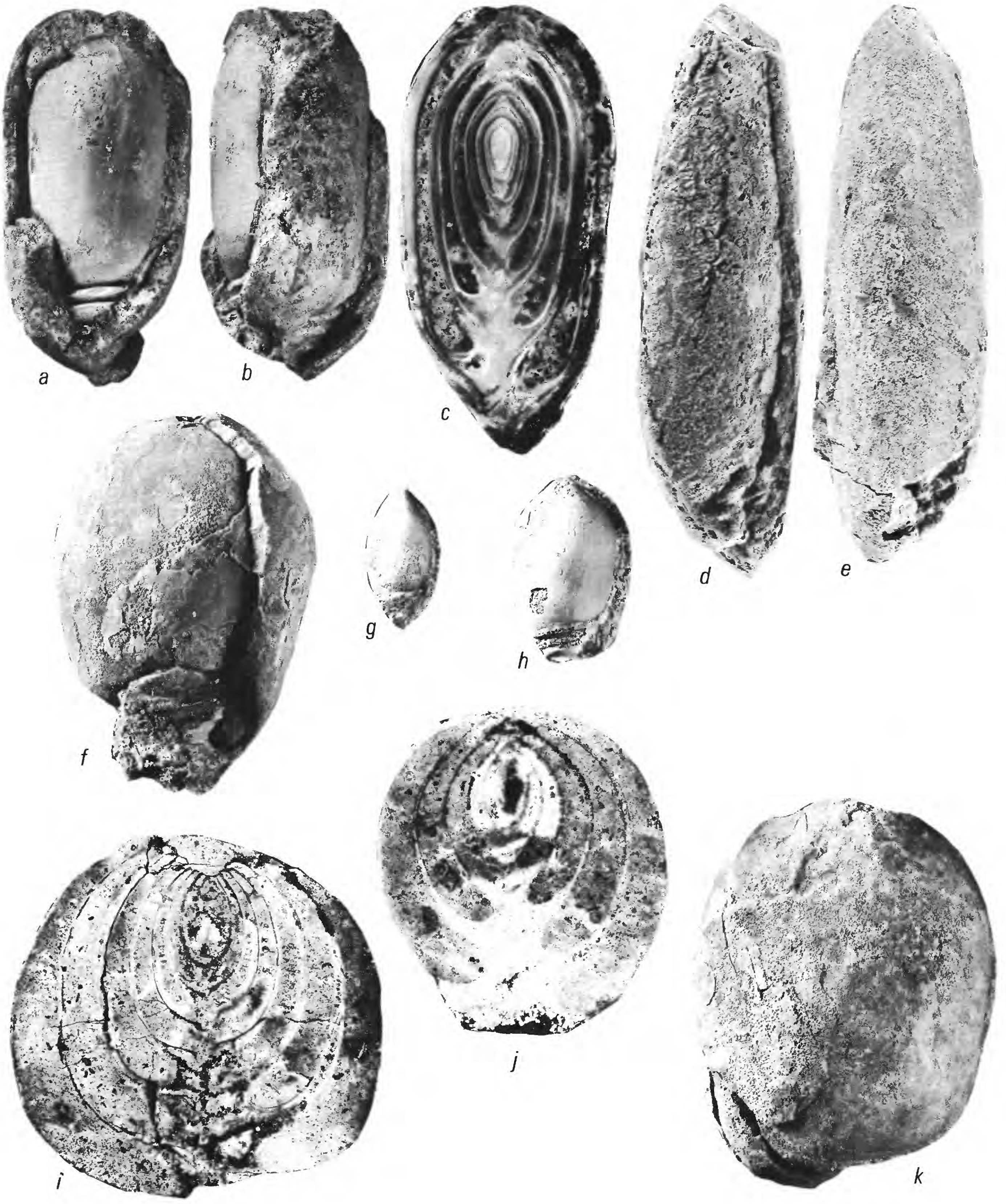
Type species.—*Actaeonella supernata* Ptselintsev, 1953, by original designation.

Diagnosis (from Djalilov, 1972). "Shell of medium to small size, ovate to cylindrical; generally it resembles a cylinder with attached cones at both ends; upper extremity trending toward a perforate condition; spire partly or completely involute."

Discussion.—Ptselintsev's (1953) figures of the type species show some other morphologic features that seem to us important for the definition of the genus:

Whorls very narrow and only slightly widened in the lower part of the shell. Columella strongly inclined toward axis at lower end and bearing three plaits; columella below plaits strongly concave; short pillar within; columella having concave sides that indicate slight basal prolongation of whorls; often with a thin hollow space between pillar and adjoining part of the columella of next whorl.

Sognianella zekelii (Kollmann, 1965) was originally described as an *Actaeonella* and later correctly included by Djalilov (1972) in his new genus. In addition to the generic features we describe from the type species, paratypes of *Sogdianella zekelii* from the Upper Cretaceous of Kaiserhaus, northern Tyrol, Austria, show the principal constructional features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of the posterior exhalant siphon; namely, the growth lines, which are orthocline throughout most of the shell, are curved backward in the uppermost immediate subsutural part. The cut sections show that the first-formed parts of the outer and inner walls of the whorls are secondarily thickened in the upper part of the aperture, which thus become narrowed considerably. Between this point and the suture, the whorls again increase in width and widen interiorly. The whole structure is then filled by later shell layers. The exhalant siphon is, therefore, a combination of a notch as indicated by backcurving sinused growth lines and a funnellike structure. It opens on top of the shell and is more or less twisted to one side. In large specimens, this siphon opens into the apical perforation.

Actaeonella has a shell with convex sides, the whorls are broader interiorly than in *Sogdianella,* and the columella has more or less parallel sides and is solid. In addition, the axis above the shell center is solid, and the whorls do not join together loosely as in *Sogdianella.* In *Actaeonella,* the posterior extension of the aperture opens on top, but, unlike *Sogdianella,* it is not twisted to the side and there is no notch.

FIGURE 6.—*Sogdianella subcylindrica* Kollmann and Sohl, n. sp.; *Sogdianella peruviana* (Olsson); and *Peruviella dolium* (Roemer).

a, b. Back and front views (× 1) of the holotype from the Habana Formation in Oriente Province, Cuba (USGS 19464; USNM 251302).

c. Axial section (× 1.5) of a paratype from the type locality (USGS 19464, USNM 251303).

d, e. *Sogdianella peruviana* (Olsson). Front and back views (× 1) of the holotype from the Pananga Formation, Pan de Azucar, Amotape region Peru. Paleontological Research Institute, Ithaca, N.Y.)

f–k. *Peruviella dolium* (Roemer)

f. Front view (× 1) of a specimen from the Finlay Limestone (?), at Flat Mesa, El Paso County Tex. (USGS 1809; USNM 77559).

g. Front view (× 1) of a specimen from the same locality as figure *f* (USGS 1809; USNM 253110).

h. Front view (× 1) of a specimen from the same locality as figure *f* (USGS 1809; USNM 253110).

i. Axial section (× 1) of a specimen from the Finlay Mountains. Hudspeth County, Tex. (USGS 1909; USNM 251308).

j. Axial section (× 1) of a specimen from Lower Cretaceous of Texas (TU21030).

k. Back view (× 1) of a specimen from the Finlay Limestone (?) at Flat Mesa, El Paso County, Tex. (USGS 1809; USNM 253112).

Peruviella Olsson has wide whorls with a longer anterior canal than *Sogdianella,* and the columella has much hollow space between the central pillar and the columellar lip of the following whorls.

In *Ovactaeonella* Djililov, the whorls are broadly rounded at the base and the shell has, at least in later growth stages, an umbilicus. *Omphaloactaceonella* Hacobjan, 1972, is so similar morphologically that we here place it in synonymy of *Ovactaeonella.*

Sogdianella ranges from strata of Albian Age through the Late Cretaceous. Both the earliest record (*Sogdianella peruviana* (Olsson)) and the youngest record (*Sogdianella subcylindrica* Kollmann and Sohl) are from the Western Hemisphere. Through middle Cretaceous time, however, *Sogdianella* is known only from central Europe, the Middle East and Transcaucasia. The lack of record in North and South America from Cenomanian time to the Maestrichtian may, however, be due to lack of knowledge and proper facies rather than absence of the genus.

Sogdianella subcyclindrica, Kollman and Sohl, n. sp.

Figures 6 *a, b, c*

1955. *Actaeonella* (*Volvulina*) n. sp. Lewis and Straczek, U.S. Geol. Survey Bull. 975–D, p. 194.

Diagnosis.—A *Sogdianella* with a moderate apical perforation and a body whorl that is, in profile, slightly depressed medially.

Description.—Medium-size, subcylindrical involute shells; body whorl slightly depressed medially; uppermost part in small growth stages has an obtuse tip; in later stages rounded and in the last growth stages moderately perforate. Aperture very narrow, slightly wider in lower part; columella short with three plaits that decrease in strength anteriorly, lowermost one is very weak and rounded on top. Edge of columella bends downward just outside aperture; basal lip narrow, slightly beaklike, prolonged, and excavated over its whole width.

Measurements.—Holotype, H, 66.6mm; MD, 36.1 mm. Paratype, H, 53.2mm; MD, 25.8mm.

Discussion.—Although the aperture of the holotype is broken, the narrow basal lip is preserved and together with the palatal lip forms the characteristic small beaklike protrusion (fig. 6*a*). The three columellar plaits, the completely involute shell in juvenile stage, and the posterior perforation or pit in large shells are all features characteristic of *Sogdianella.*

Sogdianella peruviana Olsson has more convex whorl sides and is, thus proportionally more narrow both anteriorly and posteriorly.

Occurrence.—Habana Formation; (USGS 19464) 25.5 km east of Central Miranda, on the La Caoba–Sumidero road, Oriente Province, Cuba.

In addition, several incomplete specimens from the Habana Formation on the El Macho River, south coast of Oriente Province, Cuba (USGS 23743), may belong to this species.

Age.—Available evidence from associated fossils suggests a Maestrichtian Age. Reeside (*in* Lewis and Staczek, 1955) considered the Habana Formation in which *Sogdianella* has been found as "late Upper Cretaceous."

Types.—Holotype, USNM 251302. Paratype, USNM 251303.

Sogdianella peruviana (Olsson)

1934. *Actaeonella peruviana* Olsson, Bulls. Am. Paleontology, v. 20, no. 69, p. 71–72, pl. 9, fig. 7.

Description (from Olsson, 1934), p. 71.—"Shell large, elongate, cylindrical, somewhat broader in the anterior portion than in the posterior; body-whorl completely enveloping the preceding whorls but with the posterior portion of the shell somewhat contracted and produced; section of the shell shows numerous whorls which are not resorbed; columella with three plaits; external surface smooth; aperture narrow, linear, following the contour of the shell."

Measurements.—The holotype of *S. peruviana* (Olsson) measures 104 mm (posterior end lacking) in total height and has a maximum diameter of 30 mm.

Discussion.—Olsson (1934, p. 72) indicated that *Sogdianella peruviana* is among the most common and characteristic fossils present in limestone of the Pananga Formation of the Amotape region of northern Peru. Unfortunately, only the holotype is available for study as Dr. K. Palmer (written commun., 1974) stated that no additional specimen of the species are present in the collections of the Paleontological Research Institute, Ithaca, N.Y. As shown in figure 6*d*, the holotype lacks the upper part of the aperture, and the columellar plaits are not readily apparent. Thus, information on variability and plait characters must rest on Olsson's description and discussion, which was evidently based upon sections made from specimens other than the holotype. In his discussion of *S. peruviana,* Olsson (1934) mentioned that young shells are less cylindrical than the adult forms and that sections show numerous whorls.

Although the holotype is not sufficiently preserved for positive generic identification, its similarity to the specimens described under *S.* aff. *S. peruviana* makes a strong argument for their placement in *Sogdianella.*

Occurrence.—Pananga Formation, Pan de Azucar, Quebrada Muerto, and Quebrada Culebra, Peru (Olsson, 1934).

Age.—Albian.

Type.—Holotype, Paleontological Research Institute, Ithaca, N.Y.

Sogdianella aff. S. peruviana (Olsson)

Figure 4*a*

1928. *Actaeonella* (*Volvulina*) sp. Gerth, Leidse Geol. Meded., v. 1928, pt. 2, Afl. 4, p. 233.

Discussion.—Six specimens in the collections of the U.S. Geological Survey from Cerro Negro, Paita Region, northern Peru (USGS 31236) may be related to Olsson's species. They differ mainly in having more convex sides and are broader proportional to height. They are similar to *A. peruviana* Olsson in the many narrow whorls seen in section and in the whorls being almost equally narrow in both anterior and posterior parts of the whorl (fig. 4*a*). The shells lack a palatal ridge, the columella is broad and low, and anteriorly it is strongly inclined toward the shell axis. The columella bears three plaits that decrease in strength anteriorly and is concave below the plaits.

The above mentioned features are characteristic of *Sogdianella.* Their specific identity with *Actaeonella peruviana* Olsson is tentative not only because of the morphologic differences mentioned above, but also because of differences in age of the two stratigraphic levels represented. *Actaeonella peruviana* Olsson occurs associated with an Albian ammonite assemblage (Olsson, 1934, p. 13). Our specimens seemingly come from the "Actaeonellen-Rudistinkalkstein" of Gerth (1928), which Olsson (1944, p. 15) has called the "Actaeonella limestones." This limestone occurs above beds containing sphenodiscid ammonites. The presence of *Praebarrettia peruviana* Gerth in these beds suggests that the age is early Maestrichtian. Olsson himself vascillated on the affinities of the "Actaeonella limestone" gastropod species, first (Olsson, 1934, p. 10) considering the two to be possibly the same, but later (Olsson, 1944, p. 72) stating that the two were probably distinct.

Although the generic status of *Actaeonella peruviana* Olsson cannot be proved, its gross similarity to the specimens discussed here from Cerro Negro suggests that it belongs in *Sogdianella.*

Occurrence (USGS 31452).—"Actaeonella limestone," Cerro Negro, Paita Region, Peru.

Age.—Early Maestrichtian.
Type.—Hypotype USNM 251304.

Genus Peruviella Olsson, 1944

(Synonym: Peruvia Olsson, 1934 non Peruvia Scudder, 1890.)

Type species.—*Peruvia gerthi* Olsson, 1934, by original designation.

Diagnosis.—Globose shell with involute to immersed apex. Aperture with basal beak, columella either solid or hollow, and bearing three plaits.

Discussion.—Olsson described this genus first in 1934 and named it *Peruvia*. As that name was preoccupied, he substituted *Peruviella* (Olsson, 1944). The following description of the genus is taken from Olsson, 1934:

> Shell ovate, globose; the spire is pointed, its sides impressed but completely enveloped by the last whorl; base of the shell is rounded with a short, projecting beak; aperture narrow, somewhat wider in front and extending the full length of the shell; the pillar and the anterior portion of each whorl is strongly thickened with callous deposit; columellar folds are absent at maturity or they are reduced to a single, small plait situated at the upper edge of the callus on the parietal wall.

An examination of the holotype of the type species *Peruviella gerthi* shows that the first whorls of the shell and the basal parts of the whorl are filled with calcite (fig. 5*j*). As the shell is also calcified, the plaits are hardly visible. Other paratypes show three plaits clearly (fig. 4*d*).

Peruviella gerthi Olsson, 1934

Figures 4*d*, 5*f-k*

1928. *Actaeonella* cf. *gigantea* Sowerby.– Gerth, H., Leids. Geol. Meded., v. 1928, pt. 2, Afl. 4, p. 232–241.
1934. *Pervia gerthi* Olsson, Bulls. Am. Paleontology, v. 20, no. 69, v. 59, p. 73, pl. 9, fig. 1–3.
1936. *Trochactaeon sergipensis* Maury. Brazil, Servico Geol. Mineralog. Mon., v. 11, p. 222 (225) pl. 13, figs. 2, 5, 6, 8.
1944. *Peruviella gerthi* Olsson. Bulls. Am. Paleontology, v. 28, no. 111, p. 6.

Diagnosis.—A *Peruviella* with the upper part of the whorls compressed and the base of the aperture extended to a beaklike process.

Description (from Olsson, 1934, p. 73).—"Shell of medium size, ovate, globose; spire completely enveloped by the last turn but with the posterior or apical portion of the shell somewhat produced and pointed; the sides of the whorls in the posterior region are noticeably impressed, while just below the whorl appears slightly shouldered; the base of the body whorl is rounded ending in a small, projecting beak; surface smooth except for lines of growth; character of complete aperture unknown * * * (Olsson, 1934).

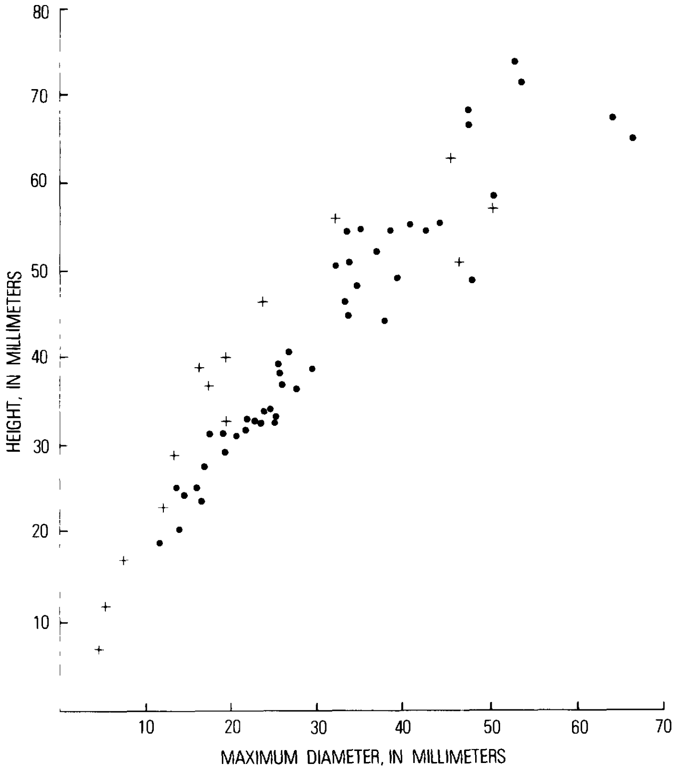

FIGURE 7.—Relationship of height and maximum diameter in *Peruviella gerthi* Olsson (cross) and *Peruviella dolium* (Roemer) (circle).

Measurements (fig. 7).—Holotype: H, 63.0 mm; MD, 45.0 mm (upper part of shell incomplete). Paratypes: H, 39–51 mm; MD, 57–71 percent of total height.

Discussion.—Restudy of the available material provides the following additional information on shell characters. The middle of the shell is consistently the broadest dimension. The columella of *Peruviella gerthi* is highly inclined to the shell axis (fig. 5*j*) and bears three plaits of which the posterior-most is stronger than the others and is inclined upward. The columella below the plaits constitutes about one-third its total height.

The species *Trochactaen sergipensis* from Brazil, described by Maury (1936, p. 222), appears to belong to this species. In addition to Maury's illustrations, we have been able to examine two specimens collected by Peter Bengston of the University of Uppsala, Sweden. These specimens came from the Carapeba Quarry, 2.4 km northwest of the village of Pedra Branca on the west side of the Pedra Branca to Riachuelo road in the State of Sergipe, Brazil. The specimens were collected from an oolitic limestone within the Maruin Member of the Riachuelo Formation. Associated with the *Peruviella* specimens were the ammonites *Elobiceras inter-*

medium Spath and *Elobiceras subelobiense* Spath indicative of a late Albian Age. Although this is not the same locality as that from which Maury's specimens came, they are from the same stratigraphic unit.

Compared with *Peruviella dolium* this species is proportionally narrower (compare figures 4*d* and 4*f* and *g*) and has a longer columella.

Occurrence.—Peru, Pananga Formation at Pan de Azucar, Amotape region. Brazil, Riachuelo Formation, Marium Member, near Riachuelo, Sergipe Province.

Age.—Middle to late Albian.

Type.—Holotype, PRI 3753. Paratype, PRI 3752. Hypotypes, USNM 251305, 251306.

Peruviella dolium (Roemer), 1849

Figures 4*e-g*, 6*f-k*

1849. *Actaeonella dolium* Roemer, Texas, p. 411.
1852. *Actaeonella dolium* Roemer. Roemer, Die Kreidebildungen von Texas, p. 43, pl. 4, fig. 4.
1888. *Acteonella anchietai* Choffat *in* Choffat and de Loriol, Soc. Physique et Histoire Nat. Genève Mém, v. 30, no. 2, p. 73, pl. 3, fig. 3–5.
1928. *Volvulina texana* (Roemer). Adkins, Texas Univ. Bull. 2838, p. 196.
1947. *Actaeonella dolium* Roemer. Stanton, U.S. Geol. Survey Prof. Paper 211 p. 109, pl. 67, figs. 1, 3, 4, 7, 10–12.
1956. *Actaeonella anchietai* Choffat. Darteville and Brébion. Mus. Royal Congo Belg Ann., Sci. geol. v. 15, p. 95 (all records in Africa).

Diagnosis.—A *Peruviella* that has a broadly oviform to globular and anomphalous shell. Small shells are involute, but larger shells are apically perforate. The columella is proportionally short.

Description (from Roemer, 1852).—"Shell rather long; truncate at the base, pointed at the top, surface smooth; without spire, whorls concealed by the preceding ones; much broader at the lower end, sloping slowly to the upper end; inner surface folded near the base; three regular and acute plaits."

Supplementary description.—Shell form varies according to growth stage, small specimens are strongly convex medially, apical slopes broadly concave terminating in pointed apex (fig. 6*g*) ; large specimens have a barrellike to globular form with midwhorl only slightly convex to vaguely concave, apical and basal slopes broadly rounded. Shell completely involute in early stages but in later stages body whorl not completely enveloping thus leaving an apical pit (fig. 6*i*). Growth lines are broadly sinuate over upper half whorl surface in area coincident with maximum shell diameter. Aperture narrow throughout length, anterior part terminates in a small beak. Columella, in form of an inverted cone, is hollow between beak and preceding whorl, bears three equally spaced plaits over upper part, and is smooth over an equal distance anteriorly.

Measurement (fig. 7).The holotype is an internal mold of no value for measurement. Other specimens are as much as 93 mm in height and have a maximum diameter of about 60–100 percent of total height.

Discussion.—*Peruviella dolium* (Roemer) is a widely distributed species that is variable in several morphologic features. For example, the apical pit is exceptionally large in globular specimens from the Finlay Mountains (Fredrickburgian) of west Texas (USGS 1909, see fig. 6*i*). Stanton (1947, p. 110) mentioned that a large suite of specimens collected near Sierra Blanca, also in west Texas, showed a typically larger size and lesser convexity of whorls, and he suggested that they might deserve subspecific distinction. Reexamination of these collections shows a polymorphous assemblage of specimens, which, although variable, show intergradation of character that provides no justifiable basis for separation. The range of variability of the material from the lower and middle Albian of Texas encompass the form described from the Albian of Dombe-Grande Angola by Choffat (1888) as *Actaeonella anchietai.*

The maximum diameter of *Peruviella gerthi* Olsson is proportionally smaller compared with its total height than is *P. dolium* (compare figs. 5*k*, 6*k*) and even in large shells the upper part is pointed and has concave sides. In addition, the columellar lip is higher within the whorls and not so much inclined (compare figs. 4*d* and *g*). The Late Cretaceous species of *Peruviella* described by Djalilov (1972) from the U.S.S.R. are all broadly umbilicate.

Types.—Holotype, University of Bonn, Germany. Hypotypes, USNM 77559, 251307, 251308.

Occurrence—Texas.—The holotype is believed to be from an unknown position within the Fredrickburg Group (middle Albian) near Fredericksburg. Tex. Paluxy Sand, between Bertram and Hopewell, Coryell County (UT 1029) : Walnut Clay, road cut just west of Gatesvile, Coryell County; Cox Sandstone (and (or) Finlay Limesone) ; Eagle Mountain (UT 8402, 8407, 8408; Finlay Mountains (USGS 1909, 1922) ; Quitman Canyon (USGS 1912, 1917) ; Sierra Blanca (USGS 1809, 1812, 15974) ; Eagle Flat area (USGS 3603) ; Bell County, locality and stratigraphic position unknown (USNM 8306b) ; Lampasas County, locality and stratigraphic position unknown (USNM 18802).

Mexico.—Cox Formation, Sierra Pilares (UT 31437) and Benevides (UT 43538) State of Chihuahua.

Angola.—Dombe-Grande.

Age.—Early to middle Albian in North American and middle to late Albian of Angola.

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Ostracode Biostratigraphy of Pliocene and Pleistocene Deposits of the Cape Fear Arch Region, North and South Carolina

By THOMAS M. CRONIN *and* JOSEPH E. HAZEL

SHORTER CONTRIBUTIONS TO PALEONTOLOGY, 1979

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March 3, 1849

CONTENTS

ILLUSTRATIONS

[Figures 4–9 follow References Cited]

TABLE

OSTRACODE BIOSTRATIGRAPHY OF PLIOCENE AND PLEISTOCENE DEPOSITS OF THE CAPE FEAR ARCH REGION, NORTH AND SOUTH CAROLINA

By Thomas M. Cronin and Joseph E. Hazel

ABSTRACT

Species-range and concurrent-range-zones of ostracode species from the Duplin, "Bear Bluff," Waccamaw, and "Canepatch" Formations (Pliocene and Pleistocene) were determined from numerous samples from the Cape Fear Arch region, North and South Carolina. On the basis of occurrence data, chronozones of the *Orionina vaughani* and *Puriana mesacostalis* Assemblage-Zones established for the Virginia and northern North Carolina region can be recognized in the Cape Fear Arch region and as far south as the Santee River, S.C. Deposits mapped as the Duplin Formation (Pliocene) represent the chronozone for the *Orionina vaughani* Assemblage-Zone and are in part equivalent to the Yorktown Formation. Deposits of the Bear Bluff (upper Pliocene) and the Waccamaw (Pleistocene) Formations correspond respectively to the lower and upper parts of the *Puriana mesacostalis* Assemblage-Zone and are time equivalents of the lower and upper beds in the Croatan Formation. Middle Pleistocene deposits mapped as the Canepatch Formation yielded distinctive assemblages containing high percentages of extant species.

INTRODUCTION

Recently, Hazel (1971a, 1977, 1980) proposed quantitatively defined ostracode assemblage-zones and determined biostratigraphically diagnostic species-range and concurrent-range-zones for Pliocene and lower Pleistocene deposits of Virginia and northern North Carolina. From previously published data and analysis of new ostracode samples, Hazel (1977) presented a correlation scheme for the Pliocene and lower Pleistocene deposits of the central and southern Atlantic Coastal Plain and Florida. In connection with several U.S. Geological Survey projects, many Pliocene and Pleistocene samples have been obtained from the Cape Fear Arch region of North and South Carolina. Calcareous microfossils from these samples, particularly ostracodes, are presently being studied for their biostratigraphic, paleoecologic, and systematic value. This paper presents preliminary biostratigraphic results of this study. Figure 1 shows the region of study, which extends from the South River, N.C., south to the Santee River, S.C.

The stratigraphic distribution of ostracode species in deposits mapped as Duplin, "Bear Bluff," Waccamaw, and "Canepatch" Formations has been determined. The "Bear Bluff" and "Canepatch" are terms introduced by DuBar (1971) and DuBar and others (1974). They are used informally in this paper. Many ostracode species from these deposits were found by Hazel (1971a, 1977) to be useful biostratigraphic indicators in Pliocene and lower Pleistocene deposits of Virginia and northern North Carolina. Some of the chronozones of the ostracode assemblage-zones proposed by Hazel (1971a) can be recognized in the Cape Fear Arch region by the presence of species having limited stratigraphic ranges and by the concurrent-range-zones of several pairs of species. Thus, the biostratigraphic equivalents of the ostracode zones established for regions to the north can, at least in part, be recognized south to about the Santee River, S.C. Moreover, other species, rare to absent in deposits north of Cape Hatteras (north of area shown on fig. 1), were found to have relatively short local stratigraphic ranges in the study area; hence, they are useful for correlation of lithostratigraphic units within the Cape Fear Arch region.

ACKNOWLEDGMENTS

Blake W. Blackwelder, U.S. Geological Survey, and Jules R. DuBar, Morehead State University, Morehead, Ky., freely gave their insights into Atlantic Coastal Plain geology.

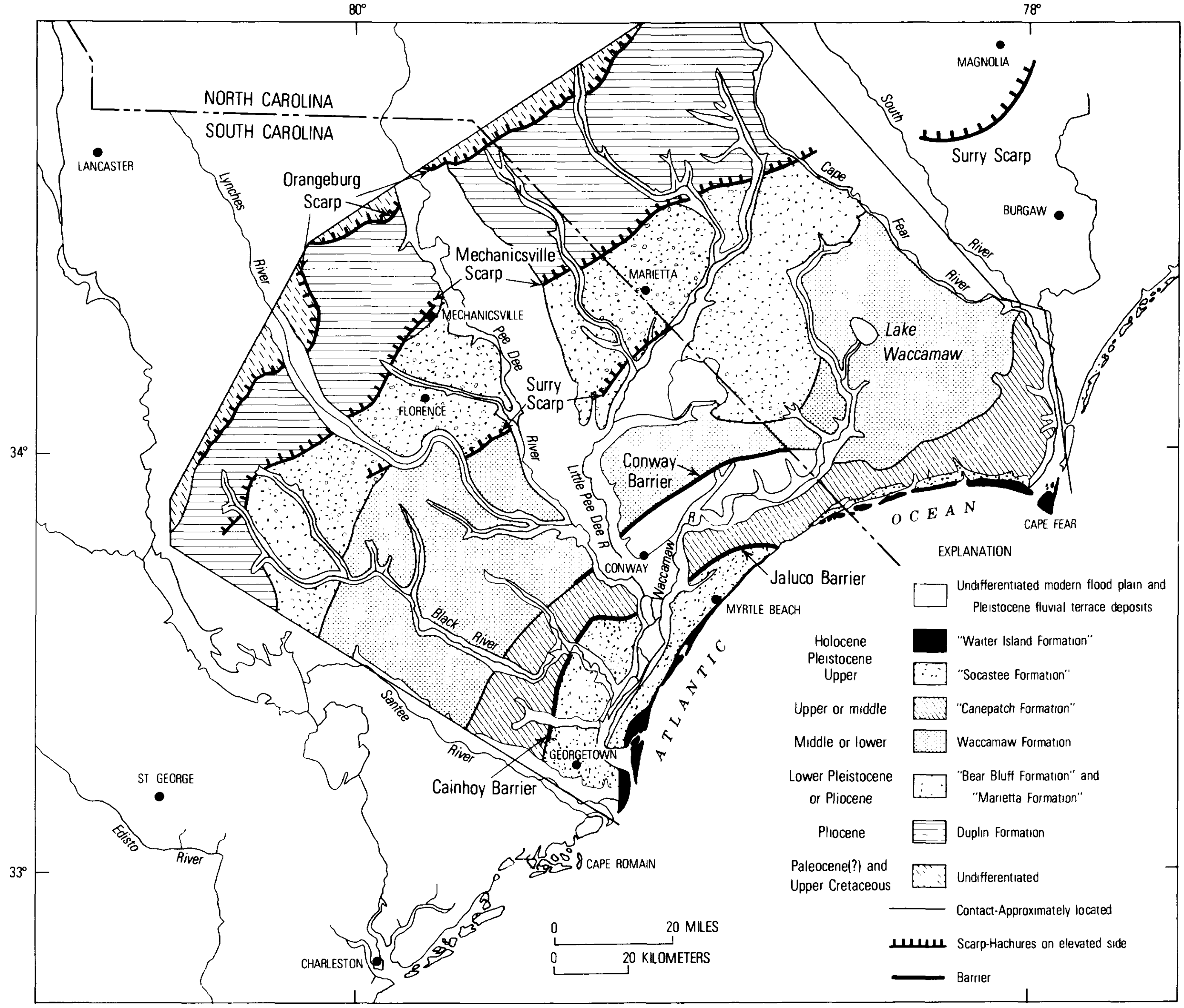

FIGURE 1.—Generalized geologic map of Pliocene and Pleistocene formations in the study area, the Cape Fear Arch region of North Carolina and northeastern South Carolina, showing major scarps and barriers. (Adapted from DuBar and others, 1974).

LITHOSTRATIGRAPHIC UNITS

The term "Duplin Beds" was proposed by Dall (1898, p. 338) for "late Miocene" shelly marls in Duplin County, N.C. In 1903, Dall listed molluscan species from Natural Well, Magnolia, N.C., a locality that has since been regarded as the Duplin type locality (see DuBar and others, 1974). B. L. Miller (Clark and others, 1912) was first to use the term "Duplin Formation" for these deposits. In the Cape Fear Arch area, the Duplin Formation rests on Cretaceous to Paleocene strata and is exposed at the surface between the Orangeburg and Mechanicsville Scarps (fig. 1). Consisting of calcareous silt and sand, the Duplin Formation extends from the study area north to the Neuse River and south into Georgia. Whereas earlier workers assigned the Duplin a late Miocene age, recent work has shown that the Duplin is in fact Pliocene (Akers, 1972; Akers and Koeppel, 1974; Hazel, 1977, 1980).

Previous studies of Duplin ostracodes include those by Edwards (1944), Brown (1958), and Swain (1952) for North Carolina; Pooser (1965) for South Carolina; and Howard (1974) for the Cape Fear Arch region. Material for the present study comes from the type locality of the Duplin at Natural

Well, Magnolia, N.C. (loc. 16); four samples come from outcrops on the Lumber River near Lumberton, N.C. (loc. 15); and six samples come from the Robeson family farm, Robeson County, N.C. (loc. 14). Locality data for the studied samples are given in the Collection Localities section at the end of this report.

DuBar (1971) named the Bear Bluff Formation for a sequence of calcareous sandstone and sandy limestone cropping out along the Waccamaw River in Horry County, S.C. The Bear Bluff has been traced in the subsurface from southeastern North Carolina to the Santee River and from the coast inland to the Surry Scarp. DuBar and others (1974) assigned the Bear Bluff Formation a late Pliocene or early Pleistocene age, and Hazel (1977) considered it late Pliocene.

Except for the few data used by Hazel (1977), ostracodes from the Bear Bluff Formation have not been described or listed in detail. Howard (1974) stated that the lower parts of deposits from North Carolina, which he called the Waccamaw Formation, may actually be the Bear Bluff Formation of DuBar (1971), but Howard could not distinguish the two formations.

Ostracode material from the Bear Bluff for the present study came from the William Bird Ashley mine (loc. 17) near Conway, S.C., the Intracoastal Waterway, Horry County, S.C. (locs. 2 and 5), and the open pit mine at Calabash, N.C. (loc. 12). An additional sample from a Horry County drill hole (loc. 13) was obtained from J. R. DuBar.

Fossiliferous clayey and silty quartzose sands exposed along the Waccamaw River, Horry County, S.C., were named the "Waccamaw Beds" by Dall (1892). Deposits of the Waccamaw Formation are present east of the Surry Scarp and from the Cape Fear River south as far as Charleston, S.C. Stratigraphically, the Waccamaw Formation is above the Bear Bluff and below the Canepatch Formations. Recent stratigraphic and faunal evidence suggests that the Waccamaw Formation is early Pleistocene in age (Hazel, 1977; DuBar and others, 1974).

Previous studies of Waccamaw ostracodes include those by Swain (1968) and Howard (1974). Abundant material used in the present study was collected from outcrops of the Waccamaw at the following localities: the Intracoastal Waterway, Horry County, S.C. (locs. 3 and 5); Calabash, N.C. (loc. 12); Walker's Bluff (loc. 7), Greenback Landing (loc. 10), and Niels Eddy Landing (loc. 9) on the Cape Fear River, N.C.; Old Dock, N.C. (loc. 6); the Town Creek Pierce Brothers Pit, Brunswick County, N.C. (loc. 8); the pit west of Acme, Columbus County, N.C. (loc. 11); and the type Waccamaw locality (loc. 1) near Tilly Lake on the Waccamaw River, S.C.

The term "Canepatch Formation" has been used by DuBar (1971) and DuBar and others (1974) for lithologically variable deposits exposed along the Intracoastal Waterway, Horry County, 10.4 km northeast of Myrtle Beach, S.C. Forming the surface of the Jaluco-Cainhoy and Conway Barriers, the Canepatch Formation unconformably overlies the Waccamaw, Bear Bluff, and Duplin Formations and other older deposits. It consists of a complex of sand, clay, silt, and peat deposited in barrier, estuarine, lagoonal, and shelf environments. DuBar and others (1974) assigned a middle to late Pleistocene age to the Canepatch Formation. Material for the present study comes from exposures of the Canepatch Formation on the Intracoastal Waterway, Horry County (locs. 2, 3, 4, and 5). No data on Canepatch ostracodes have been published previously.

PHYSIOGRAPHIC UNITS

The Duplin, Bear Bluff, Waccamaw, and Canepatch Formations were deposited during submergent periods of submergent/emergent cycles related to glacial eustatic adjustments, possibly complicated by tectonic movements (see below). However, any discussion of Atlantic Coastal Plain deposits must include consideration of the physiographic units that owe their formation to these submergent episodes. These features include many prominent shoreline scarps and terrace-formations for which a complex nomenclature has evolved (Cooke, 1931, 1932). The traditional approach to correlation of these deposits was to associate a shoreline scarp with a stand of sea level, a physiographic surface, and a lithostratigraphic unit. Thus, for example, the Duplin sea shoreline would correspond to the Orangeburg Scarp, and sediments that make up the Duplin Formation were deposited between the Orangeburg Scarp and the topographically lower Mechanicsville Scarp. Early workers, most notably Cooke (1936, 1943), correlated these units solely on the basis of their altitude. This approach, however, has serious drawbacks. It assumes that once a shoreline scarp has been formed, sea level never reaches that position again. Recent evidence indicates that Pliocene and Pleistocene inundations may have reached the Mechanicsville and Surry Scarps (fig. 1) more than once (DuBar and others, 1974). Consequently shoreline-scarp and terrace formation seems to result from a more complex geological history than previously believed. More importantly, the technique of correlation on the basis only of altitude hinges on the assumption that the Atlantic Coast has been tectonically stable during the Pliocene and Pleistocene, an assumption that appears to be unwarranted in light of recent evidence. Bloom (1967) was one of the first to warn against correlation of terraces simply by their altitude. Recently, Winker and Howard (1977), using topographic maps as data, suggested that relict shorelines are neither horizontal nor parallel to each other. Thus, correlation by altitude is unreliable, and alternative means of correlation must be sought for a better understanding of the relationships between the physiographic and lithostratigraphic units and the history of submergence and tectonic warping. In light of this need, the present study attempts to enhance our biostratigraphic correlation techniques for the Cape Fear Arch region.

BIOSTRATIGRAPHY

Biostratigraphically diagnostic ostracode taxa for the Cape Fear Arch region are listed alphabetically in table 1. Figure 2 schematically illustrates the stratigraphic distribution of 50 selected ostracode taxa in the Cape Fear Arch region. Species ranges are plotted against a composite lithostratigraphic section for the region; hence, range endpoints appear to coincide exactly with formational boundaries. Species that are common to both the Virginia and northern North Carolina region and the Cape Fear Arch region and whose range endpoints and concurrent-range-zones are useful in recognizing the chronozones of ostracode assemblage-zones are indicated in figure 2. For the few taxa having different stratigraphic ranges in each of the two regions, a solid line shows the distribution in deposits in the Cape Fear Arch region, and a dashed line shows the distribution for Virginia and northern North Carolina, plotted against the assemblage-zonation for that region. Figures 4–9 (see the back of this report) illustrate the 50 taxa.

CHRONOZONES OF OSTRACODE ASSEMBLAGE-ZONES

Hazel (1977) suggested that Pliocene and Pleistocene deposits north of the Neuse River, N.C., might be correlated with those in the Cape Fear Arch region by using range-zones and concurrent-range-zones of species common to both regions. Indeed, the results of the present study indicate that two of the chronozones of ostracode assemblage-zones of Hazel (1971a, 1977) can be recognized south of Cape Hatteras; thus, correlation between the two regions is possible by using ostracodes. Additional sampling and faunal study are still needed, however, to obtain

TABLE 1.—*Alphabetical listing of species used in this study*

Species	Species No. (Fig. 2)	Figure No. (this report)
Actinocythereis captionis Hazel	38	*6g*
A. captionis Hazel (large form)	4	*6h*
Bensonocythere aff. *B. bradyi* Hazel	1	*6a*
B. gouldensis Hazel	14	*5a*
B. ricespittensis Hazel	43	*5b*
B. rugosa Hazel	16	*5c*
B. whitei (Swain) s.s.	29	*5g*
B. whitei (Swain) (straight form)	50	*5h*
B. sp. A	35	*5d*
B. sp. B	3	*6b*
B. sp. C	2	*5e*
B. sp. D	49	*5f*
Caudites paraasymmetricus Hazel	42	*8i*
Echinocythereis leecreekensis Hazel	32	*9f*
Hermanites ascitus Hazel	7	*6f*
Hulingsina sp. N	48	*8j*
Loxoconcha edentonensis Swain	19	*9d*
L. matagordensis (Swain)	40	*9c*
L. sp. A	6	*9b*
L. sp. B	5	*9a*
Malzella conradi (Howe and McGuirt)	8	*4h*
M. evexa Hazel	15	*4g*
M. floridana (Benson and Coleman)	46	*4f*
Microcytherura choctawhatcheensis (Puri)	20	*7c*
M. expanda Hazel	31	*7f*
M. minuta Hazel	11	*7g*
M. similis (Malkin)	17	*7d*
M. sp. B	36	*7b*
M. sp. C	22	*7a*
M. sp. D	44	*7e*
Muellerina bassiounii Hazel	27	*6e*
M. wardi Hazel	12	*6c*
M. sp. B	33	*6d*
Neocaudites triplistriatus (Edwards) s.l.	25	*8g*
N. variabilis Hazel	23	*8h*
Orionina vaughani (Ulrich and Bassler)	21	*8e*
Palaciosa minuta (Edwards)	41	*9h*
Paracytheridea altila Edwards	24	*8f*
P. sp. A	45	*8c*
P. edwardsi Hazel	26	*8d*
P. mucra Edwards	9	*8a*
P. rugosa Edwards	30	*8b*
Paracytheroma stephensoni (Puri)	39	*7h*
Perissocytheridea sp. B	34	*9g*
P. sp. C	10	*9e*
Puriana carolinensis Hazel	13	*4b*
P. convoluta Teeter	37	*4d*
P. mesacostalis (Edwards)	28	*4c*
P. sp. A	47	*4a*
Radimella confragosa (Edwards)	18	*4e*

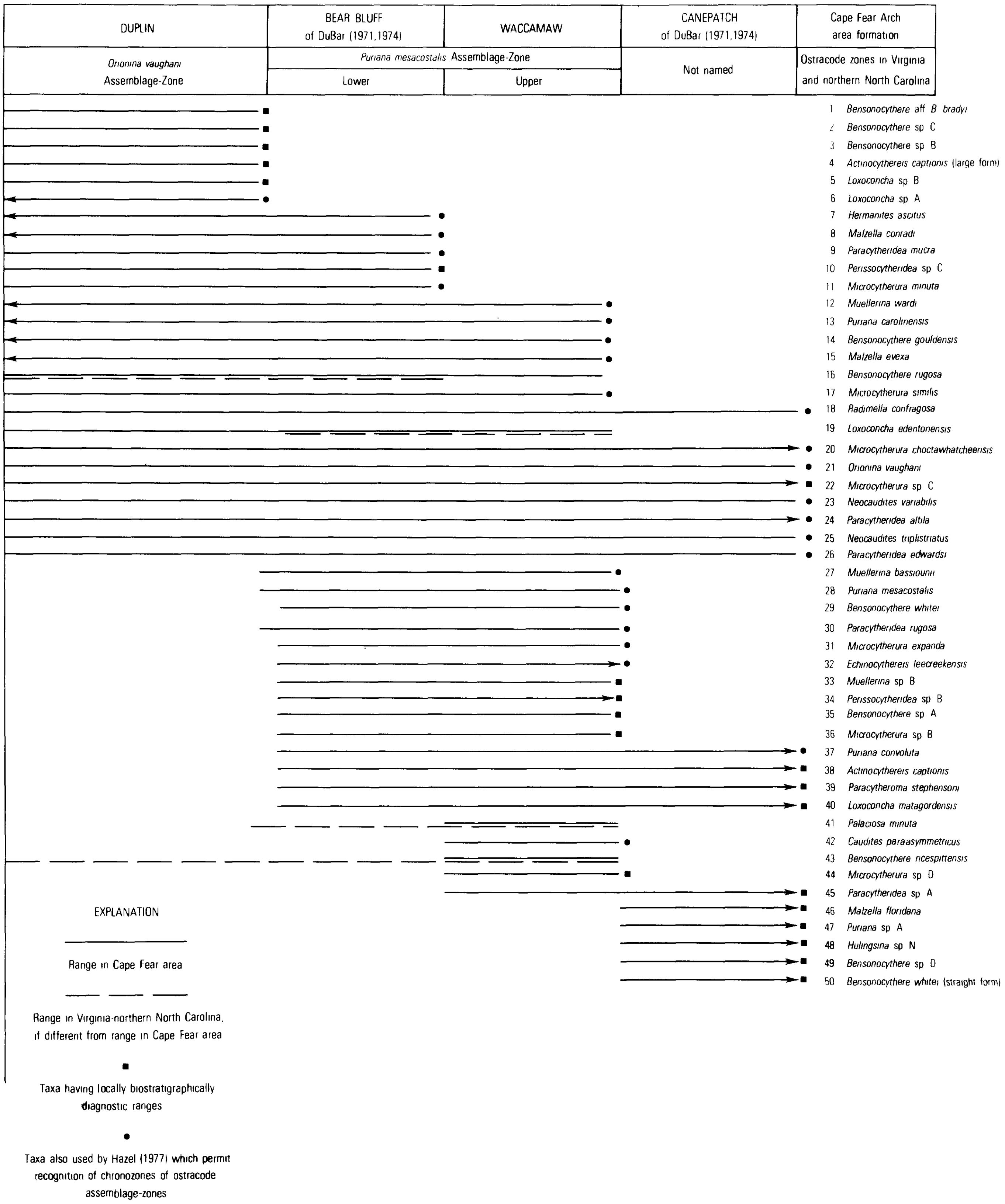

FIGURE 2.—Range chart for 50 ostracode species whose range-zones and concurrent-range-zones are useful in recognizing the chronozones of ostracode assemblage-zones in the Cape Fear Arch area. Solid lines indicate the ranges of species in the Cape Fear Arch area. Dashed lines indicate ranges of species in northern North Carolina and southern Virginia for species whose ranges are different in the two areas. The species are listed alphabetically in table 1 and are illustrated in figures 4–9.

more data on the geographic and stratigraphic distribution of ostracodes and to establish a more refined correlation of Atlantic Coastal Plain Neogene deposits.

The deposits considered in the present study span the interval from about 4.0 m.y. to 0.5 m.y. (million years) ago, a period encompassing the chronozone of the *Orionina vaughani* and *Puriana mesacostalis* Assemblage-Zones and younger deposits for which no ostracode zonation has been established (the Canepatch Formation). The presence of *Paracytheridea edwardsi* in coastal-plain deposits is indicative of this 3.5-m.y. interval.

The chronozone of the combined *Orionina vaughani–Puriana mesacostalis* Assemblage-Zones is suggested by the following species: *Bensonocythere rugosa, Microcytherura minuta, M. similis, Radimella confragosa, Paracytheridea mucra,* and *Loxoconcha edentonensis. Microcytherura minuta* and *Paracytheridea mucra,* however, are not known from the upper part of the *Puriana mesacostalis* Assemblage-Zone, and, similarly, *Microcytherura similis* is not known from the lower part of the *Orionina vaughani* Assemblage-Zone. Other species such as *Malzella evexa, Bensonocythere gouldensis, Puriana carolinensis,* and *Muellerina wardi* characterize this interval as well, but they are also known from the older *Pterygocythereis inexpectata* Assemblage-Zone in Virginia and northern North Carolina.

A reliable indicator of the chronozone of the *Orionina vaughani* Assemblage-Zone appears to be the concurrent-range-zone of *Loxoconcha* sp. A and *Paracytheridea mucra, Microcytherura minuta,* and *Bensonocythere rugosa.*

The chronozone of the *Puriana mesacostalis* Assemblage-Zone was recognized by the range-zones of *Microcytherura expanda, Puriana mesacostalis,* and *Muellerina bassiounii.* However, *Puriana mesacostalis,* along with *Palaciosa minuta* and *Paracytheridea rugosa,* has been reported by Edwards (1944) from deposits assigned to the upper part of the Duplin Formation near Lumberton, N.C. Thus, they may have first appeared during the chronozone of the upper part of the *Orionina vaughani* Assemblage-Zone, or perhaps *Puriana mesacostalis* Assemblage-Zone deposits are present in this topographically high area. Additional sampling is necessary to clarify this problem. The concurrent-range-zones of several pairs of species also permit the recognition of the chronozone of the *Puriana mesacostalis* Assemblage-Zone (fig. 2).

In the Cape Fear Arch region, the chronozone for the lower part of the *Puriana mesacostalis* Assemblage-Zone is indicated by the concurrent-range-zones of *Bensonocythere whitei, Puriana mesacostalis, Paracytheridea mucra, Muellerina bassiounii, Hermanites ascitus, Malzella conradi,* and *Microcytherura minuta.*

The period encompassing the upper part of the *Puriana mesacostalis* Assemblage-Zone is characterized along the Atlantic Coastal Plain from northern North Carolina to Florida by the distinctive species *Caudites paraasymmetricus.*

Hazel (1971a, 1977) did not consider middle oı upper Pleistocene deposits of Virginia or North Carolina, and no ostracode zonation exists for this interval. Nevertheless, the ostracode assemblage of the Canepatch Formation is distinguished by the presence of *Malzella floridana, Puriana sp.* A, *Bensonocythere* sp. D, *Hulingsina* sp. N, and a distinctive form of *Bensonocythere whitei.*

LOCAL RANGE-ZONES

Today the Cape Hatteras region is a major zoogeographic boundary where many cryophilic and thermophilic species cease their equatorward and poleward expansion, respectively. Similarly, Pliocene and Pleistocene faunas from north and south of Cape Hatteras are distinct from one another, apparently because of paleooceanographic differences such as bottom-water temperature. Many cryophilic species, congeners of *Cytheridea* and *Thaerocythere* for example, are biostratigraphically diagnostic north of Cape Hatteras (Hazel, 1977) but are absent in the Cape Fear Arch region. Conversely, several species from the Cape Fear Arch region are absent from correlative deposits to the north, yet they are useful locally for correlation of lithostratigraphic units. These taxa, many of which are undescribed species, are indicated in figure 2.

Deposits of the Duplin Formation yielded several species that suggest a Yorktown age; these include *Bensonocythere* aff. *B. bradyi, Bensonocythere* sp. C, *Bensonocythere* sp. B, and a large form, *Actinocythereis captionis.* The cold-water species *Loxoconcha* sp. B characterizes this interval south of Cape Hatteras but is common in lower Pliocene to Holocene deposits to the north.

The chronozone of the *Puriana mesacostalis* Assemblage-Zone can be recognized locally by the presence of *Muellerina* sp. B, *Perissocytheridea* sp. B, *Bensonocythere* sp. A, and *Microcytherura* sp. B. Characteristic of the chronozone of the upper part of this assemblage-zone are *Microcytherura* sp. D and *Bensonocythere ricespittensis.* This latter species ranges into the *Orionina vaughani* Assemblage-Zone north of Cape Hatteras.

The presence of *Paracytheroma stephensoni* and *Loxoconcha matagordensis* signifies the chronozone of the combined *Puriana mesacostalis* Assemblage-Zone and the unnamed zone representing the Canepatch Formation.

A middle Pleistocene (Canepatch) age is indicated in the Cape Fear Arch region by the first appearance of the following species: *Malzella floridana, Puriana* sp. A, *Hulingsina* sp. N, and *Bensonocythere* sp. D. All these taxa except *Bensonocythere* sp. D are living on the shelf today.

The above discussion indicates the significance of paleoclimatic and paleooceanographic conditions on the geographic and stratigraphic distributions of ostracodes. Just as modern geographic ranges for ostracodes are often limited by bottom-water temperatures, so too, were there distinct zoogeographical faunal provinces during the Pliocene and Pleistocene. Moreover, the Pliocene and Pleistocene geographic distribution of extant species of the North Atlantic was quite different from that of today because of significant oceanographic changes. Studies of ostracodes from the late Pleistocene of the St. Lawrence lowlands (Cronin, 1977), the Norfolk Formation (Pleistocene) of Virginia (Valentine, 1971), and the Yorktown and Croatan Formations (Pliocene and Pleistocene) of Virginia and North Carolina (Hazel, 1971b) have documented the distribution of many species during various periods in the Pliocene and Pleistocene and have permitted valuable paleoclimatic inferences to be made. Thus, any attempt to use ostracodes for regional correlation of Atlantic Coastal Plain deposits must necessarily include consideration of climatic effects on the distribution, both temporal and geographic, of particular species.

REGIONAL CORRELATION

On the basis of (1) the data presented above, (2) examination of material from deposits from the Chowan River assigned to the "Yorktown" by Hazel (1977), and (3) previously published data of Hazel (1971a, 1977, 1980), Edwards (1944), and others, a tentative correlation scheme for the Pliocene and Pleistocene of the central Atlantic Coastal Plain was developed. This chart (fig. 3) is a modification of figure 2 of Hazel (1977).

The Duplin Formation is in part Yorktown in age and can be correlated with the *Orionina vaughani* Assemblage-Zone. However, the upper part of the Duplin Formation has yielded several species characteristic of the *Puriana mesacostalis* Assemblage-Zone in Virginia and northern North Carolina (Edwards, 1944); hence, the precise placement of the upper part of the Duplin Formation is as yet uncertain.

Deposits at the Lee Creek mine, North Carolina, were assigned to the Yorktown and Croatan Formations by Hazel (1980). Whereas the Duplin Formation is in part equivalent to the Yorktown Formation, the Bear Bluff Formation of DuBar and others (1974) appears to be correlative with the lower part of the Croatan, and the Waccamaw Formation is equivalent to the upper part of the Croatan. Deposits on the Chowan River assigned to the "Yorktown" Formation (Hazel, 1971a, 1977) appear to be time-equivalents of the Bear Bluff Formation of DuBar and others (1974) and of at least the lower part of the Croatan, on the basis of the presence of species indicating the chronozone of the lower part of *Puriana mesacostalis* Assemblage-Zone. Deposits at Yadkin, Va., also referred to as "Yorktown" (Hazel, 1977), may also be correlative with deposits of this late Pliocene interval.

The ostracode assemblage of the Canepatch Formation shows a distinctly modern character because several extant taxa appear for the first time in these deposits. Although no formal regional biostratigraphic zonation exists for middle and upper Pleistocene deposits, and, although many ostracode species have not yet been formally described, the present study indicates that ostracodes have great potential for local biostratigraphic correlation within the Pleistocene.

CONCLUSIONS

Detailed examination of ostracode assemblages from the Duplin, Bear Bluff, Waccamaw, and Canepatch Formations from the Cape Fear Arch region permit the following conclusions:

1. Ostracodes are useful biostratigraphic indicators in this region, as many species have well-defined, relatively short stratigraphic ranges and can be used for correlation of lithostratigraphic units.
2. The ostracode zonation of Hazel (1971a, 1977) can in part be extended south to the Santee River, S.C. The chronozones of the *Orionina vaughani* and the *Puriana mesacostalis* Assemblage-Zones can be recognized in the Cape Fear Arch region by the presence of diagnostic species.

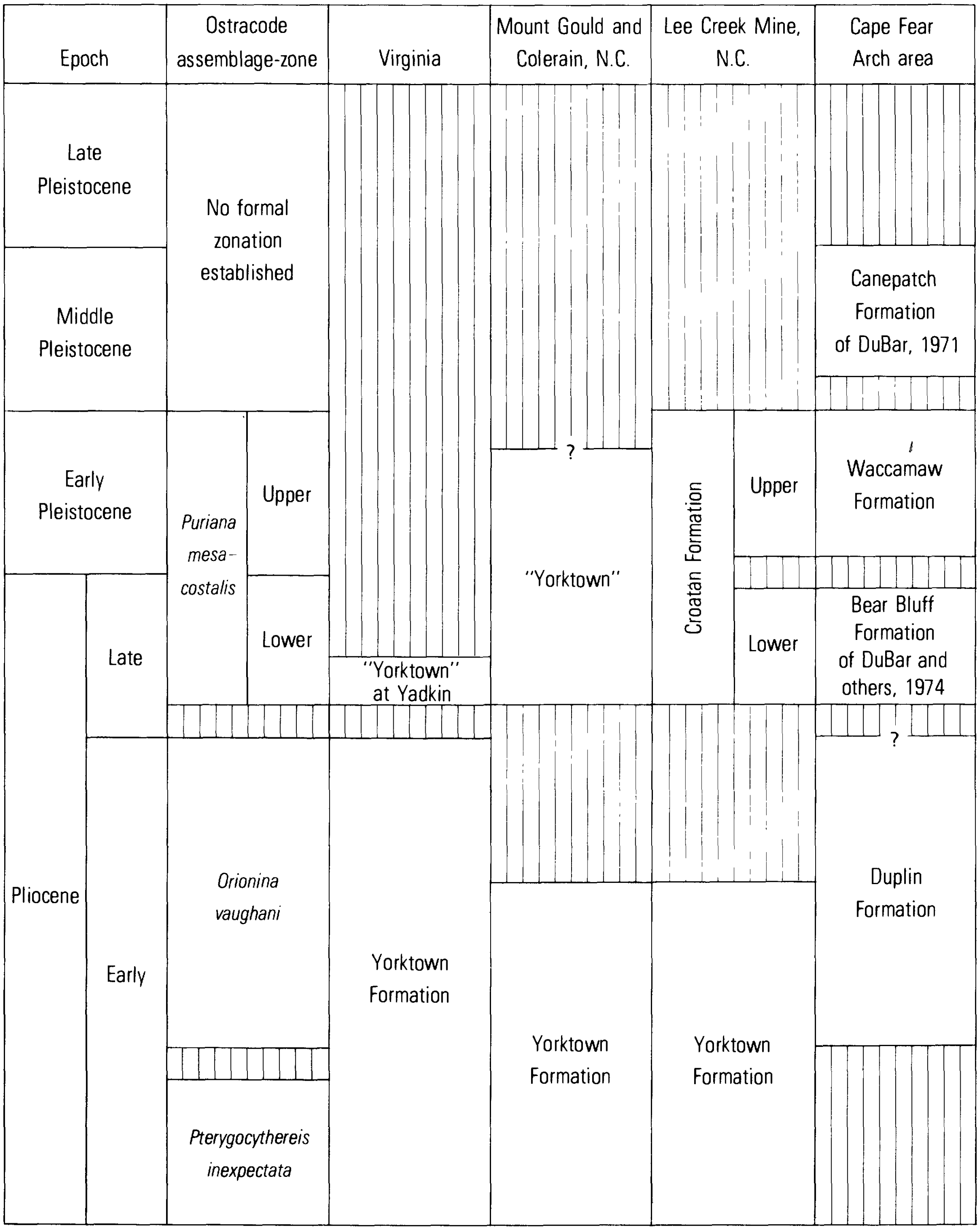

FIGURE 3.—Tentative correlation chart for the Pliocene and Pleistocene deposits of southern Virginia, North Carolina, and northeastern South Carolina. Ostracode assemblage-zones are those used by Hazel (1971, 1977).

3. Some ostracode taxa that are rare to absent in Pliocene and Pleistocene deposits north of Cape Hatteras are locally useful as biostratigraphic indicators in the Cape Fear Arch region.

COLLECTION LOCALITIES

Locality 1.—Bank of Waccamaw River, 9.7 km east of intersection of South Carolina Routes 90 and 544 at Conway, S.C.; left off route 90 at Richardson's family house, 0.5 km to river. Section is 225 m downstream from Richardson's house, near Tilly Lake. Type locality of Waccamaw Formation exposes 3 m of shelly sands from which four samples (55–58) were obtained.

Locality 2.—Outcrop on Intracoastal Waterway, Wampee 7.5-minute quadrangle, Horry County, S.C.; 6.7 km upstream from South Carolina Route 9 bridge over waterway. Sample 59 from *Tagelus* bed of Canepatch Formation, 3.3 m above peat bed. Sample 60, 0.6 m above sample 59, also Canepatch Formation. Samples 61 and 62 from crossbedded coquina of Bear Bluff Formation.

Locality 3.—Northwest corner of Wampee 7.5-minute quadrangle, outcrops on Intracoastal Waterway at northeast end of Windy Hill Airstrip, Horry County, S.C., 0.3 km downstream from locality 2. (See DuBar, 1971, locality WA56, page 21, for detailed lithostratigraphy.) Three samples (64–66) from the Waccamaw Formation and one sample (63) from the Canepatch Formation.

Locality 4.—Outcrops on Intracoastal Waterway at type locality of Canepatch Formation, Nixonville quadrangle, Horry County, S.C. (See DuBar, 1971, for details.) One sample (68) from *Mercenaria*-Bryozoan facies.

Locality 5.—Right bank of Intracoastal Waterway, 5.5 km upstream from west edge of Wampee 7.5-minute quadrangle, behind Myrtle Beach Shrine Club, Horry County, S.C. (Our locality 5 is loc. WA19 of DuBar, 1971.) Sample 70 from Canepatch Formation bed 5 of DuBar, 1971; samples 71 and 72 from beds 4 and 2 of DuBar, 1971, both from Waccamaw Formation.

Locality 6.—Pit on right side of North Carolina Route 130, 3.8 km north of the center of Old Dock, Columbus County, N.C. Four samples (73–76 in ascending order) from about 2 m of Waccamaw Formation.

Locality 7.—Walker's Bluff on west bank of Cape Fear River, 2.4 km northeast of North Carolina Route 87, about 12.5 km northeast of Lisbon, Bladen County, N.C. Sample 79 from lower 30 cm of Waccamaw Formation just above contact with Cretaceous; sample 80 from 1.3 m above sample 79.

Locality 8.—Pierce Brothers pit, about 14.5 km southeast of Town Creek, Brunswick County, N.C. Pit is 6.4 km east of Mill Creek, about 1.6 km north of road that intersects North Carolina Route 87 at Mill Creek. Samples 84–82 (in ascending order) from 1 m of Waccamaw Formation; samples 85 and 86 from spoil piles of material, stratigraphically below sample 84.

Locality 9.—Cape Fear River, 400 m downstream from Niels Eddy Landing and about 9.5 km northeast of Acme, Columbus County, N.C. sample 88 from oyster bed near top, sample 87 from 0.3 m below top; sample 89 from 0.5 m below sample 87. All samples from Waccamaw Formation.

Locality 10.—Greenbank Landing on south bank of Cape Fear River, 12.5 km northeast of Acme, Brunswick County, N.C., 0.8 km upstream from confluence of Cape Fear River with Bryant Mile Creek.

Three samples (90–92) in ascending order) from 1 m of shelly sand of Waccamaw Formation.

Locality 11.—West part of pit, 1.6 km west of Acme, Columbus County, N.C., 2.5 m of Waccamaw Formation exposed. Samples 97–95 (in ascending order) from lowermost meter; samples 93–94 (ascending order) from upper meter of blue-gray sand.

Locality 12.—Pit just east of Calabash, Brunswick County, N.C. Five samples (132–136) were taken. Two samples (132, 133) from the Bear Bluff Formation of DuBar (1971) and three samples (134–136) from the overlying Waccamaw Formation.

Locality 13.—Auger-drill-hole sample of Bear Bluff Formation, Hole H275 of DuBar (1971) from about 3.2 km south of Lake Swamp, Bayboro 7.5-minute quadrangle, Horry County, S.C. One sample (H 275).

Locality 14.—Robeson family farm, 6.2 km southeast of intersection of Center Road and North Carolina Route 87 at Tar Heel, Bladen County, N.C. About 2 m of Duplin Formation is exposed. Four samples (45–42 in ascending order) were examined from this section. Two additional samples, stratigraphically above the others, were examined, one sample (46) from 50 m west of the section and the other (47) from 100 m west of section.

Locality 15.—Left bank of Lumber River, 2.4 km south of intersection of North Carolina Routes 211 and 74, 14.0 km southeast of Lumberton, Robeson County, N.C. Three samples (50–48 in ascending order) were taken from 1.3 m of Duplin Formation gray shelly sands, and one sample (51), from 4 m above water level.

Locality 16.—Matthews family farm, 2.6 km southwest of Magnolia, N.C., and 2.9 km southwest of intersection of North Carolina Route 117 in Magnolia and road to Delway (Bladen County, Route 1003). Exposure in Natural Well 500 m behind house. One sample (41) was from a fossiliferous bed of the Duplin just above contact with Eocene.

Locality 17.—South face of the William Bird Ashley mine across South Carolina Route 378 from the Old Smokehouse about 5 km west of Conway, S.C., along Route 378. One sample was from the Bear Bluff Formation of DuBar (1971).

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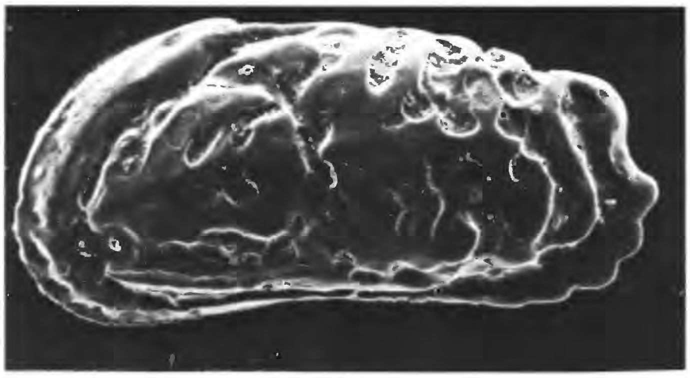
FIGURES 4-9

FIGURE 4.—*Puriana*, *Radimella*, and *Malzella*.

a, *Puriana* sp. A, female left valve, Canepatch Formation, sample 68, × 153, USNM 251996. *b*, *Puriana carolinensis* Hazel, male left valve, Duplin Formation, sample 48, × 157.5, USNM 251997. *c*, *Puriana mesacostalis* (Edwards), female left valve, Waccamaw Formation, sample 91, × 120.5, USNM 251998. *d*, *Puriana convoluta* Teeter, female left valve, Waccamaw Formation, sample 87, × 126, USNM 251999. *e*, *Radimella confragosa* (Edwards), female left valve, Waccamaw Formation, sample 75, × 126, USNM 252000. *f*. *Malzella floridana* (Benson and Coleman), female carapace, Canepatch Formation, sample 68, × 139.5, USNM 252001. *g*. *Malzella evexa* Hazel, female left valve, Waccamaw Formation, sample 91, × 108, USNM 252002. *h*. *Malzella conradi* (Howe and McGuirt), female left valve, Duplin Formation, sample 43, × 144, USNM 252003.



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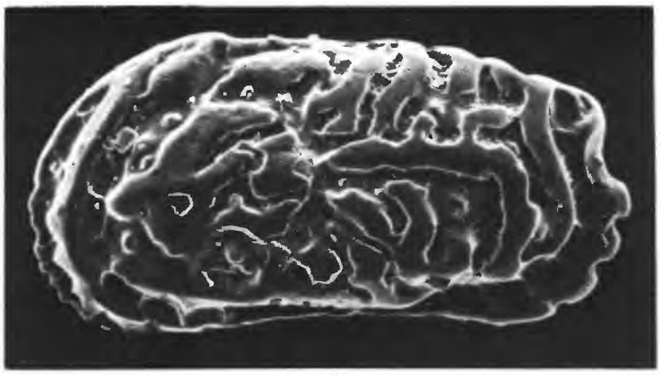

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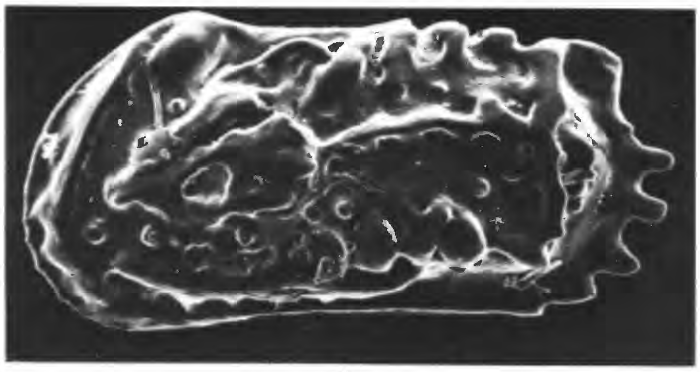

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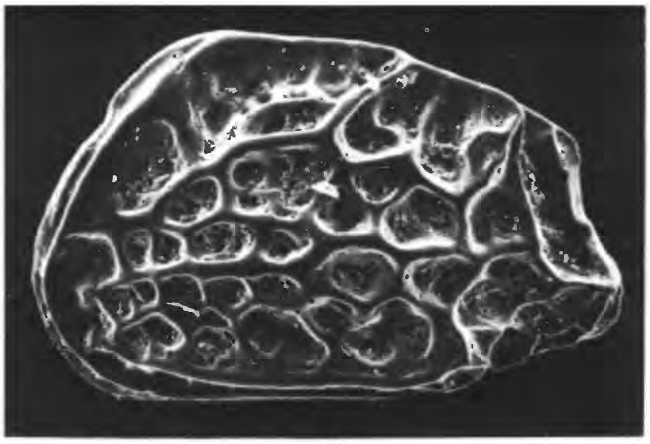

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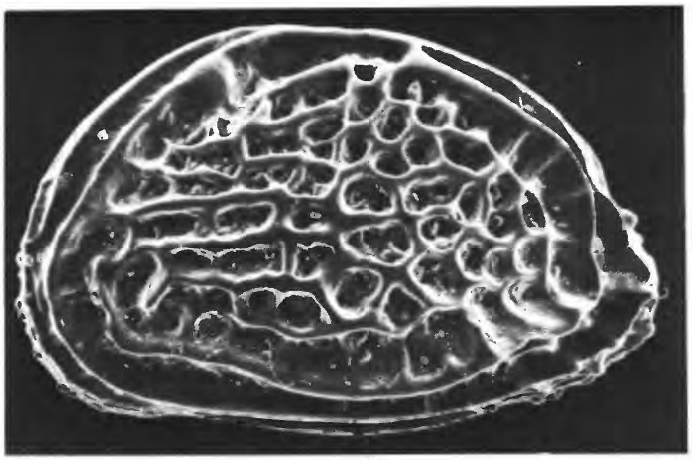

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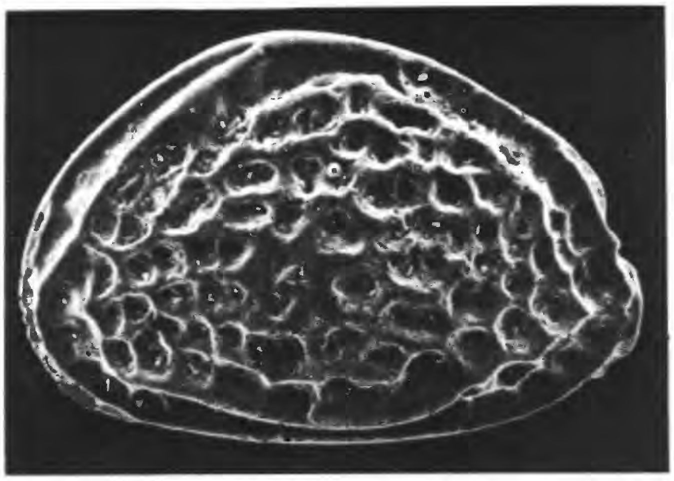

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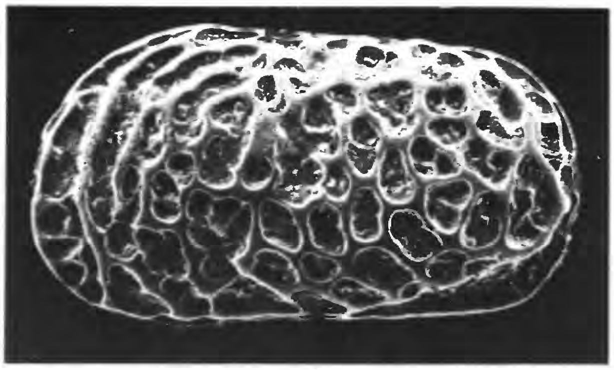
FIGURE 5.—*Bensonocythere.*

a, Bensonocythere gouldensis Hazel, female left valve, Waccamaw Formation, sample 90, × 90, USNM 252004. *b, Bensonocythere ricespittensis* Hazel, male left valve, Waccamaw Formation, sample 135, × 112.5, USNM 252005. *c, Bensonocythere rugosa* Hazel, male left valve, Duplin Formation, sample 47, × 126, USNM 252006. *d, Bensonocythere* sp. A, female left valve, Bear Bluff Formation, sample 133, × 112.5, USNM 252007. *e, Bensonocythere* sp. C, female left valve, Duplin Formation, sample 47, × 112.5, USNM 252008. *f, Bensonocythere* sp. D, female left valve, Canepatch Formation, sample 68, × 126, USNM 252009. *g, Bensonocythere whitei* (Swain) s.s., female left valve, Waccamaw Formation, sample 135, × 90, USNM 252010. *h, Bensonocythere whitei* (Swain) (straight form), male left valve, Canepatch Formation, sample 68, × 112.5, USNM 252011.



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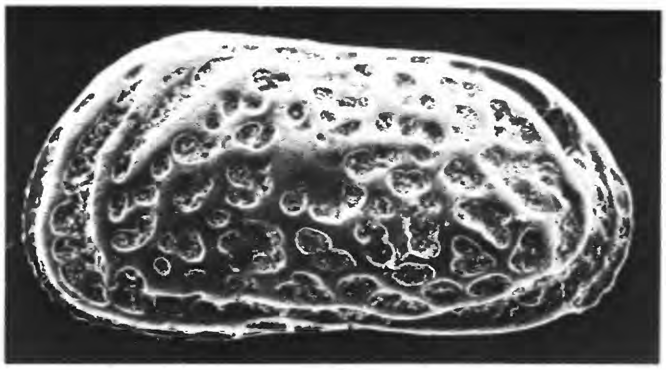

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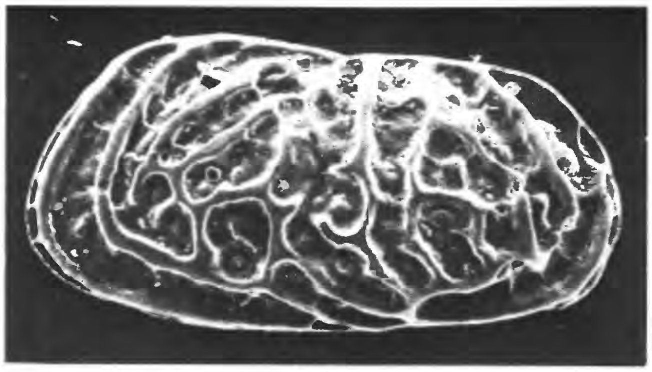

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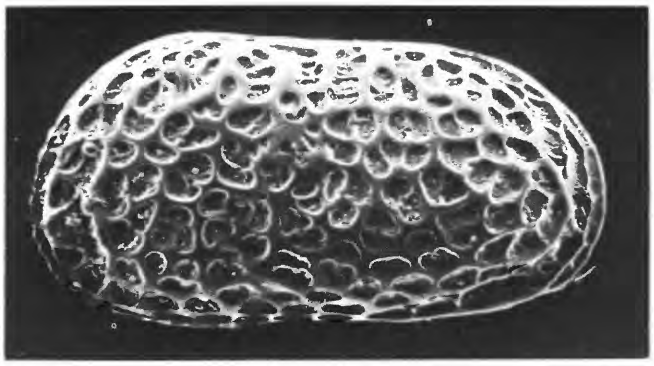

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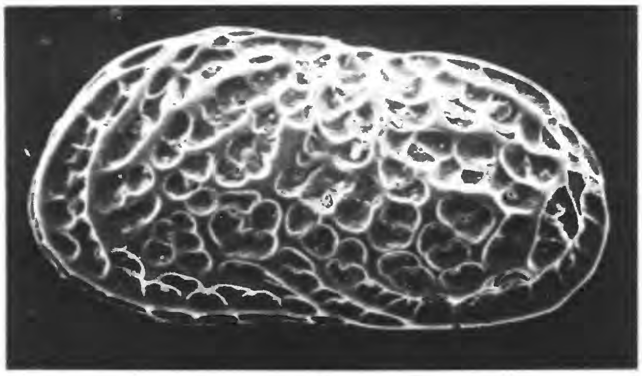

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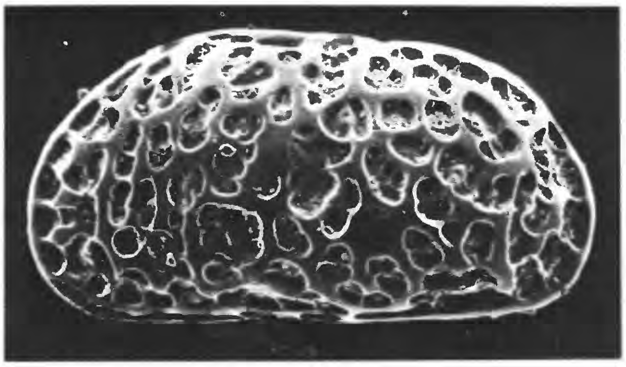

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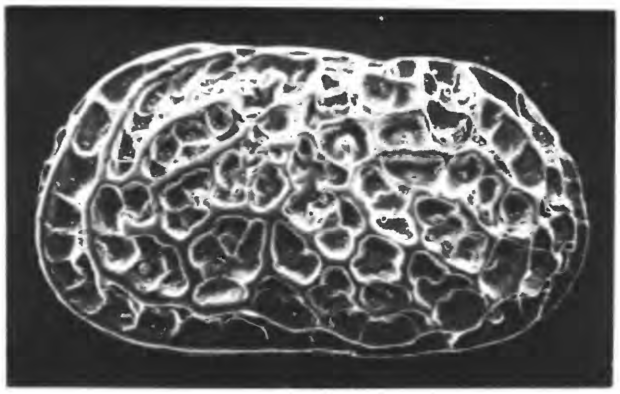

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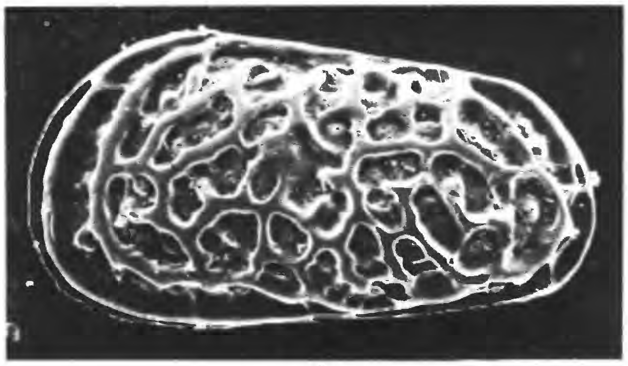

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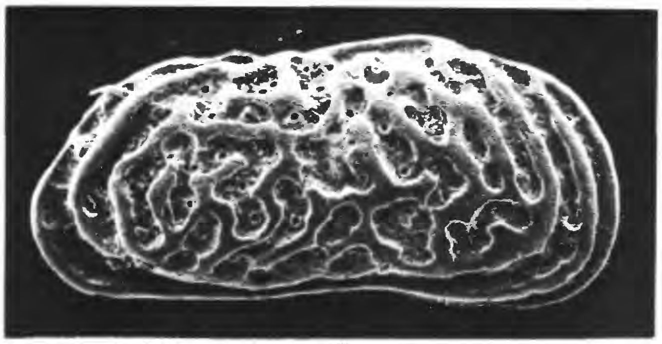
FIGURE 6.—*Bensonocythere*, *Muellerina*, *Hermanites*, and *Actinocythereis*.

a, *Bensonocythere* aff. *B. bradyi* Hazel, male right valve, Duplin Formation, sample 45, × 90, USNM 252012. *b*, *Bensonocythere* sp. B, female right valve, Duplin Formation, sample 47, × 112.5, USNM 252013. *c*, *Muellerina wardi* Hazel, male left valve, Waccamaw Formation, sample 79, × 135, USNM 252014. *d*, *Muellerina* sp. B, male left valve, Waccamaw Formation, sample 88, × 120.5, USNM 252015. *e*, *Muellerina bassiounii* Hazel, male left valve, Duplin Formation, sample 49, × 135, USNM 252016. *f*, *Hermanites ascitus* Hazel, female carapace, Duplin Formation, sample 45, × 144, USNM 252017. *g*, *Actinocythereis captionis* Hazel, female right valve, Waccamaw Formation, sample 76, × 117, USNM 252018. *h*, *Actinocythereis captionis* Hazel (large form), female right valve, Duplin Formation, sample 43, × 103.5, USNM 252019.



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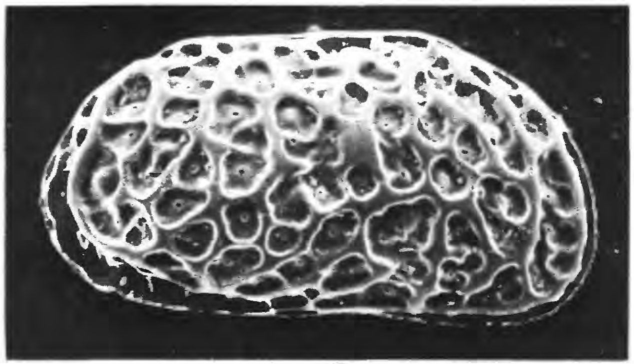

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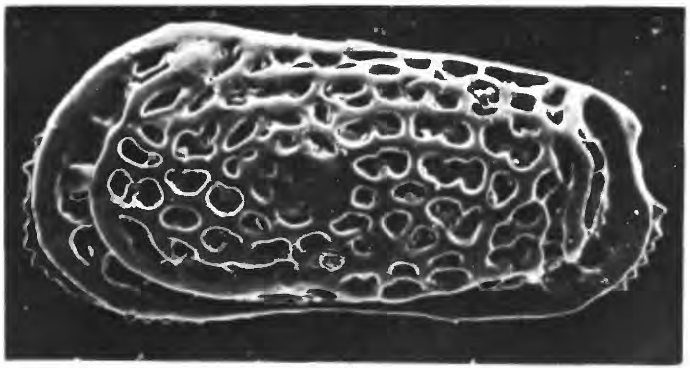

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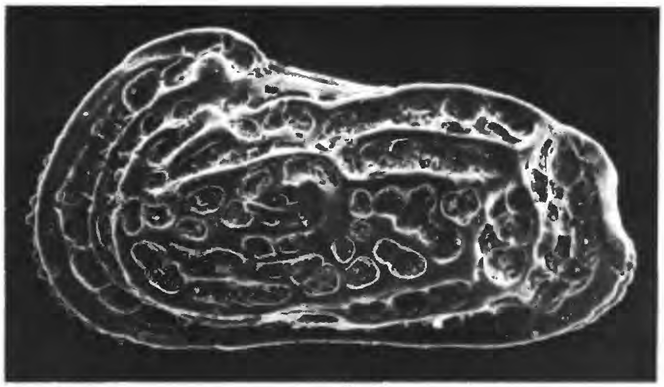

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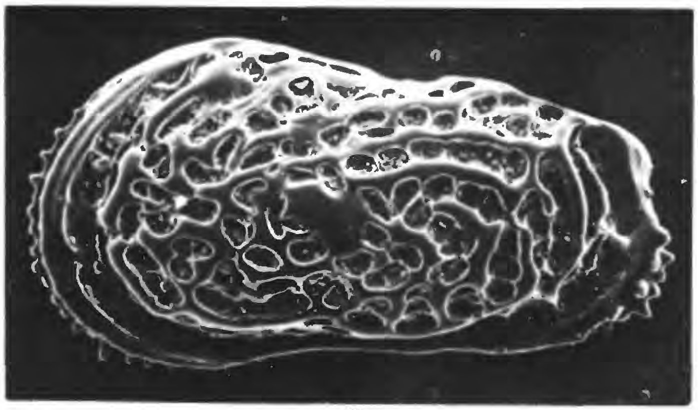

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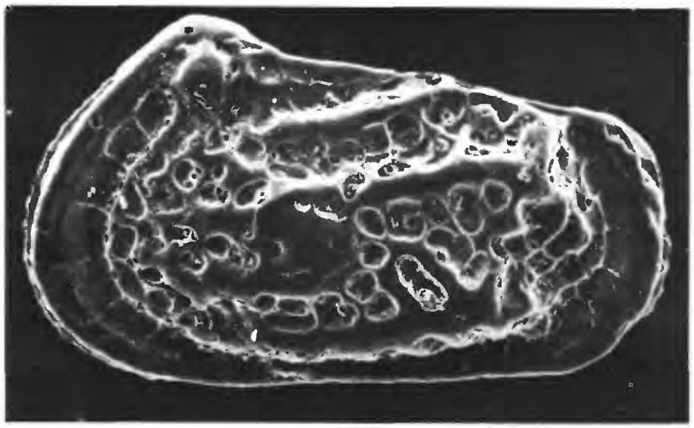

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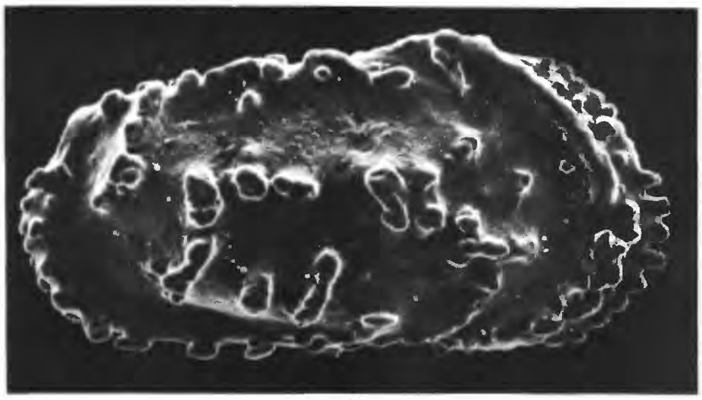

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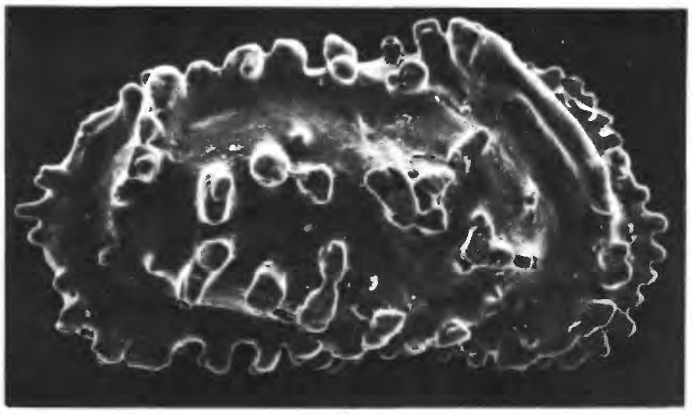

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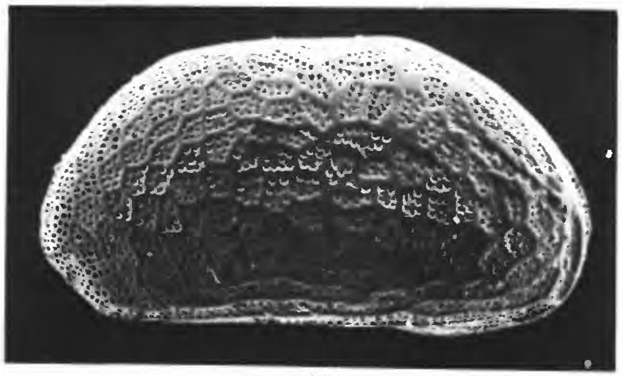
FIGURE 7.—*Microcytherura* and *Paracytheroma.*

a, Microcytherura sp. C, female right valve, Canepatch Formation, sample 68, × 135, USNM 252020. *b, Microcytherura* sp. B, female right valve, Waccamaw Formation, sample 76, × 112.5, USNM 252021. *c, Microcytherura choctawhatcheensis* (Puri), female right valve, Waccamaw Formation, sample 87, × 112.5, USNM 252022. *d, Microcytherura similis* (Malkin), female right valve, Waccamaw Formation, sample 87, × 157.5, USNM 252023. *e, Microcytherura* sp. D, female? right valve, Waccamaw Formation, sample 87, × 180, USNM 252024. *f, Microcytherura expanda* Hazel, male? right valve, Waccamaw Formation, sample 73, × 112.5, USNM 252025. *g, Microcytherura minuta* Hazel, female right valve, Duplin Formation, sample 48, × 135, USNM 252026. *h, Paracytheroma stephensoni* (Puri) female left valve, Waccamaw Formation, sample 83, × 135, USNM 252027.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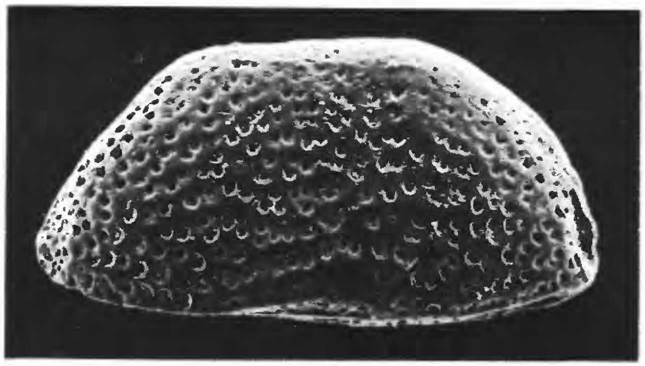
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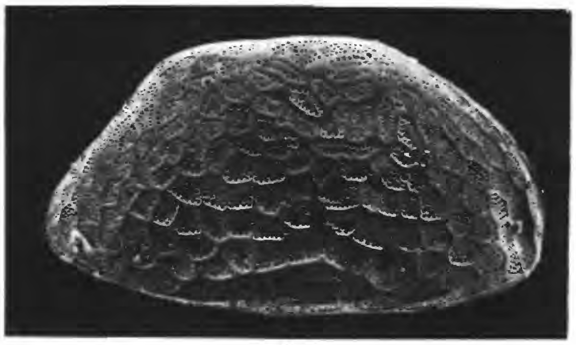
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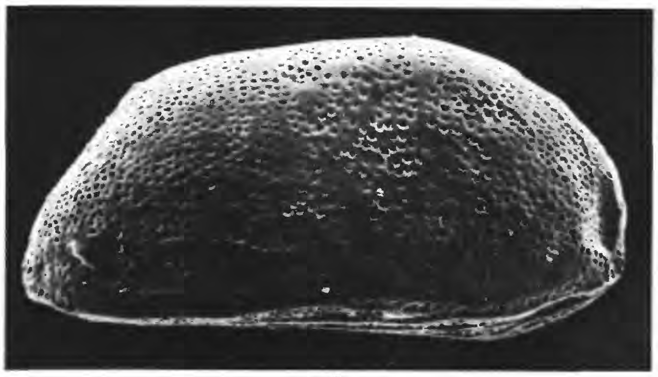
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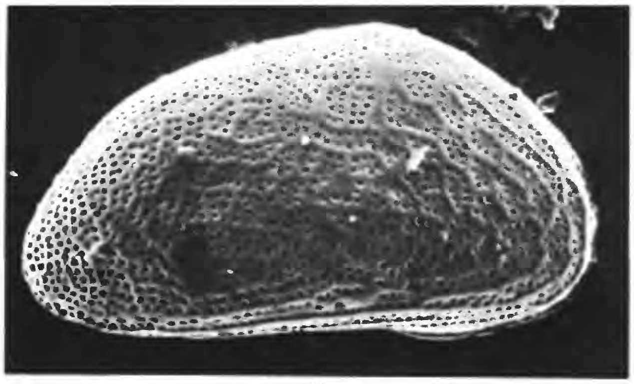
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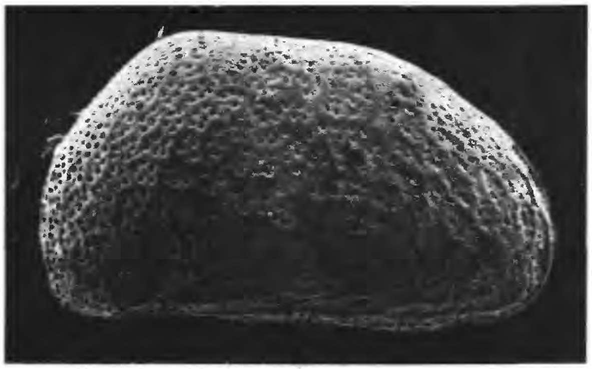
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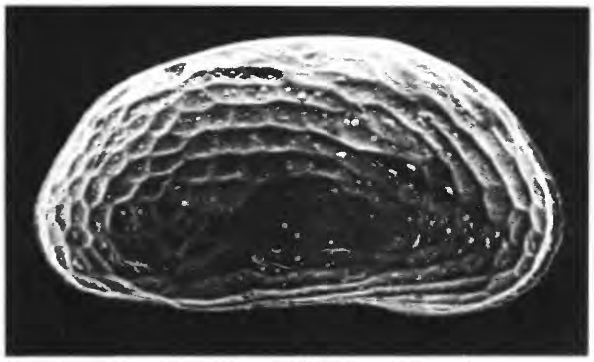
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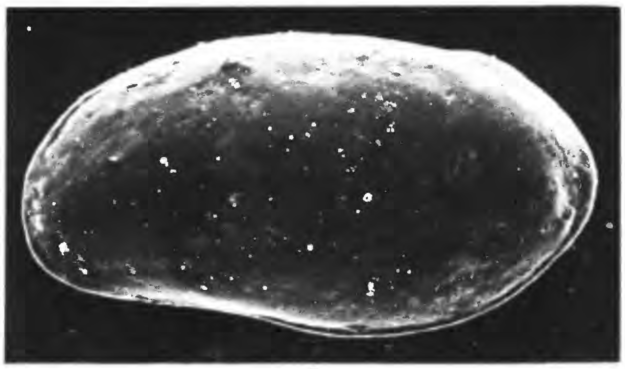
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FIGURE 8.—*Paracytheridea, Orionina, Neocaudites, Caudites,* and *Hulingsina.*

a, Paracytheridea mucra Edwards, female right valve, Bear Bluff Formation, sample H 275, × 117, USNM 252028. *b, Paracytheridea rugosa* Edwards, female right valve, Duplin Formation, sample 87, × 126, USNM 252029. *c, Paracytheridea* sp. A, male? right valve, Canepatch Formation, sample 68, × 144, USNM 252030. *d, Paracytheridea edwardsi* Hazel, male right valve, Canepatch Formation, sample 68, × 135, USNM 252031. *e, Orionina vaughani* (Ulrich and Bassler), female carapace, Duplin Formation, sample 48, × 90, USNM 252032. *f, Paracytheridea altila* Edwards, female right valve, Waccamaw Formation, sample 81, × 130.5, USNM 252033. *g, Neocaudites triplistriatus* (Edwards) s.l., elongate form, male carapace, Duplin Formation, sample 50, × 117, USNM 252034. *h, Neocaudites variabilis* Hazel, male carapace, Waccamaw Formation, sample 84, × 117, USNM 252035. *i, Caudites paraasymmetricus* Hazel, female carapace, Waccamaw Formation, sample 74 × 108, USNM 252036. *j. Hulingsina* sp. N, female? left valve, Canepatch Formation, sample 68, × 135, USNM 252037.

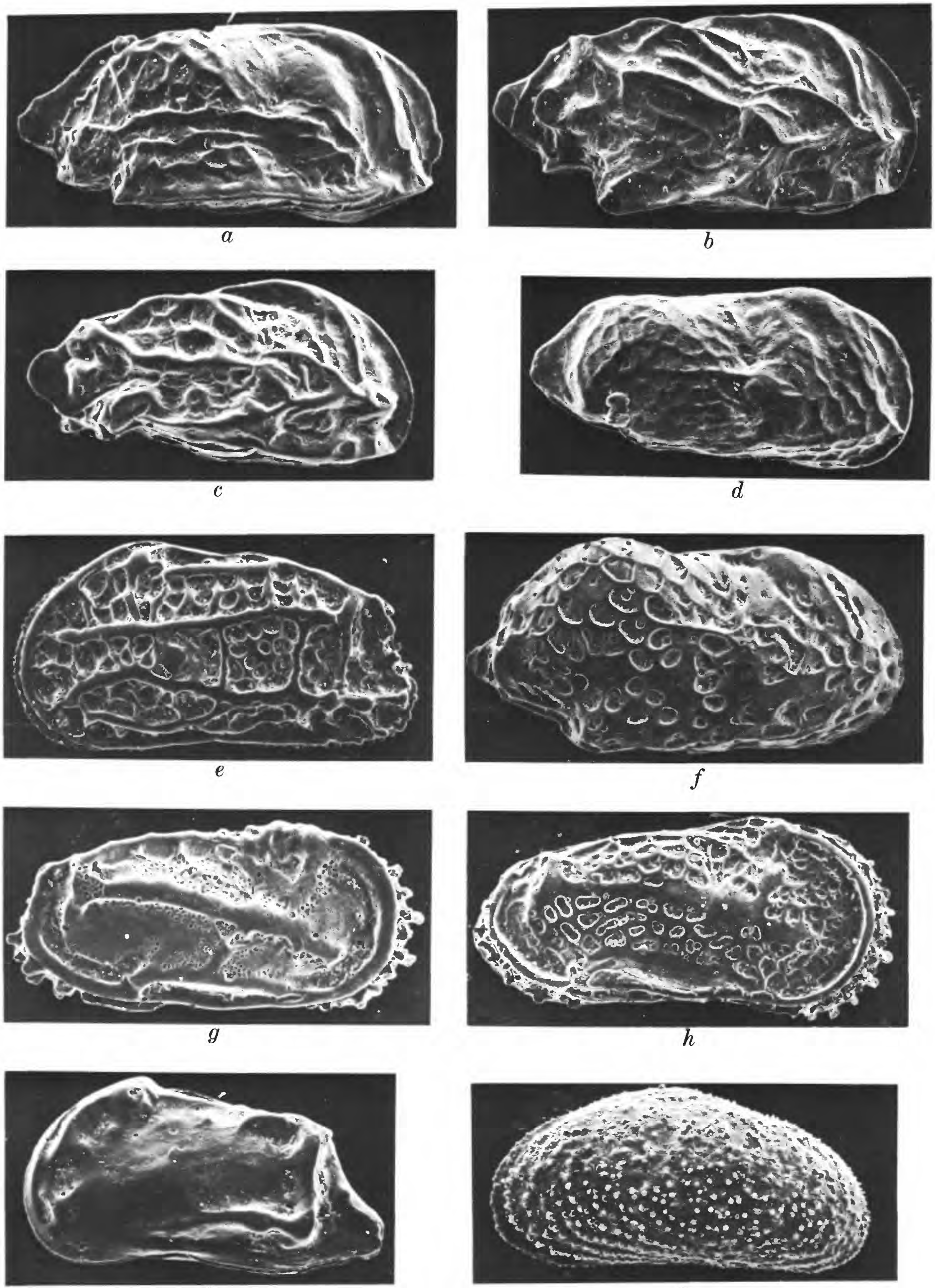
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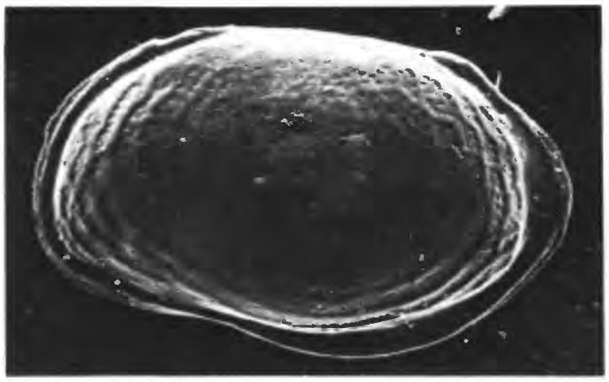
FIGURE 9.—*Loxoconcha, Perissocytheridea, Echinocythereis,* and *Palaciosa.*

a, Loxoconcha sp. B, male left valve, Duplin Formation, sample 50, × 112.5, USNM 252038. *b, Loxoconcha* sp. A, female left valve, Duplin Formation, sample 48, × 135, USNM 252039. *c, Loxoconcha matagordensis* (Swain), female left valve, Waccamaw Formation, sample 76, × 144, USNM 252040. *d, Loxoconcha edentonensis* Swain, female left valve, Waccamaw Formation, sample 76, × 126, USNM 252041. *e, Perissocytheridea* sp. C, female left valve, Duplin Formation, sample 48, × 148.5, USNM 252042. *f, Echinocythereis leecreekensis* Hazel, male? left valve, Waccamaw Formation, sample 73, × 72, USNM 252043. *g, Perissocytheridea* sp. B, female left valve, Canepatch Formation, sample 60, × 153, USNM 252044. *h, Palaciosa minuta* (Edwards), female left valve, Waccamaw Formation, sample 81, × 171, USNM 252045.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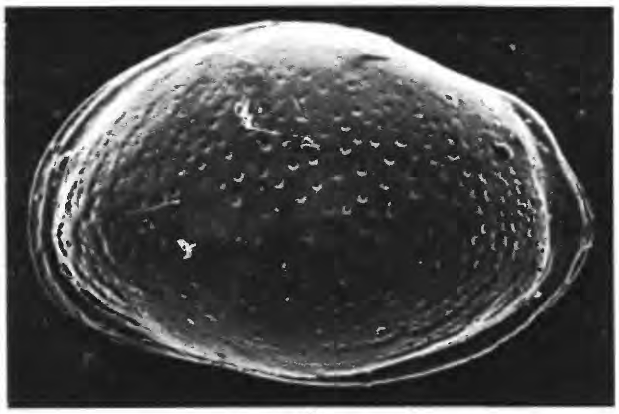
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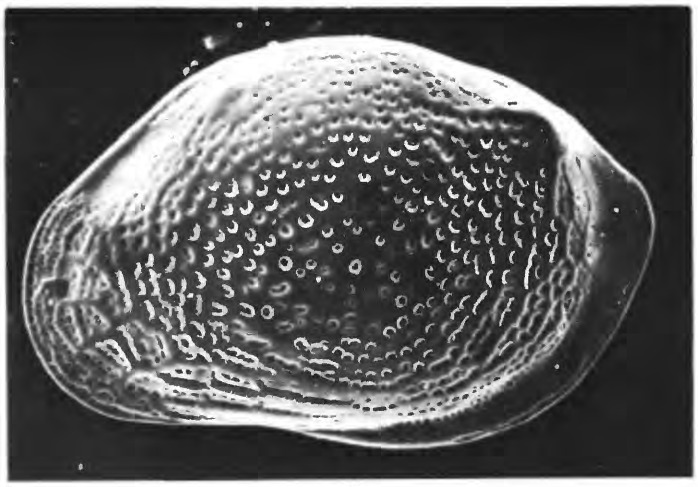
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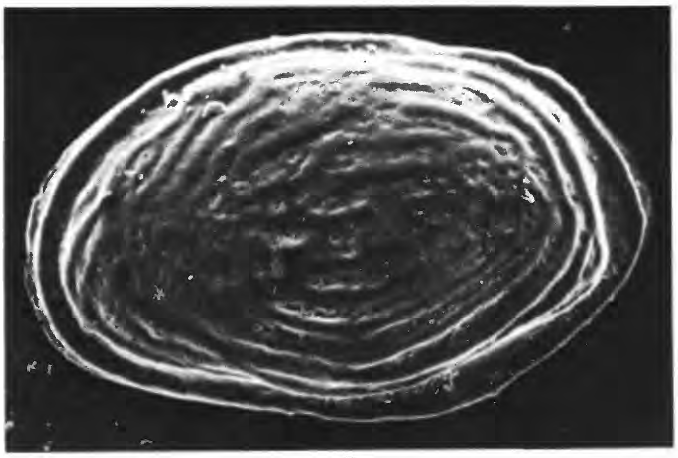
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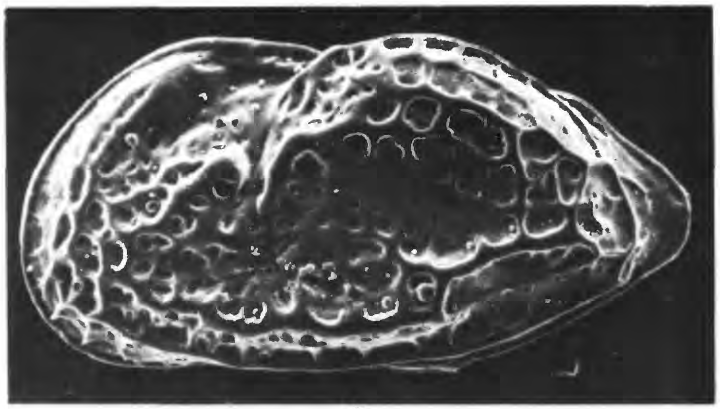
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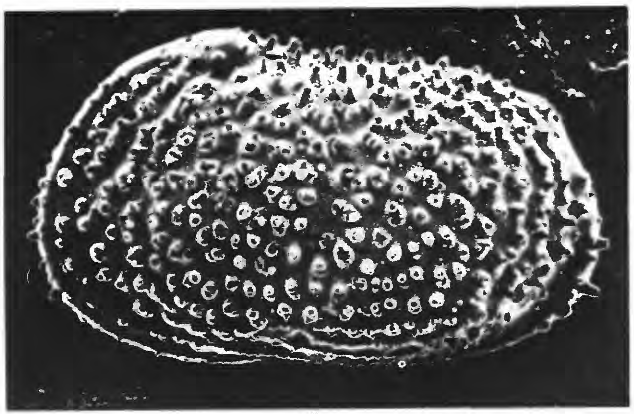
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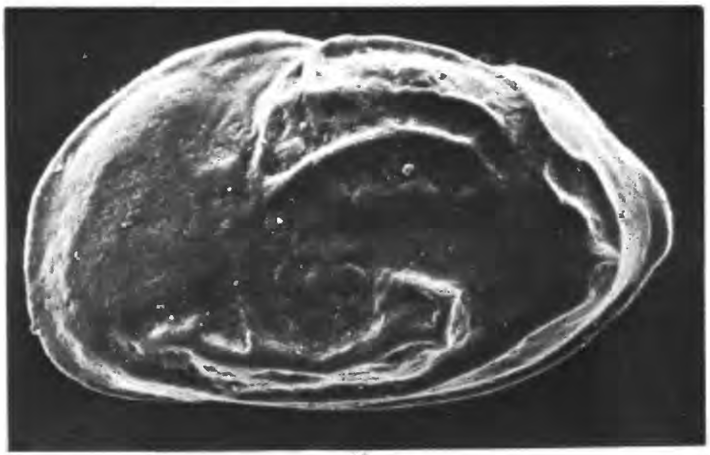
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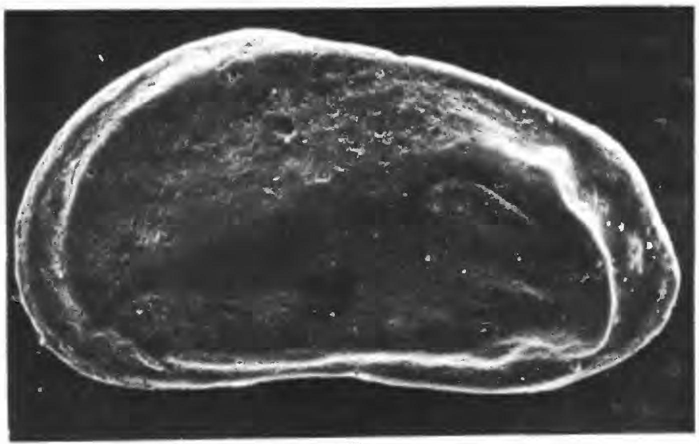
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Miocene Mollusks of the Topsy Formation, Lituya District, Gulf of Alaska Tertiary Province, Alaska

By LOUIE MARINCOVICH, JR.

SHORTER CONTRIBUTIONS TO PALEONTOLOGY, 1979

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CONTENTS

ILLUSTRATIONS

TABLE

SHORTER CONTRIBUTIONS TO PALEONTOLOGY, 1979

MIOCENE MOLLUSKS OF THE TOPSY FORMATION, LITUYA DISTRICT, GULF OF ALASKA TERTIARY PROVINCE, ALASKA

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ABSTRACT

The Topsy Formation in the Lituya district of the Gulf of Alaska Tertiary Province contains a molluscan fauna of Newportian age (late early Miocene to early middle Miocene) that correlates with similar faunas in the Pacific Northwest and in the lower part of the Yakataga Formation at Cape Yakataga, in the nearby Yakataga district. Topsy mollusks with living representatives or homologues suggest deposition in cool-temperature water at inner sublittoral depths of about 20 to 50 m.

INTRODUCTION

Sedimentary rocks of the Topsy Formation occur in the southeastern part of the Gulf of Alaska Tertiary Province (fig. 1), an area which extends about 600 km along the arcuate coast of the eastern Gulf of Alaska from the Katalla district in the west to the Lituya district in the east (Plafker, 1967). In this province, the Poul Creek and Yakataga Formations are the principal marine sedimentary units and together consist of upper Eocene to Holocene deposits with an aggregate thickness of about 6,100 to 7,600 m (Plafker, 1971). The Yakataga Formation alone consists of about 5,000 m of lower Miocene to Holocene marine deposits that preserve a continuous record of localized glacial conditions in this area of the North Pacific (Plafker and Addicott, 1976). The Lituya district (fig. 1), centered on Lituya Bay, contains the southeasternmost outcrops of Tertiary marine sedimentary rocks in the Gulf of Alaska region and is the only area in which the Topsy Formation occurs.

The Topsy Formation consists of marine siltstone and sandstone that crop out between Lituya Bay and Icy Point (fig. 1) and that extensively underlie foothills of the Fairweather Range for about 40 km adjacent to the Gulf of Alaska shoreline. Outcrops are generally small and isolated owing to cover by dense vegetation and glaciers. Persistent rain and fog in summer also limit access to Topsy exposures. Because discontinuous outcrops and structurally complex geology in this area preclude reliable lithologic correlations with other formations in this region and because no well-preserved, age-diagnostic fossils have been reported before from these strata, the age and depositional environment of the Topsy have been subjects for speculation. Molluscan fossils collected in 1975 now shed light on the age and depositional environment of the Topsy and suggest correlations with sedimentary rocks elsewhere in the Gulf of Alaska Tertiary Province and in the Pacific Northwest (Oregon and Washington). Benthic foraminifers (Rau and others, 1977) or other microfossils have not been found in Topsy strata.

The outcrop extent of the Topsy Formation shown in figure 1 is modified from that previously published (Plafker, 1967). Strata adjacent to the coastline immediately north of Icy Point, which were formerly assigned to the Yakataga Formation, are now included in the Topsy Formation, on the basis of 1975 fieldwork done by George Plafker and Travis Hudson. The Topsy does not occur on Cenotaph Island in Lituya Bay (fig. 1), so sand dollar echinoids reported from the Topsy by Wagner (1974) should be attributed to the Yakataga Formation.

Sedimentary rocks now included in the Topsy Formation were first discriminated from those of the Yakataga Formation by Miller (1953, 1961), who considered them to be, in part, stratigraphically equivalent to volcanic rocks on Cenotaph Island and on the southern margin of Lituya Bay (fig. 1). Sparse and poorly preserved invertebrates in these rocks indicated a Tertiary age, and Miller (1961) thought that they were likely of Miocene age because of their conformable relation with overlying

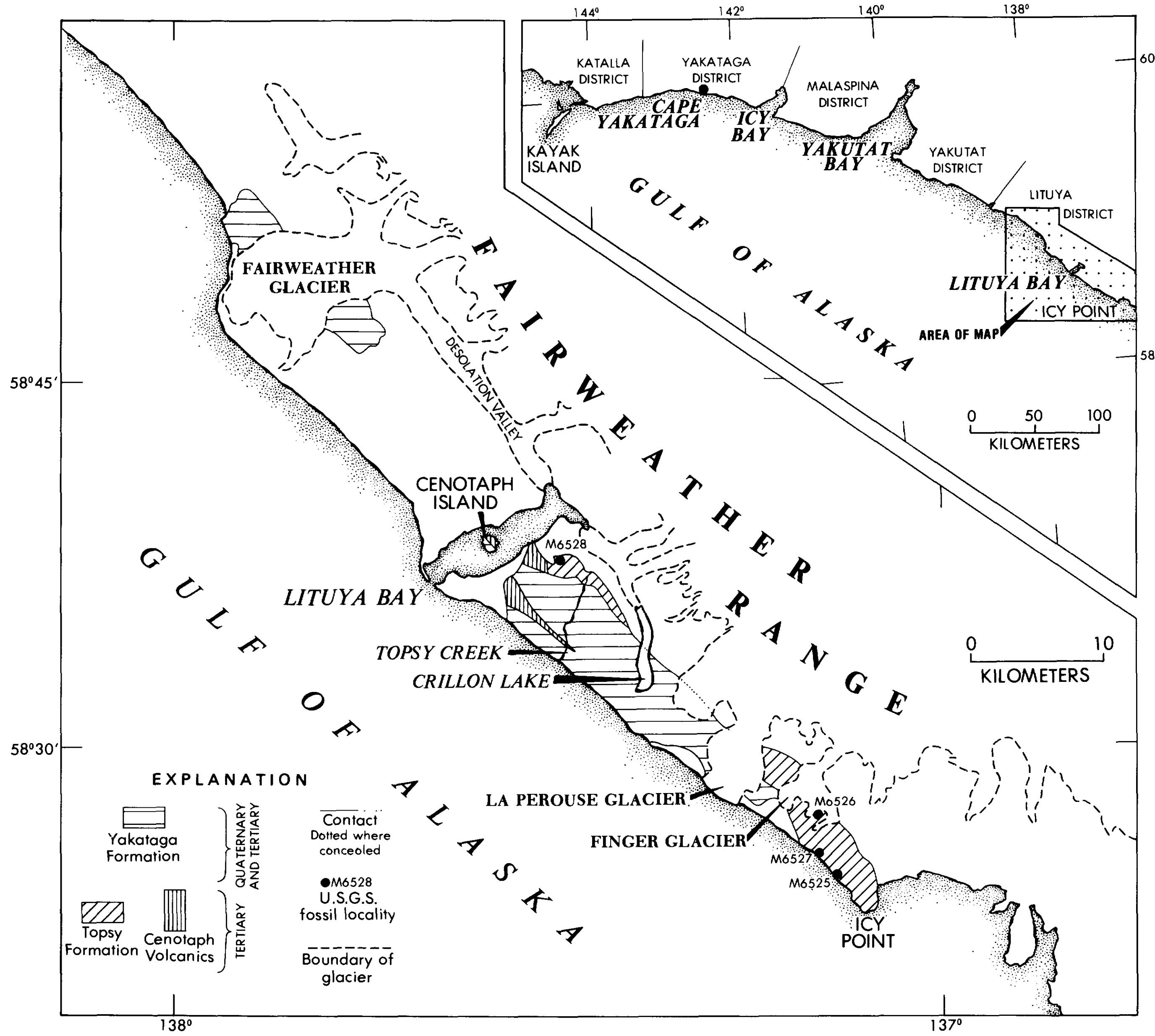

FIGURE 1.—Distribution of the Topsy Formation and other Cenozoic marine sedimentary and volcanic rocks in the Lituya district, Gulf of Alaska Tertiary Province (inset). Geology modified from Miller (1961) and Plafker (1967).

beds thought to contain late Miocene fossils. A tentative Miocene age was also assigned to these rocks by MacNeil and others (1961). Plafker (1967) named the Topsy Formation and Cenotaph Volcanics, noting that the Topsy consists of about 365 m of hard calcareous siltstone and sandstone that intertongue with and, in part, conformably overlie the Cenotaph Volcanics. Plafker (1967) did not specify an age for the Topsy strata but assigned the Cenotaph Volcanics an age of "post-early Oligocene(?) to pre-middle Miocene," thereby implying an age of about late Oligocene to early Miocene or younger for the Topsy. Later, Plafker (1971) considered most of the Topsy Formation to be Miocene, possibly containing beds as old as middle Oligocene and as young as middle Miocene. Notes on the molluscan fauna by Marincovich (1976a, b), from which the present report is expanded, suggested an early or middle Miocene age for the Topsy Formation.

ACKNOWLEDGMENTS

Helpful discussions of molluscan taxonomy and geologic field relations were held with Warren O.

Addicott and George Plafker, U.S. Geological Survey. Richard C. Allison, University of Alaska, critically read this work and provided valuable unpublished information on Alaskan Tertiary mollusks. Catherine Ariey, Atlantic Richfield Co., also provided useful data on molluscan biostratigraphy at Cape Yakataga, based on her unpublished thesis work. Kenji Sakamoto, U.S. Geological Survey, photographed the specimens.

FAUNAL COMPOSITION

No well-preserved molluscan taxa have been reported previously from the Topsy Formation. The present collections, made in 1975, consist of 20 taxa, consisting of 8 gastropods and 12 bivalves. Four additional bivalves tentatively assigned generic or specific names are too poorly preserved for confident identification. The preponderance of bivalve taxa and individuals over gastropods (table 1) is usual for Gulf of Alaska Cenozoic faunas, including modern ones. The Topsy genera are each represented by a single species except for *Macoma, Neptunea,* and *Natica.*

Seven of the bivalve taxa are represented by articulated and closed specimens, suggesting little or no post mortem transport of these faunal elements. However, the known Topsy molluscan taxa probably represent a small fraction of the original fauna. The absence of fossils from most outcrops of the Topsy contrasts sharply with the known abundance of faunas from coeval strata of the Yakataga Formation. This absence suggests either an original low-diversity fauna or post mortem destruction of fossils by wave and current action. The paucity of observed fossils also could be an artifact of collecting, considering the difficulties imposed by topography, and weather in the Lituya district.

TABLE 1.—*Fossils of the Topsy Formation*

[Number of specimens given for each entry; A, articulated bivalve; F, fragment]

Species	Localities			
	M6528	M6527	M6526	M6525
Gastropods				
Calliostoma sp.	1	---	---	---
Turbinidae	1F	---	---	---
Natica (Cryptonatica) clausa Broderip and Sowerby	1	---	---	---
Natica (Cryptonatica) oregonensis (Conrad)	---	---	---	1
Fusitriton oregonensis (Redfield)	1	---	---	---
?Neptunea (Neptunea) plafkeri Kanno	---	---	---	1F
Neptunea (Sulcosipho) cf. *N. (S.) tabulata* (Baird)	---	---	---	1F
?Colus sp.	1F	---	---	1F
Bivalves				
Acila (Truncacila) taliaferroi Clark	1	---	---	1,4A
Acila (Truncacila) sp.	---	---	2,1A	7,3A
Nuculana (?Saccella) sp.	1	---	---	---
?Chlamys sp.	1F	---	---	---
Lucinoma acutilineata (Conrad)	1	14A,3F	---	---
Thyasira cf. *T. disjuncta* (Gabb)	---	---	---	1F
Macoma albaria (Conrad)	---	---	---	1A
Macoma aff. *M. albaria* (Conrad)	1	---	---	---
Macoma incongrua (von Martens)	2	---	---	---
Macoma cf. *M. incongrua* (von Martens)	1A	---	---	---
Macoma aff. *M. twinensis* Clark	1,4A	---	---	---
Spisula addicotti Kanno	1	---	---	---
?Spisula sp.	1F	---	---	---
Periploma (Aelga) besshoense (Yokoyama)	1	---	---	---
?Periploma sp.	1A,2F	---	---	---
Mya sp.	---	---	1F	---
Sand dollar echinoid	1F	---	---	---
Fish vertebra	1F	---	---	---

AGE AND CORRELATION

Some of the Topsy mollusks are known in Tertiary strata of the Pacific Northwest. The overlapping stratigraphic ranges of these species (fig. 2), as they are known in the Pacific Northwest, place the Topsy fauna within the Newportian Stage of Addicott

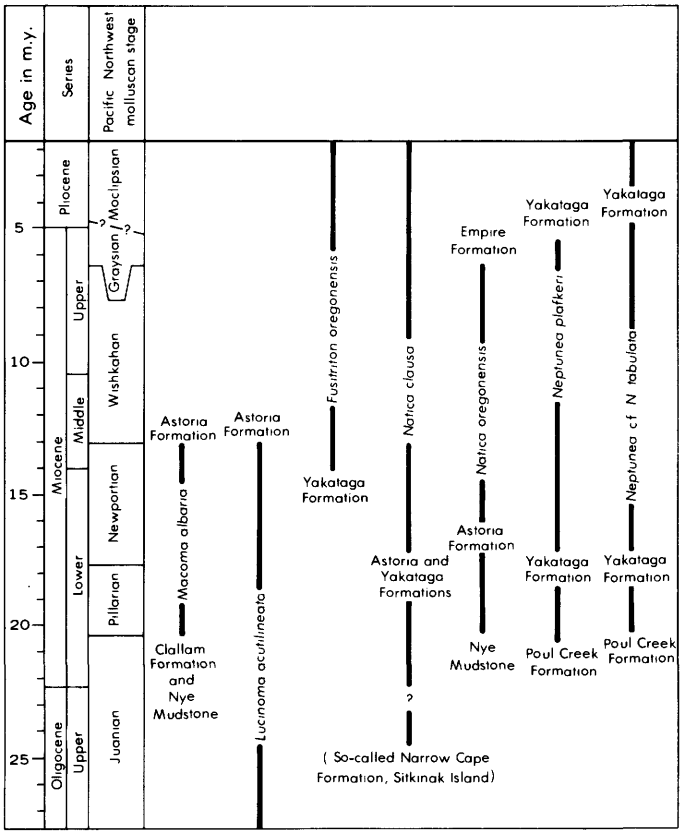

FIGURE 2.—Known stratigraphic ranges in Pacific Northwest and Gulf of Alaska Tertiary Provinces of selected Topsy Formation mollusks. Occurrences in Alaskan formations (Pouls Creek, Yakataga, and so-called Narrow Cape Formation) are based on literature reports and unpublished studies of C. A. Ariey and R. C. Allison. Formations of first and last occurrences as well as other relevant stratigraphic occurrences are shown. Pacific Northwest molluscan stages from Addicott (1976b), as modified by Allison (1976). The Topsy Formation is inferred to be of Newportian age.

(1976b). When first proposed, the Newportian Stage was assigned exclusively to the middle Miocene, encompassing the whole of that subseries (Addicott, 1976b). Subsequently, Allison (1976) reinterpreted the stage boundaries by relying more heavily on Berggren and Van Couvering's (1974) planktonic microfossil correlations with European Cenozoic strata. He concluded that the Newportian Stage is of late early Miocene and early middle Miocene age (fig. 2). In terms of California benthic foraminiferal stages, this interval includes the upper half of the Saucesian Stage and the overlying Relizian and Luisian Stages (Allison, 1976). Allison's interpretation of the Newportian Stage is used here in assessing the age of the Topsy molluscan fauna. However, the work of relating Alaskan Cenozoic faunas to biostratigraphic schemes proposed for other regions is still in its early stages, and major changes in the inferred age relations of Alaskan faunas may yet occur.

Ironically, because Cenozoic molluscan faunal composition and biostratigraphy in the Gulf of Alaska region are not yet well known, correlations from the Topsy fauna to other Gulf of Alaska faunas are more speculative than are those to Tertiary faunas in the Pacific Northwest. However, the basal part the Yakataga Formation at Cape Yakataga (fig. 1) bears a molluscan fauna of Newportian age (Kanno, 1971; Plafker and Addicott, 1976; Allison, 1976; and Ariey 1978a, b) and thus is approximately coeval with the Topsy Formation. Both *Neptunea* species in the Topsy, *N. plafkeri* (questionably identified) and *N.* cf. *N. tabulata* of Kanno (1971), have previously been reported only in the Yakataga Formation, at several localities (Nelson, 1974). Their earliest reported occurrences are in the lower part of the Yakataga Formation at Cape Yakataga (Clark, 1932; Kanno, 1971; Nelson, 1974), although they evidently occur in the underlying Poul Creek Formation at that location (Ariey, 1978a). The earliest occurrence of *Fusitriton oregonensis* in the northeast Pacific, or what may be a closely allied or new species (Smith, 1970), is also at Cape Yakataga. Smith (1970, p. 492) reported specimens of "*Fusitriton* sp. ? aff. *F. oregonensis*" from either the Poul Creek or Yakataga Formations. More recent collecting of the Cape Yakataga section (Ariey, 1978a) showed *F. oregonensis* missing in the upper part of the Poul Creek Formation but present in the stratigraphically highest Newportian fauna (early middle Miocene) and in the immediately overlying Wishkahan fauna (late middle Miocene to late Miocene) of the basal Yakataga Formation (fig. 2).

Lucinoma acutilineata and *Macoma albaria* have their highest stratigraphic occurrences in the Astoria Formation of southwestern Washington and of the Newport embayment of coastal Oregon, in faunas of Newportian age (Addicott, 1976b). *Macoma albaria* is reported in faunas no older than Pillarian in the Clallam Formation in northwestern Washington and the Nye Mudstone of the Newport area in Oregon (Moore, 1963; Addicott, 1976a). In the Pacific Northwest, *Natica clausa* first occurs in Newportian faunas of the Astoria Formation. Its reported first occurrence in Alaska is in lower Miocene strata in the upper Poul Creek Formation (Marincovich, 1977), and it has since been recognized in the Juanian fauna of the so-called Narrow Cape Formation on Sitkinak Island in the western Gulf of Alaska (R. C. Allison, oral commun., 1977). *Natica oregonensis* was formerly known only in the Pacific Northwest, where it ranges from the Pillarian (Nye Mudstone) to Wishkahan (Empire Formation); it has been questionably identified in the Newportian fauna of the Narrow Cape Formation on Kodiak Island in the western Gulf of Alaska (R. C. Allison, oral commun., 1977).

The single Topsy species with Asian affinities is *Periploma besshoense,* which is known in Eocene or Oligocene to upper Miocene strata in Japan (Kanno, 1971; Hatai and Nisiyama, 1952). This species has a variable shell outline in Japanese faunas, and Kanno (1971) noted the presence of two distinct morphologic forms of *P. besshoense* in strata at Cape Yakataga. Kanno (1971) collected the typical Japanese form, nearly circular in outline, in the upper part of the Poul Creek Formation and a more elongate and somewhat rostate form in the overlying Yakataga Formation. The elongate form in the lower part of the Yakataga Formation is also present in the Topsy (fig. 3), so if Kanno's (1971) tentative conclusions are correct, this form of *P. besshoense* would strengthen correlation of the Topsy Formation with the lower Yakataga Formation at Cape Yakataga.

In summary, the Topsy molluscan fauna correlates with Newportian faunas at Cape Yakataga and in Washington and Oregon. Further, the occurrence together of *Fusitriton oregonensis, Macoma albaria,* and *Lucinoma acutilineata* suggests probable assignment of the Topsy to the upper Newportian Stage of latest early Miocene and early middle Miocene age. This interval is approximately equivalent to the Relizian and Saucesian Stages of California benthic foraminiferal terminology, based on interpretations of Pacific Northwest molluscan stages by Allison (1976).

PALEOECOLOGY

WATER DEPTH

The Topsy molluscan fauna represents a shallow, cool-temperature marine environment. The deep-burrowing bivalve *Mya* lives between the intertidal zone and 50 m depth in the northeastern Pacific (Keen and Coan, 1974), and large individuals such as the Topsy specimen (52 mm in height, incomplete) dwell under optimal growth conditions in the shallower portion of this range. The bivalve genera *Spisula* and *Periploma* also have narrow bathymetric ranges in the modern northeastern Pacific; *Spisula* is known from the intertidal zone to 100 m on sand, and *Periploma* is known between 20 and 90 m (Burch, 1945; Keen and Coan, 1974). The modern homologue of *Lucinoma acutilineata, L. annulata* (Reeve, 1850), lives in depths of 20 to 800 m and occurs abundantly, as in the Topsy, in the shallowest part of its range. *Thyasira disjuncta,* tentatively identified in the Topsy, is reported in water as shallow as 10 m or less in the Gulf of Alaska (Kanno, 1971) but only between 150 and 750 m off of western Canada (Bernard, 1972). Noting the occurrence of *T. disjuncta* at 10 m or less in the Gulf of Alaska but no shallower than 60 m off of Japan, Kanno (1971) speculated that depth distribution is a function of water temperature for this species, which is further suggested by Bernard's relatively deep-water records for western Canada.

All of the Topsy gastropod taxa are known in shallow marine habitats. *Fustriton oregonensis* lives between the southern Bering Sea and San Diego, Calif., from the intertidal zone to 2,370 m. It occurs in increasingly deep water southward, reflecting its preference for cool water. From Washington northward, it is found intertidally except where winter sea ice occurs and to depths of 430 m; it has been observed spawning in the intertidal zone (Smith, 1970). *Natica clausa* has its depth distribution strongly controlled by water temperature, so it may occur as shallowly as 9 m in Arctic seas but only below 150 m off southern California (Marincovich, 1977). The closely related species *Natica oregonensis* is extinct and known from Oregon and Washington in Neogene faunas of shallow to moderate depth (Moore, 1963; Marincovich, 1977). *Calliostoma* ranges from the intertidal zone to 915 m in the modern northeastern Pacific (Keen and Coan, 1974) and is most common in depths of about 70 m or less, commonly associated with kelp beds (Burch, 1946; McLean, 1969).

In summary, mollusks of the Topsy Formation collectively suggest water depths of about 20 to 50 m. Even though some taxa are known to range into shallower or greater depths, a range of 20 to 50 m is the broadest interval necessary to account for the presence of all of the Topsy mollusks. None of the Topsy taxa or their modern counterparts are known to live exclusively in greater or lesser depths. The fact that most of the bivalves are articulated indicates that post mortem transport had little or no effect on species composition of the Topsy fauna.

WATER TEMPERATURE

Cool-temperate water temperatures similar to those of the modern open coastline of the Lituya district are indicated by the Topsy mollusks, although few reliable data are known on natural temperature tolerances for their living representatives. Some of the species, such as *Fusitriton oregonensis, Natica clausa,* and *Thyasira disjuncta,* have geographic ranges extending as far south as California or Baja California. However, such species inhabit low latitudes by living in cold bottom-water below the influence of warmer surface-water masses. They inhabit inner sublittoral areas only when surface waters are of cool-temperate to arctic temperatures. All of the Topsy species still living or with modern homologues include the Lituya district within their geographic ranges.

The bivalve genus *Acila,* represented in the Topsy fauna by *Acila (Truncacila) taliaferroi,* can survive in temperate water ranging from about 4.4°C to 21.1°C and *Truncacila* favors cool-temperate habitats (Schenck, 1936), presumably ranging from about 4.4°C to 12.7°C. The lowest temperature in which living *Truncacila* have been recorded is 3.6°C (Schenck, 1936). Living *Acila* are not known below a depth of 1,465 m, nor are they known in the intertidal zone (Schenck, 1936).

Fusitriton oregonensis lives in temperate to cold water along the North Pacific rim from Japan to southern California in depths to 2,370 m. It has been observed in the intertidal zone from Puget Sound, Wash., to southeastern Alaska and has been collected from depths as shallow as 18 m in the southern Bering Sea and 9 m in the Gulf of Alaska (Smith, 1970). Southwestward from the Bering Sea and south of Puget Sound, it lives in progressively greater depths. This species has also been reported in temperatures of 7°C to 11°C in Puget Sound and


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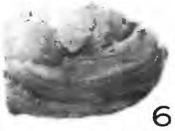
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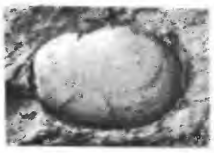
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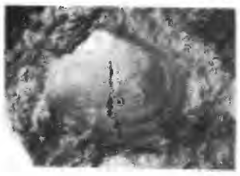
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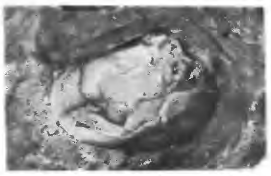
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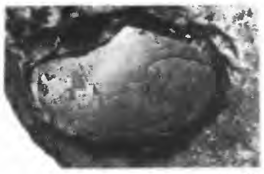
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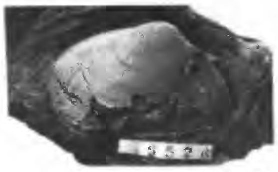
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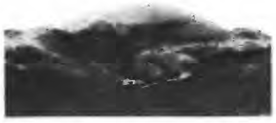
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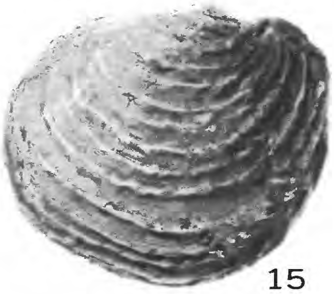
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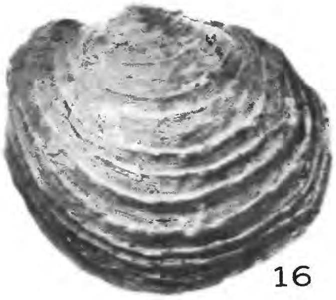
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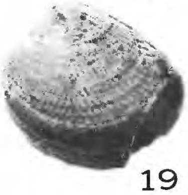
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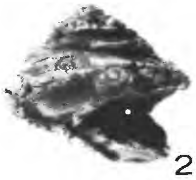
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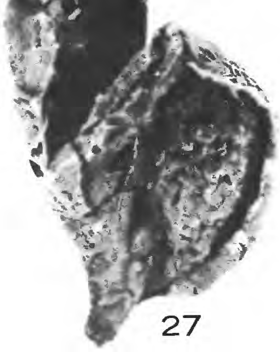
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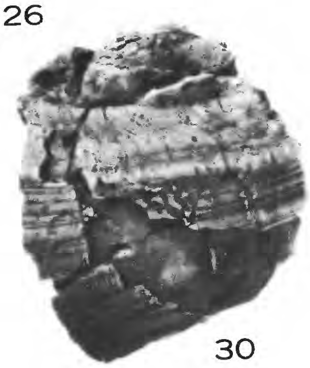
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FIGURES 3. *Periploma (Aelga) besshoense* (Yokoyama). USNM 250860. Height 33.4 mm, length 54.2 mm.
4–6. *Macoma albaria* (Conrad). USNM 250862. Height 16.5 mm, length 22.1 mm.
  4. Right valve.
  5. Dorsal aspect.
  6. Left valve.
7–9. *Macoma* aff. *M. twinensis* Clark.
  7. USNM 250866, right valve, height 12.7 mm, length 20.0 mm.
  8. USNM 250865, left valve, height 17.5 mm, length 23.4 mm.
  9. USNM 250865, dorsal aspect.
10. *Macoma incongrua* (von Martens). USNM 250864. Right valve, height 14.7 mm, length 19.1 mm.
11. *Spisula addicotti* Kanno. USNM 250871, right valve, height 14.6 mm, length 22.7 mm.
12. *Nuculana (Saccella)* sp. USNM 250867, right valve, height 11.3 mm, length 17.0 mm.
13–14. *Macoma* aff. *M. albaria* (Conrad). USNM 250863.
  13. Left valve, height 15.3 mm, length 24.8 mm.
  14. Dorsal aspect.
15–16. *Lucinoma acutilineata* (Conrad). USNM 250861. Specimen distorted.
  15. Left valve, height 40.0 mm, length 44.4 mm.
  16. Right valve.
17. *Thyasira* cf. *T. disjuncta* (Gabb). USNM 250870, left valve, height 36.5 mm, length 36.2 mm.
18–19. *Acila (Truncacila) taliaferroi* Clark. USNM 250868, height 15.8 mm, length 17.3 mm.
  18. Dorsal aspect.
  19. Right valve.
20–21. *Fusitriton oregonensis* (Redfield). *USNM* 250874, height 39.7 mm, diameter 22.5 mm. Specimen distorted.
  20. Apertural view.
  21. Backside view, showing spiral sculpture.
22–23. *Calliostoma* sp. USNM 250872, height 22.8 mm, diameter 26.2 mm. Specimen distorted.
  22. Apertural view.
  23. Backside view, showing fine spiral sculpture.
24. ?*Colus* sp. USNM 250876, height 27.6 mm, diameter 16.2 mm. Specimen distorted and worn.
25. *Natica (Cryptonatica) clausa* Broderip and Sowerby. USNM 250869, height 10.4 mm, diameter 10.0 mm.
26. *Natica (Cryptonatica) oregonensis* (Conrad). USNM 250873, height 11.1 mm, diameter 8.0 mm.
27. ?*Neptunea (Neptunea) plafkeri* Kanno. USNM 250875, height 54.0 mm. diameter 36.3 mm. Apertural view, specimen distorted.
28–30. *Neptunea (Sulcosipho)* cf. *N. (S.) tabulata* (Baird). USNM 250877, height 42.3 mm, greatest diameter 39.0 mm, least diameter 22.9 mm. Specimen distorted.
  28. Oblique apertural view, showing spiral sculpture.
  29. Apertural view, showing shoulder tabulation.
  30. Backside view, showing spiral sculpture.

in waters less than 8°C off of southern California (Valentine and Emerson, 1961).

Modern surface-water temperatures in the eastern Gulf of Alaska range from monthly averages of 6.7°C in February to 14.4°C in August (LaViolette and Seim, 1969). Nearshore marine temperatures significantly different from those of the modern Lituya district are not required to account for the Topsy fauna.

SYSTEMATIC PALEONTOLOGY

Acila (Truncacila) taliaferroi Clark, 1932

Figures 18–19

This species is characterized by its moderate size and relatively high shell, somewhat inflated valves, nearly vertical axis of bifurcation of its fine, subdued radial sculpture and by the shape of its escutcheon. Interior features of the valves are unknown.

Acila (Truncacila) taliaferroi is most similar to *A. (T.) conradi* (Meek, 1864), which occurs in the lowermost Pillarian and Newportian Stages of the Pacific and in coeval beds in California, and to *A. (T.) empirensis* Howe, 1922, known from the Wishkahan and Graysian(?) Stages of the Pacific Northwest. *Acila taliaferroi* and *A. conradi* are identical in shell outline and inflation of their valves. However, *A. taliaferroi* may be distinguished by its smaller size (*A. conradi* attains a height of 21.7 mm; Schenck, 1936), relatively greater height, less elongate escutcheonal area, and distinctly more vertical axis of bifurcation of the radial ribs. The last two features are most useful for quickly separating specimens of the two species. Both species show a band of obsolete radial ribbing along the adult ventral shell margin, but the occurrence of secondary bifurcation of the radial ribs is more pronounced on *A. conradi* than on *A. taliaferroi.*

Compared to *A. empirensis*, *A. taliaferroi* is smaller (the former species is as much as 19.3 mm high and 25.9 mm long; Schenck, 1936), has a more acutely rounded anterior extremity and finer radial sculpture standing in much lower relief. In addition, the angle of bifurcation of the radial sculpture is more vertical in *A. taliaferroi* and the secondary bifurcation is less pronounced than in *A. empirensis*. Undistorted individuals of *A. taliaferroi* usually have more inflated valves than specimens of *A. conradi* or *A. empirensis.*

The largest individual of *A. taliaferroi* from the Topsy Formation is 15.8 mm high and 17.3 mm long, and the smallest is 12.0 mm high and 12.1 mm long. Specimens from the lower part of the Yakataga Formation throughout the Gulf of Alaska region are of similar size. Wherever they occur, however, most individuals are somewhat distorted from burial compaction and tectonic forces.

The precise stratigraphic range of *A. taliaferroi* has not been established. It has been reported previously only from about the upper 213 m of the Poul Creek Formation (Clark, 1932; Addicott and others, 1971) and from the lower part of the Yakataga Formation (Kanno, 1971) in the Yakataga district. These occurrences span a stratigraphic interval approximately equal to the Pillarian and Newportian Stages (early Miocene through early middle Miocene) of the Pacific Northwest.

Lucinoma acutilineata (Conrad, 1849)

Figures 15–16

The combination of nearly circular outline, regularly spaced and sharply raised concentric lamellae, and concentric interspaces with numerous fine threads distinguishes this species. As noted by Addicott (1976a), *L. acutilineata* is usually preserved with articulated valves, as it is in the Topsy Formation. All Topsy specimens are distorted.

The specimens at hand are the first ones reported from Alaska, although this species is found commonly in middle Tertiary strata in Washington, Oregon, and California. The earliest occurrence of *L. acutilineata* is in the Eugene Formation of west-central Oregon (Hickman, 1969), strata which have been assigned to the late Eocene to early Oligocene part of the Galvinian Stage by Armentrout (1975). Its highest startigraphic appearance is in the Astoria Formation in northwestern Oregon (Moore, 1963), which is included in the Newportian Stage (Addicott, 1976b). The presence of *L. acutilineata* in the Topsy fauna provides a significant tie with the better known Tertiary faunas of Washington and Oregon and is evidence that the Topsy is no younger than early middle Miocene.

The modern homologue of this species is *Lucinoma annulata* (Reeve, 1850), which lives in depths of 20 to 800 m between Alaska and Baja California, Mexico, but is found most abundantly in the inner sublittoral zone (0–100 m) (Burch, 1944). Compared to *L. acutilineata, L. annulata* has a shorter posterior dorsal margin (Stewart *in* Tegland, 1933) and a heavier hinge (Moore, 1963). As also pointed out by Moore (1963), the anterior tooth on the right valve of *L. acutilineata* is short and blunt, rather than thin and bladelike on *L. annulata,* and the cardinal tooth seems to be shorter on *L. annulata.* In addition, the left anterior tooth of *L. acutilineata* is heavier and not so deeply incised as on *L. annulata* (Moore, 1963).

Macoma albaria (Conrad, 1849)

Figures 4–6

This species is characterized by its relatively small size, by the proximity of its beaks to the posterior end, and by its posteriorly flexed valves.

Macoma albaria has not been recognized previously from Alaska. Its presence in the Topsy provides a new tie between Tertiary strata of the Gulf of Alaska and the Pacific Northwest. This bivalve is well known in Miocene deposits in Oregon and Washington, where it has been reported in the Pillarian Nye Mudstone and Newportion Astoria Formation in western Oregon (Moore, 1963) and in the Pillarian Clallam Formation in northwestern Washington (Addicott, 1976a). As noted by Addicott (1976a), *M. albaria* is similar to *M. twinensis* Clark, 1925. The latter species is known from upper Oligocene rocks in northwestern Washington and is doubtfully reported from the lower Miocene Clallam Formation (Addicott, 1976a) in the same area. The importance of *M. albaria* in the Topsy rests on its last known occurrence in middle Miocene strata of Oregon. Even if its stratigraphic range were extended to encompass the upper Oligocene records now assigned to *M. twinensis,* its value in dating the Topsy Formation would not be diminished.

Macoma aff. M. albaria (Conrad, 1849)

Figures 13–14

This species is represented by a single left valve that is well preserved and nearly complete but shows only exterior features. Its shape is most similar to that of *M. albaria* (Conrad, 1849), which occurs in lower and middle Miocene strata of Oregon and Washington (Moore, 1963; Addicott, 1976a). However, the Topsy specimen is distinctly more inflated than *M. albaria,* has a straighter ventral margin, a more prominent umbo, and blunter posterior termination. This valve is also similar to *M. twinensis* Clark, 1925, which is found in faunas of late Oligocene and possibly early Miocene age in Oregon and Washington (Addicott, 1976a), but differs from the latter species by its more prominent umbo, smaller relative height, and more inflated left valve. Another similar species is *M. brota* Dall, 1916, which lives from Arctic Canada to Puget Sound, Wash., and is reported in Pleistocene faunas in Arctic Canada and British Columbia (Coan, 1971). The Topsy *Macoma,* however, is distinguished from *M. brota* by having a less elevated anterior dorsal margin, a more narrowly rounded anterior end and straighter ventral margin, and a distinctly more inflated left valve. Future studies may reveal an ancestral relation between *M. brota* and the Miocene Macomas mentioned here.

Macoma incongrua (von Martens, 1865)

Figure 10

This relatively small *Macoma* is characterized by its inflated valves, broadly and evenly rounded anterior end, and acutely angled posterior end. The posterior dorsal and ventral margins are straight and steeply sloping, and there is a distinct flexure to the right and a slight gape at the posterior end.

This species is the most frequently encountered *Macoma* in Gulf of Alaska Tertiary strata. It is well represented in beds of the lower part of the Yakataga Formation in the Yakataga and Lituya districts (of presumed early to late Miocene age) and has been reported in the upper part of the Poul Creek Formation at Cape Yakataga (Kanno, 1971) in beds of presumed early Miocene age. Its occurrence in the Pliocene and Pleistocene portions of the Yakataga Formation has been reported but not well documented, and it has been questionably reported in strata as old as late Oligocene (Kanno, 1971).

As noted by Coan (1971) and Kanno (1971), Holocene specimens from the northeastern Pacific referred to *M. incongrua* differ in interior shell features from Holocene specimens of Japan (from which the holotype comes). Northeastern Pacific Pleistocene and Holocene specimens referred to *M. incongrua* by earlier workers have been placed in *Macoma* (*Macoma*) *obliqua* (Sowerby, 1917) by Coan (1971), a species also recognized in the Red Crag (lower Pleistocene) of England. Because interior shell features are not observable in most Alaskan Tertiary specimens referred to *M. incongrua,* and differences between *M. incongrua* and *M. obligue* are not always expressed in exterior morphology, the identity of specimens from the upper part of the Poul Creek and lower part of the Yakataga Formations is uncertain. It is most probable that these Miocene specimens belong to *M. incongrua* rather than *M. obliqua,* but proof of this will depend on collecting more Alaskan specimens in which interior features can be observed.

Individuals from the Topsy Formation figured here are of average size for Gulf of Alaska Tertiary specimens.

Macoma aff. M. twinensis Clark, 1925

Figures 7–9

Specimens from the Topsy Formation are juveniles and young adults, resembling the holotype of *M. twinensis* Clark, 1925, which is also a juvenile specimen. Juveniles of *M. twinensis* differ from adults by having a more acutely rounded posterior end and less distinct umbones.

Macoma twinensis is reported in faunas of late Eocene through early Miocene age in the Pacific Northwest, its highest stratigraphic occurrence being doubtfully identified specimens from the lower Miocene Clallam Formation (Addicott, 1976a). The largest Topsy specimens are much more inflated than young adults of *M. twinensis* from the Pacific Northwest, so their species assignment will be uncertain until adult Topsy specimens are collected.

Mya sp.

This genus is represented in the Topsy Formation by a single right valve with its posterior end missing. The specimen is 52 mm high, with its umbo and ventral margin nearly intact.

The Topsy specimen most probably is *Mya* (*Mya*) *cuneiformis* (Boehm, 1915), which commonly occurs in Yakataga Formation faunas of presumed middle Miocene age in the Lituya district and is especially abundant in the Cenotaph Island section. MacNeil (1965) cited records of *M. cuneiformis* from presumed middle Miocene strata in the Cape Yakataga area and on Kodiak Island, Alaska, and from presumed middle Miocene to lower Pliocene beds in Japan and Sakhalin. *Mya* (*Mya*) *truncata* Linnaeus, 1758, is also common in middle Miocene to Holocene faunas of southern Alaska (MacNeil, 1965), though it is not so common as *M. cuneiformis* in the Yakataga Formation of the Lituya district.

In the modern northeastern Pacific, *Mya* species occupy a bathymetric range from the intertidal zone to 50 m (Keen and Coan, 1974), burrowing into sandy mud.

Nuculana (Saccella) sp.

Figure 12

Saccella is characterized by having a pointed posterior rostrum, sculpture of strong concentric rugae, posterior and anterior series of teeth equal, and a

U-shaped pallial sinus. The Topsy specimens are molds and casts that preserve only small portions of exterior sculpture and hinge lines and that lack impressions of pallial lines. The visible features of these specimens, however, suggest placement in *Saccella.* This subgenus is represented by many North Pacific Tertiary species, although it has not yet been recognized in the Yakataga Formation.

Periploma (Aelga) besshoense (Yokoyama, 1924)

Figure 3

When typically developed, the shell of this species is nearly equidimensional, with its posterior extremity distinctly compressed and slightly produced; the anterior margin is broadly rounded. The most common variation is for the posterior end to be greatly produced and broadly rounded, whereas the anterior end is reduced and often slightly truncated (Kanno, 1971).

This species was described from Japan, where it occurs in Oligocene and Miocene strata. Kanno (1971) recognized it in the upper part of the Poul Creek Formation and the lower part of the Yakataga Formation of the Yakataga district. He further noted that the posteriorly elongate variety seemed to occur only in the lower part of the Yakataga Formation, whereas the typical variety was found only in the upper part of the Poul Creek Formation. The Topsy Formation specimen is of the elongate variety known in the lower part of the Yakataga Formation, which provides a possible link between these two stratigraphic intervals. As emphasized by Kanno (1971), the seeming division of shell forms between the Yakataga and Poul Creek Formations requires confirmation.

Periploma lives in the modern northeastern Pacific in depths of 20 to 90 m (Burch, 1944; Keen and Coan 1974) ranging from Alaska to Peru.

Spisula addicotti Kanno, 1971

Figure 11

The shell of this species is elongate anteriorly, with prominent umbones situated posteriorly, and broadly rounded anterior and posterior extremities (especially in younger individuals).

This species has been reported only from the Poul Creek Formation (upper Eocene to lower Miocene; Allison, 1976) in the Yakataga district (Clark, 1932; Kanno, 1971; Addicott and others, 1971). Thus, its presence in the Topsy Formation is its highest known stratigraphic occurrence. The Topsy specimen is a juvenile showing the broadly rounded extremities that seem to characterize this species, especially in younger individuals.

Spisula addicotti may be a junior synonym of *S. trapezoides* (Clark, 1932), which is known from the upper part of the Poul Creek Formation (lower Miocene; Allison, 1976) in the Yakataga district (Clark, 1932; Addicott and others, 1971) and from Wishkahan faunas of the upper part of the Bear Lake Formation (upper middle Miocene to upper Miocene) on the Alaska Peninsula (R. C. Allison, oral commun., 1977). Compared to illustrations of the holotype of *S. trapezoides,* (Clark 1932; Addicott and others, 1971), *S. addicotti* appears to have a distinctly more elongate posterior end and a more evenly rounded posterior termination. However, the Topsy specimen of *S. addicotti* and the holotype of *S. trapezoides* are juveniles, making comparisons difficult.

Modern northeastern Pacific *Spisula* species inhabit depths from the intertidal zone to 100 m in sand substrates of exposed beaches and bays (Keen and Coan, 1974).

Thyasira cf. T. disjuncta (Gabb, 1866)

Figure 17

This lucinacean bivalve is characterized by its trigonal shape, broadly arched posterior dorsal margin, nearly straight anterior dorsal margin, strong sulcus that extends along the posterior dorsal slope from the umbo to the anterior ventral margin, and edentulous hinge.

Although some molluscan specialists have considered *T. disjuncta* to be synonymous with *T. bisecta* (Conrad, 1849), Bernard (1972) has exhaustively documented the anatomical differences and pointed out the distinctive shell morphology of each. I follow Bernard (1972) in considering *Conchocele* Gabb, 1866, into which *T. disjuncta* has often been placed, a junior synonym of *Thyasira.* The straight rather than concave anterior dorsal margin and less prominent umbo of *T. disjuncta* that distinguish it from *T. bisecta* are missing from the Topsy specimen. *T. bisecta* has never been reliably reported in Alaska Tertiary faunas, and illustrated *Thyasira* specimens from the Poul Creek Formation (Clark, 1932; Kanno, 1971; Addicott and others, 1971) are undoubtely *T. disjuncta.* It is highly probable that the Topsy specimen is also *T. disjuncta,* although confirmation of this will depend on finding additional specimens.

Thyasira disjuncta is known in the North Pacific from late Eocene or early Oligocene to Holocene and in the modern Caribbean fauna (Boss, 1967). Because of confusion by past workers between *T. disjuncta* and *T. bisecta,* it is difficult to determine from literature records the exact geographic range of the former species in the North Pacific. In Gulf of Alaska Tertiary strata, *T. disjuncta* is recorded from the lower part of the Poul Creek Formation (Kanno, 1971) as well as from the upper part (Clark, 1932; Addicott and others, 1971) in the Yakataga district. Specimens from a large erratic boulder at Cape Yakataga were judged by Kanno (1971, p. 62) to have come from the Poul Creek Formation, though he considered it possible they could have come from the overlying Yakataga Formation. The only known record of this species from the Yakataga Formation in the Yakataga district is that of Kanno (1971, p. 22) from the Chaix Hills in strata of probable late Miocene or Pliocene age. Because its stratigraphic occurrence represents such an extensive time interval, even though the species occurs widely, it is not useful for correlation or age determination.

Besides *T. disjuncta,* the only other Tertiary *Thyasira* known in Alaska is *T. alaskana* Kauffman, 1969. This species occurs on the Arctic coastal plain of northeastern Alaska, in the upper Miocene(?) and Pliocene Nuwok Member of the Sagavanirktok Formation, and is of Atlantic affinities.

Calliostoma sp.

Figure 22–23

This genus has not been reported previously as a fossil in Alaska, although species of *Calliostoma* do live today as far north as southeastern Alaska. The species from the Topsy Formation is most similar to *Calliostoma cammani* Dall, 1909, from the middle to lower Pliocene Empire Formation in Oregon. However, sculptural features of the Topsy specimen exclude it from *C. cammani.* It might belong to one of the Tertiary species described from Japan, the oldest of which is said to be Oligocene in age (Hatai and Nisiyama, 1952), or from the eastern Soviet Union. At present, no comparative specimens of Japanese or Soviet *Calliostoma* species are available, and literature citations are not sufficient to evaluate them, so comparisons with the Topsy specimen must be deferred.

?Colus sp.

Figure 24

The elongate fusiform shell and relatively small aperture of the Topsy specimen suggest placement in *Colus* or an allied genus. This specimen is too worn and incomplete for certain generic placement, but parts of the exterior surface appear to be intact and smooth, further suggesting *Colus* as the most likely genus. *Colus* specimens are in the Poul Creek and Yakataga Formations, but are often too worn for specific identification, considering that differences among many *Colus* species are subtle.

Natica (Cryptonatica) clausa Broderip and Sowerby, 1829

Figure 25

A smooth, nearly globular shell with a semicircular callus concealing the umbilicus characterizes this species. It is distinguished from *N.* (*C*) *oregonensis* (Conrad, 1865) by its less elongate body whorl and lower spire. In general, fossil specimens of *N. clausa* also have distinctly thicker shells than *N. oregonensis;* modern individuals of *N. clausa* tend to have somewhat thinner shells than fossil specimens.

Natica clausa occurs commonly in cool- and cold-water Miocene to Holocene faunas of the North Pacific and is the only naticid found routinely in Alaskan Neogene and Pleistocene strata. Its reported first occurrence in the Gulf of Alaska Tertiary Province is in the upper part of the Poul Creek Formation (lower Miocene) of the Yakataga district (Marincovich, 1977), from strata of presumed late Juanian or Pillarian age. A coeval or possibly older occurrence is now known in the Juanian fauna of the so-called Narrow Cape Formation on Sitkinak Island in the western Gulf of Alaska (R. C. Allison, oral commun., 1977).

The single specimen of *N. clausa* from the Topsy Formation is 10.4 mm in height and 10.0 mm in diameter, which is average for Miocene specimens and much smaller than Pliocene to Holocene individuals. All fossil and modern occurrences of *N. clausa* are in faunas of decidedly cool- or cold-water aspect or in faunas with a well-developed cold-water element (Marincovich, 1977), so the presence of this species in the Topsy is strong evidence for a cool-temperate or slightly colder marine hydroclimate.

Natica (Cryptonatica) oregonensis (Conrad, 1865)

Figure 26

This species is characterized by its smooth whorls and its semicircular callus concealing the umbilicus and by its elevated spire and elongate body whorl. These last two characters distinguish *N. oregonensis* from the related *N. clausa* Broderip and Sowerby, which also occurs in the Topsy Formation.

This is the first certain report of *N. oregonensis* north of Washington and Oregon, although it has been questionably identified in the Newportian fauna of the Narrow Cape Formation on Kodiak Island in the western Gulf of Alaska (R. C. Allison, oral commun., 1977). It was previously known from the Astoria Formation of western Washington and western Oregon (Newportian Stage) and from the Empire Formation at Coos Bay, Oregon (Wishkahan and Graysian(?) Stages as used by Allison, 1976) (Marincovich, 1977). It is now also known in the Nye Mudstone (Pillarian Stage) of northwestern Oregon, on the basis of reassignment to the Nye Mudstone of localities formerly attributed to the Astoria Formation in northwestern Oregon (W. O. Addicott, oral commun., 1977). These verified occurrences range in age from early Miocene to early late Miocene.

?Neptunea (Neptnnea) plafkeri Kanno, 1971

Figure 27

This species is discriminated from other Tertiary Neptuneas and similar large gastropods in the Gulf of Alaska region by its high spire, acute apical angle, long anterior canal, and nearly smooth shell sculptured only with fine incremental growth lines and a few radial varices of low relief near the aperture (Kanno, 1971; Nelson, 1974).

The poor condition of the Topsy specimen, missing all but an incomplete and worn body whorl, makes identity uncertain. This specimen is not deeply sculptured as are many Neptuneas, and the best preserved parts of the exterior surface show only fine incremental growth lines.

Neptunea plafkeri was described from specimens collected in the lower part of the Yakataga Formation at Cape Yakataga (Kanno, 1971), and it has also been collected in the upper part of the Poul Creek Formation there (C. A. Ariey, 1978a). This species is also reported from several Miocene localities of the Yakataga Formation in the Yakataga district and in beds now assigned to the Topsy Formation at Icy Point in the Lituya district (Nelson, 1974). The sum of its known stratigraphic occurrences suggests a range of about early Miocene to middle or possibly late Miocene for *N. plafkeri.*

Neptunea (Sulcosipho) cf. N. (S.) tabulata (W. Baird, 1863)

Figures 28–30

When seen as well-preserved fossil or modern specimens, *N. tabulata* is easily recognized by its elongate shape, strongly tabulate shoulder bounded by a thickened and minutely scaly spiral cord, and by its fine spiral ribs covering the whole outer surface. The Topsy specimen is a distorted and incomplete body whorl lacking earlier whorls or an anterior canal. The tabulate shoulder and fine spiral sculpture show up well and suggest placement of the specimen in *N. tabulata.* Even though there appear to be three sizes of spiral ribs on both *N. tabulata* and the Topsy specimen, however, the ribs of true *N. tabulata* are more boldly sculptured, seem to occur in a more regular sequence, and appear to be separated by wider interspaces than the ribs of the Topsy individual.

The specimens figured by Kanno (1971) as *Neptunea* (*Sulcosipho*) cf. *N.* (*S.*) *tabulata* appear to be the same as the Topsy shell. A specimen cited by Clark (1932) and refigured by Addicott and others (1971) as *Neptunea* aff. *N. tabulata* also probably is the same species. Kanno's (1971) specimens were collected from the lower part of the Yakataga Formation at Cape Yakataga, and Clark's (1932) specimens from the same area also probably came from the lower part of the Yakataga Formation (Addicott and others, 1971). Nelson (1974) reported this species in middle Miocene to lower Pliocene beds of the Yakataga Formation throughout the Gulf of Alaska Tertiary Province. Recent collecting at Cape Yakataga has produced this species from the upper part of the Poul Creek Formation (C. A. Ariey, 1978a). Thus, the known occurrences of this species indicate an approximate age range of early Miocene to early Pliocene.

Fusitriton oregonensis (Redfield, 1846)

Figures 20–21

The characteristic features of this high-spired snail are its coarse axial ribs and fine, flattened spiral costae that are usually bifurcated. Most spiral interspaces on the Topsy specimen contain one slender thread, although such threads may be absent or as numerous as three per interspace (Smith, 1970).

This species is well known in North Pacific Miocene and younger faunas, being most abundant in Pliocene and younger strata from Japan and Alaska south to California (Smith, 1970). Until recently, no precise data were known on the earliest occurrence of *F. oregonensis.* Smith (1970) reported specimens of *"Fusitriton* sp. ? aff. *F. oregonensis"* from Cape Yakataga Miocene strata of either the Poul Creek or Yakataga Formations. Recent collecting by C. A. Ariey (oral commun., 1977), however, showed *F. oregonensis* missing from the upper part of the Poul Creek Formation at Cape Yakataga but present in the stratigraphically highest Newportian fauna and in the Wishkahan fauna of the lower part of the Yakataga Formation there. Thus, the oldest verified occurrence of this species is in the early middle Miocene portion of the Newportian Stage, thereby making *F. oregonensis* the species most important for inferring a maximum age for the Topsy fauna.

Modern occurrences are in temperate to cold waters of the North Pacific rim from Japan to southern California. Although *F. oregonensis* is known from depths as great as 2,370 m, it has been observed in the intertidal zone from Puget Sound, Washington, to southeastern Alaska, and in depths as shallow as 18 m in the southern Bering Sea and 9 m in the Gulf of Alaska (Smith, 1970). Southwest from the Bering Sea and south of Puget Sound, it lives in progressively greater depths. It has been collected in temperatures of 7–11°C in Puget Sound and in waters less than 8°C off of southern California (Valentine and Emerson, 1961).

FOSSIL LOCALITY DESCRIPTIONS

The following locality numbers for the Topsy Formation are assigned by the Menlo Park, Calif., center of the U.S. Geological Survey. Fossil collections are housed in the Branch of Paleontology and Stratigraphy, Menlo Park, Calif., except for illustrated specimens, which are kept in the National Museum of Natural History, Washington, D.C.:

M6525 (Plafker field locality 75APr45A).—Isolated outcrop in intertidal zone of rock and sand beach about 3.3 km northeast of Icy Point; 669 m south and 274 m west of NW. cor. sec. 15, T. 40 S., R. 50 E., Mt. Fairweather (B–4) quadrangle, Lituya district, southeastern Alaska. Collected by George Plafker and Travis Hudson, June 1975.

M6526 (Plafker field locality 75APr40A).—Isolated outcrop along southern margin of Finger Glacier, 182 m south and 486 m west of NE. cor. sec. 33, T. 39 S., R. 50 E., Mt. Fairweather (B–4) quadrangle, Lituya district, southeastern Alaska. Collected by George Plafker and Travis Hudson, June 1975.

M6527 (Plafker field locality 75APr43D).—Isolated outcrop in intertidal zone of rock and sand beach, about 5.8 km north of Icy Point; 730 m south and 30 m east of NW. cor. sec. 10, T. 40 S., R. 40 E., Mt. Fairweather (B–4) quadrangle, Lituya district, southeastern Alaska. Collected by George Plafker and Travis Hudson, June 1975.

M6528 (Marincovich field locality 75AM65).—Isolated outcrop near head of Fall Creek, along strike from lower part of type-section of Topsy Formation, 289 m south and 274 m west of NE. cor. sec. 33, T. 37 S., R. 48 E., Mt. Fairweather (C–5) quadrangle, Lituya district, southeastern Alaska. Collected by Louie Marincovich, George Plafker, and Travis Hudson, June 1975.

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Variability in *Trithyrodinium* Drugg 1967

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 1125-D

The considerable amount of archeopyle variation observed in Trithyrodinium *Drugg 1967 cautions the use of archeopyle outline in peridinioid dinoflagellate cyst taxonomy*

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

CONTENTS

ILLUSTRATIONS

VARIABILITY IN *TRITHYRODINIUM* DRUGG 1967

By Fred E. May and Don G. Benson, Jr.[1]

ABSTRACT

The shape, size, and number of sides of each opercular piece are highly variable in the two species of *Trithyrodinium* Drugg 1967 reported on in this paper. Populations of both *Trithyrodinium striatum* Benson 1976 and *T.* cf. *T. fragile* Davey 1969 from the northern New Jersey Coastal Plain have 3I/3I archeopyles that display considerable variation in the opercular pieces on the endocyst. The variation results from the differing height in the 2a paraplate. Specimens with a reduced 2a that does not contact the apical series but is separated from the apical series by the anterior joining of the 1a and 3a have hexagonal 1a and 3a paraplates, a pentagonal 2a paraplate, and an 11-sided endoarcheopyle. Specimens with a "typical" 2a paraplate that makes contact with the apical series, separating the 1a and 3a paraplates, have pentagonal 1a and 3a paraplates, a hexagonal 2a paraplate, and a 12-sided endoarcheopyle. The only exception to the last example is in specimens where the 2a, because of its increased height, just makes contact with the apical series. In such specimens the 1a, 2a, and 3a are all pentagonal in outline, and the archeopyle is 11 sided. The delicate nature of the pericyst makes it difficult to study, although it appears to be 3I for the types reported here.

INTRODUCTION

Fossil peridinioid dinoflagellate cysts having archeopyles formed of the 1a, 2a, and 3a paraplates have been assigned to the genus *Trithyrodinium* Drugg, 1967, Initially Drugg (1967) felt that the archeopyle of the type species *T. evittii* was 3I/3I (after Evitt's 1967 classification); however, he was not certain, and he felt that all the opercular pieces were removed as a unit. Subsequent observations by Evitt and Drugg (written commun., 1976) using interference contrast have shown the archeopyle to be 3I/3I. Davey (1969) emended Drugg's (1967) generic description and suggested that the archeopyle formula is I/3I. Lentin and Williams (1976) emended the archeopyle formula to 3I/3I. Only one investigation thus far (Evitt, 1967) has reported any morphologic variability in the opercular pieces of *Trithyrodinium*. The present study provides the first specific examples, however, of the gradation in variability in both the archeopyle and opercular pieces. Two species, *T. striatum* Benson, 1976, and *T.* cf. *T. fragile* Davey, 1969, observed from Maestrichtian sedimentary rocks of the Atlantic Coastal Plain of New Jersey and Maryland (fig. 1), possess the same type of variability referred to by Evitt (1967, p. 38–39). The purpose of this report is to illustrate this gradation in variability in archeopyle

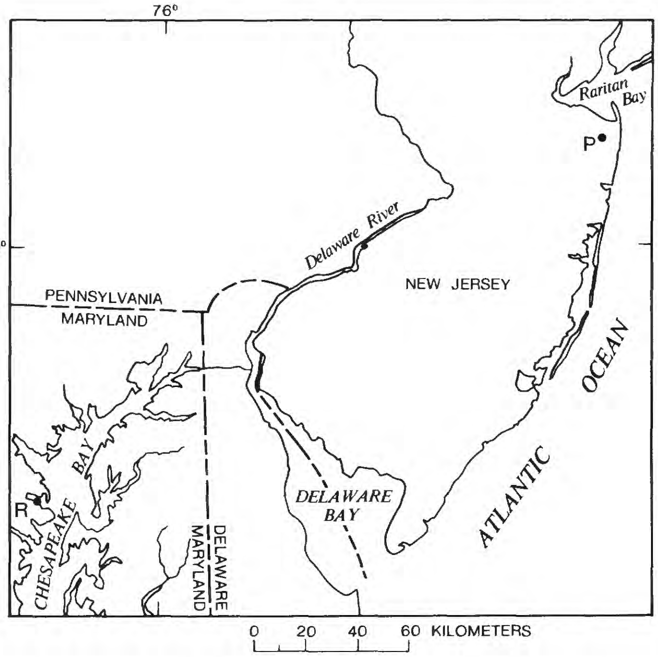

Figure 1.—Map of the northern Coastal Plain, showing collecting areas at Round Bay (R), Md., and Poricy Brook (P), N.J. Specimens were collected from Upper Cretaceous units, the Severn Formation at Round Bay, and the Navesink Formation and Red Bank Sand at Poricy Brook.

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[1] Amoco Production Co., New Orleans, La.

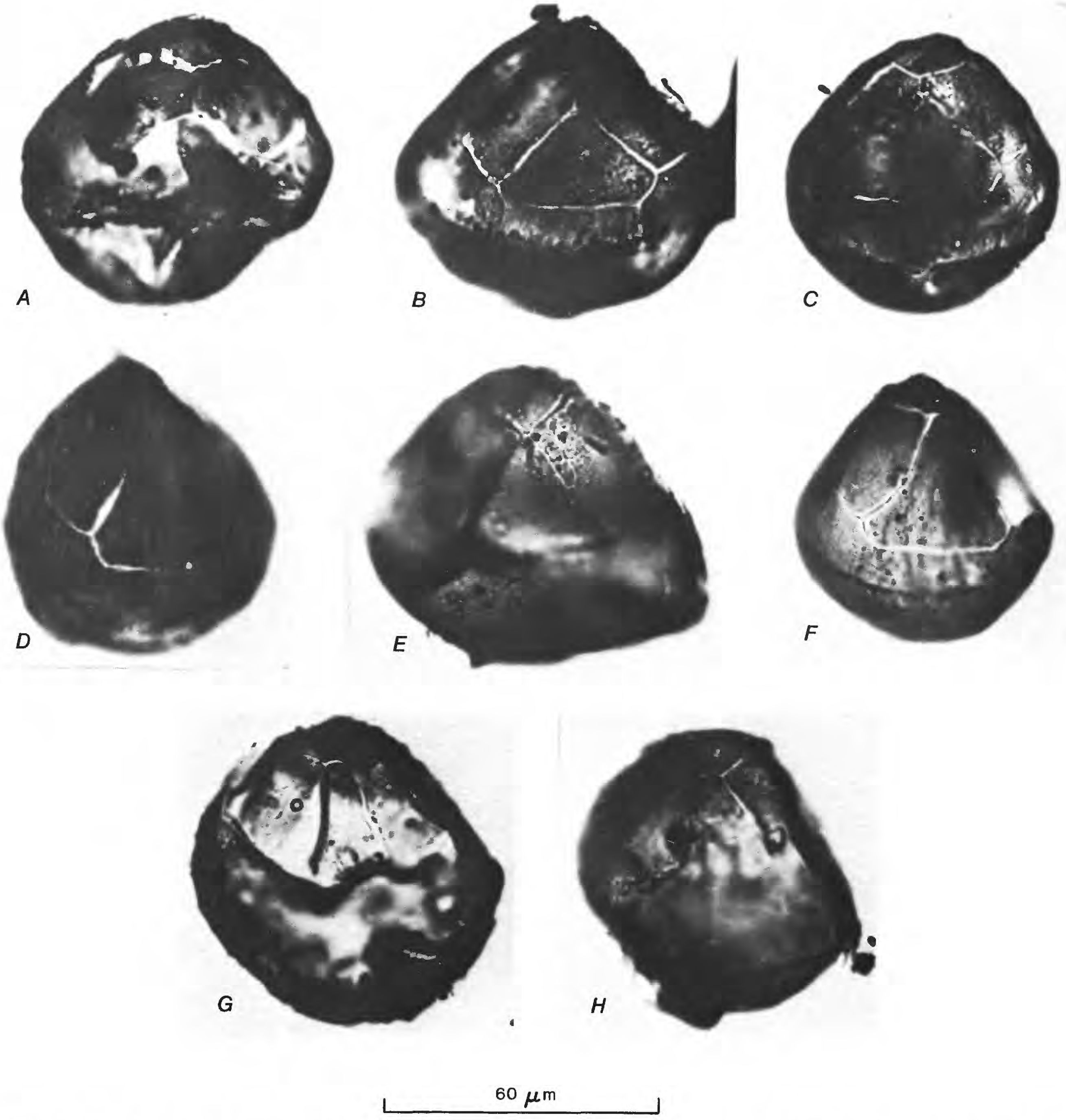

FIGURE 2.—Specimens of *Trithyrodinium* cf. *T. fragile* collected from Poricy Brook, N.J., showing gradation in the morphologic variability of anterior intercalary paraplates. (Also see fig. 3, sketches of endopercular pieces on the above specimens.) *A–C*, reduced 2a paraplates separated from the apical series by anterior joining of the 1a and 3a paraplates. *D*, a 2a paraplate that just makes contact with the apical series. *E–H*, 2a paraplates that make contact with the apical series and are increasingly broadened along their anterior margins.

and opercular-piece morphology for two species of one peridinioid genus.

OBSERVATIONS

Although Evitt (1967) reported the existence of variability in *Trithyrodinium* archeopyle and opercular-piece morphology, until now no particular species have been described or illustrated showing this gradation. We first observed the complete gradation in samples from the Navesink Formation at Poricy Brook, Monmouth County, N.J. Specimens from this locality demonstrating the gradation are

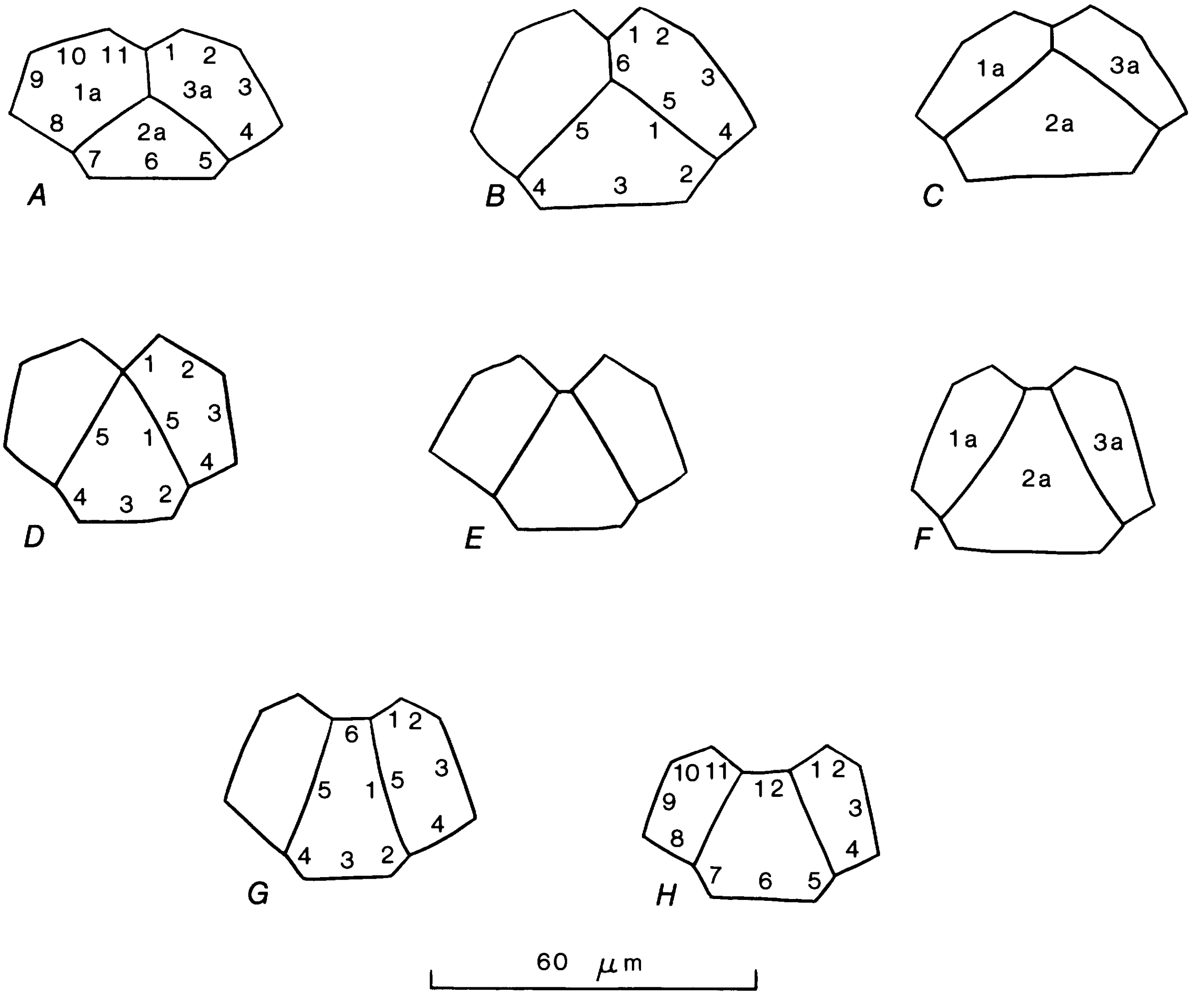

FIGURE 3.—Sketches of endopercular pieces from specimens shown in figure 2, in same sequence. Position of 1a, 2a, and 3a paraplates are shown in figure 3*A*, *C*, and *F*. Note the increasing height of 2a paraplate, which does not contact apical series in *A–C*; 3*D* shows the 2a paraplate just making contact with the apical series; *E–H* shows 2a paraplates, which make contact with the apical series. The 11-sided archeopyle outline is shown in *A*; the 12-sided archeopyle outline is shown in *H*. Hexagonal 1a and 3a paraplates and a pentagonal 2a paraplate are shown in B; pentagonal 1a and 3a paraplates and a hexagonal 2a paraplate are shown in *G*. The clockwise numbering of endoarcheopyle and paraplate sides is not intended as a formal morphologic nomenclature but is used only for illustration.

shown in figure 2*A–H*, and sketches illustrating the gradation within the same specimens are shown in figure 3*A–H*. All specimens illustrated come from one sample (R1023K), collected about 5 m above the base of the section at Poricy Brook (fig. 1).

In *T.* cf. *T. fragile* the morphologic gradation in the anterior intercalary series consists of variations in the height of the 2a paraplate, the number of sides per paraplate, and the relative positions of the anterior paraplate margins. At one extreme the 2a is reduced in height, the 1a and 3a paraplates join anterior of the 2a, and the 1a and 3a paraplates are hexagonal whereas the 2a is pentagonal (fig. 2*A–C*, fig. 3*A–C*). Where the 2a is increased in height, it makes contact with the apical series, separating the 1a from the 3a, and causes all three anterior intercalary paraplates to become pentagonal (fig. 2*D*, fig. fig. 3*D*). At the other extreme, the 2a paraplate, in contact with the apical series, is broadened along its anterior margin, causing further separation of the 1a and 3a paraplates and thus forming a standard anterior intercalary series. In this series, all three paraplates make contact with the apical series, and the 1a and 3a paraplates are pentagonal whereas the 2a is hexagonal (fig. 2*E–H*, fig. 3*E–H*). This paraplate configuration can be referred to as a standard configuration, whereas the other configuration, in which only the 1a and 3a paraplates make contact with the apical series, can be referred to as a nonstandard configuration. These terms will be used in this report for the purpose of discussion. Close examination of the pericyst shows the periarcheopyle to be similar in size and outline to the endoarcheopyle, indicating a 3I/3I archeopyle formula (as in Evitt, 1967); however, the delicate nature and frequent absence of the pericyst make it difficult to study in the same detail as the endocyst.

A few specimens of *T.* cf. *T. fragile* have lost their anterior intercalary paraplates (the endopercular pieces). Although in such specimens the geometry of the adjacent endopercular paraplate boundaries cannot be seen, the existence of the extremes in gradation can still be determined by the number of sides and morphology of the endoarcheopyle. Where the 2a paraplate is reduced and does not make contact with the apical series (fig. 2*A–C*, Fig. 3*A–C*), the archeopyle is 11 sided, and the central anterior margin of the archeopyle is V shaped (fig. 4*A*). Where the 2a contacts the apical series and is broadened along its anterior margin, the archeopyle is 12 sided, and the central anterior margin of the archeopyle forms a truncated V (fig. 4*B*). Thus, this type of variability in *Trithyrodinium* endopercular pieces and endoarcheopyle outline can be detected whether the anterior intercalary paraplates are in position or not.

Another example of this type of endoarcheopyle and endopercular-piece variability is seen in *T. striatum* Benson, 1976. Specimens displaying this variability occur in the Upper Cretaceous Severn Formation (formerly Monmouth Formation) of Round Bay, Md. (fig. 1). Less variable specimens were recovered from the Navesink Formation and Red Bank Sand (both of the Monmouth Group) at Atlantic Highlands, N.J. (May, 1976, p. 240). As with *T.* cf. *T. fragile,* the complete gradation exists within single populations of *T. striatum* from the Severn Formation. Although specimens of *T. striatum* frequently have lost their endopercular pieces, the general variation in the endoarcheopyle outline supports the idea that they too vary the same way. Also, the same variation is seen in the few specimens that retain part or all of their opercular pieces (fig. 5*A–D*). Where the endopercular pieces are missing, the 11- and 12-sided endoarcheopyles are apparent.

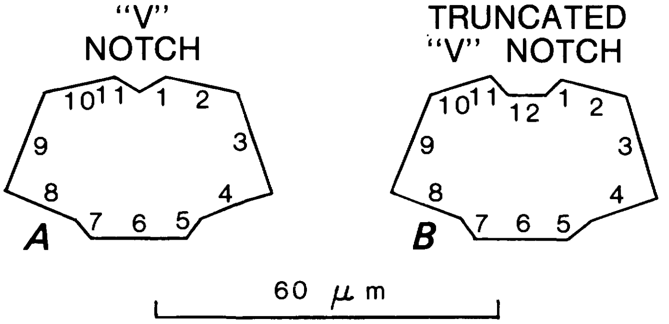

FIGURE 4.—Variation in endoarcheopyle outline for trithyrodinioid cysts discussed in this report. *A*, Specimens where reduced 2a paraplates do not make contact with the apical series have 11-sided endoarcheopyles with V notch along central anterior margin of endoarcheopyle. *B*, Specimens where 2a paraplates do make contact with apical series are somewhat broadened along anterior margin of the 2a paraplate have 12-sided endoarcheopyles with truncated V notch along central anterior margin of endoarcheopyle.

In both *T.* cf. *T. fragile* and *T. striatum* the high degree of variability in endoarcheopyle and endopercular-piece morphology does not occur on all specimens observed, nor was it present on specimens from all collecting horizons. Similar-age specimens of *T.* cf. *T. fragile* observed in the U.S. Geological Survey Clubhouse Crossroads Core (depth 317 m; late Campanian) near Charleston, S.C., exhibited little variability in the anterior intercalary paraplates. All the nearly 50 specimens observed had 2a paraplates that made contact with the apical series. The specimens of *T. striatum* that we observed in the Navesink Formation and Red Bank Sand at Atlantic Highlands, N. J., also lacked the extreme variability, although Evitt (oral commun., 1976) reported that he has observed the complete gradation in specimens from that area. At Round Bay, Md., the complete gradation was observed in some samples but not in others.

TAXONOMIC CONSIDERATIONS

Although it might seem tempting to assign those trithyrodinioid variants with standard and those with nonstandard anterior intercalary paraplate configurations to different taxonomic groups, in the biological sense such assignments would be highly artificial. As illustrated and described herein, the standard and nonstandard configurations can be intergradational within some single populations. The fact that nonintergrading populations can be found does not change this. For this reason we suggest that the archeopyle formulas I/3I and 3I/3I include whatever intergradable morphologic variation can be demonstrated in single populations. W. R. Evitt (written commun., 1976) expressed the feeling that the endoarcheopyle and endopercular-piece morphologic variation reported herein is within the intended use of the archeopyle formula 3I/3I. This

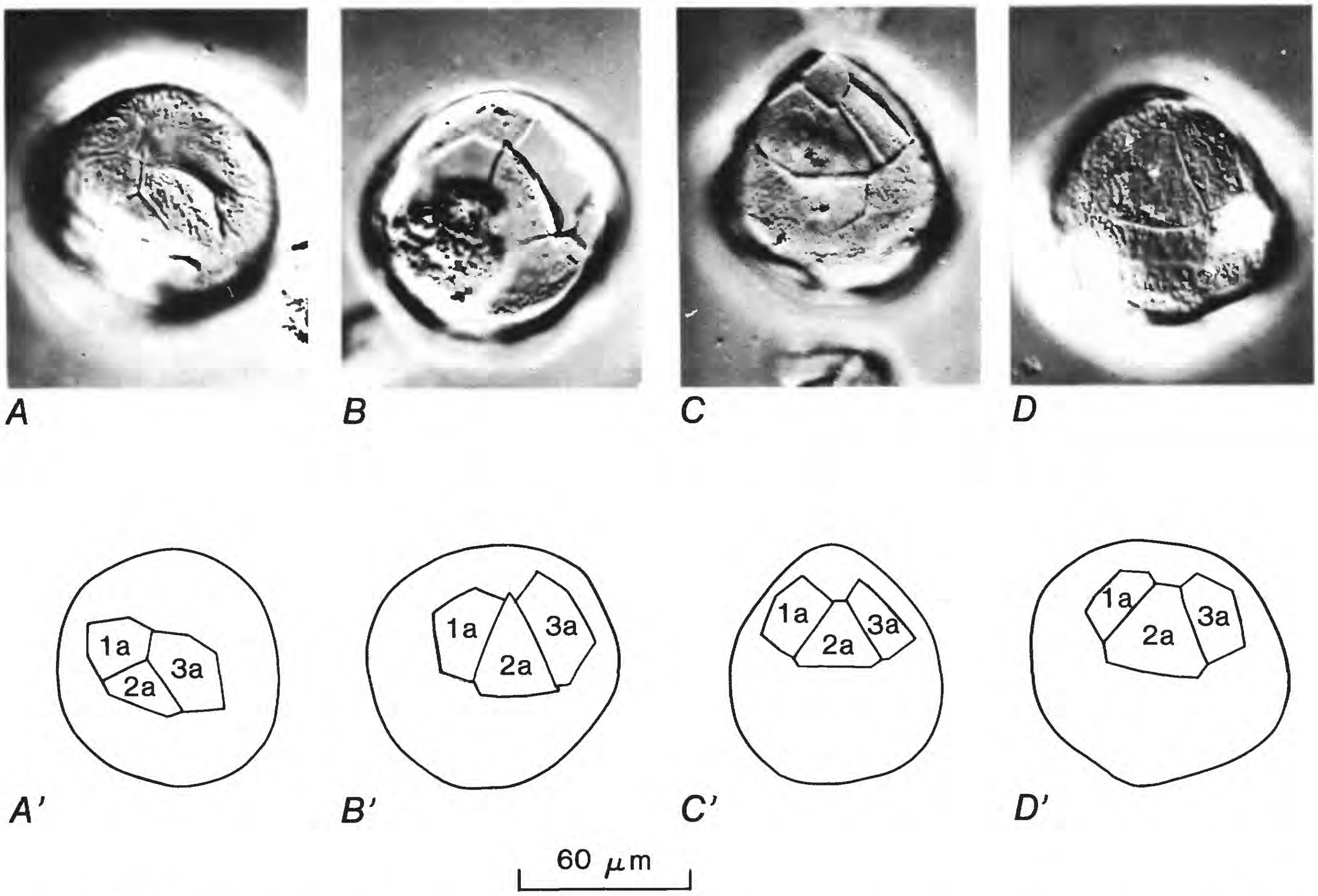

FIGURE 5.—Photomicrographs and sketches of specimens of *Trithyrodinium striatum* Benson, 1976, showing variabiilty in the morphology of endopercular pieces and in the outline of endoarcheopyle. Sketches were made from the photomicrographs above them, so that *A'* corresponds to *A*, *B'* corresponds to *B*, and so on. Gradation in variability of endopercular pieces can be seen from left to right in both the photomicrographs and sketches. *A*, *A'*, reduced 2a paraplate separated from apical series by anterior joining of 1a and 3a paraplates. *B*, *B'*, 2a paraplate just making contact with apical series, separating 1a and 3a paraplates. *C*, *C'* nd *D*, *D'*, 2a paraplate in contact with apical series has a broadened anterior margin, further separating 1a and 3a paraplates.

use would preclude any further formal emendation of the generic description of *Trithyrodinium*. However, such endoarcheopyle and endopercular-piece variability should be reported in the species description.

The selection of the term "nonstandard paraplate configuration" for the anterior intercalary series that includes the reduced 2a paraplate is intended herein only to simplify the discussion and not to introduce any formal taxonomic terminology. The term "nonstandard" suggests our feeling that the configuration that includes the reduced 2a paraplate is perhaps uncommon. It is difficult to evaluate how stratigraphically and geographically extensive the nonstandard configuration is in the fossil record. However, we point out that after finding one species exhibiting the variation, we had little difficulty in finding another.

Whether nonstandard, variable, or uncommon opercular paraplate configurations exist for other peridinioid taxa has not yet been reported. Peridinioid cysts that are typical broad-shouldered forms, such as *Chatangiella granulifera* (Manum) Lentin and Williams 1976 and *Isabelidinium dakotaense* (Stanley) Lentin and Williams 1977, have been illustrated with I/3I archeopyles (Manum, 1963, pl. 3, fig. 8; Stanley, 1965, pl. 19, figs. 1–3). However, the broad-shouldered peridinioid forms are typically I/I. Population studies of types such as these might further increase our understanding. The only solution to the problem of how variable peridinioid-cyst archeopyles and opercular pieces might be lies in population studies of taxa in single localities, in different geographic areas, and from different stratigraphic intervals. Exceptions to standard archeopyle and opercular-piece paraplate configurations may be rare, but before they are assumed to be rare, further detailed studies should be done. How common such variability is should be critically tested before archeopyle morphology is used as a main criterion in peridinioid cyst taxonomy. Evitt (written commun., 1976) stated that modern dinoflagellates are much more variable in paraplate outline and configuration than are the fossil cysts. This difference may only be apparant, because population variation in the fossil cysts may not have been adequately studied and reported.

CONCLUSIONS

Trithyrodinium striatum Benson 1976 and *T.* cf. *T. fragile* Davey 1969 display a considerable range in endoarcheopyle and endopercular-piece variation. The variation ranges from a nonstandard anterior intercalary series on the endocyst, in which the pentagonal 2a paraplate is reduced in height and the hexagonal 1a and 3a paraplates are allowed to join anterior to the 2a, separating it from the apical series, to a standard anterior intercalary series on the endocyst, in which the 1a and 3a paraplates are pentagonal in outline, the 2a is hexagonal, and all three intercalaries make contact with the apical series along their anterior margins. In specimens where the 2a paraplate just makes contact with the apical series, all three intercalaries are pentagonal. The archeopyle for a nonstandard anterior intercalary series is 11 sided; the archeopyle for a standard series is 12 sided.

The presence of the variability at some localities or horizons but not at others may be caused by ecophenotypic response to only particular environments. If a species existing at one time was composed of a group of populations separated geographically and existing in a variety of environments, ecophenotypic response may have affected the morphology of each population differently, and archeopyle variability within one species, for example, need not be expected to be the same everywhere at that time. Likewise, as environments change through time in one area, ecophenotypic response to those changes may cause degrees of variation not observed at each level in the sedimentary record. Thus, within the fossil record in one geographic area, the appearance and disappearance of degrees or types of variation may simply reflect changing environments.

The archeopyle formula 3I/3I should include whatever degree of intergradational variation that can be demonstrated within single populations. For example, we feel that the nonstandard anterior intercalary series on the endocysts reported herein for *T. striatum* and *T.* cf *T. fragile* fall within the 3I/3I archeopyle formula.

Archeopyle studies should be done on other peridinioid cyst populations, such as those of *Chatangiella granulifera* (Manum) Lentin and Williams 1976 *C. verrucosa* (Manum) Lentin and Williams 1976 and *Isabelidinium dakotaense* (Stanley) Lentin and Williams 1977, to see if the I/3I archeopyles of the different species are natural variants of the I/I formula and if other kinds of variantions exist.

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