

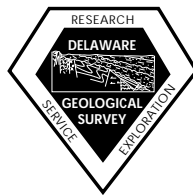
GEOLOGY AND PALEONTOLOGY
OF THE LOWER MIOCENE
**POLLACK FARM
FOSSIL SITE**
DELAWARE



RICHARD N. BENSON, Editor

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THE COVER

Aerial view of the Pollack Farm Site viewed toward the east in 1992. The Leipsic River is in the upper left. Right-of-way for Delaware State Route 1 runs from left to right in foreground. Photograph by Tim O'Brian.

INTRODUCTION

Richard N. Benson¹

The Pollack Farm Site, Kent County, Delaware, is named for a borrow pit on the former Pollack property that was excavated during 1991 and 1992 for road material used in the construction of Delaware State Route 1 (see cover photograph). The site lay east of U.S. Route 13 on the divide between the Leipsic River on the north and Alston Branch on the south (Fig 1). The Delaware Geological Survey (DGS) identifier for the site is Id11-a (39°14' 08" N, 75°34' 36" W). By 1993, the pit was back-filled, graded, and developed into a wetlands mitigation site.

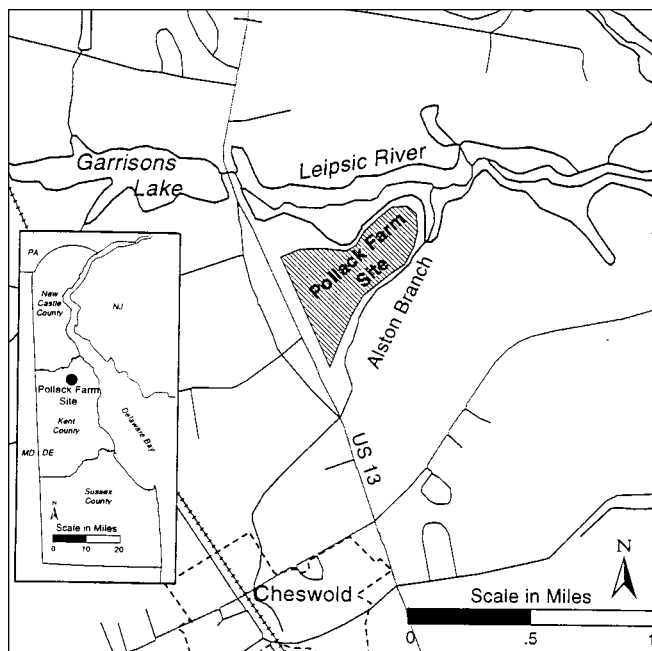


Figure 1. Map showing the location of the Pollack Farm Fossil Site, Delaware

In the summer of 1991 during their routine check of excavations of earth materials as highway construction proceeded, DGS staff members recognized an exposure of a mud bed of the Calvert Formation beneath Quaternary sediments at the Pollack Farm Site. As the pit was deepened to extract sands of the Cheswold aquifer below the mud bed, the first (upper) shell bed was revealed with its abundant molluscan fossils. As the quality of the sand was excellent for highway construction, the pit was deepened below the water table but kept dry by continuous pumping. Thus began a series of visits to the site as excavation continued through 1992, not only by DGS geologists but by scientists from other institutions when the lower shell bed with its fragmentary vertebrate remains was exposed.

Kelvin W. Ramsey of the DGS proposed that the results of the studies of the geology and paleontology of the site be gathered together in one volume. Thomas E. Pickett agreed to coordinate the project and was instrumental in obtaining commitments and, indeed, several of the 13 manu-

scripts from the 19 contributors to this volume. With Pickett's retirement from the DGS in 1996, the project was on hold until I took over the task of editing the volume in 1997.

The geology of the Pollack Farm Site is reported in the first five papers. Richard N. Benson describes a radiolarian assemblage indicating a strong degree of neritic versus oceanic conditions and with taxa that identify the late early Miocene *Stichocorys wolffii* Zone with an age estimated between 17.3 and 19.2 Ma, thus establishing correlation of the beds containing both marine and terrestrial fossils at the site to a formal marine global biostratigraphic zone. He also correlates the Miocene fossil vertebrate assemblages of the middle Atlantic Coastal Plain (Maryland to New Jersey) to global foraminiferal, calcareous nannofossil, and radiolarian biozones, to regional diatom and dinoflagellate biozones, and to the geomagnetic polarity time scale by means of published strontium-isotope studies.

From analyses of strontium isotope ratios of marine mollusks from the lower shell bed at the site, Douglas S. Jones, Lauck W. Ward, Paul A. Mueller, and David A. Hodell determined the mean age of the shells as 17.9 ± 0.5 Ma, which is consistent with the age determined by the radiolarians and with the early Hemingfordian age assigned to the land mammal fossils.

Kelvin W. Ramsey interprets the depositional environments of the sediments exposed at the Pollack Farm Site: marine inner shelf at the base of the pit; succeeded in order by a tidal channel represented by the lower shell bed and lower sand; a subtidal channel margin; a cross-bedded sand (same stratigraphic level as the upper shell bed) representing a subtidal sand flat shoaling upward to a subtidal to intertidal flat; and an intertidal to supratidal flat represented by the upper mud, the part of the Calvert first exposed by excavation.

Molly F. Miller, H. Allen Curran, and Ronald L. Martino interpret the cross-bedded sand underlying the upper mud as deposited in a broad tidal or estuarine channel, and they identify channel-axis and channel-margin facies on the basis of relative densities of *Ophiomorpha nodosa* burrows.

A. Scott Andres and C. Scott Howard describe several types of soft-sediment- and brittle-deformation features in the Calvert and overlying Quaternary formations and ascribe some to cold-climate freeze-thaw processes and others possibly to movements along faults, to erosional unloading, or to weathering and mineralization processes.

With the exception of the palynomorphs from the Pollack Farm Site, most if not all of the invertebrate and vertebrate fossils were collected from the lower shell bed by construction workers at the site, during the many visits by David J. Bohaska, Robert J. Emry, Ralph E. Eshelman, and Robert W. Purdy and others from the Smithsonian Institution and Lauck W. Ward of the Virginia Museum of Natural History, and by others invited to the site. Most but not all fossil groups recovered from the site are described in the eight paleontology papers.

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Johan J. Groot reports that palynomorphs from the Pollack Farm Site indicate an early Miocene climate similar to one that now prevails in the coastal region of Georgia or northern Florida. The diversity and abundance of the palynomorphs representing trees and shrubs and the near absence of herbaceous pollen indicate a dense forest growing right up to the coast. Marine palynomorphs decrease stratigraphically upward indicating a slight regression or a change from an open marine to an estuarine environment.

Lauck W. Ward describes a prolific, well-preserved invertebrate fossil assemblage, principally of mollusks, that is the equivalent of that collected from the Kirkwood Formation near Shiloh, New Jersey. The molluscan assemblage is analyzed, and 104 species are discussed and/or figured. The mollusks appear to have originated in a deltaic setting where fresh-water, brackish-water, and marine mollusks have been mixed and rapidly deposited in a channel. The assemblage consists of a number of new species, first occurrences, last occurrences, subtropical and tropical species, and taxa not previously reported from North America.

From the lower shell bed Robert W. Purdy identifies 30 fossil fish taxa comprising 24 cartilaginous and 6 bony fishes. Except for the relative abundances of the taxa, the assemblage is identical to those of equivalent age from the Calvert and Pungo River formations of Maryland and North Carolina, respectively, and indicates a subtropical, shallow-water, nearshore paleoenvironment with a water temperature warmer than that found in the Carolina Bight today.

J. Alan Holman reports a unique reptile fauna from the Pollack Farm Fossil Site that, among other species, has yielded the first North American remains of small Miocene lizards and snakes east of the Great Plains and north of Florida, including *Pollackophis depressus*, a distinctive new genus and species of small colubrid snake, and *Pterygoboa delawarensis*, a new species of a distinctive small booid genus. Also identified are aquatic turtles, a very large tortoise, and a very large crocodile. Large reptiles such as giant tortoises and crocodylians indicate that the climate in Delaware during deposition of the Pollack Farm sediments was probably subtropical. The terrestrial reptile assemblage suggests a group of forms that probably occupied a rather open grassy or brushy habitat with loose or sandy soil. This habitat was probably near a large sluggish lake or oxbow as crocodiles normally need large, permanent bodies of water in which to live.

Only 11 specimens of fossil birds, all fragmentary and unassociated, have been recovered from the Pollack Farm Fossil Site. The five avian taxa Pamela C. Rasmussen identified are mostly or exclusively marine in distribution—modern loons and sulids, the two most common taxa at the site, and pseudodontorns which were strictly marine. The fossils apparently all belong to species already known from the younger part of the Calvert Formation of the western shore of Chesapeake Bay in Maryland. The composition of the avifauna supports the depositional hypothesis of a nearshore area of a large embayment.

The land mammals from the Pollack Farm Site are represented predominantly by single teeth and parts of postcranial elements. Robert J. Emry and Ralph E. Eshelman write that the collection of fossils grew to become the most diverse Tertiary land mammal fauna known in eastern North America north of Florida. The age established by the land

mammals is early Hemingfordian (early Miocene). The assemblage, termed the Pollack Farm Local Fauna, includes at least 26 species representing at least 17 families in 7 orders. Families represented include shrew, hedgehog, bat, beaver, mice and other rodents, ancestral bear(?), racoon, dog, horse, chalicothere, rhinoceros, peccary, hippopotamus-like artiodactyl(?), oreodont, and deer-like ruminant. The land mammal assemblage suggests a nearby forested habitat, probably with some open grassy areas, and fresh water. Possible settings are a coastal barrier island or a delta with flowing fresh-water rivers and streams, oxbow lakes and ponds, with marshes and swamps developed in the lowlands and forest and open park-like grasslands on the higher elevations. Beaver, peccaries, browsing and grazing horses, chalicotheres and rhinos could all find suitable habitats in such places.

Alan H. Cutler's observations of the surface features of terrestrial mammal bones suggest that the bones were exposed subaerially for a period of time before burial and that they were buried and permineralized prior to transport and abrasion. Carcasses washed to sea by flooded rivers is therefore unlikely, and reworking is the favored model of assemblage formation.

David J. Bohaska reports that the marine mammal collection from the Pollack Farm Site is more fragmentary and less diverse than the marine mammal fauna from the Calvert Formation of Maryland and Virginia, lacking the more nearly complete skulls and skeletons found there. At least six cetaceans are present—five porpoises and a sperm whale. Also present is a dugong, and one of the earliest records of a true seal. The long-beaked porpoise *Zarhachis flagellator* suggests a non-open ocean habitat as it has a body plan resembling modern river porpoises. A dead river-dwelling porpoise could easily float downstream into the marine environment and be preserved. Sirenians (dugong) tend to occur in fresh and near-shore marine waters and are generally tropical to subtropical in distribution.

The authors of the studies of the sediments and fossils from the Pollack Farm Site presented in this volume are remarkably consistent in their age determinations and paleoenvironmental interpretations. The age is well-established as early Miocene, about 18 Ma, as corroborated by the radiolarian, molluscan, and strontium isotope studies, and early Hemingfordian as determined by the land mammal assemblage.

The bulk of the invertebrate and vertebrate macrofossils, ranging from terrestrial to fully marine taxa, are from a channel deposit, therefore, transported from where they lived. The terrestrial mammal assemblage consists of disassociated elements. Articulated bones were probably buried and permineralized before they were transported and abraded. The abraded condition of the marine mammal bones resembles that of the terrestrial mammals.

The likely depositional setting for the sands at the site was a tide-dominated delta with shallow open marine waters nearby as indicated by the radiolarian bed at the site. Depositional environments at the site include marine inner shelf, subtidal to tidal channels with *Ophiomorpha* burrows, and tidal flats. Both the land climate and marine environment were subtropical. Densely forested uplands with open areas of grasslands grew right up to the coast. Lowland environments consisted of fresh-water rivers and streams with swamps, marshes, and large lakes on the floodplain.

Acknowledgments

Gordon Simonson, supervisor at the Pollack Farm Site for Pierson Engineering, is acknowledged by all authors who collected fossils at the site. He personally found many of the specimens, encouraged his fellow workers at the site to donate or loan fossils they collected for study by contributors to this volume, and even operated a backhoe to dig out fresh material for collecting. Simonson, David Duke of the Delaware Department of Transportation (DelDOT), and Edward S. Adams of Century Engineering were cooperative in granting access to the site. Kevin W. Cunningham, DelDOT Archaeologist, was enthusiastic about the plans for this volume and was instrumental in arranging financial support by DelDOT for its publication. Finally, I express my sincere appreciation to the authors contributing to this volume and the reviewers of their manuscripts. All were cooperative in responding to my schedule for producing this volume after I became its editor.

RADIOLARIANS AND DIATOMS FROM THE POLLACK FARM SITE, DELAWARE: MARINE–TERRESTRIAL CORRELATION OF MIOCENE VERTEBRATE ASSEMBLAGES OF THE MIDDLE ATLANTIC COASTAL PLAIN¹

Richard N. Benson²

ABSTRACT

The Pollack Farm Site near Cheswold, Delaware, is named for a borrow pit excavated during highway construction. The excavation exposed a portion of the Cheswold sands of the lower Miocene Calvert Formation. Two sand intervals (Cheswold C-3 and C-4) yielded a diverse assemblage of land and marine vertebrate remains and more than 100 species of mollusks. An isolated occurrence of a sandy silt (the radiolarian bed) stratigraphically between the two macrofossil-bearing units yielded only siliceous microfossils—radiolarians, diatoms, and sponge spicules.

Radiolarians from the radiolarian bed identify the *Stichocorys wolffii* Zone, which has an age estimated between 17.3 and 19.2 Ma. This is compatible with the strontium-isotope age estimate of 17.9 ± 0.5 Ma on mollusks from the lower shelly sand bed (Cheswold C-3 sand) at the site. Both age determinations are compatible with the early Hemingfordian North American Land Mammal Age that was assigned to the land mammal fossils recovered from the C-3 sand.

The lower Miocene diatom *Actinoptychus heliopelta* from the radiolarian bed identifies East Coast Diatom Zone (ECDZ) 1. This taxon also occurs within “Bed 3A” of the Calvert Formation, the older part of the highly diatomaceous silty clays of Bed 3 that crop out in the Coastal Plain of Maryland and Virginia.

Correlation of borehole geophysical logs between Delaware and New Jersey places the vertebrate and molluscan assemblages collected from outcrops of the Shiloh marl of the lower Kirkwood Formation of New Jersey stratigraphically below those from the Pollack Farm Site. Estimates between about 19 and 20 Ma are calculated from a published Sr-isotope ratio for one mollusk shell from the Shiloh site. This indicates a possible unconformity between the Shiloh-equivalent beds (Cheswold C-2 sand, not exposed) and the ~18-Ma lower shell bed (Cheswold C-3 sand) at the Pollack Farm Site. The vertebrate assemblage from the Pollack Farm Site is of early Hemingfordian age, but vertebrates from the Shiloh site are not age-diagnostic. Both assemblages occur about 150–200 feet above the base of the Miocene section.

The Farmingdale vertebrate fossils of the northeastern Coastal Plain of New Jersey occur just above the base of the Miocene section (Kirkwood Formation) with an estimated age of 20.5–22.6 Ma based on published strontium-isotope data from boreholes in the vicinity. This age is compatible with the revised interpretation of late Arikarean for the age of the Farmingdale land mammal fossils.

The Popes Creek vertebrate assemblage of Maryland is from beds nearly stratigraphically equivalent to the Pollack Farm Site exposures, which agrees with the close temporal correlation of vertebrate remains from both sites. The Barstovian-age vertebrate assemblages from the Calvert Formation and basal part of the overlying Choptank Formation at the Calvert Cliffs exposures of Maryland are from units equivalent to the early middle Miocene *Dorcadospyrus alata* Radiolarian Zone.

Radiolarian criteria that are used to indicate the degree of neritic versus oceanic conditions for the Miocene of the middle Atlantic Coastal Plain show increased neritic influence for the Pollack Farm Site and nearby exposures of beds of the *S. wolffii* Zone in Delaware, as compared with the more oceanic influence interpreted for other occurrences of the zone to the south and west in Maryland. This is consistent with the regional deltaic influence indicated for Delaware and New Jersey during the early Miocene and with the shallow inner neritic to intertidal paleoenvironments interpreted by other contributors to this volume for the Pollack Farm Site.

INTRODUCTION

The Pollack Farm Site is named for a large borrow pit for highway construction that was located near Cheswold, Delaware (Fig. 1). Exposed during the 1991–1992 excavation were two stratigraphically separated shelly sand beds (lower and upper shell beds, Fig. 2) correlated with the Cheswold sands (DGS informal lithostratigraphic unit named for the Cheswold aquifer) of the lower Miocene Calvert Formation. It was mainly the lower shell bed that yielded a diverse assemblage of terrestrial and marine vertebrate remains along with more than 100 species of mollusks plus other invertebrate fossils. The site subsequently was covered and converted to a wetland.

During the early part of the excavation, a small test trench, located several hundred feet east of the main excavation (see Ramsey, 1998, fig. 1), revealed about five feet of a planar-bedded sandy silt (30–35 percent sand), herein called the “radiolarian bed,” that yielded abundant radiolarians and diatoms, rare siliceous sponge spicules, and no other fossils from an elevation of about 5 ft below sea level (Fig. 2). On the basis of surveyed elevations in the pit, the trench in the silt bed was just below the stratigraphic level of the upper shell bed (Fig. 2). At the same stratigraphic level in the main part of the pit to the west, a parallel-bedded silty sand yielded rare, poorly preserved diatoms but no radiolarians (Fig. 2). The area of the pit where the radiolarian-bearing silt was

¹ In Benson, R.N., ed., 1998, Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 5–19.

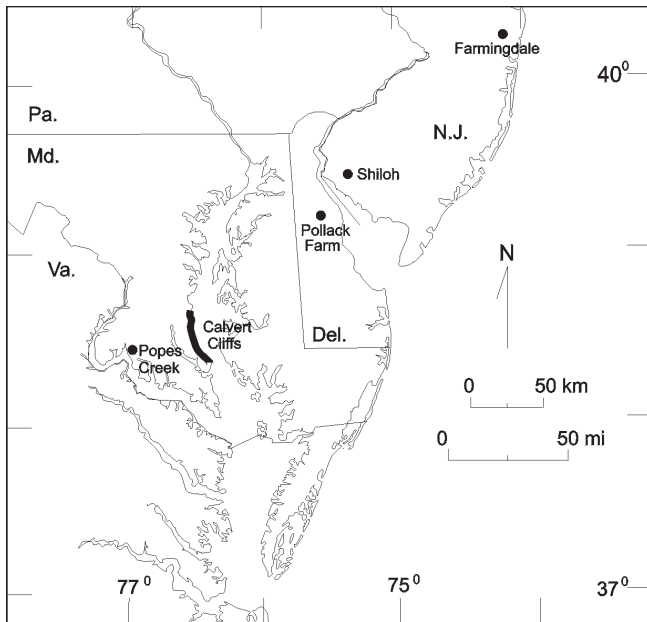


Figure 1. Location map of mid-Atlantic Miocene vertebrate fossil sites. The Pollack Farm Site (39°14' 08" N, 75°34' 36" W) is identified as Delaware Geological Survey (DGS) site Id11-a.

trenched was excavated and back-filled prior to my subsequent visits to the Pollack Farm Site; therefore, the extent and stratigraphic relationships of the radiolarian bed to the other units exposed at the site remain unknown. It represents an isolated occurrence, possibly an erosional remnant, of an offshore marine deposit within the predominately inner neritic to estuarine environments interpreted for the sediments at the site by other contributors to this volume.

On the basis of its microfossil content, the radiolarian bed correlates with a fine-grained deposit containing biosiliceous remains that crops out in Maryland west and southwest from the Chesapeake Bay and identified by Andrews (1988) and Wetmore and Andrews (1990) as Bed 3A, after the lower part of Shattuck's (1904) "zone 3" of the Fairhaven Member of the Calvert Formation of Maryland.

The fortuitous occurrence of radiolarians between the two macrofossil-bearing intervals at the Pollack Farm Site provides the means for correlating the vertebrate assemblage to a standard marine radiolarian microfossil zone, namely, the *Stichocorys wolffii* Zone (Riedel and Sanfilippo, 1978). On the bases of geophysical well log correlation and stratigraphic position (150–200 ft above the unconformity at the base of the Miocene section), I have also determined that the vertebrate fossils from the Pollack Farm Site are nearly the same age (early Hemingfordian) but slightly younger than the Shiloh Local Fauna of nearby New Jersey. Both vertebrate assemblages are considerably younger than the Farmingdale Local Fauna (Tedford and Hunter, 1984) of the northeastern Coastal Plain of New Jersey (Fig. 1) which occurs near the base of the Miocene section there.

Acknowledgments

Kelvin W. Ramsey of the DGS provided the composite stratigraphic section of the Pollack Farm Site shown in Figure 2. Ramsey and A. Scott Andres of the DGS measured and described the exposures and tied them to surveyed ele-

vations within the pit as excavation proceeded during 1991 and 1992. Bruce W. Brough and C. Scott Howard of the DGS and Andres measured the natural gamma-ray responses of the exposed units above the lower shell bed with a portable scintillometer and provided the composite gamma-ray log of Figure 2. I thank Thomas G. Gibson, Amanda Palmer Julson, and Thomas E. McKenna for their thoughtful reviews of the manuscript and valuable suggestions for its improvement.

MICROFOSSIL BIOSTRATIGRAPHY

Results reported here of microfossil content refer only to those specimens retained on a 230-mesh (63-micron openings) sieve. Samples were dried, weighed, and washed through the sieve. Sand percentages were calculated, and all counts of microfossils were normalized to number of tests per gram of original sediment (Fig. 2).

Radiolarians and diatoms are common and calcareous microfossils are absent in a sandy silt underlying the upper shell beds at the Pollack Farm Site (Fig. 2). This radiolarian bed was found at only one locality within the excavation, and its lithology and age are representative of Bed 3A of Wetmore and Andrews (1990). At the same stratigraphic level about 500 ft west of the radiolarian bed locality only rare centric diatoms that had been replaced by iron oxides, presumably after pyrite, were recovered from a parallel-bedded sand unit. An increased gamma-ray response at the stratigraphic level of these two units, between about 5 and 10 ft below sea level, is recorded on the composite gamma-ray log of the exposed units above the lower shell bed at the site (Fig. 2).

The lowermost bed exposed at the site, the shelly mud bed underlying the lower shell bed (Fig. 2), yielded rare diatoms, a few radiolarians, and rare to common benthic foraminifers typical of the Chesapeake Group (e.g., *Florilus pizarrensis*, *Caucasina elongata*, *Uvigerina subperegrina*, *Hanzawaia concentrica*, *Bolivina paula*, and *Buliminella elegantissima*). Ward (1998) found scattered *in situ* mollusks, many in living position, in this bed and interpreted this to indicate a nearshore, open-marine, quiet-water setting. The open-marine radiolarian bed ("Bed 3A") differs in microfossil content from this lowermost unit at the site in the absence of calcareous fossils.

Stichocorys wolffii Radiolarian Zone

The presence of the radiolarian *Spongasteriscus marylandicus* in the radiolarian bed identifies the *Stichocorys wolffii* Zone (Riedel and Sanfilippo, 1978) as defined for the Miocene of the mid-Atlantic Coastal Plain by Palmer (1986b). Other radiolarian species present that have stratigraphic ranges including all or part of the Zone are *Calocycletta virginis* (but not *C. costata*), *Carpocanopsis cingulata*, *Cyrtocapsella cornuta*, *C. elongata*, *C. japonica*, *C. tetrapera*, *Didymocyrtis bassani*, *D. prismatica*, *D. tubaria*, *D. violina* (but not *D. mammiifera*), *Dorcadospyrus simplex*(?), *Eucyrtidium calvertense*, *E. diaphanes*, *Liriospyris stauropora*, *Stichocorys delmontensis*, *S. diploconus*, and *S. wolffii*.

Actinoptychus heliopelta Diatom Zone (ECDZ 1)

The stratigraphic range of the diatom *Actinoptychus heliopelta* identifies Abbott's (1978) Zone 1 named for that species and referred to as East Coast Diatom Zone (ECDZ)

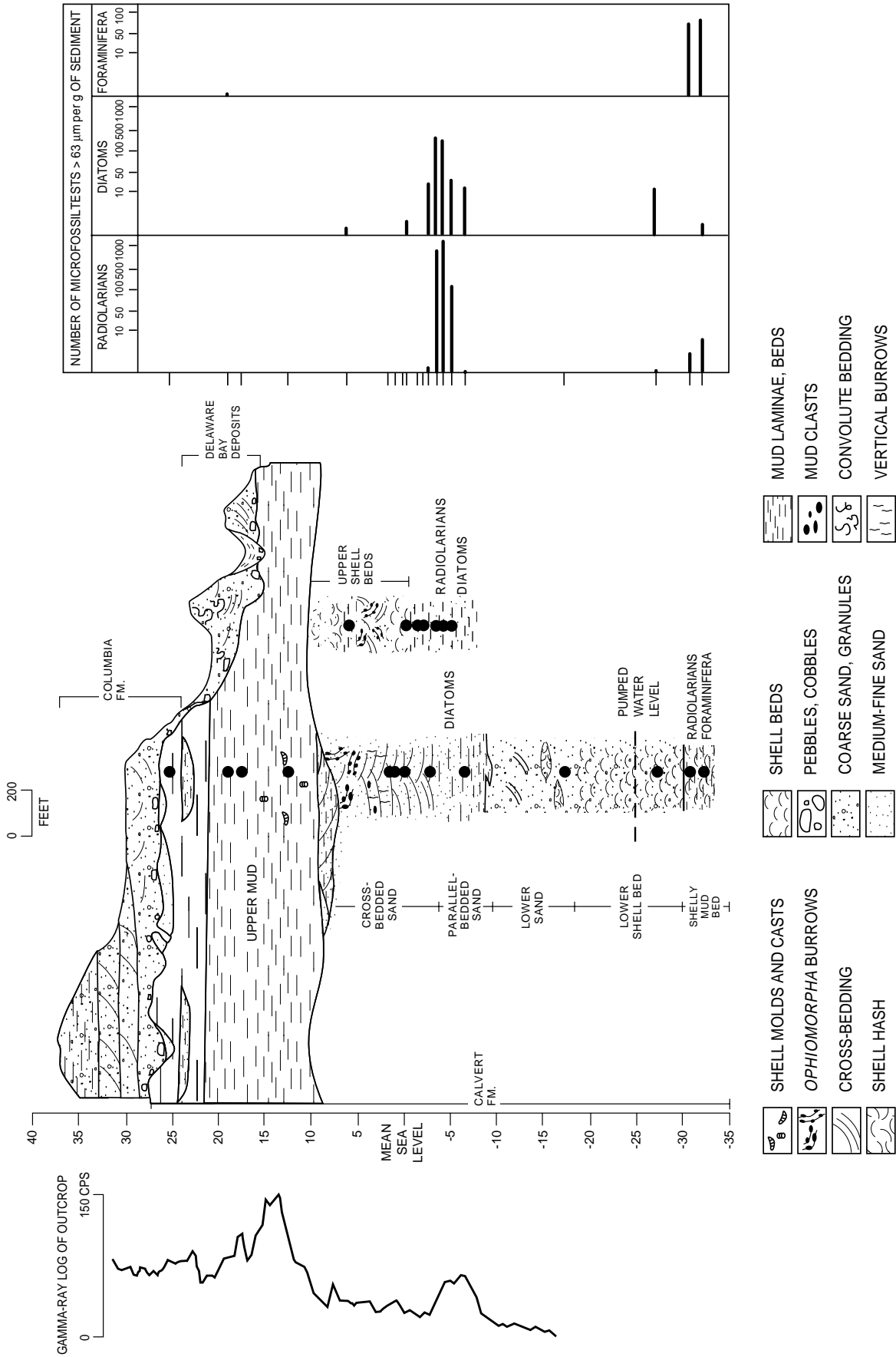


Figure 2. Composite west (on left) to east stratigraphic section of the Calvert Formation (lower Miocene) exposed at the Pollack Farm Site, Delaware (after Ramsey et al., 1992), with composite gamma-ray log of outcrop and results of microfossil counts. Solid circles are microfossil sample locations which correspond to tick marks along the left margin of the fossil count chart. The Columbia Formation and Delaware Bay deposits (Scotts Corners and Lynch Heights formations) are of Quaternary age.

1 by Andrews (1988). Abbott (1978) defined the top of the zone by the extinction of the nominate species but left the base of the zone undefined. A few specimens of this species were found in the radiolarian bed at the Pollack Farm Site. More recent studies by Benson (1990) and Sugarman et al. (1993) show that this species has a long stratigraphic range, almost the entire lower Miocene, and is, therefore, not useful for high resolution biostratigraphy.

CORRELATION

In Delaware, there are two other known exposures of the silts containing radiolarians of the *Stichocorys wolffii* Zone, both of them updip from the Pollack Farm Site (Id11-a). One (Ic22-c) is in a gravel pit located between boreholes 6 and 10 of Figure 3 and the other (Ic14-a) along the southern bank of Garrisons Lake between boreholes 6 and 5. *Spongasteriscus marylandicus* and *Stichocorys wolffii* were found at both sites. The diatom *Actinoptychus heliopelta* was found at the gravel pit site where radiolarians and diatoms are common to abundant, but not at Garrisons Lake where radiolarians and diatoms are rare.

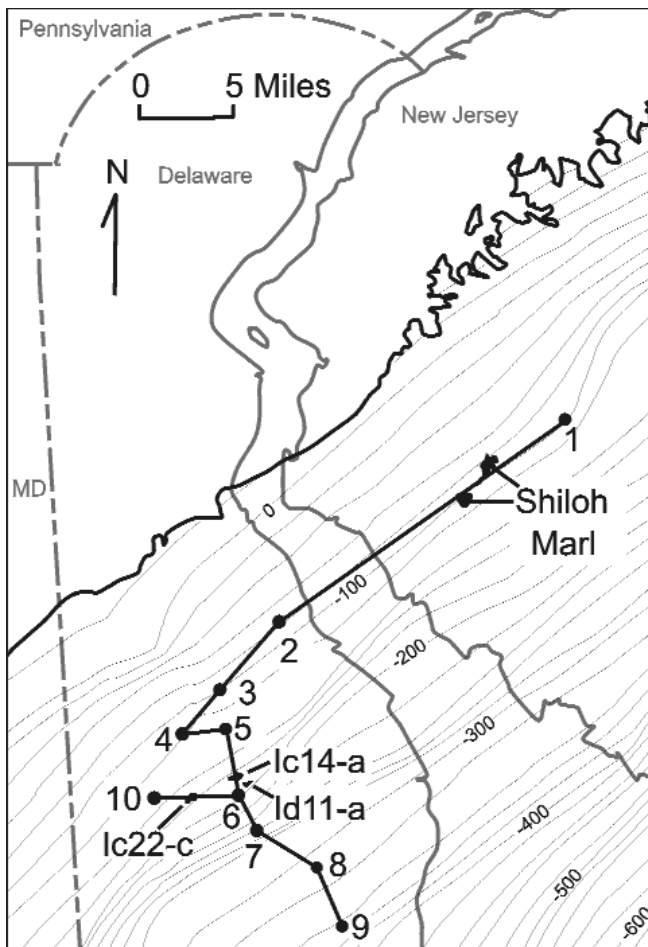


Figure 3. Location map of boreholes 1 through 10 and outcrops shown in Figures 4 and 5. Outcrops in Delaware (DGS alphanumeric designations) are of silts with radiolarians of the *Stichocorys wolffii* Zone and in New Jersey of the Shiloh marl. Structure contours in feet (sea level datum) are on the unconformity at the base of Miocene rocks (control wells not shown); the locations of faults shown in Figure 5 are where the contours are closely spaced.

Figure 4 shows the correlation of the increased gamma-ray response of the radiolarian bed on the composite gamma-ray log of the exposures at the Pollack Farm Site (Id11-a) with a similar response on the log of nearby borehole Ic25-12 (6 in Fig. 3). With the Ic22-c gravel pit exposure of the *S. wolffii* radiolarian bed as control, the structural cross section shown in the bottom panel of Figure 5 confirms the correlation of the bed between boreholes 6 and 10 (Ib25-06). The radiolarian bed projected updip from the Pollack Farm Site intersects Garrisons Lake at site Ic14-a as shown in the middle panel of Figure 5.

Downdip from the Pollack Farm Site in boreholes Id31-26 and Je32-04, radiolarians identifying the *Calocycletta costata* Zone, namely *C. costata* and *Didymocyrtilis mammifera* (Riedel and Sanfilippo, 1978; Palmer, 1986b), are present in the silty interval above the C-5 sand (Fig. 4). Andrews (1988) and Wetmore and Andrews (1990) identified the biosiliceous interval that correlates to the *C. costata* Zone in Maryland as Bed 3B. On the basis of diatom and silicoflagellate biostratigraphy, Wetmore and Andrews (1990) suggested a hiatus of approximately 1 million years between Bed 3A and Bed 3B. The radiolarian data from Id31-26 and Je32-04 are insufficient to indicate a hiatus between the two successive radiolarian zones. Abbott's (1978) study of diatoms from Je32-04 did not indicate a major hiatus between his diatom zones I (equivalent to ECDZ 1) and II+III (equivalent to ECDZ 2) correlated with beds 3A and 3B, respectively.

With the stratigraphic control provided by the siliceous microfossil data, the stratigraphic relationships between the vertebrate assemblages of the Pollack Farm Site and the Shiloh marl of New Jersey (Fig. 3) can be established by means of geophysical log correlation. The datum for the stratigraphic correlation shown in Figure 4 is the unconformity at the base of the lower Miocene rocks of Delaware (Calvert Formation) and New Jersey (Kirkwood Formation). Rocks below the unconformity are of middle Eocene age. The unconformity is marked by a distinctive gamma-ray log signature and is documented by microfossil data (Benson et al., 1985; Benson and Spoljaric, 1996). I subdivided the Cheswold sands into five informal, laterally equivalent intervals on the bases of their stratigraphic position above the unconformity and their relationship to the radiolarian zones. Most of the vertebrate and mollusk fossils from the Pollack Farm Site were collected from the lower shell bed which I correlate with the C-3 Cheswold sand. As shown on the structural cross section of Figure 5, this interval is missing by erosional truncation just updip from the Pollack Farm Site and does not crop out as does the overlying *S. wolffii* radiolarian bed. Parallel to strike in New Jersey, the Grenloch Sand Member of the Kirkwood Formation (Ispording, 1970) as indicated in borehole 1 of Figure 4 occupies the same stratigraphic position above the unconformity as the C-1 and C-2 sands in Delaware. Cook (1868) described the several marl pits located along the headwaters of Stow Creek near Shiloh and Jericho, New Jersey. Although his descriptions are not precise, he characterized the fossil-bearing units mined for the marl as generally of gray color and consisting of fine sand and a little clay mixed with varying amounts of calcareous matter. Pit excavations were as deep as 23 feet, and he noted that they are sandier near the bottom. Gibson (1983, Fig. 19) described a well near Shiloh with about 20

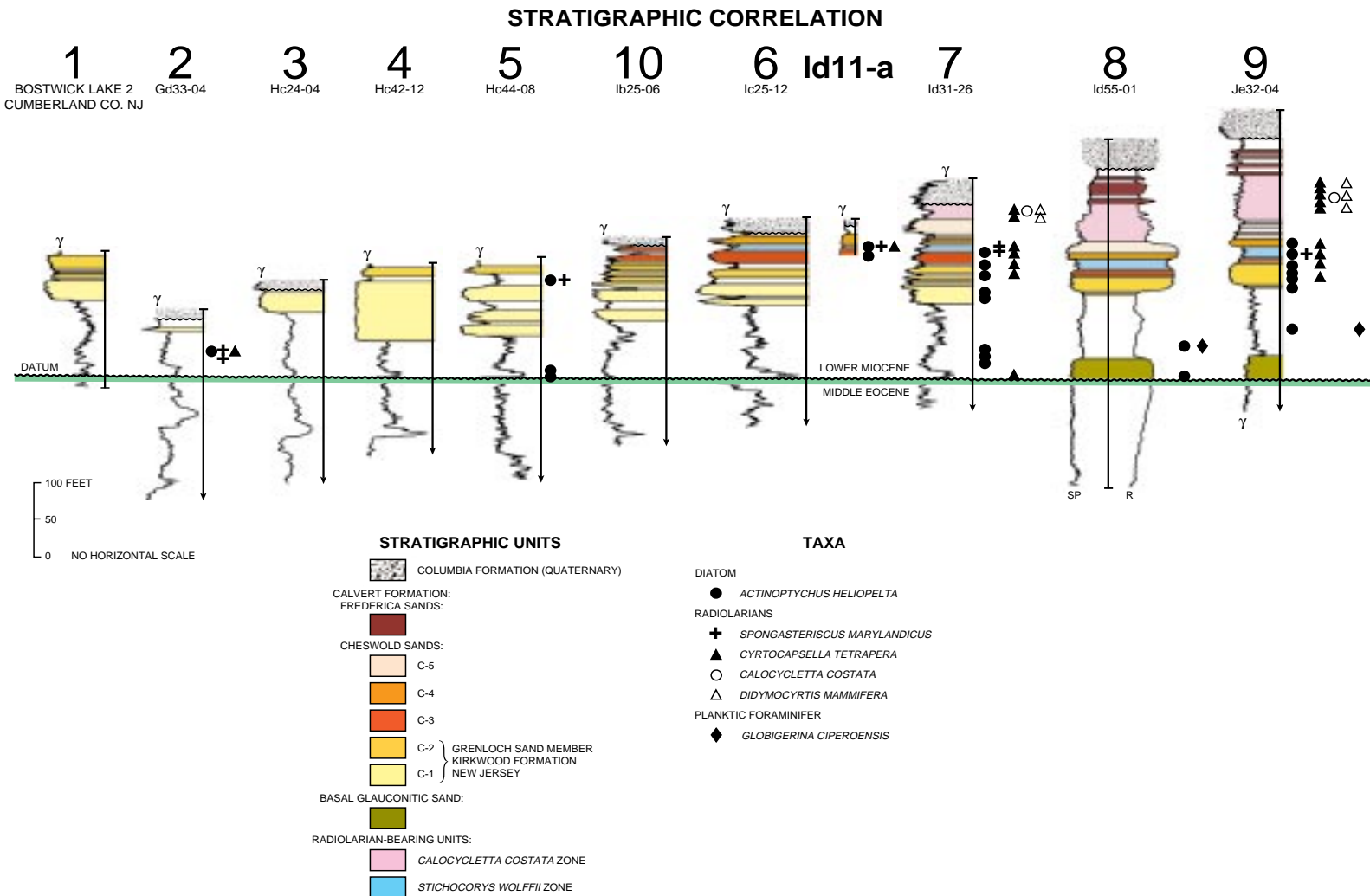


Figure 4. Stratigraphic correlation of geophysical logs of boreholes of Figure 3 and the composite gamma-ray log of the Pollack Farm Site section, Id11-a. DGS alphanumeric designations identify boreholes 2–10. Datum is the middle Eocene-lower Miocene unconformity. Taxa identifying biozones are shown where they were observed. Radiolarian-bearing units identified as representing the *Stichocorys wolffii* and *Calocycletta costata* zones correlate to beds 3A and 3B, respectively, as identified by Andrews (1988) and Wetmore and Andrews (1990). The occurrences of the foraminifer *Globigerina ciproensis* in sediments dated by radiolarians and diatoms in boreholes 8 (Id55-01) and 9 (Je32-04) as lower Miocene precludes its usefulness as an identifier of Oligocene rocks; therefore, the section indicated as upper Oligocene between 297 and 370 feet in Je32-04 by Benson et al. (1985) is now placed in the lower Miocene (Benson and Spoljaric, 1996). Also in Je32-04, the 34-ft glauconitic sand interval overlying the unconformity on middle Eocene rocks and indicated as “reworked Piney Point Formation” by Benson et al. (1985) is here considered the basal glauconitic sand of the Calvert Formation that is present in downdip localities (Benson, 1990; Benson and Spoljaric, 1996).

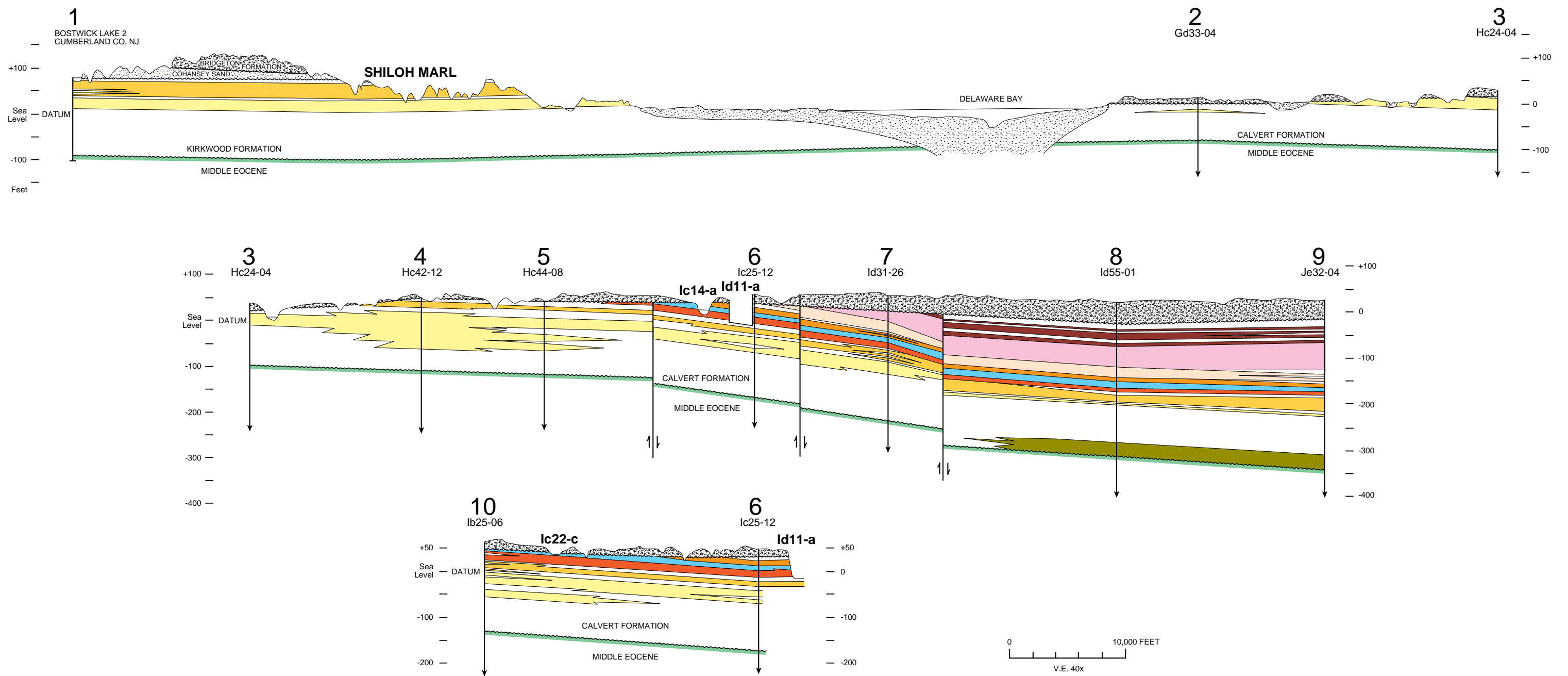


Figure 5. Structural cross section (sea level datum) showing stratigraphic relationships of Miocene rocks of boreholes and outcrops of Figures 3 and 4. See Figure 4 for identification of stratigraphic units.

feet of brown sand at the top of the section overlying about 10 feet of blue clayey sand with shells, the latter corresponding to descriptions of the Shiloh marl. The remaining 130 feet of the Kirkwood Formation below this is predominantly clay with sand interbeds at the top and base. In borehole 1 of Fig. 4, the upper thick portion of the C-2 sand corresponds in position to the brown sand, and the lower silty portion of the C-2 corresponds to the shelly interval indicated by Gibson (1983). The C-1 sand identified in the well apparently fines to a silt or clay near Shiloh as indicated by Gibson (1983, Fig. 19), although I have shown its stratigraphic position at that locality in Figure 5. Owing to the absence of a prominent sand body (the C-1 sand) below the outcropping Shiloh marl, Ispording (1970) placed the Shiloh marl in the upper part of the Alloway Clay Member of the Kirkwood. As the Shiloh marl correlates with the basal part of or just below the C-2 sand of Delaware, the Shiloh Local (vertebrate) Fauna, therefore, does not correlate with the Chesapeake Bay Fauna of Barstovian Age from the Calvert Cliffs of Maryland as proposed by Tedford and Hunter (1984) but instead is nearly coeval with but slightly older than the Pollack Farm Local Fauna of Delaware. Emry and Eshelman (1998) assign an early Hemingfordian age to the land mammal fossil assemblage from the Pollack Farm Site, but they state that the single specimen of the land vertebrate *Tapirus validus* that constitutes the Shiloh Local Fauna is not age-diagnostic.

Tedford and Hunter (1984) note that the Farmingdale vertebrate collection of O.C. Marsh came from the basal sands of the Asbury Park Member of the Kirkwood Formation of the northeastern Coastal Plain of New Jersey. As the Pollack Farm and Shiloh faunas occur about 150–200 feet above the base of the Calvert and Kirkwood formations, respectively (Fig. 5), the Farmingdale Fauna must be older than those two, assuming the base of the Miocene is of the same age at all three locations. Emry and Eshelman (1998) conclude that the Farmingdale land mammal fossils are of late Arikareean rather than early Hemingfordian age as indicated by Tedford and Hunter (1984).

Figure 6 summarizes the North American land mammal ages assigned to the mid-Atlantic Miocene fossil vertebrate assemblages (Fig. 1) and correlations of the stratigraphic units in which they are found to global and regional Miocene biozones. Berggren et al. (1995) correlated the global planktic foraminiferal and calcareous nannofossil biozones to the geomagnetic polarity time scale of Cande and Kent (1992, 1994). The calibration of the North American land mammal ages to the time scale is that of Tedford et al. (1987). Radiolarian zones are those of Riedel and Sanfilippo (1978), and the ages in Ma of the biostratigraphic datums defining the zonal boundaries are from Hodell and Woodruff (1994, Table 3) who calibrated the datums in cores from DSDP site 289 (western Pacific) to their composite strontium seawater curve for the Miocene using the time scale of Cande and Kent (1992). Riedel and Sanfilippo (1978) define the base of the *Stichocorys wolffii* Radiolarian Zone by the first appearance datum (FAD) of *S. wolffii* and also indicate the last appearance (LAD) of *Dorcadospyrus ateuchus* as coincident with the FAD of *S. wolffii*. Hodell and Woodruff (1994) do not give an age for the FAD of *S. wolffii* but do indicate the LAD of *D. ateuchus* at DSDP site 289 as 19.22 Ma. The top of the *S. wolffii* Zone is defined by the FAD of

Calocyclus costata which Hodell and Woodruff (1994) give as 17.30 Ma. The radiolarians at the Pollack Farm Site, therefore, indicate the age of the fossil beds there as between 17.3 and 19.2 million years old. From analyses of strontium-isotope ratios of marine mollusks from the lower shell bed (C-3 sand) at the site, Jones et al. (1998) determined the mean age of the shells as 17.9 ± 0.5 Ma, which is consistent with the age determined by the radiolarians and with the early Hemingfordian age assigned by Emry and Eshelman (1998) to the Pollack Farm Site vertebrate fossils (although 17.9 Ma is within the earliest late Hemingfordian according to Tedford et al., 1987).

As discussed previously, the Shiloh marl of nearby New Jersey is stratigraphically below the shell beds of the Pollack Farm Site. Sugarman et al. (1993, Table 1) determined a $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.708499 ± 7 for one mollusk shell from the outcropping Shiloh marl and estimated its age using three different regression equations to correlate to the geomagnetic polarity time scale of Berggren et al. (1985) as 20.3, 20.1 and 20.0 Ma (solid dots in Shiloh marl column of Figure 6). The two open dots for the Shiloh marl in Figure 6 show that same ratio calibrated to the time scale of Cande and Kent (1992), giving age estimates of (1) about 19 Ma as read from Hodell and Woodruff's (1994, Fig. 10) composite strontium seawater curve for the Miocene, and (2) about 20 Ma as read from the linear regression line of Oslick et al. (1994, Fig. 6). This range in the age estimates for the Shiloh Local Fauna as shown in Figure 6 is consistent with either a latest Arikareean or an early Hemingfordian age. The strontium-isotope age estimates for the Delaware and New Jersey sites indicate a possible unconformity between the 19–20-Ma Shiloh-equivalent beds (Cheswold C-2 sand, not exposed) and the ~18-Ma lower shell bed (Cheswold C-3 sand) at the Pollack Farm Site.

As noted previously, the Farmingdale land vertebrate fossils occur in the basal sands of the Kirkwood Formation. Strontium-isotope age estimates of the basal Kirkwood located closest to the Farmingdale sites are from the Berkeley and Lacey wells reported by Sugarman et al. (1993, Fig. 3, Table 1) who estimated ages of 22.2, 22.0, and 21.7 Ma for the former and 22.6, 22.3, and 22.0 Ma for the latter (solid dots in Figure 6) by using three different regression equations to correlate to the geomagnetic time scale of Berggren et al. (1985). The total range of 20.5–22.6 Ma for the age estimate for the Farmingdale Fauna shown in Figure 6 was determined in the same manner as that for estimating the age of the Shiloh mollusk: strontium-isotope ratios reported by Sugarman et al. (1993, Table 1) for the Berkeley and Lacey wells calibrated to the time scale of Cande and Kent (1992) by means of Hodell and Woodruff's (1994) curve give age estimates of about 20.5 and 21 Ma for the Berkeley and Lacey wells, respectively, and by means of the regression line of Oslick et al. (1994) give estimates of about 21.9 and 22.2 Ma, respectively (open dots in Figure 6). The age estimates thus determined give the Farmingdale Local Fauna a late Arikareean land mammal age (Fig. 6), which is consistent with that age interpretation by Emry and Eshelman (1998) and confirms that the Shiloh and Pollack Farm vertebrate faunas are stratigraphically higher (by 150–200 ft?) than the Farmingdale Fauna.

The ages of the Miocene vertebrate fossils from Maryland can be bracketed by means of correlation with the



Figure 6. Correlation of the stratigraphic units containing the mid-Atlantic Miocene fossil vertebrate assemblages to global foraminiferal, calcareous nannofossil, and radiolarian biozones and regional diatom and dinoflagellate biozones calibrated to the geomagnetic polarity time scale of Cande and Kent (1992, 1994). Diagonal ruling indicates the maximum range of the age estimate for each fossil vertebrate assemblage. Solid dots are strontium-isotope age estimates for the New Jersey assemblages and Kirkwood sequences published by Sugarman et al. (1993), and open dots are my recalibrations of their published isotope ratios. Dashed lines indicate uncertainty in correlations by authors cited and in this study. See text for further explanation.

global radiolarian biozones shown in Figure 6. Palmer (1984, 1986b) identified the biozones in her study of mid-Atlantic Miocene radiolarian occurrences and correlated them to the “zones” of Shattuck (1904), which she referred to as Miocene Lithologic Units (MLU) as recommended by Andrews (1978). Andrews (1988) and Wetmore and Andrews (1990) likewise correlated the East Coast Diatom Zones (ECDZ) and silicoflagellate zones to the MLUs.

Palmer (1984) assigned the highly diatomaceous clayey silts of the Dunkirk beds of Gibson (1982) to the *Stichocorys wolffii* Radiolarian Zone (Fig. 6). They are the lowermost outcropping beds of the Calvert Formation in Maryland but are not present in surface sections at Calvert Cliffs on the western shore of Chesapeake Bay (Fig. 1). Palmer (1984) identified the entire Fairhaven Member of the Calvert Formation at the base of the Calvert at Calvert Cliffs as MLU 3 and assigned it to the *Calocycletta costata* Zone, but Andrews (1988) and Wetmore and Andrews (1990) indicate this as their Bed 3B (Fig. 6). Following the analysis of Gibson (1982), Palmer (1984) states that the Dunkirk beds correspond to MLU 1, MLU 2, and the lower part of MLU 3. The Dunkirk beds, therefore, are equivalent, at least in part, to Bed 3A, recognized as the lower part of the Fairhaven Member of the Calvert Formation by Andrews (1988) and Wetmore and Andrews (1990), and to the radiolarian bed at the Pollack Farm Site in Delaware (Fig. 6). Gibson (1982) identified the Popes Creek sand as occurring stratigraphically between the Dunkirk beds and the Fairhaven Member but also not present at Calvert Cliffs. Emry and Eshelman (1998) compared peccary fossils from the Popes Creek locality along the lower Potomac River to a small peccary from the Pollack Farm Site and concluded that there is a close temporal correlation between the sites (early? to late? Hemingfordian); therefore, the Popes Creek vertebrate assemblage is considered approximately coeval with part of the *Stichocorys wolffii* Zone (Fig. 6). Palmer’s (1984, 1986b) correlation of the Popes Creek sand follows that of Gibson (1982) who placed the Popes Creek stratigraphically between the Dunkirk (*S. wolffii* Zone) and the Fairhaven Diatomaceous Earth Member (*Calocycletta costata* Zone) of the Calvert Formation. The Popes Creek sand, therefore, is coeval or nearly so with the Cheswold sands exposed at the Pollack Farm Site (Fig. 6). On the other hand, on the basis of their dinoflagellate biostratigraphy de Verteuil and Norris (1996) correlate the Popes Creek sand with foraminiferal zone N5 and calcareous nannofossil zone NN2 as shown in figure 6. This places the Popes Creek in the early Hemingfordian; therefore, two possibilities for the age of this unit are shown in the Chesapeake Bay column of Figure 6.

Andrews (1988) and Wetmore and Andrews (1990) assigned Bed 3A to ECDZ 1 and observed the extent of this diatom zone into New Jersey. Strontium-isotope dating of ECDZ 1 (lower Kirkwood) in New Jersey by Sugarman et al. (1993) indicates that its upper limit is older than 19.2 Ma, therefore, older than the upper limit of the ECDZ 1 interval (and *Stichocorys wolffii* Zone) in Maryland and Delaware, although the error bars for the strontium-isotope age estimates shown in Figure 6 for the New Jersey reference section and the Pollack Farm Site (also ECDZ 1) nearly overlap. The strontium-isotope ratios that yielded minimum age estimates of 19.2 Ma for ECDZ 1 in New Jersey (Sugarman et al., 1993, Table 1) when calibrated to the time scale of Cande

and Kent (1992) using the composite strontium seawater curve of Hodell and Woodruff (1994) yield age estimates of about 18.3–18.4 Ma (open dots in Figure 6), closer to the age estimate for the Pollack Farm Site. In borehole Oh25-02 near Lewes, Delaware, Benson (1990) found *Actinoptychus heliopelta*, the identifying taxon for ECDZ 1, above the highest occurrence of planktic foraminiferal Zone N7 (16.7–16.4 Ma; Berggren et al., 1995), which is stratigraphically higher than indicated by Sugarman et al. (1993) for ECDZ 1 in New Jersey (Fig. 6). Sediments of the *S. wolffii* Zone in the Dover Air Force Base well Je32-04 correlate with the same interval at the Pollack Farm Site (Fig. 5). In that well, the top of the *S. wolffii* Zone occurs at the top of ECDZ 1 (Benson and Spoljaric, 1996), but the base of the latter extends below the base of the radiolarian zone (Fig. 6). Also in Je32-04, radiolarians that identify the *Calocycletta costata* Zone occur only in the upper half of the interval assigned to ECDZ 2 (Benson and Spoljaric, 1996).

Emry and Eshelman (1998) summarize the occurrences of fossil land mammals from the Calvert Cliffs as from beds 10 and 13–15 of the Calvert Formation and the basal part of the overlying Choptank Formation (bed 17, see Andrews, 1988). The left half of the Chesapeake Bay column of Figure 6 shows the correlation of these beds to the radiolarian zones after Palmer (1984, 1986b), and the right half shows de Verteuil and Norris’s (1996) slightly different correlation of beds 10–17 based on dinoflagellate biostratigraphy. Palmer (1984) assigned the Plum Point Member of the Calvert (MLU 4–13) to the lower part of the *Dorcadospyris alata* Zone, older than the LAD of *Calocycletta costata* (14.46 Ma as given by Hodell and Woodruff, 1994) as that species occurs within the stratigraphic interval. Palmer (1984) noted that radiolarians are sparse in MLU 14 through 19, and, therefore, no zonal assignment could be made for that interval, although she does suggest that it may correspond to the *D. alata* Zone. Whether they are correlated by radiolarian or dinoflagellate biostratigraphy, the beds containing the Calvert Cliffs land mammal fossils correspond to the *D. alata* Zone and span the early to late Barstovian, which conforms to the age assigned to the vertebrate fossils by Tedford and Hunter (1984) and Emry and Eshelman (1998).

The only other radiolarian zone in Maryland identified by Palmer (1984) is the *Diartus petterssoni* Zone for MLU 20 (Conoy Member) of the Choptank Formation.

PALEOENVIRONMENTAL INTERPRETATION

The high numbers of radiolarians and diatoms in the radiolarian bed at the Pollack Farm Site (Fig. 2) reflect open marine, biologically productive, relatively low-energy conditions. The presence of 30–35 percent fine sand in this silt bed, however, indicates that the environment was near a source of sand. This contrasts with the lithology of Bed 3A in Maryland, part of which is coeval with the radiolarian bed. Bed 3A is a diatomaceous silt with some included clay but very little fine sand that Wetmore and Andrews (1990) interpret as having been deposited in a shallow marine environment with no apparent influence from rivers supplying clastic sediments and fresh water.

The Cheswold sands that predominate at the Pollack Farm Site are evidence of a deltaic influence. Gibson (1982, 1983) shows the regional paleoenvironments for the lower

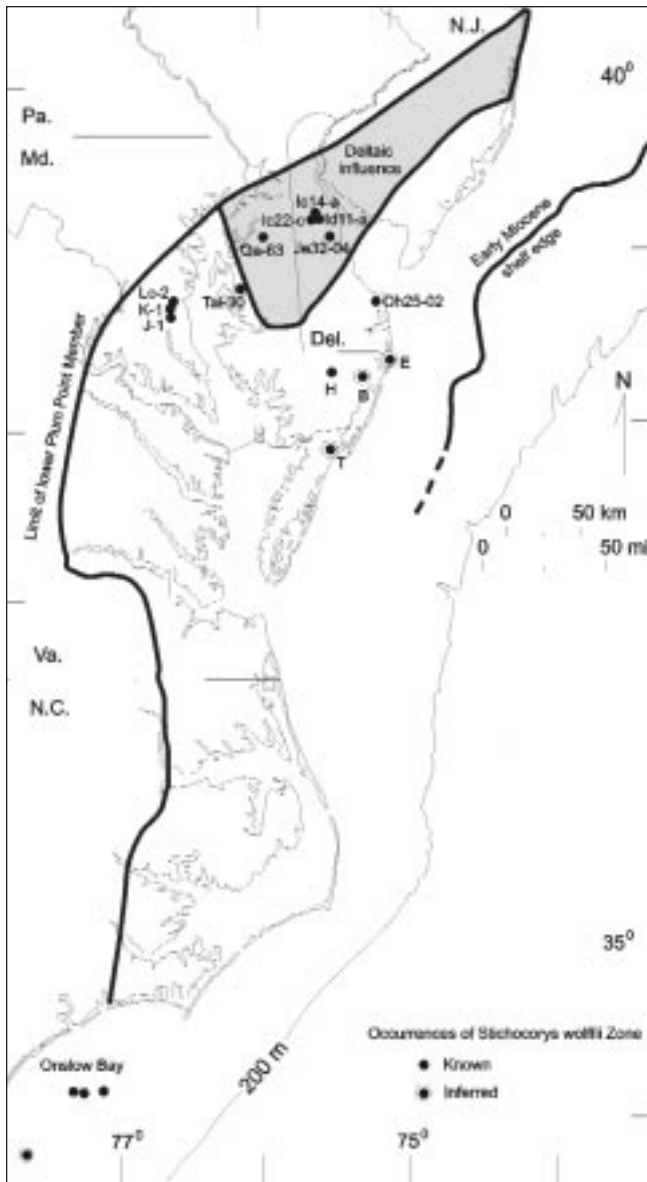


Figure 7. Known and probable occurrences of the early Miocene *Stichocorys wolffii* Radiolarian Zone of the middle Atlantic Coastal Plain after Palmer (1984, 1988) and this study. Included are the locations of samples with counts of radiolarian assemblages shown in Table 1. The area of deltaic influence for the early middle Miocene Plum Point Member of the Calvert Formation and equivalents is after Gibson (1982, 1983). Outcrops are Lc-2, K-1, J-1, Ic14-a, Ic22-c, and Id11-a. All other locations are of boreholes including H, B, E, and T which are, respectively, the Hammond, Bethards, and Esso wells in Maryland and the Taylor well in Virginia.

half of the Plum Point Member of the Calvert Formation and its equivalents (early middle Miocene) throughout the middle Atlantic Coastal Plain and indicates the area of deltaic influence from the north into New Jersey and the northern Delmarva Peninsula as shown in Figure 7. That same area of deltaic influence likely prevailed during the early Miocene in central New Jersey where the Grenloch Sand Member of the Kirkwood Formation dominates the Coastal Plain section (Isphording, 1970, Fig. 1) and during the later early Miocene when the Cheswold sands prograded into Delaware. To the

west of the area of deltaic influence, Gibson (1982, 1983) shows a protected embayment in which biosiliceous remains, particularly diatoms, accumulated in numbers sufficient to produce diatomites. To the south in Virginia and North Carolina, phosphatic to carbonate, inner to middle shelf environments predominated.

Ramsey (1998) interprets the depositional environments represented by the sediments exposed at the Pollack Farm Site (see Figure 2): (1) shelly mud bed—marine inner shelf; separated by a disconformity from (2) lower shell bed and lower sand—tidal channel; separated by a ravinement surface or disconformity from (3) parallel-bedded sand (in which I found rare centric diatoms and which is at the same stratigraphic level in the pit as the radiolarian bed about 500 ft to the east)—subtidal channel margin; (4) cross-bedded sand—subtidal sand flat shoaling upward to a subtidal to intertidal flat with channel axis and channel-margin facies identified by Miller et al. (1998) on the basis of relative densities of *Ophiomorpha nodosa* burrows; separated by a ravinement surface from (5) upper mud—intertidal to supratidal flat.

A sandy silt with abundant radiolarians and diatoms representing biologically productive open marine waters in close proximity to the environments just listed in which the mix of marine, brackish-water, fresh-water, and terrestrial fossils were deposited presents a challenge to interpretation. An added difficulty is that the area in the pit where the test trench uncovered the radiolarian bed was excavated and back-filled prior to subsequent visits to the site for study; therefore, the stratigraphic relationships of the radiolarian bed to the other units exposed at the Pollack Farm Site could not be determined. As the silts containing the radiolarians of the *Stichocorys wolffii* Zone are widespread as shown in Figures 4, 5, and 7, the Cheswold sands can be considered as the deposits of a delta prograding into the widespread open marine environment supporting production of biogenous silica, and the radiolarian bed at the Pollack Farm Site represented an isolated area such as an interdistributary bay where sand influx was minimal. Alternatively, the radiolarian bed may have been an erosional remnant of the biosiliceous unit “Bed 3A” that was preserved in one small area of the Pollack Farm Site, surrounded by younger marginal marine deposits. A third interpretation is that the radiolarian bed represents a deeper water deposit than the rest of the sediments at the Pollack Farm Site and that its base (not observed) may represent a flooding surface—one separating younger from older strata across which there is evidence of an abrupt increase in water depth, thus defining a parasequence boundary (Van Wagoner, 1995). The fact that the parallel-bedded sand/radiolarian bed interval has a gamma-ray log response correlatable over a large area (Figs. 4 and 5) supports the interpretation that it represents a parasequence, at least the deeper-water basal part of one.

Radiolarians, which are generally associated with the oceanic realm, are not usually found in abundance in shelf environments. Palmer (1984, 1986a) investigated the radiolarians in diatomaceous Miocene shelf sediments of the mid-Atlantic region and was able to apply criteria from her and others’ studies to show the potential value of these siliceous microfossils as indicators of neritic versus oceanic conditions. In her model, she infers that radiolarians were trans-

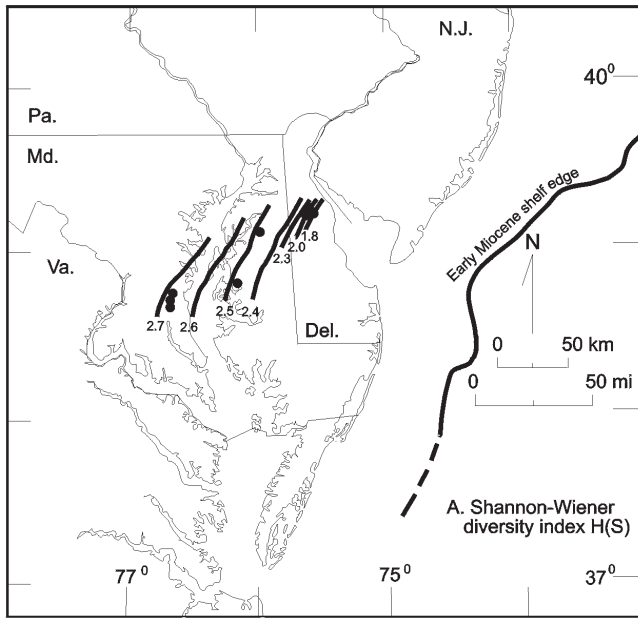


Figure 8A.

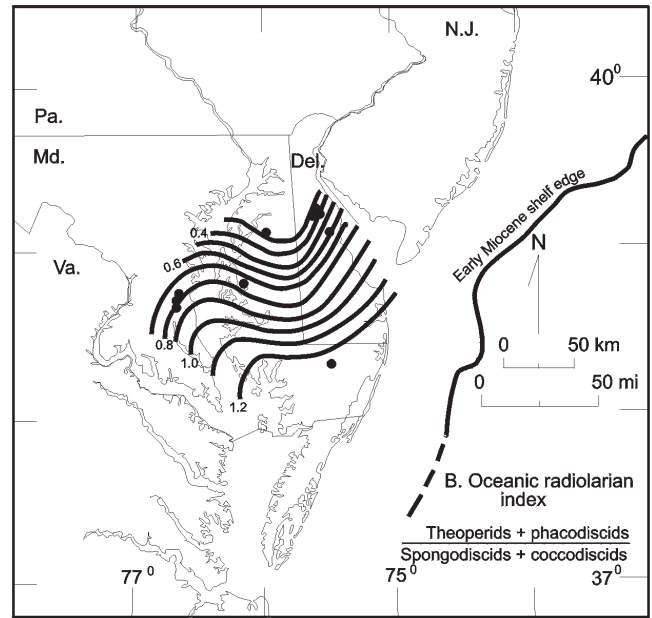


Figure 8B.

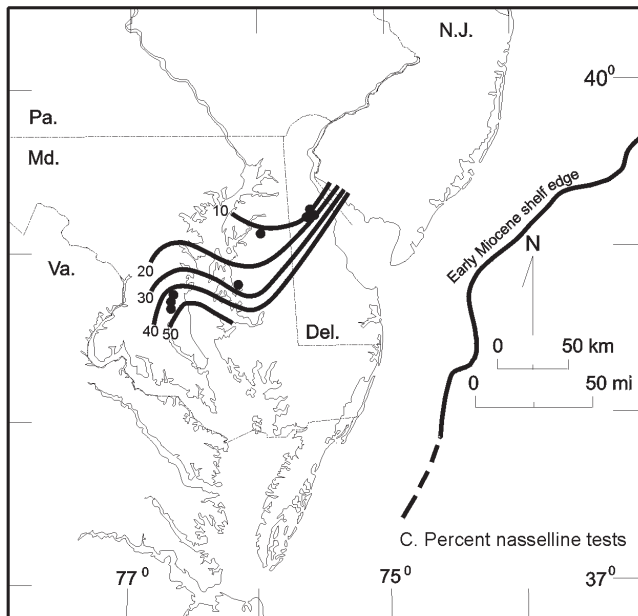


Figure 8C.

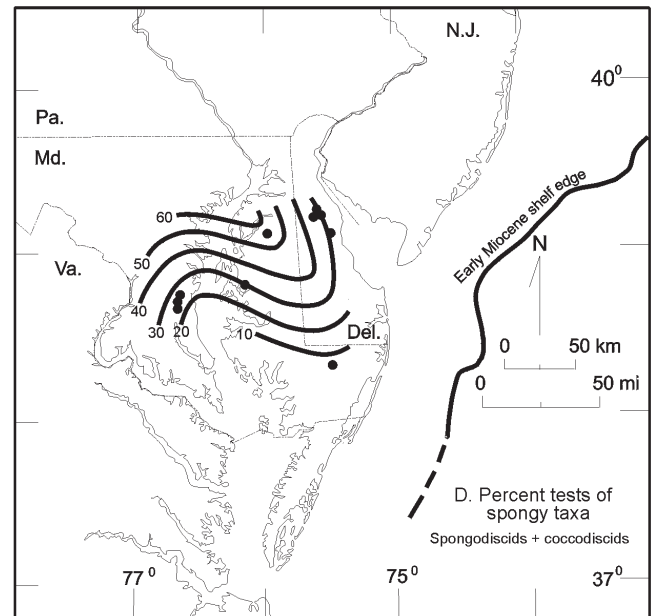


Figure 8D.

Figure 8. Maps of contoured data from Table 1 showing radiolarian criteria indicating oceanic versus neritic conditions.

ported to the Virginia to New Jersey shelf (Salisbury Embayment) from slope waters by warm-core rings (eddies) spawned from the Miocene Gulf Stream and to the phosphate-rich North Carolina shelf by upwelling from or intrusion by the ancient Gulf Stream (Palmer, 1988). The early Miocene shelf edge off New Jersey and Delmarva (Fig. 7) was 50–100 km landward of the modern shelf edge as inferred from analysis of offshore seismic reflection data by Roberts (1988) and Poag (1992); therefore, the source of oceanic slope waters was that much closer to the Pollack Farm Site than it is today.

Palmer (1984, 1986a) reasoned from her results of quantitative analyses of the radiolarian assemblages that radi-

olarian populations transported into shelf waters would encounter ecologic stresses, particularly in the vicinity of the mouths of large rivers. These stresses would result in a decrease in overall diversity, with increased dominance by taxa more tolerant of shelf conditions. The emphasis in her study was determining the changes in oceanic versus neritic conditions through time. In this study, in order to characterize the regional paleoenvironmental setting of the Pollack Farm Site, I have analyzed the assemblages only of the *Stichocorys wolffii* Zone. Known (presence of *Spongasteriscus marylandicus* with other zonal markers) and probable (by correlation) occurrences of the zone in the mid-Atlantic Coastal Plain are shown in Figure 7.

Table 1A lists the radiolarian counting groups of Palmer (1984, 1986a) which I used in analyzing the Delaware assemblages of the *Stichocorys wolffii* Zone and the one sample of the zone from the Hammond well of Maryland. Palmer's (1984, Appendix C) data from Maryland outcrop and well samples of the zone are included in the table. Criteria derived from the data (Table 1B) that indicate the degree of neritic versus oceanic influence (Palmer 1984, 1986a) are contoured in Figure 8.

The assemblages at the Pollack Farm Site (Id11-a) and the two nearby outcrop sites Ic14-a and Ic22-c are nearly the same. Three combined counting groups (Table 1) dominate, all spumellines: 1) actinommids, averaging 29.1% for the three sites; 2) spongodiscids + coccodiscids, spongy taxa considered by Palmer (1984) to contain symbiotic algae, averaging 29.4%; and 3) litheliids, averaging 26.3%. The next most abundant groups include one spummelline family—phacodiscids (2.9%)—and two nasselline genera—*Cyrtocapsella* (3.4%) and *Stichocorys* (2.6%).

Only one core sample from Je32-04 (depth 197–199 ft) and one sample from the Hammond well (depth 1100–1110 ft) yielded rare tests of *Spongasteriscus marylandicus*. Only 34 radiolarian tests were found in the Je32-04 sample, a diatomite, because of their dilution by diatoms, particularly *Actinoptychus heliopeneta*; therefore, results of counts in Table 1 for that sample are not statistically significant. The sample examined from the Hammond well is a float sample of poorly washed drill cuttings; radiolarians likewise are not clean but most counting groups could be identified under a low power binocular microscope. I suspect that counts of that sample may be biased (perhaps by the laboratory flotation process or by the sample being of drill cuttings rather than of core or outcrop) as actinommids account for 88.4% of the assemblage, which seems too high for its offshore (more oceanic) location compared to the Pollack Farm Site. The low diversity of the sample (Shannon-Wiener index, H(S), of 0.90, Table 1B) likewise does not fit a more nearly oceanic setting.

Palmer's (1986a) outcrop samples from the Dunkirk beds of Maryland (LC-2, K-1, and J-1 in Fig. 7) are highly diatomaceous silts and diatomites containing hundreds to thousands of radiolarians per gram of sediment. Radiolarians are well preserved (grades 2 to 3 of Westberg and Riedel, 1978). From her interpretation, high rates of biological productivity with little dilution by clastic sediments yielded the large concentrations of diatoms in a shallow, open-marine environment in a quiet aerobic setting below storm-wave base. Closer to or within the area of deltaic influence, the two well samples from the Maryland Eastern Shore (Qa-63 and TAL-30, Fig. 7) are from less diatomaceous and sandier sediments with higher amounts of carbonate and organic matter. Radiolarians are more poorly preserved (grade 4 of Westberg and Riedel, 1978), less abundant, and less diverse than those from the Dunkirk outcrops (Palmer, 1986a). Likewise, I interpret radiolarian preservation at the Pollack Farm and nearby sites as grade 4 on the basis of the dominance of the assemblages by robust tests (thick test walls and pore bars) and the paucity of delicate forms. The robust tests, however, may reflect uptake of high dissolved silica concentrations brought into the area by nearby rivers and may not represent pronounced distortion of the assemblage by dissolution of the more delicate forms which characterizes grade

4 preservation (Westberg and Riedel, 1978). The robust tests are generally well-preserved and do not show much evidence of pitting by dissolution.

Results of radiolarian counts of the Delaware samples continue the trend of increasing neritic influence from the open marine embayment as exemplified by the Dunkirk beds northeastward to the region of deltaic influence. Diversity as measured by the Shannon-Wiener information function (Gibson and Buzas, 1973) decreases in that direction (Table 1B, Fig. 8A). Equability, which equals 1.0 when all taxa are equally distributed (Gibson and Buzas, 1973), likewise is much less in the Delaware samples than those from Maryland (Table 1B) and reflects the dominance of just a few taxa that could flourish in the stressed nearshore environment of the Pollack Farm and nearby sites.

Three other criteria that Palmer (1984, 1986a) used to indicate neritic versus oceanic conditions are shown in Figures 8B–D. All three show the trend of increased neritic conditions from the area of the Dunkirk outcrops toward the area of deltaic influence to the northeast. Palmer's (1984) oceanic radiolarian index of Figure 8B increases away from the deltaic region as the oceanic-enhanced families theoperids and phacodiscids increase in relative abundance. A similar trend is shown by the percentage of nasselline tests (Fig. 8C) which also are more indicative of oceanic conditions. Palmer (1984) cites several studies by Casey and his students (e.g., Casey et al., 1982) that report the presence of symbiotic algae in shallow-water-dwelling spongy taxa, the spongodiscids and coccodiscids, which dominate in shelf waters of tropical and temperate regions. Figure 8D shows the shoreward increase to nearly 60 percent domination by these groups which are indeed excellent indicators of neritic conditions.

Palmer (1984) did not find a clear pattern of abundance distribution for the actinommids and litheliids in her study of Coastal Plain assemblages. These groups occur at similar levels of abundance at all sites she studied. At the Pollack Farm and nearby Delaware sites, however, these two groups (plus the spongy taxa) dominate the assemblages and have greater abundances than in the Maryland samples to the west (Table 1B). They may be useful in indicating environments closer to ancient shores than those paleoenvironmental settings sampled by Palmer (1984).

SUMMARY AND CONCLUSIONS

Radiolarians recovered from the Pollack Farm Site provided the means to correlate the rich molluscan and vertebrate fossil remains found there to the record of global marine biostratigraphic zones and the geomagnetic polarity time scale. The early Miocene *Stichocorys wolffii* Radiolarian Zone (17.3–19.2 Ma) identified at the site is compatible with the 17.9 ± 0.5 Ma age of mollusks as determined from strontium-isotope ratios (Jones et al., 1998) and with the early Hemingfordian age of the fossil land mammal remains (Emry and Eshelman, 1998). The close temporal relationships between the Popes Creek vertebrate remains of Maryland and the vertebrates and mollusks from the Pollack Farm Site of Delaware and the Shiloh marl of New Jersey as determined from analyses by Emry and Eshelman (1998) and Ward (1998) are supported by radiolarian studies of Palmer (1984, 1986b) and by stratigraphic correlation of borehole geophysical logs in this study.

TABLE 1

Results of counts of radiolarian assemblages of the *Stichocorys wolffii* Zone, Delaware and Maryland. Abundances are percentages of the total number of tests counted for each site (P=present).

A. COUNTING GROUPS	Id11-a	lc14-a	lc22-c	Tal-30	Qa-63	J-1	K-1	LC-2	Je32-04	Hammond
SPUMELLINE TAXA:										
CUBOTHOLIIDS:										
<i>Cubotholus</i>			0.16							
COLLOSPHAERIDS										
ACTINOMMIDS:										
<i>Hexacantium</i>	6.30	8.14	5.67	23.00	8.70	1.40	19.10	13.60		1.62
<i>Stylosphaera</i>	2.70	6.70	9.49							6.94
other actinomids	14.20	17.46	16.65			5.00	1.20		26.50	79.86
PHACODISCIDS										
COCCODISCIDS:										
<i>Didymocorytis</i>	3.10	5.02	4.19	3.20	2.40	5.80	6.90	4.30	5.90	0.46
SPONGODISCIDS:										
<i>Dictyocoryne</i>	2.80	4.07	2.55	9.70	7.90	11.50	7.30	7.90		0.46
<i>Porodiscus</i> -narrow rings	1.60		1.11	7.20	13.40	2.90	4.50	2.90		
<i>Porodiscus</i> -wide rings	0.60	0.24	0.74	0.80			0.40			
<i>Spongasteriscus</i>	0.60	0.72	0.16	1.60	5.50	2.90	2.00	2.90	2.90	0.46
<i>Spongodiscus</i>	15.20	18.42	16.97	6.40	19.70	2.90	8.50	1.40		3.01
<i>Stylodictya</i>	0.20	0.24	0.11	0.80	7.10		0.80	1.40	8.80	
spongodiscid group A	2.00	2.87	3.82				0.40	0.70	5.90	0.46
spongodiscid group B	0.10	0.24	0.16							
other spongodiscids	0.50		0.05						5.90	
PYLONIIDS										
LITHELIIDS:										
<i>Lithelius</i>	20.40	18.42	22.38	12.90	11.00	0.70	7.30	3.60		0.46
<i>Pylospira</i>	1.90	0.72	0.16	0.80	2.40	7.20	3.20	4.30		
other litheliids	12.10	1.20	1.75							
NASSELLINE TAXA:										
SPYRIDS:										
<i>Dendrospyris</i>	2.20	0.72	1.22	1.60	1.60	0.70	1.20	10.00	2.90	
<i>Desmospyris</i>	0.20		0.05			0.70				
<i>Liriospyris</i>	0.04									
other spyrids										
PLAGONIIDS:										
<i>Ceratospiris</i> group A	0.10	0.96	0.32	3.20	1.60	19.40	3.20	11.40		
<i>Ceratospiris</i> group B	0.10	0.24								
<i>Lithomelissa</i>	0.30	0.72	0.74			5.00	3.70	11.40	26.50	
<i>Pseudocubus</i>										
<i>Pseudodictyophimus</i>						2.90	0.40	0.70		
plagoniid group A				1.60		1.40	0.80	2.90		
other plagoniids	0.10	0.24	0.16		0.70	4.30				
THEOPERIDS:										
<i>Bathropyramis</i>	0.10	P								
<i>Cyrtocapsella</i>	3.20	4.31	2.55	4.80	3.90		0.80		5.90	4.17
<i>Eucyrtidium</i> group A	0.90	1.20	1.17	4.00	0.70	2.90	2.80	3.60		
<i>Eucyrtidium</i> group B	0.20	0.24	0.16							
<i>Gondwanaria</i>	0.04	P	0.16	2.40		15.80	19.10	10.00	2.90	
<i>Lithopera</i>										
<i>Lychnocanoma</i>	0.10		0.11							0.23
<i>Stichocorys</i>	3.10	2.15	2.44	4.80	3.90	2.20	0.80	2.10	5.90	0.23
other theoperids	0.04						0.40			
CARPOCANIIDS										
PTEROCORYTHIDS										
ARTOSTROBIIDS										
CANNBOTRYIDS										
INCERTAE SEDIS:										
<i>Carpocanarium</i>	0.50	P	0.21							
<i>Tepka</i>							P	P		
UNIDENTIFIED NASSELLINES			0.27							

B. DATA SUMMARY

NUMBER COUNTED	2505	418	1886	124	127	139	246	140	34	432
NUMBER OF GROUPS	38	25	32	19	17	23	27	21		14
NO. OF SPUMELLINE GROUPS	19	16	19	11	10	11	13	11		10
NO. OF NASSELLINE GROUPS	19	9	13	8	7	12	14	10		4
PERCENT NASSELLINE TESTS	12.20	10.80	10.23	27.20	13.20	57.60	36.00	56.30		4.86
PERCENT ACTINOMMIDS	23.15	32.30	31.81	23.00	8.70	6.40	20.30	13.60		88.43
PERCENT SPONGODISCIDS	23.60	26.62	25.67	26.50	53.60	20.20	23.90	17.20	23.50	4.39
PERCENT LITHELIIDS	34.40	20.34	24.29	13.70	13.40	7.90	10.50	7.90		0.46
PERCENT THEOPERIDS	7.68	7.90	6.59	16.00	8.50	20.90	23.90	15.70	14.70	4.63
OCEANIC RADIOLARIAN INDEX	0.39	0.34	0.33	0.75	0.31	0.86	0.88	0.76	0.60	1.24
H(S)	1.82	2.29	2.33	2.48	2.50	2.66	2.62	2.69		0.90
E (equability)	0.16	0.40	0.32	0.63	0.72	0.62	0.51	0.70		0.18
PRESERVATION	4	4	4	4	4	2	2	2		

In the northeastern Coastal Plain of New Jersey, the stratigraphic position of the Farmingdale vertebrate assemblage just above the base of the Miocene section (Kirkwood Formation) indicates that it is older than the Pollack Farm and Shiloh fossils which occur 150–200 feet stratigraphically higher, assuming the base of the Miocene is of the same age at all three locations. This is supported by the late Arikareean age assigned to the Farmingdale vertebrates by Emry and Eshelman (1998) and by strontium-isotope age estimates of 20.5–22.6 Ma, based on data by Sugarman et al. (1993), for the basal Kirkwood near the Farmingdale locality.

Radiolarian and dinoflagellate biostratigraphy support the Barstovian age (Tedford and Hunter, 1984; Emry and Eshelman, 1998) of the vertebrate assemblages from the Calvert Formation and basal part of the overlying Choptank Formation at the Calvert Cliffs exposures along the western shore of the Chesapeake Bay in Maryland.

Criteria derived from radiolarian abundance data that Palmer (1984, 1986a) used to determine the degree of oceanic versus neritic influence in radiolarian-bearing deposits of the middle Atlantic Coastal Plain were applied in this study of the radiolarian assemblages of the *Stichocorys wolffii* Zone in Delaware, including the Pollack Farm Site. Results indicate a more neritic influence at the Delaware sites than the open-marine, quiet-water offshore environments to the west and south in Maryland that Palmer's data, in comparison, indicate as more oceanic and less neritic. The increasing neritic trend toward the Pollack Farm and nearby sites from the Maryland sites is shown by decreases in (1) diversity (Shannon-Wiener information function), (2) Palmer's (1984) oceanic radiolarian index, and (3) the percentage of nasselline tests, and (4) an increase in the percentage of spongy taxa with algal symbionts. These results support the shallow inner neritic to marginal marine interpretation for the strata at the Pollack Farm Site and also the deltaic influence indicated for this area and New Jersey by Gibson (1982, 1983) as exemplified by the Cheswold sands of the Calvert Formation in Delaware and the Grenloch Sand Member of the Kirkwood Formation of New Jersey.

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AGE OF MARINE MOLLUSKS FROM THE LOWER MIOCENE POLLACK FARM SITE, DELAWARE, DETERMINED BY $^{87}\text{Sr}/^{86}\text{Sr}$ GEOCHRONOLOGY¹

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ABSTRACT

Analyses of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the shells of marine bivalve mollusks from the Pollack Farm Site in Kent County, Delaware, indicate that the fossils represent an early Miocene assemblage which lived about 17.9 ± 0.5 Ma. Faunal similarities, as well as Sr-isotopic data, support a correlation between the fossils at the Pollack Site and portions of the Kirkwood Formation to the north (New Jersey) and to the south the Fairhaven Member of the Calvert Formation (Maryland), the Pungo River Formation (North Carolina), and the Chipola Formation (Florida). A strong marine-nonmarine link with terrestrial vertebrates of the Hemingfordian North American Land Mammal Age is also suggested.

INTRODUCTION

The U. S. Atlantic Coastal Plain boasts a rich Neogene stratigraphic record which has attracted the attention of stratigraphers and paleontologists for nearly two centuries. Despite this long history of investigation, correlation and age determinations of particular deposits often have proven difficult because of poor and sporadic exposures combined with a lack of age-diagnostic index taxa (planktic micro- and nanofossils) in these predominantly shallow-water deposits. We believe that strontium (Sr)-isotope chronostratigraphy represents a powerful tool for correlating shallow-marine units of the Atlantic and Gulf Coastal Plains with one another as well as to deep-sea reference sections and the geomagnetic polarity time scale (Jones et al., 1993; Miller and Sugarman, 1995). Sr-isotope stratigraphy is one of the few techniques that offers promise of worldwide correlation because the Sr-isotopic composition of seawater is constant at any point in time owing to rapid ocean mixing and the relatively long residence time of Sr in the oceans. As a result, it is independent of ocean basin, latitude, or water depth—attributes particularly relevant for correlating and dating the shallow-water sequences of the Coastal Plains.

Within the last decade, $^{87}\text{Sr}/^{86}\text{Sr}$ chronostratigraphy has emerged as an important geochronologic technique in marine sedimentary systems. Investigations of well dated marine carbonates throughout the Phanerozoic have demonstrated significant and regular variations in the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of seawater throughout geologic time (Burke et al., 1982; Veizer, 1989). During intervals characterized by rapid Sr-isotopic change with respect to time, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio allows rather precise relative and absolute age determinations of unaltered marine carbonates and phosphates. Fortunately for geologists interested in Atlantic Coastal Plain stratigraphy, the Sr-isotopic ratio of seawater increased, often rapidly, through much of the Cenozoic (Elderfield, 1986; Hess et al., 1986). In fact, the best temporal resolution is offered for the early Miocene, between about 23 and 16 Ma, when the seawater Sr-isotope curve was steepest (Hodell and Woodruff, 1994). Refinements to the global seawater Sr-isotope curve for particular segments of the Paleogene and the Neogene (e.g., Miller et al., 1988, 1991;

Hess et al., 1989; Capo and DePaolo, 1990; Hodell et al., 1991; Hodell and Woodruff, 1994; Oslick et al., 1994) indicate that high-resolution chronostratigraphy is possible for strata deposited from the latest Eocene through the middle Miocene, as well as from the late Pliocene through the Pleistocene. In this investigation we apply Sr-isotope geochronologic techniques to marine mollusk shells collected from the Pollack Farm Site, located in Kent County between Dover and Smyrna, Delaware (see Benson [1998], Ramsey [1998], and Ward [1998] for details of location and geologic setting), to help resolve chronostratigraphic uncertainties and provide a better temporal framework for stratigraphic and paleontologic interpretations.

Several recent studies have successfully incorporated isotopic analyses to help unravel age relationships for strata of the Gulf and Atlantic Coastal Plains. These include: Pliocene-Pleistocene of Florida (Webb et al., 1989; Jones et al., 1991; Jones et al., 1995); Oligocene and Miocene of Florida (Bryant et al., 1992; Compton et al., 1993; Jones et al., 1993; Sugarman et al., 1997); Paleogene of Alabama, Mississippi, and Louisiana (Denison, et al., 1993b); Cretaceous to Pleistocene of North Carolina (Denison et al., 1993a); and the Miocene of New Jersey (Sugarman et al., 1993; Miller and Sugarman, 1995; Miller et al., 1997). These studies demonstrate the clear potential for $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic analyses to provide independent age information for shallow-marine strata. We apply these same techniques to mollusks from the Pollack Farm Site where we are interested in resolving the age relations of this richly fossiliferous, shallow-marine deposit which also contains the remains of terrestrial vertebrates. Such sites are particularly significant to paleontologists as they present opportunities to improve marine-nonmarine correlations (Tedford and Hunter, 1984).

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MATERIALS AND METHODS

Five valves from articulated specimens of marine bivalve mollusks were selected from four individuals collected by L.W. Ward in November 1991 and by L.W. Ward and D.S. Jones on 15 June 1992. The specimens came from the main shelly unit, the approximately 3.0 m-thick Bed b of Ward (1998) which is the lower shell bed at the site as described by Ramsey (1998). Three individuals (Table 1, A-C) of *Mercenaria ducatelli* (Conrad), with aragonitic shells, and one *Crassostrea virginica* (Gmelin) (Table 1, D), with a calcitic shell, were used.

Table 1.

$^{87}\text{Sr}/^{86}\text{Sr}$ ratios, within-run error, and age estimates for marine mollusk samples from the Pollack Site, Kent County, Delaware. Columns 1 and 2 are based on the time scale of Berggren et al. (1985) whereas column 3 is based on Cande and Kent (1992) which is essentially the same time scale as Berggren et al. (1995) over this interval.

Specimen	$^{87}\text{Sr}/^{86}\text{Sr}$	Age (Ma)		
		1	2	3
A. <i>Mercenaria ducatelli</i>	0.708479±6	+++	+++	+++
A'. <i>Mercenaria ducatelli</i>	0.708618±6	17.8	18.0	17.8
B. <i>Mercenaria ducatelli</i>	0.708599±5	18.1	18.3	18.1
C. <i>Mercenaria ducatelli</i>	0.708619±11	17.8	18.0	17.8
D. <i>Crassostrea virginica</i>	0.708604±9	18.1	18.3	18.0
mean	0.708610	18.0	18.2	17.9

1 - Hodell et al. (1991); 2 - Miller et al. (1991); 3 - Oslick et al. (1994).
+++ - Sample diagenetically altered (see text).

Each specimen was examined microscopically for evidence of alteration or recrystallization. In addition, X-ray diffraction (XRD) and analysis of Sr/Ca ratios by atomic absorption spectrophotometry were performed on specimens of *Mercenaria ducatelli* to assess potential diagenetic effects which, in all but one case, were found to be minimal (Stanley, 1992). Scanning electron microscope (SEM) examination of the exterior shell surface of the right valve of specimen A revealed destruction and overgrowth of original shell microstructure. XRD analysis of powdered shell material indicated the presence of both calcite and aragonite, suggesting partial diagenetic alteration of this shell. SEM inspection and XRD analyses of the opposing (left) valve of this specimen indicated pristine microstructure without calcite. Both right and left valves were analyzed for comparative purposes (Table 1 - specimens A, A').

Sample powders, drilled from the outer shell layer of each valve, were analyzed for strontium isotopic composition ($^{87}\text{Sr}/^{86}\text{Sr}$) in the Department of Geology at the University of Florida using standard techniques of dissolution, centrifugation, evaporation, cation exchange chemistry, and mass spectrometry (Hodell et al., 1991). Five separate analyses, including one "duplicate" (same individual mollusk, opposite valve) were made. $^{87}\text{Sr}/^{86}\text{Sr}$ analyses were normalized to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$. The NBS standard SrCO_3 (SRM-987) was measured at 0.710244 during the course of this study with a long-term analytical precision (2σ) of $\pm 2 \times 10^{-5}$. The ratios reported in Table 1 are corrected to SRM-987 = 0.710235 so that they may be directly correlated to the Sr-isotope seawater curve of Hodell et al. (1991) and Hodell and Woodruff (1994). Corrections to SRM-987 = 0.710252 and = 0.710255 permit comparisons with seawater Sr-isotope

reference curves developed by Miller et al. (1991) and Oslick et al. (1994), respectively.

Measured Sr-isotope ratios were converted to estimates of absolute age using the regression equations of Hodell et al. (1991), Miller et al. (1991), and Oslick et al. (1994). Discrepancies between age estimates arising from these three different equations are relatively small for the early Miocene, within the error of the various age estimates. Detailed discussions of errors associated with Sr-isotopic ages can be found in Hodell et al. (1991) and Miller et al. (1991). For the time interval considered here, errors about single sample Sr-isotopic age estimates typically fall into the range of ± 0.5 to no more than ± 1.0 Ma at the 95% level of confidence.

RESULTS: AGE ESTIMATES

The results of the Sr-isotopic analyses are reported in Table 1. Values for $^{87}\text{Sr}/^{86}\text{Sr}$ range from 0.70848 (right valve of specimen A with calcitic alteration) to 0.70862. Excluding specimen A (right valve), the ratios of the other samples cluster tightly about the mean ratio value (0.70861), falling well within the range of long-term analytical precision ($2\sigma = \pm 2 \times 10^{-5}$). There is very little heterogeneity among the unaltered samples at the site.

As indicated in Table 1, the $^{87}\text{Sr}/^{86}\text{Sr}$ of the right valve of specimen A (0.70848) was significantly lower than the others. Because the right valve of this shell revealed evidence of secondary calcite overgrowth and replacement near the shell exterior, and because its $^{87}\text{Sr}/^{86}\text{Sr}$ was substantially lower than that of the left (unaltered) valve, as well as the other specimens, this ratio was not included in age determinations.

The $^{87}\text{Sr}/^{86}\text{Sr}$ values for specimens A'-D all gave ages in the range 17.8-18.3 Ma. Errors associated with these ages are on the order of ± 0.5 -1.0 m. y. (Hodell, 1991; Miller et al., 1991; Oslick et al., 1994). When all four sample measurements (A'-D) were pooled, and an age calculated for the mean $^{87}\text{Sr}/^{86}\text{Sr}$, the resulting age was 17.9 to 18.2 Ma, depending on which seawater Sr-isotope reference curve was used (Table 1).

DISCUSSION: COMPARISON WITH OTHER Sr-ISOTOPIC DATA

The early Miocene ocean was characterized by rapidly rising $^{87}\text{Sr}/^{86}\text{Sr}$, making this portion of the Neogene particularly suitable for Sr-isotopic geochronology (Hodell et al., 1991; Hodell and Woodruff, 1994; Oslick et al., 1994). Hence, the ages calculated here from the mollusk $^{87}\text{Sr}/^{86}\text{Sr}$ measurements serve to place the fossils recovered from the Pollack Site into a fairly narrow chronostratigraphic context (Fig. 1). The ratios presented in Table 1, with their associated age calculations, suggest that the shells in this deposit range in age from approximately 17.9 to 18.2 ± 0.5 Ma.

Without additional samples from multiple specimens collected at successive stratigraphic horizons throughout the sequence, it is impossible to refine the age structure of the deposit. Stratigraphic condensation, which has been observed elsewhere in Coastal Plain shell beds, can result in mixtures of shells of different ages and different Sr-isotopic ratios (e.g., Webb et al., 1989; Jones et al., 1995), but this process does not appear to have played a major role here. However, it was interesting to discover a specimen of *Mercenaria ducatelli* in which one valve (sample A') appears to have faithfully record-

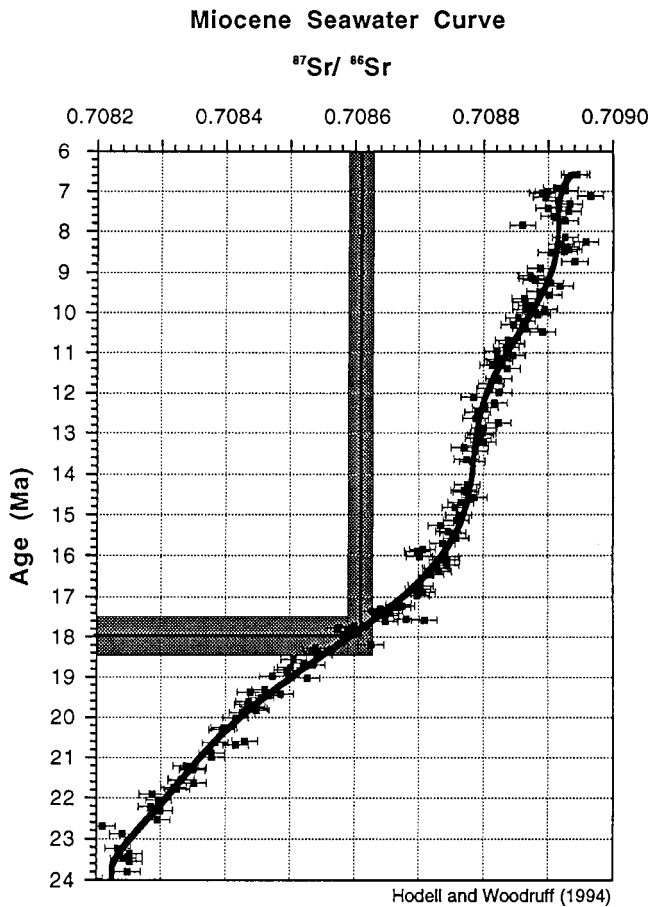


Figure 1. Composite Miocene seawater $^{87}\text{Sr}/^{86}\text{Sr}$ reference curve from Hodell and Woodruff (1994) showing the mean Sr-isotopic ratio determined from mollusk shells at the Pollack Site, $0.70861 \pm 2 \times 10^{-5}$ (2σ), and the corresponding age.

ed the $^{87}\text{Sr}/^{86}\text{Sr}$ of seawater at the time of deposition whereas the lower Sr-isotopic ratio in the other valve (sample A) appears to represent overprinting due to dissolution, replacement, and precipitation of secondary calcite. It remains unclear as to why the Sr-isotopic ratio in the altered, right valve should be lower and not higher than the other ratios at this site, derived from apparently unaltered CaCO_3 . Perhaps diagenetic fluids with relatively lower $^{87}\text{Sr}/^{86}\text{Sr}$ could have arisen from older (deeper) sediments during compaction and dewatering. Whatever the explanation, it is increasingly clear that sample preservation state must be monitored closely in order to insure reliable results.

As Sr-isotopic techniques are employed in an ever-increasing number of Coastal Plain studies, it becomes easier to refine geochronologic assessments as well as compare deposits across broad geographic regions where biogeographic, paleoenvironmental, and/or lithologic changes might otherwise obscure temporal relations. For example,

across the Delaware River, to the northeast, the Miocene Kirkwood Formation of southern New Jersey was the subject of recent Sr-isotopic investigations by Sugarman et al. (1993, 1997). These authors used mollusk shells obtained primarily from wells and boreholes for analyses of $^{87}\text{Sr}/^{86}\text{Sr}$ in order to help constrain the age of the Kirkwood. Sr-isotopic ratios helped define several sequences within this unit. The lowermost Miocene and lower Miocene Kirkwood sequences (Kw0, Kw1a and Kw1b) of Sugarman et al., 1993) correspond to East Coast Diatom Zone (ECDZ) 1 of Andrews (1988) and appear to be older than the Pollack Farm Site with ages of 23.6-18.4 Ma. After a major unconformity, the next youngest, or Kw2a sequence, covers the period 17.8 to 16.6 Ma \pm 0.5 m.y. (Sugarman et al., 1997), corresponding to ECDZ 2 of Andrews (1988). Centering around 17.9 Ma \pm 0.5 m.y., the mean Sr isotopic ages of specimens A-D from the Pollack Site are younger than the Kirkwood 1 ages and seem to correspond most closely with the Kirkwood 2a ages. Thus, they appear to fall within the dated portions of the upper lower Miocene Kirkwood Formation of southern New Jersey.

The molluscan assemblage at the Pollack Farm Site is analyzed by Ward (1998), and it has close affinities with the assemblage from the Kirkwood Formation at Shiloh, New Jersey. Most of the taxa named from Shiloh also occur in the Delaware pit.⁵ Ward (1998) also notes similarities between the molluscan fauna of the Pollack Site and the beds at such localities to the south as Centerville, Church Hill, Sudlersville, and Wye Island, Maryland. The sediments in these equivalent beds fine to a silty clay on the western shore of the Chesapeake Bay, but are identifiable by the presence of the marker diatom, *Actinopterychus heliopelta*, on whose appearance Andrews (1988) based his ECDZ 1.⁵ This species occurs throughout the Kirkwood, but only in one bed of the Calvert Formation, Bed 3A, which occupies the lower 3 m (10 ft) of the Fairhaven Member.⁶ Sr-isotopic measurements on mollusk shells from sections along the southwestern shore of Chesapeake Bay (Jones et al., in prep.) indicate that the mollusks from the Pollack Farm Site are just slightly older (ca. 1 m.y.) than specimens recovered from Zone 4, Plum Point Marl Member of the Calvert Formation (Ward, 1992).

Ward (1998) also discusses faunal similarities between the mollusks of the Pollack Farm Site and those of the Pungo River Formation in North Carolina and the Chipola Formation exposed in the Florida Panhandle. The Chipola has been the subject of two recent geochronologic investigations using Sr isotopes to help constrain its age (Bryant et al., 1992; Jones et al., 1993). Samples from the Chipola Formation at the well known Alum Bluff exposure yielded $^{87}\text{Sr}/^{86}\text{Sr}$ age estimates of 18.3-18.9 Ma (Bryant et al., 1992). Samples collected from outcrops along Tenmile Creek in nearby Calhoun County gave nearly identical $^{87}\text{Sr}/^{86}\text{Sr}$ ages, 18.4-18.9 Ma (Jones et al., 1993). The close correspondence in Sr-isotopic ratios between mollusks of the

⁵ Stratigraphic correlation of geophysical logs between the Pollack Farm Site and the Shiloh area of New Jersey by Benson (1998) shows that the Pollack shell beds are younger than the Shiloh beds and are absent at Shiloh by having been eroded. Also, Benson (1998) identified *Actinopterychus heliopelta* from a sandy silt overlying the main (lower) shell bed at the Pollack Farm Site and cites other studies in Delaware showing that this marker species identifying ECDZ 1 occurs within beds equivalent in age to the Kw2a sequence of New Jersey and, therefore, ranges stratigraphically higher than its New Jersey range as indicated by Sugarman et al. (1993).—ED.

⁶ This applies to the occurrence of Bed 3A in outcrop. The ECDZ 1 diatom assemblage zone identified by the occurrence of *Actinopterychus heliopelta* occurs within almost the entire lower Miocene section of Delaware and New Jersey as indicated by Benson (1998) and Sugarman et al. (1993).—ED.

Chipola Formation and those of the Pollack Farm Site provides strong support for the contemporaneity of these two widely separated fossil faunas, reinforcing observations of faunal similarities.

From Sr-isotopic age determinations on four specimens, it is clear that the mollusks from the Pollack Farm Site represent an early Miocene assemblage that lived about 17.9 ± 0.5 Ma. Good correlations with other, well-dated, Coastal Plain mollusk faunas to the north and south support this assessment. Marine mollusks from Florida with identical $^{87}\text{Sr}/^{86}\text{Sr}$ ages have been successfully correlated with terrestrial vertebrates of the early Hemingfordian North American Land Mammal Age (Bryant et al., 1992). A similar marine-nonmarine link is strongly suggested for the Pollack Site as well.

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DEPOSITIONAL ENVIRONMENTS AND STRATIGRAPHY OF THE POLLACK FARM SITE, DELAWARE¹

Kelvin W. Ramsey²

ABSTRACT

At the Pollack Farm Site near Cheswold, Delaware, surficial Quaternary deposits of the Columbia, Lynch Heights, and Scotts Corners formations unconformably overlie the Calvert Formation of Miocene age. The Quaternary units were deposited in fluvial to estuarine environments. The Calvert Formation at the site is subdivided into seven informal lithostratigraphic units, in ascending order—shelly mud, lower shell bed, lower sand, interbedded sand and mud, cross-bedded sand, and upper mud. The units represent deposition in shallow marine (shelly mud), subtidal (lower shell bed, lower sand, interbedded sand and mud), and subtidal to intertidal-supratidal (cross-bedded sand, upper mud) environments. The depositional setting was probably much like that of modern coastal Georgia with scattered barrier islands fronting small estuaries and tidal channels with a fresh-water influence and nearby uplands. Mixing of marine, estuarine, fresh-water, and terrestrial vertebrate and invertebrate taxa is common in such a setting. This setting was part of a much larger deltaic progradational complex that deposited, in Delaware, the Cheswold sands of the lower part of the Calvert Formation.

INTRODUCTION

The Chesapeake Group (upper Oligocene—upper Pliocene) of the middle Atlantic Coastal Plain has long received attention because of the excellent molluscan faunas preserved within its sediments (Shattuck, 1904). Most of the attention has focused on the outcropping fossiliferous sections of the group (Calvert, Choptank, and Saint Marys formations) on the western shores of the Chesapeake Bay in Maryland (Gernant, 1970; Kidwell, 1982) and along the tidal rivers of Virginia (Ward and Blackwelder, 1980). The Choptank Formation of middle Miocene age has been described in outcrop along the Choptank River on the Eastern Shore of Maryland (Shattuck, 1904; Kidwell, 1982). Jordan (1962) recognized that rocks present in Delaware are equivalents of the outcropping Miocene rocks of Maryland, but he did not differentiate the Chesapeake Group into its separate formations. In Delaware, only rare exposures of the Calvert and Choptank formations have been noted (Pickett and Benson, 1983), but all formations of the Chesapeake Group (Calvert through Bethany) are present in the subsurface (Andres, 1986; Benson, 1990; Ramsey, 1993, 1997). In New Jersey, outcrops of the age-equivalent Kirkwood and Cohansey formations have been described in terms of fossil content (Richards and Harbison, 1942) and depositional environment (Isphording, 1970).

The Pollack Farm Site provided a unique opportunity to study the depositional environments and fossil content of the lower Calvert Formation in central Delaware. The site, a borrow pit for sand aggregate for highway construction, subsequently was covered and converted to a wetland. High walls bordering the several areas of excavation within the site were excellent places for investigating the local stratigraphy and for measuring sections (Fig. 1). This paper describes and interprets the depositional environments found within the Calvert at the site, including the fossiliferous beds. In addition, units of Quaternary sediments overlying the Calvert are described.

Acknowledgments

It was through the diligence of A. Scott Andres of the Delaware Geological Survey that fossils were first found at

the site. He also assisted in mapping the locations of excavations and, with C. Scott Howard, in measuring the sections. Alfred D. Donofrio of Century Engineering, Inc., was instrumental in providing the engineering plans for the site. Ronald L. Martino shared data from his work on the burrows in the cross-bedded sands. Molly F. Miller also is acknowledged for discussions concerning the depositional environment associated with the burrows. Others at the Delaware Geological Survey including Thomas E. Pickett, Richard N. Benson, and Kathleen Butoryak helped with some phases of the field work. I thank Stefanie J. Baxter, Richard N. Benson, and Allan M. Thompson for their constructive reviews of the manuscript.

STRATIGRAPHIC UNITS OVERLYING THE CALVERT FORMATION

The Calvert Formation at the Pollack Farm Site is unconformably overlain by surficial deposits of Quaternary age (Groot et al., 1995; Ramsey, 1993, 1994, 1997): (1) on the west by the Columbia Formation, (2) in the central portion by the Lynch Heights Formation, and (3) on the east by the Scotts Corners Formation (Fig. 2). The site straddles two former shorelines of Delaware Bay represented by breaks in topography (scarps) across the middle of the site (Fig. 2). Investigation of the Quaternary units at the site was limited owing to their removal early in the excavation process and modification by heavy-equipment traffic. From the data available, the units are characterized as follows.

Columbia Formation

The Columbia Formation (Jordan, 1964) at the site consists of reddish brown to tan, medium to very coarse, gravelly sand. A section typical of the Columbia from the western end (west wall, Fig. 1) of the site is shown in Figure 3. The Columbia is cross-bedded with sets of high-angle cross beds dipping to the south or southeast that are interbedded with beds of low-angle cross-bedded sands that are finer-grained, usually in the medium- to fine-grained size range (Figs. 3, 4). Pebbles of quartz are common with lesser amounts of chert and some lithic fragments. At the sharp

¹ In Benson, R.N., ed., 1998, *Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware*: Delaware Geological Survey Special Publication No. 21, p. 27–40.

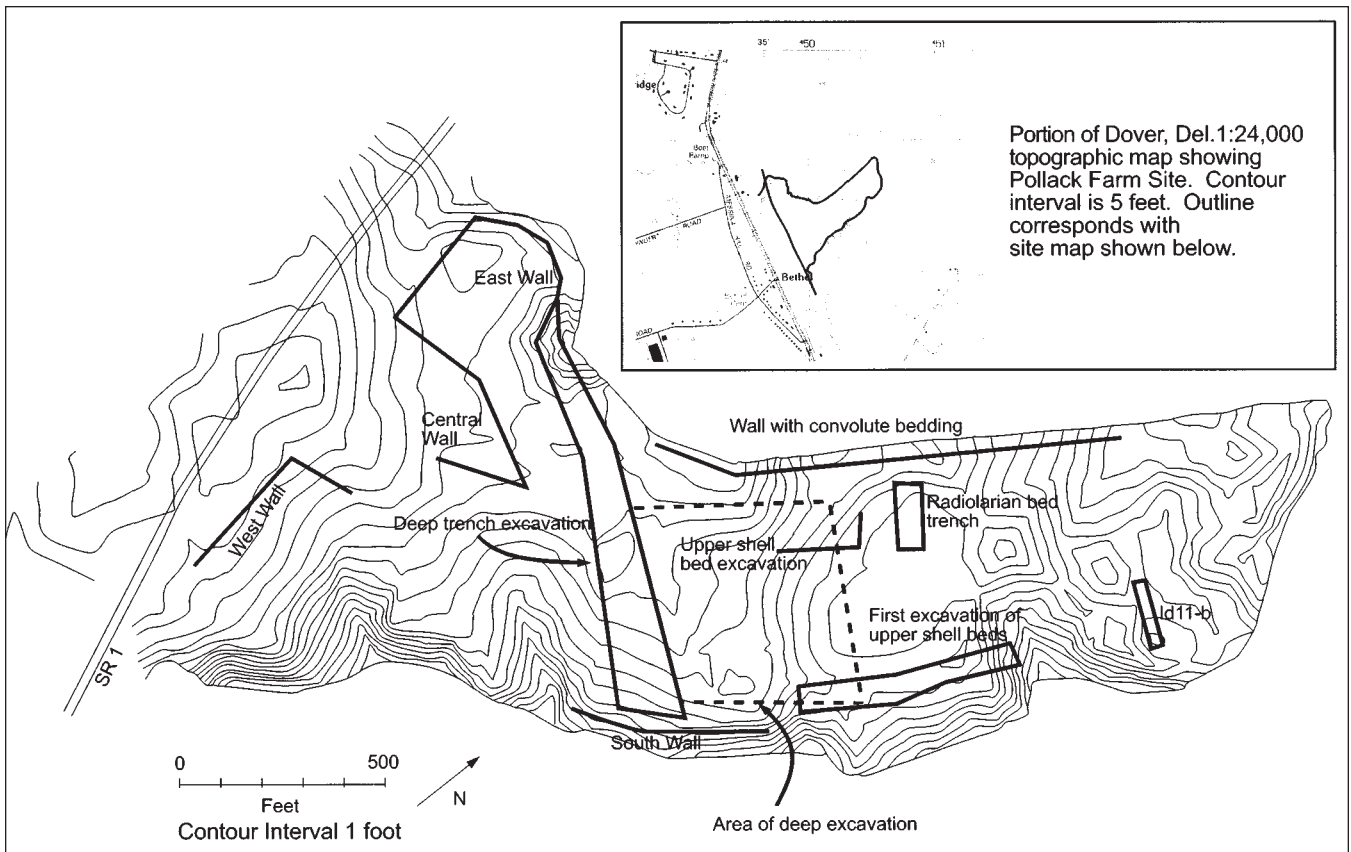


Figure 1. Map of the Pollack Farm Site (Delaware Geological Survey site Id11-a) showing locations of major excavations and sites of measured sections and fossil collections. The deep trench in the center of the site was the deepest part of the excavation. The area of deep excavation started on the east side and was moved to the west and backfilled as excavation continued.

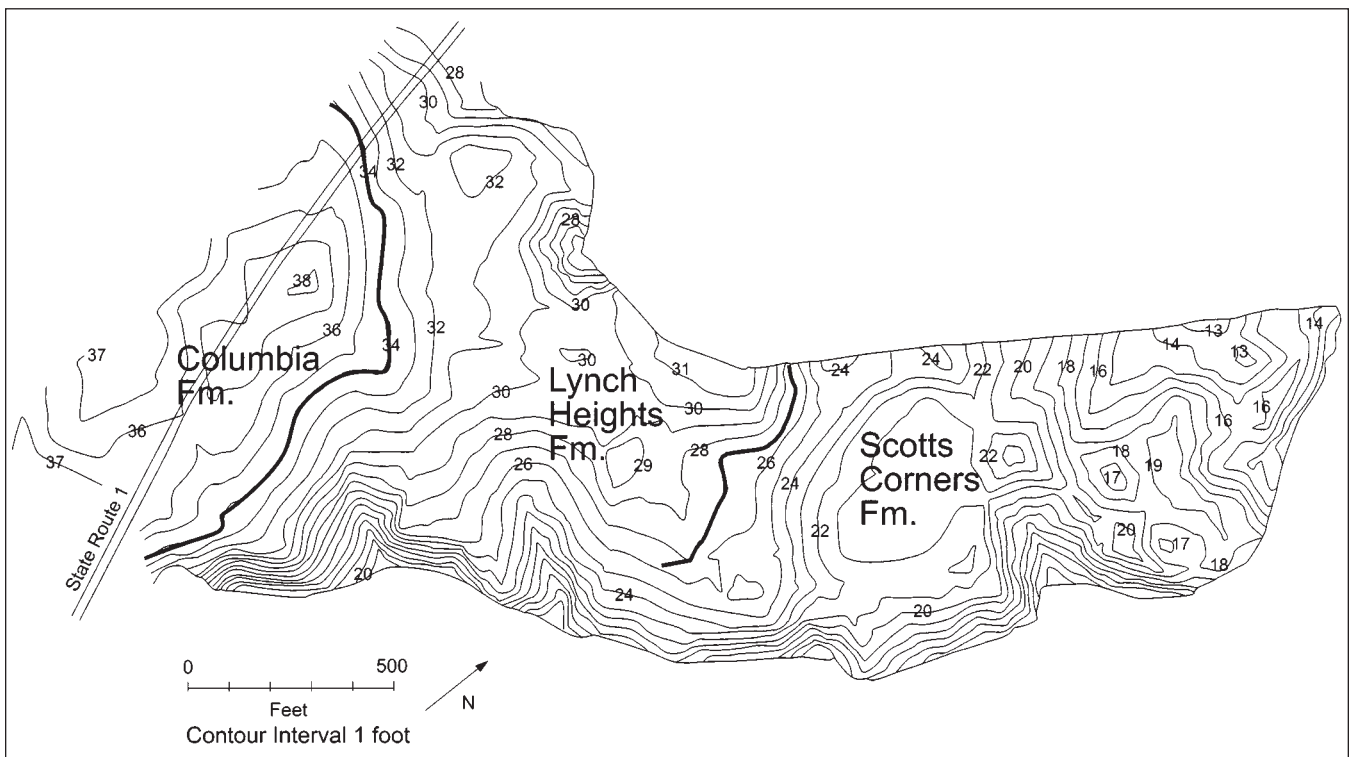


Figure 2. Geologic and topographic map of the Pollack Farm Site. Pre-excavation hypsography (datum mean sea level) is after engineering plans for the site provided by Century Engineering, Inc. Bold lines are scarps discussed in text.

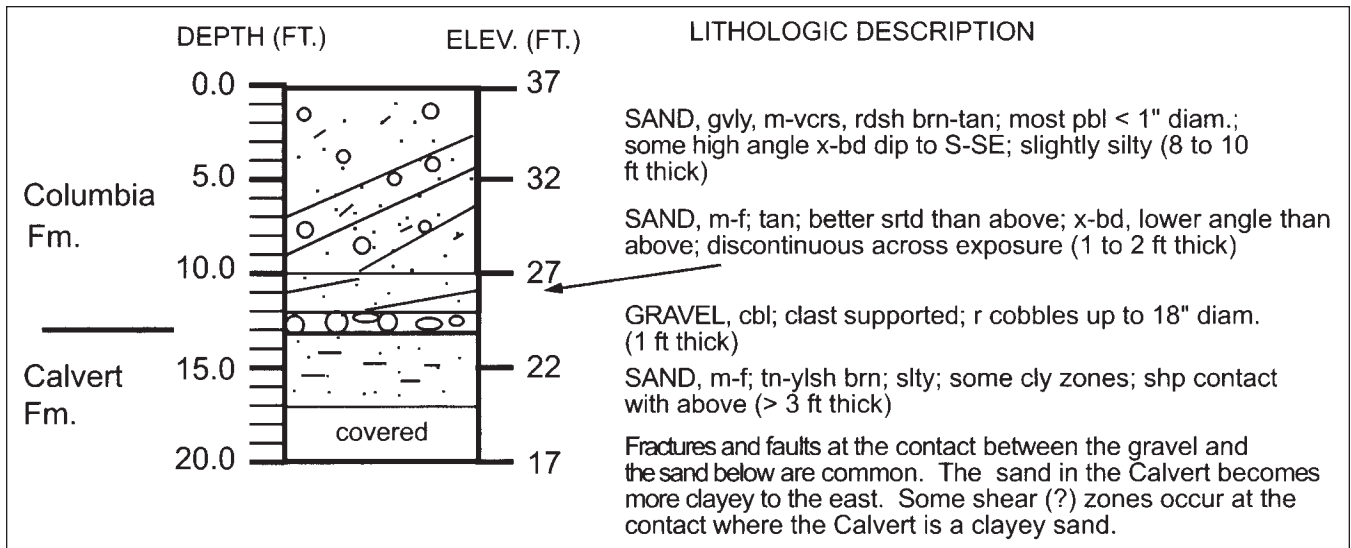


Figure 3. Measured section at the west wall (Fig. 1).

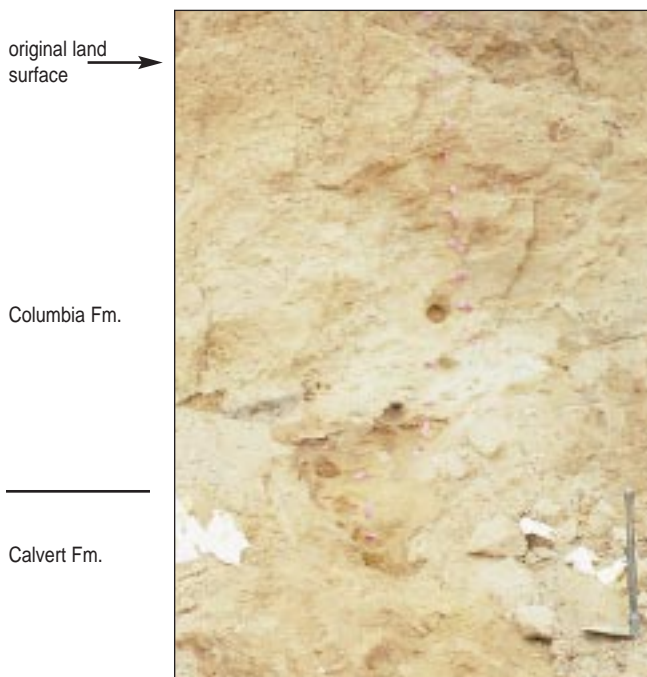


Figure 4. Photograph of a section of the west wall showing the Columbia Formation overlying the Calvert Formation. Length of shovel is 1.5 ft.

contact with the underlying Calvert Formation, a bed of gravel and gravelly sand with both pebbles and cobbles is present (Fig. 4). An interesting feature of the contact is the abundance of small-scale fractures (faults) and shear zones that have disrupted the contact and in places mixed the lithologies at the contact (Andres and Howard, 1998). It is unknown whether the disruptions are due to loading of the Columbia on the Calvert or some other cause such as cryogenic movement. Sedimentary structures within the Columbia Formation are indicative of a fluvial deposit (Jordan, 1964, 1974). Maximum thickness of the Columbia at the site is about 15 feet.

Lynch Heights Formation

To the south of the site along the present Delaware Bay margin, the Lynch Heights Formation is found in strati-

graphic position between the Columbia and Scotts Corners formations (Ramsey, 1993, 1994, 1997). The detailed, pre-excavation topographic map of the Pollack Farm Site (Fig. 2) shows a narrow platform about 27 to 32 feet in elevation across the central portion of the site. The Lynch Heights at the north end of the site along the east wall (Fig. 1) consists of a light yellowish brown, medium to fine sand (Figs. 5, 6) that fills a shallow trough (channel) cut into the underlying Calvert Formation. The sand grades down into a trough cross-bedded, coarse to medium sand at the base of the trough that has a cobble and pebble layer within it and also cobbles and pebbles at the base. There was not enough exposure to determine the extent of the cobble and pebble beds, which probably represent material eroded from the adjacent Columbia Formation and redeposited within the Lynch Heights Formation.

Scotts Corners Formation

The Scotts Corners Formation occurs east of a scarp at which land surface elevations drop from 30 to 40 ft on the west to less than 25 ft on the east. Land surface elevations on the Scotts Corners at the site range from 27 to 13 ft above sea level. The Scotts Corners throughout the site is thin, averaging less than 10 ft in thickness. It is very thin along its western extent and may be absent in places between 23 and 27 feet in elevation where the contact between the Scotts Corners and Lynch Heights is drawn (Fig. 2). It is characterized as a light yellowish brown to light reddish brown, medium to fine, quartzose sand and is structureless to trough cross-bedded. Some discontinuous, clayey silt laminae are present as well as silty clay clasts. A zone of scattered pebbles is found along its contact with the underlying Calvert Formation. The pebbles become more common closer to the scarp (to the west), and a few cobbles are present. In places, light yellowish brown to white, well-sorted sands are common as well as scattered pebbly zones. Sedimentary structures are highly disrupted, probably owing to cryoturbation (Andres and Howard, 1998). Depositional environments within the unit are estuarine, but perhaps with a stronger fluvial influence than that seen about 25 miles to the southeast in the vicinity of Milford where the formation was first described (Ramsey, 1993, 1994, 1997).

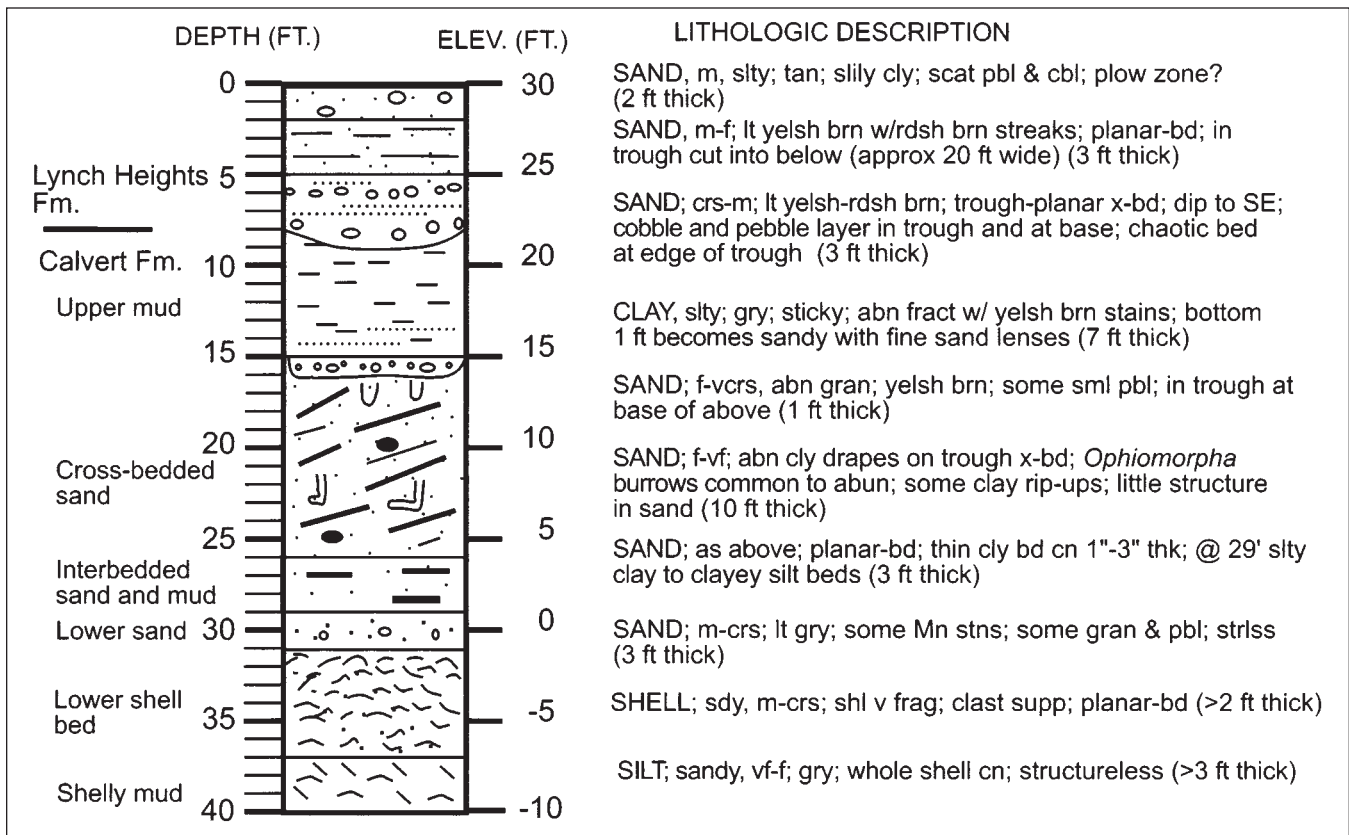


Figure 5. Measured section at the east wall (Fig. 1).

Undrained Depressions

On the surface of the Scotts Corners, several undrained depressions (Ramsey, 1994) are concentrated at the eastern end of the site (Fig. 1, inset map and around Id11-b). These consist of oval to irregularly shaped depressions that range in size from <100 to 400 ft in diameter and from 1 to 3 ft in depth from the lowest parts of the depressions to their edges.

Site Id11-b (Fig. 1), a trench cut in May 1991 as part of the site archaeological investigation across one of these depressions, revealed fine-grained sediments that nearly fill the depression and are in contact with both the Calvert and Scotts Corners formations (Fig 7). The contact with the Scotts Corners ranges from obscure to sharp. The fill consists of light gray, structureless, sandy silt to silty sand with a thin layer of organic-rich sand near its contact with the

underlying Calvert. The fill is bowl-shaped and no more than 5 ft thick. Beneath it, the Calvert contact with the Scotts Corners is highly contorted and disrupted with contorted clay blocks and flame structures from the Calvert mixed in with the sand of the Scotts Corners. A distinct, brown weathering horizon (paleosol) is present on the Calvert.

The origin of the depressions is unknown but may be related to blow-outs or cryogenic processes during the last glacial period (Andres and Howard, 1998). The sediments within the depression are a combination of sands locally reworked by seasonally ponded water and wind-blown material (silts and sands), and they post-date the deposition of the Scotts Corners which occurred during the preceding interglacial period (Ramsey, 1993, 1997).

CALVERT FORMATION

Six stratigraphic units are recognized within the Calvert Formation at the Pollack Farm Site on the bases of characteristic sedimentary structures, textures, and, where present, fossil content (Figs. 5 and 8). Figure 9 is a schematic dip cross section of the units within the Calvert at the site. In ascending order they are the shelly mud bed, the lower shell bed, the lower sand, the interbedded sand and mud, the cross-bedded sand (containing the upper shell bed), and the upper mud. Where the term "mud" as used in this report refers to a sediment that has a silt and clay component greater than that of sand. The sand beds at the site are part of the Cheswold sands (after the Cheswold aquifer of the lower Calvert in Delaware): the lower shell bed and lower sand correlate with the Cheswold C-3 sand, and the cross-bedded sand (upper shell bed) with the C-4 sand of Benson (1998).



Figure 6. Photograph of central wall excavation (Fig. 1) showing the Lynch Heights Formation overlying the Calvert Formation. The upper shell beds of the Calvert were exposed approximately 100 ft to the east (right) of this excavation.

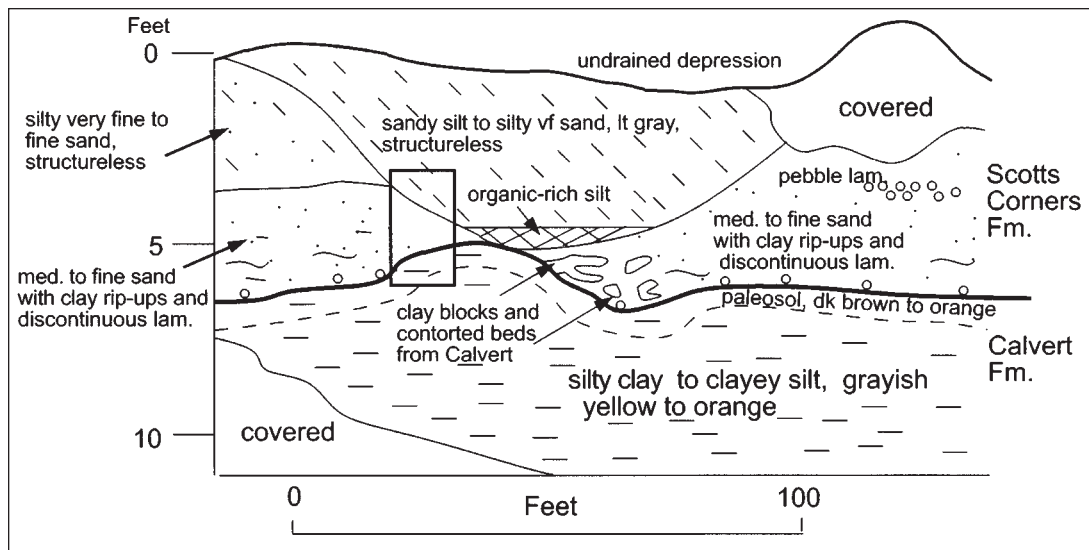


Figure 7. Sketch of site Id11-b (Fig. 1) showing the stratigraphic relationships of the undrained depression deposits and the Scotts Corners and Calvert formations. The photograph shows a portion of the exposure outlined as a box on the sketch.

Shelly Mud Bed

The shelly mud bed was the lowest part of the Calvert Formation exposed at the Pollack Farm Site. It was best exposed at the northern end of the excavation. The bed dips to the south where, at the southern end of the deep trench (Fig. 1), it was under water and only found in spoil piles from excavation below water level. Between the east wall (Fig. 5) and central wall (Fig. 8) exposures, the bed dips approximately 20 ft over a distance of about 500 ft (Fig. 1). Total thickness of the bed is unknown but is estimated to be 15 to 20 ft on the basis of correlation with the gamma log from nearby well Ic25-12 (Benson, 1998, fig. 4).

The shelly mud consists of dark greenish-gray, very fine, very silty sand to sandy silt (Fig. 10). The sand is quartzose, consisting of subrounded to subangular, clear quartz, the characteristic signature of Chesapeake Group sands in Delaware. Minor constituents include some phosphate and heavy-mineral grains (in the finest sand fraction). A few radiolarians, foraminifers, and echinoid spines were identified as well as a few sand-size vertebrate bone fragments and teeth. Shell fragments are a common constituent of the sands, ranging from granule size to 1 to 3 inches in diameter. Whole shells are also common and include disarticulated valves of *Chesapecten*, which tend to be scattered in the mud and do not form discrete shell beds. Although some shells appear to

lie along planes that may represent relict bedding surfaces, no primary sedimentary structures were found within the unit. In addition, shells of *Mytilus*, *Mercenaria*, *Panopea*, *Astarte*, and *Clementia* are found scattered throughout the bed, many in living position (Ward, 1998). Shells of gastropods, including *Turritella*, are also present. In places, the bed has a mottled appearance, the mottles containing fine sand. The mottles are probably sand-filled biogenic structures, probably burrows (R. Martino, pers. comm., 1992).

The contact of the lower shelly mud with the overlying lower shell bed is sharp (Fig. 10). There is some local relief on the contact amounting to no more than 1 or 2 ft over tens of ft of exposure. Although the lower shelly mud is burrowed, no burrows were observed that extend down from the contact or from the overlying shell bed. The marked contrast in lithologies suggests that the contact represents a disconformity.

Lower Shell Bed

The lower shell bed is the major source of the vertebrate and invertebrate fossils from the site. The primary lithology is a fossiliferous sand consisting of abundant mollusk shells (Ward, 1998). The shells are disarticulated, densely packed, and poorly sorted; articulated bivalves are extremely rare. The sand matrix consists of coarse to very coarse sand with abundant granules and pebbles of quartz,

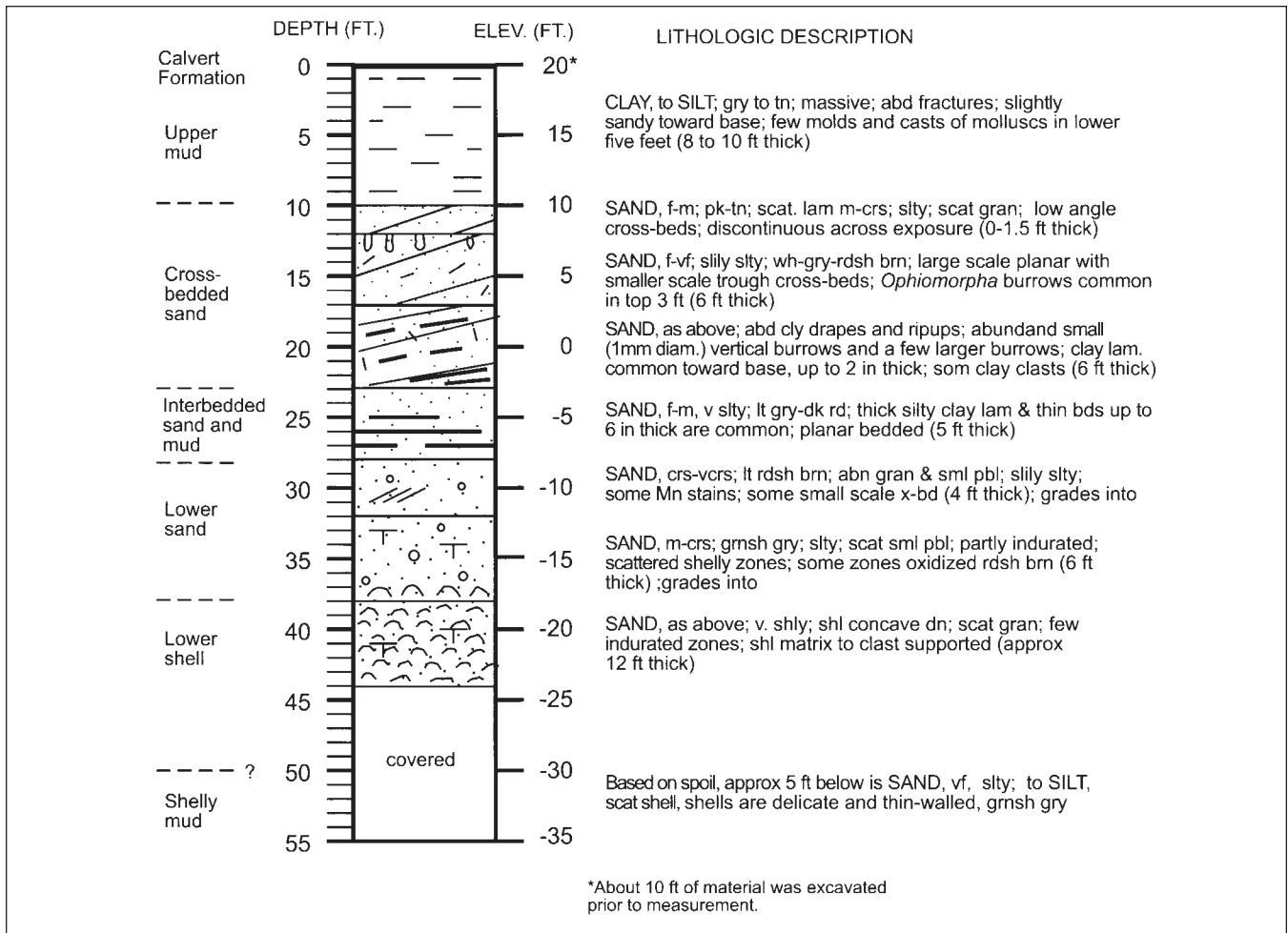
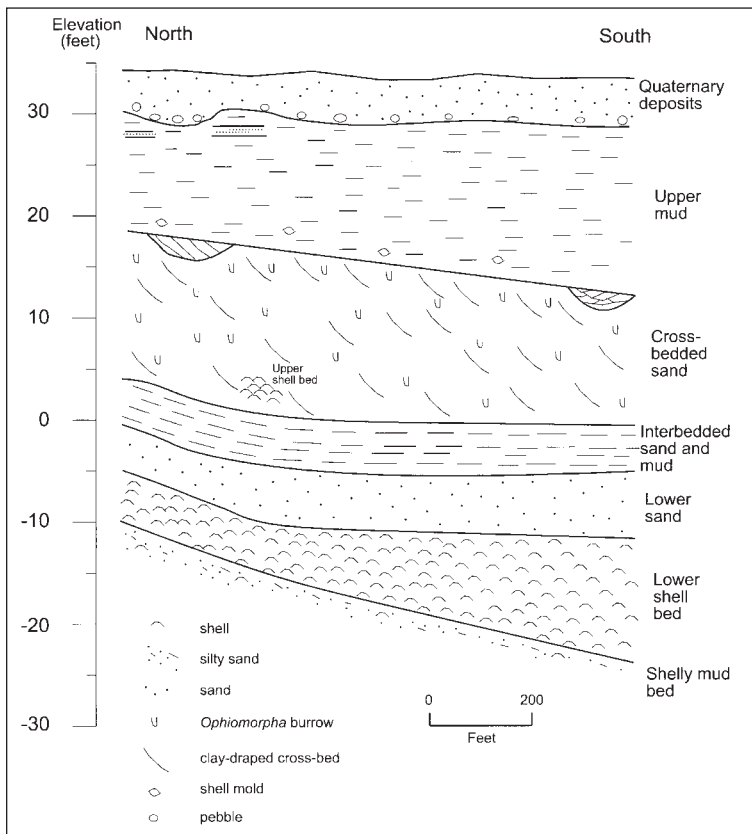


Figure 8. Measured section at the central wall (Fig. 1).



chert, and phosphate in decreasing order of abundance. Distributed throughout the bed are disarticulated bones and teeth of vertebrates that lived in a variety of habitats: marine and land mammals, terrestrial and fresh-water reptiles, fish, and birds. Only a few marine mammal vertebrae may be associated with a single individual.

The sandy shell bed is cross-bedded with dominant cross-sets dipping to the south-southeast and a secondary component, although weak, to the northwest (R. Martino, pers. comm., 1992), indicating a bimodal component to flow. Imbricate shells along cross-bed foresets emphasize the cross-bedding (Figs. 11, 12). The cross-bedding is compound with a series of stacked sets of tabular to planar cross-beds ranging from 0.5 to 2.0 ft thick. Some of the sands within the cross-sets exhibit fining-upward textures. Whole shells are very common, some of which are abraded and have lost much of their ornamentation. Others are very delicate thin shells with ornamenta-

Figure 9. North (on left) to south schematic cross section showing the stratigraphic relationships of beds within the Calvert Formation at the Pollack Farm Site. Cross section is based on measured sections and other data along the east and central walls and along the deep trench excavation.

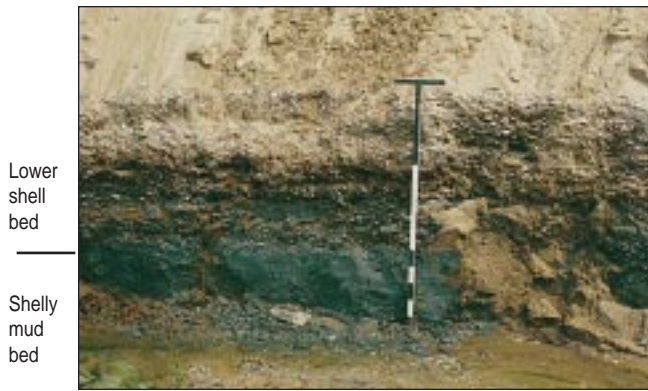


Figure 10. Photograph of the contact between the shelly mud bed and lower shell bed of the Calvert Formation. Section located along the east wall at the northern tip of the deep trench excavation (Fig. 1). Length of staff is 3 ft.



Figure 11. Photograph of cross-bedding in the approximately 4-ft-thick lower shell bed. Cross-sets are dipping to the south. Section located in the deep trench excavation opposite the central wall (Fig. 1).



Figure 12. Photograph of small-scale fining-upward sets in the lower shell bed. Glycymerid shells (maximum diameters approximately 3 in) form the large clasts and shell hash the smaller clasts that fine upward. Some of the glycymerid shells are imbricated. Dip of sets is to the south. Section located on the west side of the south end of the deep trench excavation (Fig. 1).



Figure 13. Photograph of the silt bed in the lower shell bed. Location of the section is about 50 ft to the north of the shell bed in Fig. 12. The silt bed is about six inches thick.

tion well preserved. Broken shells are also very common and with the sand form the matrix of the unit. Pieces of wood and lignite are also present as clasts. No bioturbation structures were observed within the unit. A few zones of cementation were observed (Fig. 8). The primary cement is calcium carbonate but reddish stains indicate that some iron oxide cements may be present as well.

Lenses of greenish-gray, compact, clayey, slightly sandy silt are present within the lower shell bed (Fig. 13). They have characteristic lens shapes that are thicker to the northwest and thinner to the southeast. Thicknesses of the silt beds are between 0.6 and 1.5 feet. The most noticeable characteristic is their lack of shell material, and, yet, they are surrounded by extremely shelly beds.

The lower shell bed thickens to the south. It is approximately 4 ft thick at the northern end of the exposure and is up to 10 ft thick at the southern end. Given the limited extent of exposure, it is difficult to ascertain whether the thickening of the bed is by sediment accumulation or whether it reflects a lesser degree of dissolution of the upper portion of the shell bed with increasing depth below the present land surface.

The upper contact with the lower sand is gradational

and is placed where the predominant sediment constituent passes from shell to sand. In places, the contact is sharp, but there is no discernable difference between the sand matrix in the shell bed and that of the overlying lower sand. A few scattered, cemented remnants of the shell bed lie above the contact. Along with shell “ghosts” in the lower sand, a loss of shell material by post-depositional dissolution is indicated. Information from excavation workers at the site suggests that the lower shell bed thins both to the east and the west.

Lower Sand

The lower sand consists of a light-gray to greenish-gray to light reddish-brown, coarse to very coarse sand with abundant granules and small pebbles. Its thickness ranges from 2 to 4 ft at the northern end of the site to 8 to 10 ft at the southern end. Zones of black, manganese-stained sands are common, especially just above the lower shell bed. The base of the lower sand is commonly marked by a zone of greenish-gray color that contrasts with the typical light reddish-brown of the unit (Fig. 14). The unit is, for the most part, structureless. Some small-scale (<0.5 ft-thick) cross-beds were observed in the upper 2 ft of the unit. Also present are shell “ghosts,” outlines of shells in cross-section preserved as iron oxide stains in the sand and a few outlines of vertical to horizontal burrows, generally no more than 1 inch in diameter.

By all indications, the lower sand is part of the same



Figure 14. Photograph of the lower sand above the lower shell bed. Location of the section is directly above that of Fig. 13.

depositional unit as the lower shell bed. It is compositionally and texturally the same as the sand matrix of the lower shell bed. It contains pockets of cemented shell, like that below, no more than 3 ft above the lower shell bed. No distinct break was observed between the two units. The faunal composition and poorly preserved sedimentary structures of the lower sand are similar to those of the underlying unit.

The contact of the lower sand with the overlying interbedded sand and mud unit is sharp. Some cross-beds within the lower sand appear to be truncated by the overlying clayey silt beds. Minor reworking of the coarse sand below into the overlying unit is evident from scattered coarse laminae near the base of the unit. The contact between the two units could be traced across the site.

Interbedded Sand and Mud

The interbedded sand and mud unit consists of light reddish-brown, well-sorted, fine to medium sand interbedded with light gray to light red clayey silt laminae to thin beds. The sands are quartzose, with minor amounts of heavy minerals. Rare laminae of coarse to granule sand like that of the lower sand are present, especially near the lower contact. Most of the granules are chert, but some phosphatic grains were also observed. The clayey silt laminae and thin beds contain some very thin silt to very fine sand laminae. The clayey silt beds are the dominant lithology near the base of the unit (Fig. 15). The unit grades upward into sand with clayey silt laminae and becomes wavy to flaser bedded near the top. The flasers outline asymmetrical ripples with rounded crests. Small-scale cross-beds (ripple bedding?) predominate near the top of the unit where sand-filled, vertical to inclined burrows are also present and the sand becomes burrow mottled (R. Martino, pers. comm., 1992). Bedding throughout the unit is nearly horizontal and planar. The unit is identified as the parallel bedded sand by Benson (1998, fig. 2).

The interbedded sand and mud ranges from 4 to 5 ft in thickness. The clayey silt beds are slightly thicker near the southern end of the exposure where they are as much as 6 in thick, whereas at the northern end they are typically 2 to 3 in. Pollen and diatoms were recovered from some of the clayey silt beds (Benson, 1998; Groot, 1998).

About 500 ft to the east of the deep trench excavation (radiolarian bed trench, Fig. 1), a bed of light gray sandy silt of undetermined thickness was found at the same elevation as the interbedded sand and mud. The bed yielded abundant



Figure 15. Photograph of the interbedded sand and mud. Light-colored laminae are sands; darker-colored laminae are clay drapes and silty clay laminae. Location along the east wall. Dip of cross-bedding is to the south.

radiolarians that identify the *Stichocorys wolffii* Zone, an early Miocene (Burdigalian) global biostratigraphic zone, and the diatom *Actinoptychus heliopelta* that identifies East Coast Diatom Zone 1 (Benson, 1998). The area of the Pollack Farm Site where the radiolarian bed was trenched was excavated and back-filled prior to subsequent visits to the site; therefore, the extent and stratigraphic relationship of the bed to the interbedded sand and mud remains unknown. See Benson (1998) for further discussion.

In most places, the contact between the interbedded sand and mud and the overlying cross-bedded sand is sharp, marked by the appearance above the contact of distinct trough cross-bedding and abundant clay-pebbles. In some places, the contact is almost gradational, but the changes in sedimentary structures and bedding style are distinctive enough to be able to trace the contact across the exposure.

Cross-Bedded Sand

The cross-bedded sand unit consists of light reddish-brown, fine to very fine, trough cross-bedded sand with scattered clayey silt clasts, flasers, and thin laminae. The unit is distinctively burrowed with abundant *Ophiomorpha*-type burrows as well as *Skolithos* (Miller et al., 1998) and rare *Rosellia* burrows. The sands are quartzose with scattered laminae of opaque heavy minerals. The unit can be subdivided into two parts separated by a gradational boundary.

The lower part, 4 to 6 ft thick, consists of fine to very fine sand with some laminae of medium sand, especially near the base where it is a cross-bedded sand with abundant clayey silt drapes and rip-up clasts (Fig. 16). Rounded mud clasts (pebbles) are common especially near the contact with the underlying unit. The clayey silt drapes over small ripple cross-bedding. In places, thin rip-up mud clasts derived from the drapes occur on the downflow sides of cross-sets. A few discontinuous, thin clay laminae occur near the base of the unit. Thin (1mm) clayey-silt-lined, vertical *Skolithos*-type burrows are very common in this part of the cross-bedded sand.

The upper part of the cross-bedded sand unit is between 6 and 8 ft thick and consists of fine to very fine sand with large-scale planar cross-beds with smaller scale trough cross-sets (Figs. 17–19). Clayey silt drapes and rip-ups are present, slightly less common than those in the lower part of



Figure 16. Photograph of the lower part of the cross-bedded sand. Clay draped laminae stand out in relief. Coin is a U.S. quarter, diameter approximately 1 in. Section located along the east wall.



Figure 17. Photograph of the upper part of the cross-bedded sand. Burrows, clay drapes, and clay rip-up clasts stand out in relief in the sand. Knife body is approximately 3 inches long. Section located along north end of the east wall.

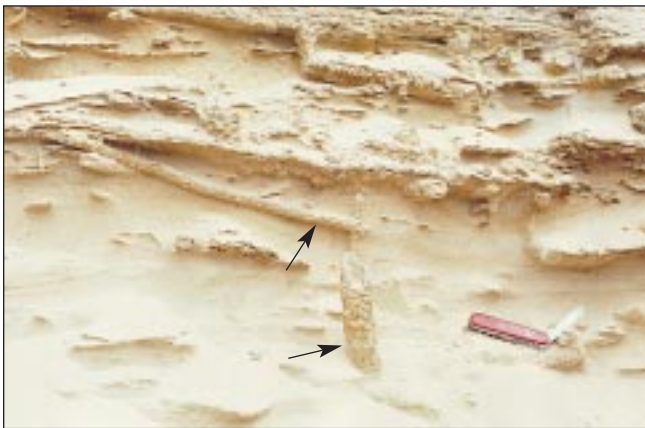


Figure 18. Close-up of Figure 17 showing *Ophiomorpha* burrows (arrows).

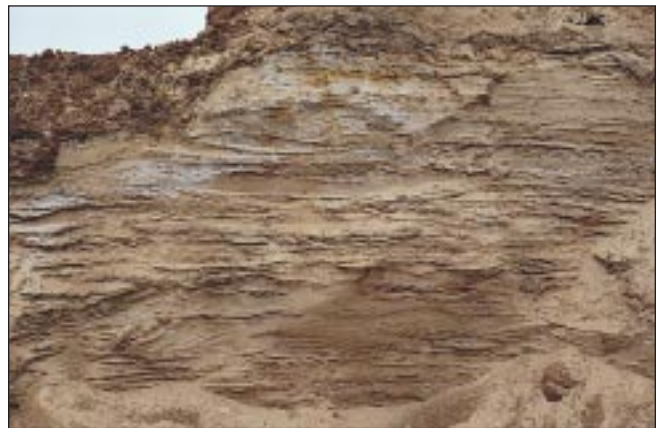


Figure 19. Photograph of the upper 10 ft of the cross-bedded sand. Clay laminae and drapes stand out in relief in the sand. Section located along the south end of the east wall near the north end of the deep trench excavation.

the unit. Clay pebbles are rare. The unit has abundant *Ophiomorpha* burrows throughout its extent (Miller et al., 1998). Where the exposure is sculpted by blowing wind, both the trough cross-bedding and the burrows stand out in relief (Figs. 17, 18). Heavy-mineral laminae are also found within the unit. Individual cross-sets are defined texturally, generally fining-upward. Limited measurements of cross-sets indicate a paleocurrent flow to the east-southeast.

Total thickness of the cross-bedded sand ranges from 10 ft on the north to 15 ft on the south. *Ophiomorpha* burrows may be less common to the south, but this part of the section was not well exposed at the southern end of the excavation.

Three other lithologies are found within the cross-bedded sand unit but are not continuous throughout the Pollack Farm Site. The first, and most laterally persistent, is a light reddish-brown, fine to medium sand with scattered laminae of medium to coarse sand with scattered granules. The sand is found just below the contact with the overlying upper mud and ranges from 0 to 1.5 ft in thickness. Low-angle planar cross beds are the most common sedimentary structure. Some clayey silt rip-up clasts are found along the foresets of the cross beds. No burrows were observed in this lithology. The contact with the underlying sands is sharp; a few *Ophiomorpha* burrows are truncated by the sand.

The second lithology is a light gray to light reddish-

brown, slightly silty, fine sand that is restricted to a bowl-shaped channel feature found between the upper mud and the cross-bedded sand (Fig. 20). The channel feature was observed in an exposure on the east wall near the bend where edge of the pit turns to the east, and again on the south wall of the exposure at the deep trench (Fig. 1). It was also seen in a short-lived exposure about halfway between these two exposures. The sands filling the channel display planar-bedding, roughly parallel to the shape of the channel. The lowermost contact with the underlying sands is sharp. No burrows were observed within the unit. It is sharply truncated by the overlying upper mud unit. The feature is about 12 ft wide and 3 ft. deep in the northern exposure and about 20 ft wide and 6 ft deep at the southern end of the exposure.

A third lithology, the upper shell beds (Benson, 1998, fig. 2), is a densely packed, poorly sorted, shell hash with a medium to coarse sand matrix with scattered granules and pebbles (Figs. 21, 22). This lithology was found along a haul road excavation heading to the eastern part of the excavation to the east of the main exposure (Fig. 1). It was subsequently removed as excavation proceeded. Continuous exposure with the main part of the excavation to the west allows for placing the shell hash



Figure 20. Photograph of a channel (light gray) at the base of the upper mud. Channel cuts into cross-bedded sand below. Approximately 20-ft exposure located along south wall.



Figure 21. Photograph of the shell hash of the upper shell bed. Note pebbles just below and to the left of the U.S. quarter. Section located in the east-central portion of the site (Fig. 1).



Upper shell bed | dissolution collapse

Figure 22. Photograph of the dissolution collapse at the eastern end of the upper shell bed. Coin is a U.S. quarter. Section location about 3 ft to the east of Fig. 21.

(or upper shell bed) within the upper part of the cross-bedded sand unit. The upper shell bed consists of a mixture of broken shell with some whole shell, primarily *Crassostrea*, and some bones and teeth of vertebrates, including abundant turtle-shell fragments. The shell beds form mound-like features surrounded by sand. At the edges of these mounds, collapse features indicate dissolution of shell and collapse of the adjacent surrounding sand (Fig. 22). The contact of the shell “mound” with the sand is very sharp. Laterally from the shelly zones, shell “ghosts” were found in the sands that laterally grade to the west into the upper part of the cross-bedded sand.

Upper Mud

The upper mud unit is the uppermost portion of the Calvert Formation exposed at the Pollack Farm Site. It consists of a light gray to light reddish-brown clayey silt. The unit tends to be massive; bedding is generally absent. A few very fine sand laminae up to 3 in thick were observed near the base of the unit, and some very fine silty sand beds were seen at the contact between the Calvert and Columbia formations at the west wall of the exposure (Fig. 1). A few

molds and casts of bivalve shells were found near the base of the unit. These were not identifiable as to genera. Within the upper mud unit, a few pyritized diatoms were found, but no other microfossils such as radiolarians or foraminifers. The most distinguishing characteristic of this unit is its highly fractured appearance. Both horizontal and vertical fractures are found throughout the unit. Some of these have slickensides, and many have mineralized zones of sulfate salt minerals. The unit thickens slightly from north to south from about 15 to 20 ft.

CALVERT DEPOSITIONAL ENVIRONMENTS

On the bases of its lithologies, stratigraphic relationships, and faunal and ichnologic remains (Ward, 1998; Benson, 1998; Miller et al., 1998), the Calvert Formation at the Pollack Farm Site is interpreted to have been deposited primarily in a marginal marine to intertidal setting; open marine environments were subordinate. The Cheswold sands at the Pollack Farm Site are part of a regional deltaic depositional system that extended from New Jersey into northern Delaware and that distributed sands over wide areas that are interbedded with correlatable mud beds also of regional extent (Benson, 1998).

The Pollack Farm Site is in a sense a snapshot of just a small portion of the entire system. It is interpreted by the author to represent a shallowing-upward sequence deposited in shallow marine to intertidal depositional environments. A setting for this site may be similar to the tidal streams and estuaries of the present Georgia barrier island coast (Greer, 1975) where small embayments and tidal flats are in juxtaposition to an open ocean setting. A difference is that the sand supply for the Calvert Formation was much higher than that for the Georgia coast. The following interpretations are based primarily on the observations of sedimentary structures and stratigraphic relationships observed at the Pollack Farm Site.

Shelly Mud Bed

The shelly mud bed (and the radiolarian bed of Benson, 1998) represents the deepest water and probably the most marine of any of the local stratigraphic units within the Calvert Formation exposed at the site. The uniformity of lithology, silty texture, and lack of abundant sedimentary structures indicate deposition in a relatively open marine,

inner shelf, quiet-water setting below storm wave base where there may have been a steady influx of sediment. The occurrences of foraminifers, radiolarians, and diatoms (Benson, 1998), and inner shelf mollusks in living position (Ward, 1998), as well as burrows, support this conclusion. Shell fragments indicate transport of some coarser material into the area. There is little evidence of *in situ* fragmentation of shells; most of the whole shells are in good condition with no indication of breakage or fragmentation. The deposits are similar to those described by Greer (1975) for inner shelf deposits off Ossabow Sound, Georgia (Fig. 23).

Lower Shell Bed

This bed has received the most attention at the site because of the abundance of the molluscan and vertebrate fossils. In terms of depositional environment, it may be the most difficult to interpret because of the mixed signals that the fossils present. The textures and bedding of the sediments clearly indicate strong currents and transport to the south-southeast with a lesser component in the opposite direction. Currents were strong enough to move quartz, chert, and phosphate pebbles and molluscan shells, and to disarticulate shells, as well as to transport large bones such as whale vertebrae and mammalian ribs. Stacked cross-sets within the bed indicate multiple periods of deposition, perhaps within a short interval of time. Within the bed, however, are lenses of silt entirely devoid of fossils, presumably indicative of quiet water. These lenses indicate that there were times when deposition of the coarse sediment and fossils ceased and fine-grained material was deposited.

The mixed molluscan assemblage consists of brackish and normal-saline marine taxa; it includes back-barrier, intertidal, shoreface, and shallow shelf forms (Ward, 1998). The shells themselves range from highly abraded specimens to delicate forms with ornamentation preserved. Estuarine (including abundant large oyster, *Crassostrea*, shells) and marine forms dominate the assemblage. The vertebrates range from open land to forest-dwelling mammals (Emry and Eshelman, 1998), birds (Rasmussen, 1998), and terrestrial and aquatic reptiles (Holman, 1998) to marine mammals such as whales (Bohaska, 1998) and abundant sharks and other fishes (Purdy, 1998). Also present are corals and abundant pieces of wood. Many of the land vertebrate bones indicate some time of subaerial exposure prior to their final deposition (Cutler, 1998).

Clearly the environment must have been one in which the various faunal elements could be concentrated and mixed. The most likely setting was at or near the mouth of an estuary or tidal channel. A comparable modern analog is that found along the present coast of Georgia where shell accumulations along with vertebrate remains have been documented (Wiedemann, 1972; Dörjes and Howard, 1975; Frey et al., 1975; Greer, 1975) in an area of mixed estuarine and marine influence. The lower shell bed does not appear to have the characteristics of the shell accumulations in a younger portion of the Calvert Formation along the western shore of the Chesapeake Bay in Maryland and Virginia (Kidwell, 1988) where the setting was more marine and had lower sedimentation rates.

Greer (1975) reports that tidal channel bars at the mouth of the Ogeechee River where it becomes Ossabow Sound consist of coarse-grained sand, shell debris, and mud

balls, as well as lenses of fine sand and laminated mud deposited in deeper holes within the channel. This is the same area where Dörjes and Howard (1975) describe a lower middle estuarine facies composed of coarse sand and shell with a mud component. The lower shell bed has the basic characteristics of migrating bodies of sand and shell (hence the imbricate structure and stacked nature of the cross-sets and shells) with a bimodality in the cross-bedding and the presence of lenses of mud deposited in protected swales within the channel (Fig. 23). The area is also a likely setting for the mixing of the various faunal elements found in the bed. Marine vertebrates such as porpoises, sharks, and other marine fish are common visitors to the lower reaches of estuaries and tidal channels. Marine mollusks are present on the shoals and inner shelf adjacent to the inlet and would be readily mixed with the estuarine forms being transported down the estuary or tidal channel to the sea. Land vertebrate remains have been reported in late Pleistocene estuarine deposits of the Georgia Coastal Plain that occur with shark teeth and estuarine mollusks (Frey et al., 1975) that, in turn, have been reworked into estuarine deposits of the modern tidal rivers.

Lower Sand

The lower sand was deposited in much the same environment as that of the lower shell bed. The lack of much shell material is in part attributable to post-depositional dissolution. The unit, however, does have a few vertical to horizontal burrows and lacks the distinctive cross-bedding of the unit below. Texturally, there is little difference between the lower sand and the matrix of the lower shell bed. This unit is still associated with a tidal channel environment, but it may represent an influx of sand that diluted the amount of shell in the channel and that signaled the beginning of the progradational cycle of tidal flat environments on the margins of the tidal channel that dominate the rest of the section above the lower sand. The unit is similar to the swash bar deposits of Greer (1975) deposited in an area still subtidal, but shallower and closer to the channel margin than the lower shell bed (Fig. 23).

Interbedded Sand and Mud

The interbedded sand and mud unit represents the transition from tidal channel to tidal flat depositional environments. The contact between the interbedded sand and mud and the underlying lower sand is sharp and, if placed in context with the units lying above and below, represents a ravinement surface produced along the margins of the tidal channel as it migrated away from the site during the progradation of the tidal flat environments. At the same stratigraphic level in the eastern portion of the Pollack Farm Site but in close proximity (~500 ft) to the marginal marine environment interpreted for the interbedded sand and mud unit, the bed of light gray sandy silt with abundant radiolarians and diatoms indicates an environment of biologically productive open marine waters (Benson, 1998).

The interbedded sand and mud unit is typical of lower tidal flat environments that are primarily subtidal and are the result of fluctuating tides with intervening periods of sand and mud deposition (Greer, 1975; Dörjes and Howard, 1975; Reineck and Singh, 1980). The unit records progressively shallower water deposits from bottom to top (Fig. 23) as

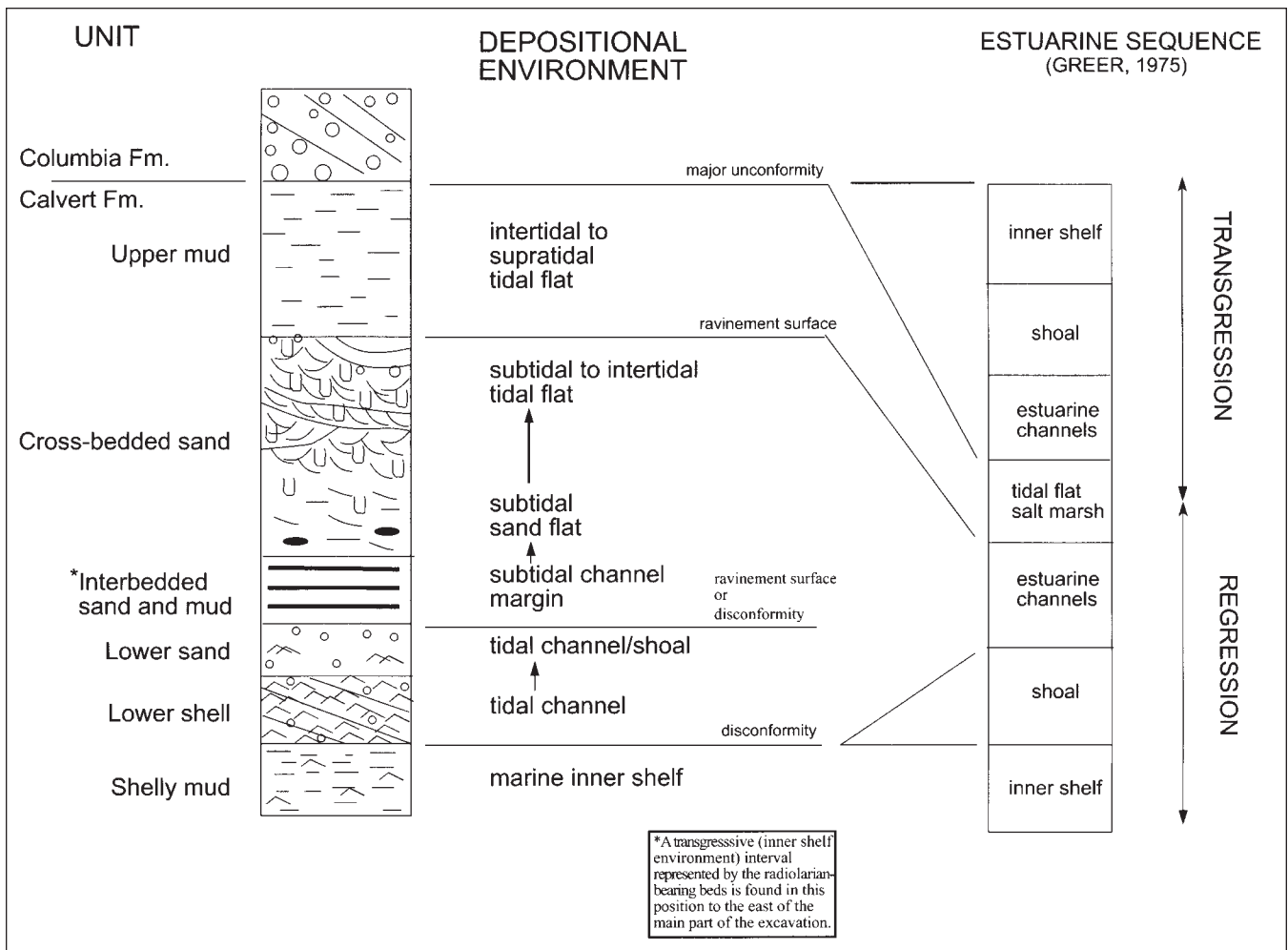


Figure 23. Comparison of the Calvert depositional environments at the Pollack Farm Site to those of a modern prograding tidal system (Greer, 1975).

indicated by the transition from thicker silt laminae horizontally interlaminated with sand to sand with wavy to flaser bedding with the flasers draping asymmetrical ripples.

Cross-Bedded Sand

The cross-bedded sand represents the transition between a subtidal environment of the interbedded sand and mud to the subtidal to intertidal environment. Both the sedimentary structures and the characteristic trace fossils of the unit (Miller et al., 1998) indicate deposition along the margins of a tidal channel in a sand-dominated system in progressively shallowing water as the channel filled and/or migrated away from the site. The presence of slightly coarser sand, abundant mud rip-up clasts, and abundant clayey silt drapes in the lower part of the unit are typical of subtidal deposits slightly off the channel center where flow is high enough to rip up and redeposit clay laminae and also has enough depth that, during slack water, clay laminae and drapes are deposited (Klein, 1977). Upward in the unit, these features give way to large-scale planar cross-sets with smaller-scale trough cross-sets composed of stacks of ripple-bedded, fining-upward sand laminae. These types of sand deposits are typical of sand flat deposits found in the shallow subtidal to intertidal margins of tidal channels (Greer, 1975; Reineck and Singh, 1980). Abundant *Ophiomorpha* burrows are found within this portion of the unit, and their presence

is consistent with the above interpretation (Miller et al., 1998).

Within the upper part of the unit are rare “mounds” of densely packed shell hash with a coarse sand matrix (upper shell beds). The mounds are composed primarily of whole and broken shells of *Crassostrea* plus *Mercenaria*, *Busycon* and other typical estuarine taxa. Mixed in with the shells are vertebrate remains; most common are turtle shell plates and shark teeth. Similar deposits are found in the modern intertidal and shallow subtidal environments in the salt-marsh estuaries of the Georgia coast (Wiedemann, 1972). They form by accumulation of shell material from various environments within the estuary into bars produced by intermittent storm surge events. The steep-sided, densely packed shell beds are typical of these deposits. It is possible that the vertebrate remains, as well as some of the shell and the coarse matrix of the bars may have been contributed by erosion of the underlying lower shell bed somewhere updip. Frey et al. (1975) report the reworking of late Pleistocene land and marine vertebrates into the modern tidal channels in the Georgia estuaries by updip erosion of older beds and incorporation of the fossil remains into the modern channels. The abraded nature of the vertebrate remains and some of the shells as well as the fragmented nature of some of the shells and the admixture of the coarse sediment and pebbles that are much like those of the lower shell bed support this

conclusion.

Near the top of the unit are two other lithologies common to the upper sand. The first is found underlying the contact with the overlying upper mud and consists of laminae of fine to medium sand interlaminated with medium to coarse sand and granules. This unit represents the intertidal zone between the sand flats below and the mud flats of the overlying upper mud. It was deposited by ebb-flow emergence runoff (Klein, 1977) that concentrated coarser grains in laminae and deposited sand in ripple-bedding that resulted in the low-angle planar bedding seen in cross-sectional view. The other lithology is a slightly silty, fine sand that fills a bowl-shaped channel feature that cuts across the site at the top of the cross-bedded sand. It represents deposition in a small tidal channel that cut across the sand flat prior to the progradation of the muds of the upper flat. Deposition within the channel was rapid as indicated by the lack of bioturbation structures within the silty sands of the channel.

Upper Mud

The upper mud represents the transition from the sand-dominated intertidal and subtidal sand flat to the mud-dominated intertidal (and supratidal?) mud flat. The upper unit is the equivalent of the mud flats of Reineck and Singh (1980). The sandy intervals at the base of the unit represent periodic influx of sand, but as whole, the silts and clays of the mud flat dominate the unit. The lack of sedimentary structures within most of the unit is likely due to bioturbation by animals rather than by rooted vegetation.

SUMMARY OF CALVERT DEPOSITIONAL HISTORY

The deposits at the Pollack Farm Site represent a shallowing-upward estuarine to intertidal sequence. Estuarine should be taken here to be descriptive of an area of semi-enclosed tidally influenced deposition which has both marine and fresh-water influence rather than descriptive of a geomorphic feature such as a drowned river valley. The sedimentary fill is progradational (Fig. 23) and is similar to the regressive sequence for sedimentary facies at the estuary-marine transition zone proposed by Greer (1975). The portion of the section missing from Greer's (1975) model is the shoal deposits which would correspond in position to the break between the shelly mud unit and the lower shell bed (Figs. 23, 9). These shoal deposits may have been removed by the scour and tidal currents associated with the estuarine channel in which the lower shell bed was deposited.

After the deposition of the fine-grained shelf deposits of the shelly mud bed, a coastal zone began to develop over the site that included an estuarine channel and associated shoals and sand bars. The channel was a zone of mixing of faunal elements, including brackish and normal-saline marine mollusks, as well as fragmentary remains of marine and terrestrial vertebrates. The tidal currents of the channel served to concentrate the coarse fossil material over time until finally buried in the bars in the channel.

Biologic productivity was high in the area as shown by the abundant molluscan and marine vertebrate remains found in the lower shell bed. The terrestrial mammal assemblage suggests habitats of nearby forested areas with some open

grassy areas and fresh-water ponds, a possible modern analog being a delta with streams, oxbow lakes and ponds, with marshes and swamps developed in the lowlands and forest and open park-like grasslands on the higher elevations (Emry and Eshelman, 1998). The vertebrate remains indicate a history of post-mortem disarticulation, subaerial exposure, burial, and permineralization prior to transport and accumulation in the lower shell bed in the tidal channel (Cutler, 1998).

The lower sand represents a filling of the channel which was in turn truncated by the progradation of a relatively complete tidal flat assemblage of the subtidal deposits of the interbedded sand and mud, the subtidal to intertidal sand flat deposits of the cross-bedded sand, and the intertidal to supratidal deposits of the mud flats of the upper mud. The tidal flat deposits prograded across the area and were followed by a new cycle of marine deposition as preserved downdip from the Pollack Farm Site (Benson, et al., 1985; Groot, 1992; Benson, 1998).

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OPHIOMORPHA NODOSA IN ESTUARINE SANDS OF THE LOWER MIOCENE CALVERT FORMATION AT THE POLLACK FARM SITE, DELAWARE¹

Molly F. Miller,² H. Allen Curran,³ and Ronald L. Martino⁴

ABSTRACT

The trace fossil *Ophiomorpha nodosa* consists of a three-dimensional network of coarsely pelleted burrows. Specimens of *Ophiomorpha*, as well as of *Skolithos linearis* and polychaete burrows, were well exposed during excavation of the Pollack Farm Site. They occur in lower Miocene sands of the Calvert Formation that were deposited in a broad tidal or estuarine channel. *Ophiomorpha* is more abundant in vertical exposures of channel-margin sands (16.5 specimens m⁻²; n = 11) than in channel-axis sands (0.36 specimens m⁻²; n = 11). This indicates that the tracemaker organism, presumably a callianassid shrimp similar to *Callichirus major*, preferred the channel-margin environment to the channel-axis environment. Environmental conditions, however, did not affect either the size of the individuals nor the thickness of the burrow walls that they constructed, as evidenced by lack of significant differences in either burrow diameter or wall thickness between *Ophiomorpha* in the channel-margin versus channel-axis facies.

At the Pollack Farm Site, *Ophiomorpha* displays the high degree of morphological variability that has been reported from other occurrences. Horizontal tunnels outnumber vertical shafts by 3 to 1. Some specimens interpenetrate, and a few have burrows within the burrows, suggesting that the burrow system was used by more than one individual.

INTRODUCTION

The trace fossil *Ophiomorpha*, particularly the ichnospecies *O. nodosa*, is widespread and abundant in marginal marine and shallow marine sands of Cretaceous to Pleistocene age exposed along the Atlantic and Gulf Coastal Plains (e.g., Pickett et al., 1971; Curran and Frey, 1977; Frey et al., 1978; Curran, 1985; Martino and Curran, 1990; Erickson and Sanders, 1991). At the Pollack Farm Site, specimens of *O.*

nodosa, which closely resemble burrows of the modern callianassid shrimp *Callichirus major* (formerly *Callianassa major*), and associated trace fossils are exposed in tidal or estuarine channel sands (the cross-bedded sand unit in figure 2 of Benson, 1998). The sands, of early Miocene age, are part of the Cheswold sands, recognized in Delaware as an informal stratigraphic unit of the Calvert Formation (Benson, 1998).

The Calvert Formation at the Pollack Farm Site was well exposed in 1992 (Fig. 1), permitting detailed examination of both the physical and biogenic structures. This allowed integration of sedimentologic and stratigraphic data with information about the density and morphology of the *Ophiomorpha* burrow systems and documentation of the paleoenvironmental factors controlling *Ophiomorpha* distribution and the behavior of the tracemaker shrimp.

Acknowledgments

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DEPOSITIONAL PROCESSES AND SETTING OF THE OPHIOMORPHA-BEARING SANDS

Description

Ophiomorpha nodosa is abundant in a 4-m-thick sand unit near the top of the excavation at the Pollack Farm Site (Fig. 1). The unit consists of fine to medium, well-sorted,

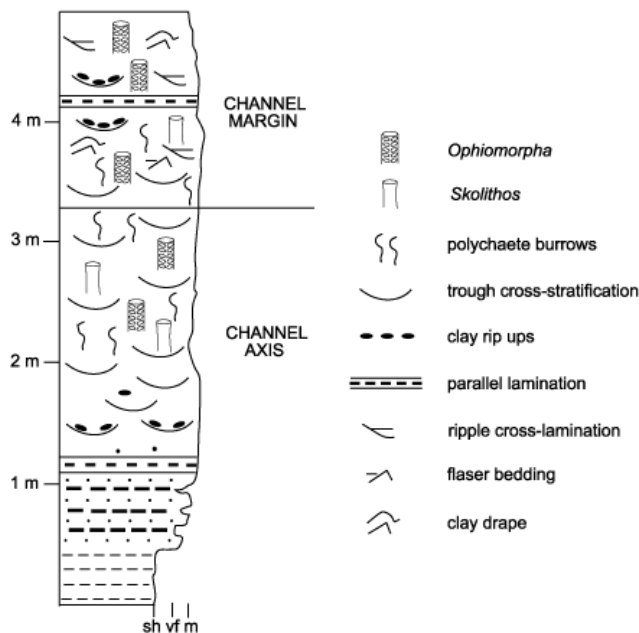


Figure 1. Stratigraphic section of *Ophiomorpha nodosa*-bearing interval (cross-bedded sand unit in Figure 2 of Benson, 1998) of the Cheswold sands of the Calvert Formation (lower Miocene) exposed during excavation of the Pollack Farm Site.

¹ In Benson, R.N., ed., 1998, *Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware*: Delaware Geological Survey Special Publication No. 21, p. 41-46.

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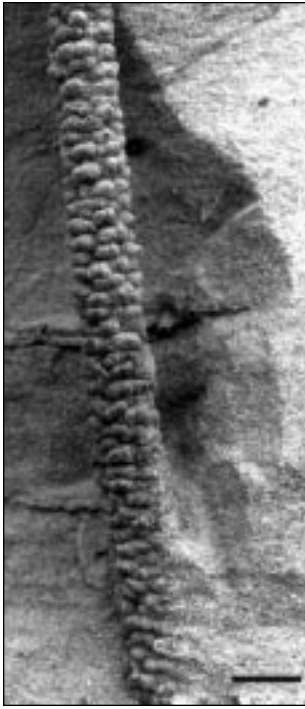


Figure 2. Specimen of *Ophiomorpha nodosa* preserved in full relief. Note brick-like arrangement of pellets toward the top of the shaft; pellet arrangement becomes somewhat less uniform downward. Scale bar = 2 cm.



Figure 3. Two sizes of *Ophiomorpha*. Pellets are less uniformly packed than in Figure 2. Note enlargement where shaft merges with tunnel at base of specimen at left. Scale bar = 2 cm.



Figure 4. Trough cross-stratified sands of channel-axis facies (Fig. 1); white trowel at right is 15 cm.

mostly quartz sand. The vertical exposure had been gently sandblasted by the wind, revealing many specimens of the relatively resistant *Ophiomorpha* in full relief (Figs. 2, 3).

Sedimentary structures within the sands include trough cross-stratification in sets up to 20 cm thick, ripple cross-lamination, and flaser bedding. Clay drapes on ripple forms are common, as are accumulations of clay clasts in the troughs of some sets of cross-stratification.

Vertical trends in the distribution of sedimentary structures within the *Ophiomorpha*-bearing unit are well defined (Fig. 1); no significant lateral changes in the 100-m-long exposure were identified. A test pit beneath the sand indicated that a 50-cm-thick clay layer is overlain by 40 cm of

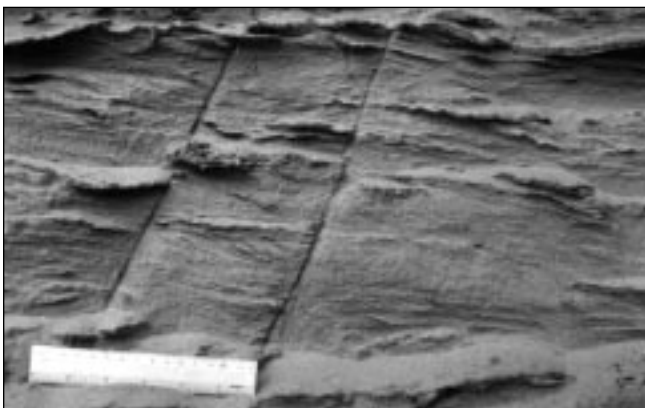


Figure 5. Ripple cross-lamination and flaser bedding, channel-margin facies (Fig. 1). Clay drapes stand in relief. Ruler at bottom left is 15 cm.

interbedded clay, sand, and silt. This interval coarsens upward to the *Ophiomorpha*-bearing sand by addition of sand layers. The contact between the sand and the underlying clay is therefore gradational rather than abrupt. The lowermost 60 cm of the sand is composed of ripple-laminated and trough cross-stratified sands with abundant clay clasts along the foresets. This is overlain by a 1.7-m-thick zone dominated by sets of large-scale trough cross-stratification that range from 10 to 20 cm thick and 1.0 to 1.25 m wide (Figs. 1, 4). Current direction was approximately north to south or northwest to southeast. The upper 1.6 m of the unit grades upward from large-scale, trough cross-stratified sands to flaser-bedded and ripple cross-laminated sands with clay drapes (Figs. 1, 5).

Interpretation

Sedimentary structures in the *Ophiomorpha*-bearing unit suggest that deposition was dominated by unidirectional flow. A reasonable interpretation is that deposition occurred in a broad (> 100 m wide) tidal or estuarine channel in which the dominant flow was to the south or southeast. Large-scale, three-dimensional bedforms migrated in the central part of the channel, as recorded by the large-scale trough cross-stratified sands in the lower part of the sequence. In areas marginal to the channel, reduced flow and periods of slack water produced current ripples, flaser bedding, and clay drapes; material from the clay drapes was subsequently reworked and redeposited as rip-up clasts. Conditions of channel-margin deposition are recorded by the upper 1.6 m of the *Ophiomorpha*-bearing zone. The fine sediments at the base of the section also record channel-margin deposition; a channel interpretation is not precluded by absence of a basal scour surface.

The features of these deposits that indicate deposition in a tidal or estuarine setting versus a shoreface setting include (1) evidence of fluctuating energy conditions (clay drapes, rip-up clasts, flaser bedding), (2) unidirectional current indicators reflecting either unidirectional flow or strong domination by either ebb or flood tidal flow, and (3) absence of features formed by wave or storm activity (e.g., oscillation ripples, hummocky cross-stratification, and laminated to burrowed sequences).

The vertical succession records an episode of channel migration. The lower sands, characterized by large-scale trough cross-stratification, reflect deposition toward the cen-

ter of the channel, whereas the upper, rippled and flaser-bedded sands record deposition closer to the channel margin; however, lack of exposure of the actual channel margins and of the adjacent facies precludes detailed reconstruction of the shoreline setting of which this broad, migrating channel was a part.

DISTRIBUTION OF *OPHIOMORPHA* WITHIN CHANNEL DEPOSITS

Cursory comparison of the number of specimens of *Ophiomorpha nodosa* in the upper channel-margin and lower channel-axis sands suggests that *Ophiomorpha* was more abundant in the channel-margin than channel-axis deposits. This observation was tested by counting the number of burrows (noting burrow orientation) in 11 one-meter square grids on vertical exposures in both the channel-margin and channel-axis deposits. The results confirmed the preliminary observation; mean densities of *Ophiomorpha* are 16.5m^{-2} in the channel margin deposits vs. 0.36m^{-2} in the channel axis sands. Based on a Student's t-test modified for inhomogeneity of variances, this difference is significant ($t = 5.81$; $df = 11$; $p < 0.05$; Dixon and Massey, 1969). Channel-margin density is sufficient to impart an ichnofabric of 2 to 3, whereas ichnofabric index in the channel axis is 1 to 2 (scale of Droser and Bottjer, 1989).

The results indicate that the *Ophiomorpha*-producers, presumably callianassid shrimp, preferred the channel margin as opposed to the center of the channel, probably because of lower current velocity, more stable substrates for burrowing, and related factors. The alternative interpretation, that the observed difference in density results from differences in preservation, is not supported. In this scenario, as many *Ophiomorpha* were produced in the channel axis as in the channel-margin facies, but they were subsequently eroded. Because callianassids burrow deeply (>50 cm), complete removal of their burrows by erosion would require multiple large erosional events that left no record (e.g., major scours, discontinuities) in the sedimentary sequence and that are not consistent with the in-channel accretion reflected by the trough-cross-laminated sands. Finally, if *Ophiomorpha* were formed and subsequently eroded in the channel axis, short shafts of truncated, partially eroded *Ophiomorpha* would be predicted to be common, but they are not.

Higher density of *Ophiomorpha* in facies deposited in protected or marginal environments than in those deposited in higher energy environments has been reported elsewhere from Mesozoic and Cenozoic deposits (e.g., Carter, 1978; Pollard et al., 1993). Pollard et al. (1993) presented evidence that *Ophiomorpha* producers colonized the sediment during low energy conditions in fluctuating hydraulic regimes. Their caution against interpreting a "high energy" environment based on the presence of *Ophiomorpha* is supported by our observations of facies-controlled abundances of *Ophiomorpha* at the Pollack Farm Site.

The distribution pattern of *Ophiomorpha* in the sands at the Pollack Farm Site also bears close resemblance to that of modern *Callianassa californiensis* in Mugu Lagoon, southern California. *C. californiensis* is abundant on the margins of the main tidal channel but absent from the center of the channel (Miller and Myrick, 1992). As sediment is transported during ebb and flood tidal flow in the channel axis, a significant amount of sand enters the burrows (M.F.

Miller, personal observation). Removing the passively deposited sand from the burrows requires burrower energy, probably explaining why the center of the channel is not the preferred habitat. In the transition zone in Mugu Lagoon between where its burrows are abundant and where they are absent, *C. californiensis* occurs in small, dense patches, a distribution pattern that differs from the apparently widely spaced distribution of *Ophiomorpha* (as seen in vertical section) in the channel-axis deposits at the Pollack Farm Site.

To test for differences in size and thickness of the burrow walls between *Ophiomorpha* in channel-margin versus channel-axis deposits, the internal and external diameters of specimens from the two facies were measured and compared. Mean inside diameter of specimens of *Ophiomorpha* from the channel margin sands ($n = 97$) is 1.68 cm versus 1.49 cm ($n = 7$) for those from the channel-axis sands. This difference is not significant ($t = 0.913$; $df = 100$; $p < 0.01$). Mean external diameter in the channel-margin specimens is 2.40 cm ($n = 126$) compared to 2.29 cm ($n = 14$) for the channel-axis specimens; again, the difference is not significant ($t = 0.162$; $df = 100$; $p < 0.01$). The mean external diameter is close to the mean external diameter of *Ophiomorpha* from the Pleistocene of South Carolina (Erickson and Sanders, 1991). There is no significant difference in burrow wall thickness between the channel axis and channel margin deposits at the Pollack Farm Site. [Channel margin mean is 0.755 cm ($n = 97$) compared to a channel-axis-mean of 0.628 cm ($n = 7$); $t = 0.858$; $df = 100$; $p < 0.01$.]

The lack of a significant difference in burrow diameter indicates that the size distributions, and presumably the age distributions, of the callianassids inhabiting the channel-margin environment were similar to those of the callianassids living in the channel-axis environment. This suggests that shrimp larvae were not excluded from the more favorable channel-margin environment, and that individuals in the less favorable channel-axis environment were able to reach full maturity.

OPHIOMORPHA: MORPHOLOGIC CHARACTERISTICS AND BEHAVIORAL IMPLICATIONS

Description

Ophiomorpha nodosa at the Pollack Farm Site resembles *O. nodosa* described from Cretaceous and Tertiary deposits elsewhere (e.g. Kern and Warme, 1974; Curran and Frey, 1977; Kamola, 1984; Merrill, 1984; Curran, 1985; Barrick, 1987; Martino and Curran, 1990; Erickson and Sanders, 1991; Anderson and Droser, 1993; Pollard et al., 1993). These burrows generally are well-lined and consist of branching, three-dimensional structures with shafts, tunnels, and oblique components that sometimes interpenetrate (Figs. 6, 7). The external wall commonly is distinctively pelleted, and bulbous enlargements are common at shaft-tunnel junctions (Figs. 2, 3). At the Pollack Farm Site, outside burrow diameters range from 1.3 to 4.0 cm; internal diameters range from 0.7 to 3.5 cm.

The pellet shape and packing is variable, but pellets are exclusively in a single layer rather than double layer. Some burrows have pellets that are brick-like (Fig. 2), but typically the pellet arrangement is less well organized (Fig. 3). In some parts of the burrow systems, usually along segments of tunnels, pellets are lacking altogether.



Figure 6. Axial section of shaft showing smooth interior and branching.

The burrow systems are dominated by their horizontal (tunnel) components (Figs. 7, 8). In the channel-margin deposits, with particularly abundant specimens of *Ophiomorpha*, horizontal components outnumber vertical components by a ratio of 3:1 (n = 182). In the lower channel-axis deposits, the horizontal to vertical ratio is 1:3, but this observation is based on a small number of burrows (n = 4). Tunnels are not clustered tightly around shafts, nor are they

consistently connected by shafts to form a boxwork pattern. Rather, several tunnels typically appear to branch off from vertical to oblique components at different levels.

Whereas most shafts and oblique components of the burrow systems are pelleted, some tunnels connect to vertically to obliquely oriented “disorganized zones” of variable diameter (6 cm maximum) characterized by swirled sediment, commonly with clearly meniscate structure. These “disorganized zones” lack well-defined margins and pelleted burrow walls, although pellets could be found scattered in the sediment (Fig. 9).



Figure 7. Closely stacked *Ophiomorpha* tunnels. Arrow points to intersection. Ruler at bottom left is 10 cm.

Behavioral Implications

Considerable variability has been documented in *Ophiomorpha*, particularly with respect to pellet shape and packing and to arrangement of the shafts and tunnels of the burrow system. Morphology of shafts and tunnels comprising the burrow network has been found to range from predominantly vertical shafts to tiered mazes to regular and irregular boxworks to spiralled structures (Frey et al., 1978) and has been observed to change vertically within a single burrow system (Curran, 1985). Pellets may be bilobed, dis-

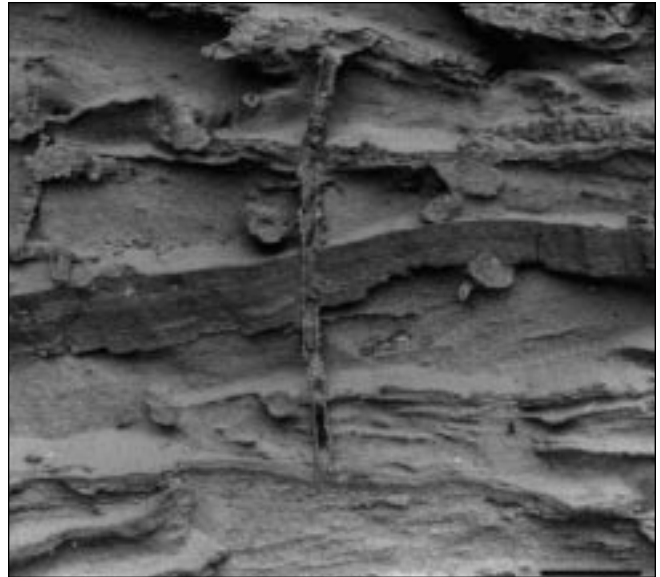


Figure 8. Axial section of *Ophiomorpha* shaft and cross-sections of many tunnels, channel-margin deposits. Scale bar = 5 cm.

oid, oval, or round, and burrow walls may be composed of one or two layers of pellets. Frey et al. (1978) considered the characteristics of the burrow wall and its pellets to be less variable than morphology of the burrow system and used the former as a criterion for discriminating between several ichnospecies.

Although there have been few suggestions regarding the behavioral factors controlling the morphology of *Ophiomorpha* burrow systems, it is inferred that non-pelleted burrow segments served a different function from pelleted sections (Asgaard and Bromley, 1974). The influence of substrate consistency on the abundance of pellets in the burrow wall has been well established. In sequences of alternating siliciclastic sandstones and mudstones, pellets commonly have been restricted to the sandstones, presumably because wall reinforcement was required in the sands but not in the more cohesive muds (Ager and Wallace, 1970; Kennedy and Sellwood, 1970; Kern and Warne, 1974). In this study, there was no significant difference found in thickness of burrow wall between specimens from the channel-axis and channel margin facies, implying that any differences in substrate consistency between the two environments were too subtle to have caused the *Ophiomorpha*-producers to alter



Figure 9. Association of meniscate-filled *Ophiomorpha nodosa* burrow with disorganized zone in upper left center. Note pelleted walls within burrow, suggesting a “burrow within a burrow.” Scale bar = 1 cm.



Figure 10.
Skolithos linearis in channel-margin sands. Scale bar = 2 cm.

rowers abandoned the burrows. In other examples, it appears that the shrimp that made the penetrating burrow subsequently used the original as well as the new burrow, thus efficiently increasing the size of the burrow network. The burrow system may have been inhabited by more than one individual simultaneously or by more than one individual at different times. Alternatively, it may have been burrowed, abandoned, and reburrowed by the same individual.

ASSOCIATED TRACE FOSSILS

Some trace fossils other than *Ophiomorpha nodosa* are common in the Miocene sands of the Pollack Farm Site. These include *Skolithos linearis* burrows approximately 0.5 cm in diameter and thread-like vertical burrows that closely resemble previously described burrows attributed to polychaetes (Figs. 10, 11; Curran, 1985). *Skolithos linearis* and the polychaete burrows occur in both the channel-axis and channel-margin deposits, but they are particularly abundant in the latter. We found no clusters of polychaete burrows in and adjacent to the walls of *Ophiomorpha*, as reported from the Cretaceous of Delaware by Curran (1985).

CONCLUSIONS

(1) The 4-m-thick sand unit of the Cheswold sand section of the Calvert Formation near the top of the lower Miocene sequence formerly exposed at the Pollack Farm Site was deposited in the axial and marginal portions of a broad, migrating tidal or estuarine channel, in which the dominant flow was toward the south or southeast. Common trace fossils in the channel sands include *Ophiomorpha nodosa*, as well as *Skolithos linearis* and small-diameter burrows attributed to polychaetes.

(2) *Ophiomorpha nodosa* is significantly more abundant in sands deposited in the channel margin (mean density 16.5 m⁻²) than in sands deposited in the more axial portion

their method of burrow construction.

A notable characteristic of the specimens of *Ophiomorpha nodosa* at the Pollack Farm Site is that they interpenetrate (Figs. 7, 9), a phenomenon that has been illustrated previously (Curran, 1985; Pollard et al., 1993). Given the relatively low density of burrows at the Pollack Farm Site, penetration of one burrow by another could easily have been avoided by the producers. Thus, the fact that they do interpenetrate suggests that some advantage is conferred by burrowing into a pre-existing burrow. Several repenetrated specimens record the following sequence of events: (1) filling of initial burrow, (2) reburrowing, (3) filling of the second burrow. This sequence implies that both the first and second bur-

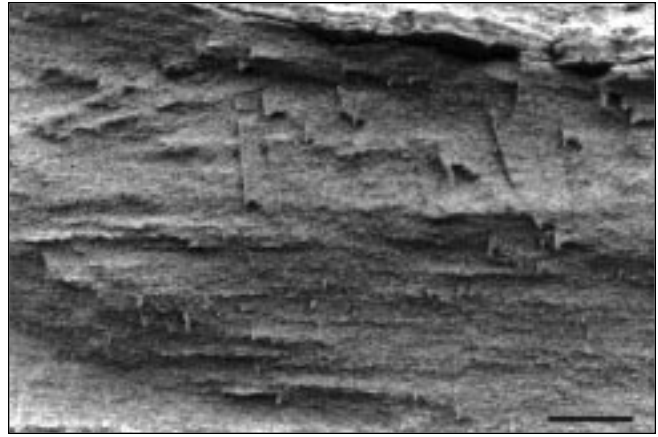


Figure 11. Burrows likely formed by polychaetes that occur in association with *Ophiomorpha*. Scale bar = 1 cm.

of the channel (mean density 0.36 m⁻²). This implies that the channel margin was a preferred habitat of the tracemaker organism, which is inferred to have been a callinassid shrimp similar to *Callichirus major*.

(3) Burrow diameter does not vary significantly between the channel-margin and channel-axis deposits, suggesting that size and age distributions of the two shrimp populations were similar. This implies that larval-adult interactions did not control the distribution of individuals and that individuals in the channel axis thrived sufficiently to reach maturity.

(4) *Ophiomorpha nodosa* at the Pollack Farm Site displays the wide range in morphology that is typical for the ichnospecies. Tunnels outnumber shafts by almost 3 to 1.

(5) Some specimens of *Ophiomorpha* interpenetrate, whereas a few others have burrows within the burrows. This suggests that these burrow systems were inhabited by more than one tracemaker, or that they were abandoned and subsequently re-occupied by the same trace maker.

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ANALYSIS OF DEFORMATION FEATURES AT THE POLLACK FARM SITE, DELAWARE¹

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ABSTRACT

Several types of soft-sediment- and brittle-deformation features were observed in the Scotts Corners, Columbia, and Calvert formations at the Pollack Farm Site. Contorted and chaotic bedding, involutions, diapiric and wedge-cast structures, dissolution collapse features, and fractures, joints, and faults were observed in all units. Cold-climate freeze-thaw processes (congeliturbation) are the most likely causes of contorted and chaotic bedding and folding. The wedge-cast features have many similarities to frost-wedge casts. Some fractures, joints, and faults appear to have formed in an extensional stress field, possibly related to movement along the Smyrna fault zone, the border fault zone associated with an inferred buried Mesozoic rift basin. Other fractures and joints may have been caused by erosional unloading or weathering and mineralization processes.

INTRODUCTION

While the Pollack Farm Site was open for study between 1991 and 1993 we observed several types of soft-sediment- and brittle-deformation features in three formations exposed at the site, Scotts Corners, Columbia, and Calvert formations (Ramsey, 1998), and also at several places in the vicinity of the site after it was back-filled (Fig. 1). In this paper we describe and illustrate the features and interpret their origins.

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CONTORTED, CHAOTIC, AND FOLDED BEDDING

Contorted, chaotic, and folded bedding were observed within the Scotts Corners, Columbia, and Calvert formations (Fig. 1, sites a, b, and c; Figs. 2–5). The deformed unconsolidated sediments range in lithology from silty clay to sandy gravel and occur between 0 and 5–10 ft below land surface under east- and northeast-facing slopes. Fold amplitudes are as much as about 3 ft, and overturned folds with intrafold shear were observed. Orientations of axial planes of overturned folds indicate that horizontal movement was down-slope toward the east. Many of the folds are detached at depth. The detachment surface occurs just above the Scotts Corners-Calvert contact at site a and in the upper mud unit of the Calvert at sites b and c. We have observed similar features at several other locations in Delaware.

The most severely deformed rocks were observed at site a within the Scotts Corners Formation (Figs. 2–4). They occur below a scarp-like topographic feature and are spatially associated with an undeformed Calvert-Scotts Corners contact and wedge-cast structures. At this location the Calvert beds are not folded. At sites b and c, it appears that the upper foot of a paleosol formed on the upper mud unit of the Calvert Formation was deformed into diapiric structures that intrude 0.5 to 1.5 ft into the overlying Columbia or Scotts Corners formations (Fig. 5). At site b the overlying Columbia is less than 5 ft thick. James E. Pizzuto (University of Delaware Department of Geology, unpub. rept., 1994) describes a similar feature developed beneath a closed depression at site c. The Scotts Corners here is less than 5 ft thick over the deformed beds of the Calvert.



Figure 1. Aerial photograph of Pollack farm (sites a, b, and c) and surrounding area before excavation. (Photograph date 7-12-54; AHP-IN-116; scale 1:20,000)

¹ In Benson, R.N., ed., 1998, Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 47–53.



Figure 2. Photograph and interpreted line drawing of involute and contorted bedding in the Scotts Corners Formation at site a. Original land surface is located approximately 1.5 ft above the frame. Shovel handle is 1.5 ft long.

WEDGE-CAST STRUCTURES

A few wedge-cast structures (Fig. 4) were observed at site a. They are near-vertical features that extend from near land surface down 6.5 ft into the underlying Scotts Corners. The casts were traced back into the face of the exposure at least 1 ft. The wedge casts are up to 1 ft wide at the top and taper downward. Some have a slightly sinuous profile, whereas others appear to be associated with involutions. Wedge-cast margins are commonly lined with vertically oriented granules and pebbles. Internal structure within a single cast ranges from structureless to faintly vertically laminated. The wedge casts appear to be filled with mixtures of the sandy materials overlying and surrounding the cast.

The amount of deformation associated with the wedge casts decreases with depth. The wedge casts completely disrupt bedding at their tops, with some surrounding beds rotated to near vertical near the cast margins. The rotation is predominately downward although some upwardly turned beds were observed. One cast is significantly deformed (Fig. 4). The top half of this cast appears to have been moved down-lope farther than the bottom half.



Figure 3. Photograph and interpreted line drawing of overturned and detached folds in the Scotts Corners Formation (Qsc) at site a. Original land surface is located approximately 1.5 ft above the frame. Tc—Calvert Formation.

No observations of the land surface were made prior to excavation, so it cannot be determined if the wedge-casts are connected or are part of a polygonal net. Aerial photographs (Fig. 1) show a variety of rounded surface textures on and around the site. These range from individual isolated features to net-like associations. The scale of the photography limits the resolution of individual features to larger than about 50 to 75 ft. From field observations many of the feature are small, seasonally wet, closed depressions. There are no circular or polygonal clast segregations associated with the depressions.

BRITTLE STRUCTURES

Three styles of brittle structures, fractures, joints, and faults (Figs. 6–9), are present in both the Columbia and Calvert formations. These structures were found in three orientations: horizontal, vertical, and conjugate sets about vertical sets. Fractures and joints exhibit no discernable offset. Fractures are differentiated from joints in that they are more irregular in form, less planar, and are not found in sets. Faults have measurable offsets of beds.

Orientation data from brittle features at the site are limited. In general, structures are upright and strike to the northeast. There is a second, minor set of fractures and joints that strikes to the northwest. Scant data indicate that there is another conjugate set striking west-northwest to east-southeast, less than 45° to the northwest-striking set.



Figure 4. Photograph and interpreted line drawing of wedge-cast feature (a) and contorted bedding observed in the Scotts Corners Formation at site a. Original land surface appears close to top of frame on left side. Note that Calvert Formation (Tc) is not deformed.

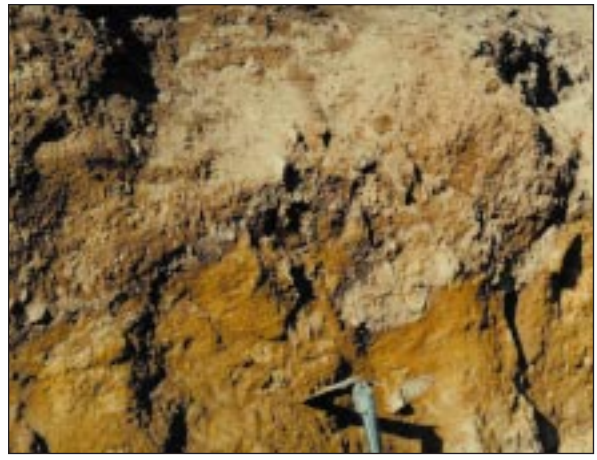


Figure 5. Photograph and interpreted line drawing of deformed Columbia-Calvert contact at site b. Diapir of weathered upper mud bed of the Calvert Formation has intruded approximately 1.5 ft into the Columbia Formation.



Figure 6. Photograph of scaly texture associated with intense fracturing and mineralization of the upper mud unit of the Calvert.

Joints and some fractures in the upper mud unit of the Calvert are typically closely spaced and regular in form. The structures commonly exceed the length of the outcrop, and terminations are rarely found. Conjugate patterns of joints and fractures are observable on a spacing scale larg-

er than that of regular joints and are superimposed over the closer-spaced vertical joint sets. In some locations close to the contact with the Columbia Formation, the close spacing of the structures have a distinctive irregular form, giving the outcrop a scaly appearance (Fig. 6). This appearance has been accentuated by mineralization. In plan view, this intense fracturing forms polygons with spacings on the order of 1–2 in.

Where fractures and joints are present in the alternating sand and clay beds in the upper mud unit of the Calvert (Fig. 7), the structures are more clearly exposed in the clay beds than in sand beds. The structures appear to be continuous from clay bed to clay bed. Thin clay beds within a sand layer are commonly disrupted approximately in line with fractures in bounding clayey beds.

Near vertical joints, fractures, and faults were observed in the cross-bedded sand of the Calvert (Fig. 8). These features are present approximately 20 ft beneath original land surface. Joint or fracture spacing is on the order of 1–3 in. No measurements were made of fracture orientations, but it appears that they are similar to those observed in the overlying upper mud unit. Half-graben features with normal displacements on the order of 0.25–0.75 in were observed in sedimentary and biogenic structures. There are no good photographs of the offset features in the cross-bedded sand unit.

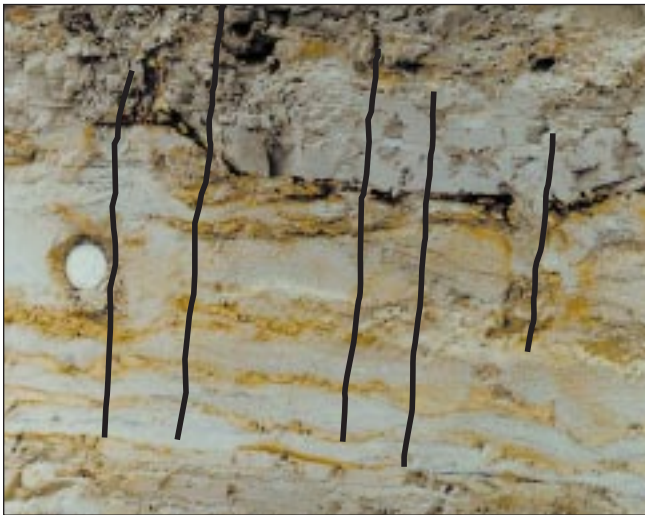
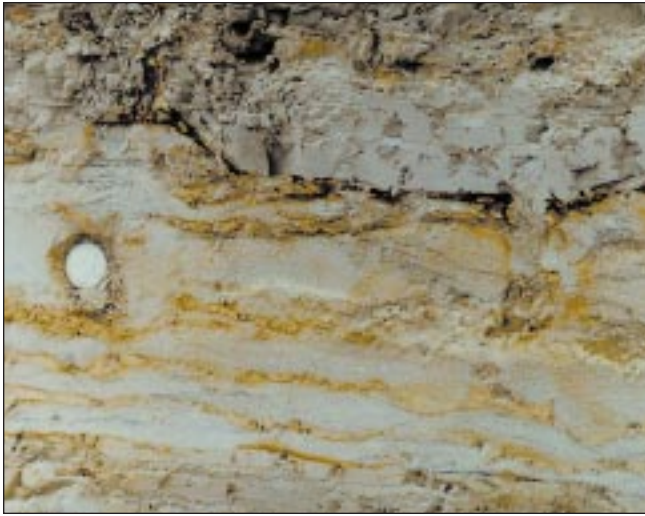


Figure 7. Photograph and interpreted line drawing of jointing and fracturing in alternating sand and mud beds within upper mud unit of the Calvert.

Faults with small offsets (<1 ft) are present within the Columbia near the contact with the Calvert at site b (Fig. 9). Half-graben features, commonly several in cascading succession, indicate normal displacements. Reverse displacements are less commonly present. Offsets appear to disrupt the upper mud unit of the Calvert.

DISSOLUTION-RELATED STRUCTURES

Structures are also associated with dissolution of the upper shell beds of the Calvert. Figure 10 (near site c) shows a sharp boundary between shelly beds and surrounding shell-free sand. The immediately adjacent sand has no visible sedimentary structures. The overlying beds a few feet away are gently warped down over the edge of the shell bed. Visible disruption of overlying bedding is restricted to within a few feet of the dissolved edge of the shell bed in overlying and horizontally adjacent materials. The dissolution features are not in close proximity to the undrained surface depressions found at the site.

DISCUSSION

Contorted, Chaotic, and Folded Bedding

These structures were observed in three different lithostratigraphic units of different ages at irregularly dis-

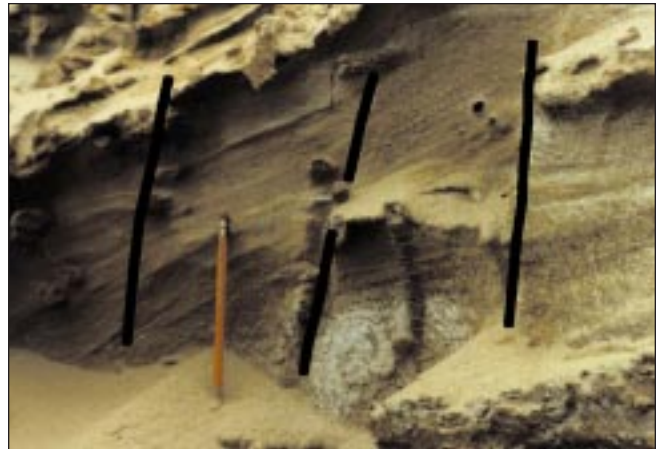
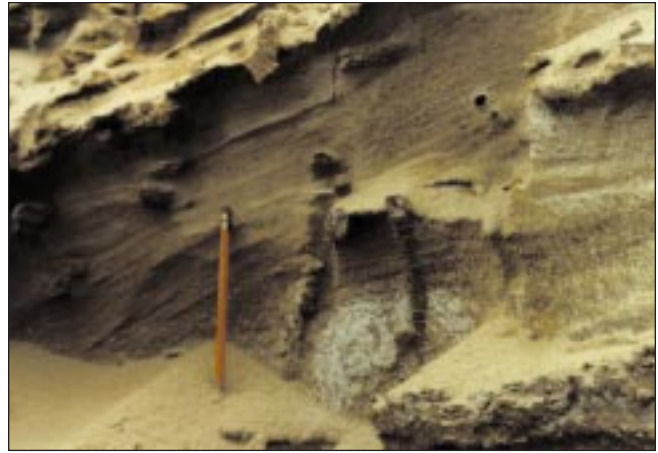


Figure 8. Photograph and interpreted line drawing of joints in cross-bedded sand unit of the Calvert. *Ophiomorpha nodosa* are cut by the joints.

tributed locations at the site, indicating that they were formed in response to highly localized conditions. Possible explanations for the structures follow.

Syndepositional Deformation of Water-Saturated Sediments

The features resemble flood-related syndepositional deformation structures in fluvial sediments as shown by Cant (1982, fig. 44) and Coleman and Prior (1982, fig. 5). Jordan (1964) and Spoljaric (1974) interpret the Columbia Formation as deposited in a fluvial environment that had fluctuating high and low energy components. Our interpretation of the chaotic sedimentary textures and structures observed at the site, however, is that they are not of syndepositional origin as they occur in three different lithostratigraphic units of different ages and depositional settings, and they cross contacts between the units.

Earthquake-Induced Liquefaction

The features do not fit the criteria identified by Obermeier et al. (1990) for earthquake liquefaction features reported in the Charleston, South Carolina, and New Madrid, Missouri, seismic zones. One of their key criteria for identifying earthquake liquefaction features is “evidence of an upward directed, strong hydraulic force that was suddenly applied and was of short duration” (Obermeier et al., 1990, p. 5). Features they cite as evidence of this criterion are vertically-oriented

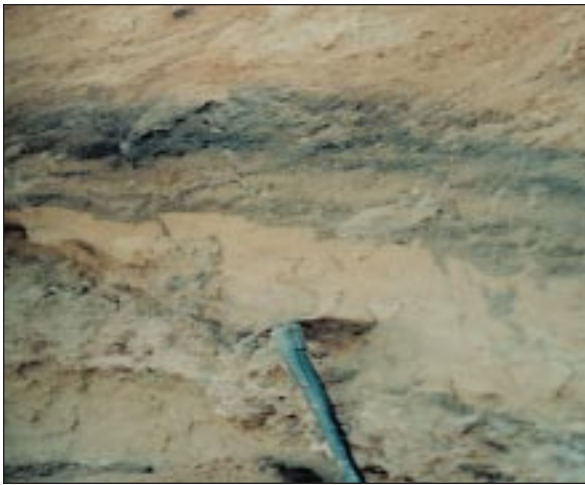


Figure 9. Photograph and interpreted line drawing of small faults in the Columbia and Calvert formations at site b. Note that the features offset the contact between the Columbia and Calvert.

sand dikes, sand fissures, filled sand blows, and vented sand volcanoes. These features are not present at the Pollack Farm Site. Features at the site indicate both horizontally and vertically oriented forces that mixed sediment of different ages.

Cryoturbation or Mass Movement Related to Freeze and Thaw Cycles

There is a wide variety of evidence for cold climates existing in Delaware and the adjacent, then exposed, continental shelf during the Pleistocene. Ramsey (1993), Groot et al. (1995), Groot (1996), and J.J. Groot (written comm., 1991–1997) interpret that cold-climate conditions, as evidenced by boreal forest to taiga flora, existed throughout this region during one or more Quaternary glacial stages. Newby et al. (1994) report boreal forest and forested tundra-type pollen assemblages in sediment samples collected from beneath a pond located within 20 mi of the Pollack Farm Site (39°22'53" N, 75°40'33" W). On the bases of lithologic and textural criteria, Jordan (1964, p. 40) argued that the Columbia is derived from glacial outwash and was deposited during one or more glacial-interglacial cycles in the Pleistocene. In summary, although there is no clear evidence of continuous permafrost or of a climate that would create permafrost in Delaware, climatic conditions should have

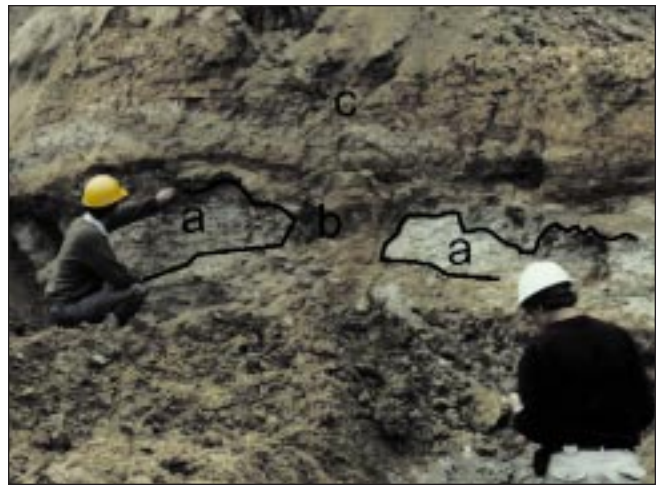


Figure 10. Photograph and interpreted line drawing of structures related to dissolution of upper shell beds. **a**—shell bed showing irregular top and bottom surfaces. **b**—the collapse zone where the overlying shell bed has been completely dissolved. **c**—the upper mud unit, which has not been significantly deformed over the collapse zone. The upper mud unit in this photograph also displays characteristic fracturing and weathering.

been sufficient to allow for a significant thickness of frozen ground to develop.

The folded, contorted, and chaotic bedding observed at the Pollack Farm Site is very similar to cryoturbation features shown in Hamelin and Cook (1967), Vandenberghe (1988), and Hamilton and Ashley (1993). Vandenberghe (1988) classifies these features as involutions, diapirs, and drops. The deformation features also are similar to those observed in the Coastal Plain of New Jersey that have been interpreted as forming in response to cold-climate processes (Newell et al., 1988).

Cryoturbation processes deform sediments through a variety of mechanisms, many of which are related to the buildup of excess water pressure in the subsurface from the freezing and thawing of interstitial water (Black, 1976; Vandenberghe, 1988; Hallet and Waddington, 1991). For example, excess hydrostatic pressure could have formed in a saturated zone between a downwardly freezing surface layer and the low permeability upper mud unit of the Calvert. The materials in the saturated zone will deform when the hydro-

static pressure exceeds the internal friction and/or cohesion of the materials. Excess hydrostatic pressure could also occur where buried lenses of ice form the lower low permeability boundary. Where excess hydrostatic pressure formed under a steeper topographic slope (e.g., site a) significant downslope mass movement occurred. In locations where the overlying Quaternary units are thin (<5 ft), the zone of excess pressure could have penetrated into beds of the older, more compact Calvert causing those beds to deform into upwardly moving diapirs. Cryoturbation features have also been attributed to forces caused by the volumetric expansion of water that occurs during freezing (Vandenberghe, 1988; French, 1988) and to thaw consolidation (Hallet and Waddington, 1991).

Wedge-Cast Structures

The wedge casts are very similar in size and morphology to ice and frost-wedge structures described and pictured in Hamelin and Cook (1967), Flint (1971), Black (1976), and Hamilton and Ashley (1993). They are narrower and more sinuous than the wedge casts observed in southern New Jersey that Newell et al. (1988) described as frost wedges. Similar structures have been observed near Middletown, Delaware (Ramsey, 1994). The wedge-cast structures do not appear to be root burrows as there are no associated roots or organic matter. They are not likely to be desiccation cracks as they have formed in non-expandable material, in this case, sand (Black, 1976). Their three-dimensional forms demonstrate that they are not slump features formed at the edge of the excavation.

As discussed in the previous section, an assortment of data from Delaware and the adjacent continental shelf indicates that the local climate was sufficient to permit development of a significant thickness of frozen ground but perhaps not permafrost. A lack of permafrost conditions would mean that these features cannot be ice wedges (Walters, 1978; Black, 1976). The downward warping of the beds adjacent to the wedge casts also indicates that these are not ice-wedge casts. Hence, it is most likely that the wedge casts are fossil frost wedges that formed in seasonally frozen ground rather than ice wedges formed in permafrost (Walters, 1978; Black, 1976). The data are not sufficient to determine if the rounded closed depressions observed on aerial photographs are relict thermokarst features.

Brittle-Deformation Structures

Offsets on near-vertical faults in both the Columbia and Calvert formations indicate that they were formed in an extensional stress field. The orientations of major and conjugate joints also indicate their formation in an extensional stress field, where the axis of the principal minimum stress was oriented approximately horizontal with a northwest-southeast strike. These structures are similar to rock and photolineament features reported by others. Thompson (1980) found similar brittle structure orientations in Coastal Plain and Piedmont rocks adjacent to the Fall Line in nearby Pennsylvania, Maryland, and Delaware. Photolineament studies on LANDSAT imagery by Spoljaric (1979) show N-S, NE-SW, and NW-SE orientations, and a nearby possible fault.

The orientations and association of faults with vertical and conjugate joint and fracture sets indicate a tectonic origin possibly related to regional Cenozoic stress regimes. The faults and fracture and joint sets could be related to motion

on deeper faults associated with the Smyrna fault zone (R.N. Benson, oral comm., 1990; Benson and Spoljaric, 1996, fig. 6) possibly associated with the border fault zone of an inferred buried Mesozoic rift basin (Queen Anne Basin), which, in turn, may be a reactivated Paleozoic thrust fault (Benson, 1992). Because the faults offset the Columbia-Calvert contact and there are no blocks of Calvert sediment in the Columbia, or other chaotic zone, it is highly unlikely that the faults were caused by syndepositional bank collapse or slope failure. The horizontal set of structures is probably related to erosional unloading.

One important factor in discussing the origin of fractures and joints is the coincidence of sulfate minerals alunite, jarosite, gypsum, and anhydrite (Nenad Spoljaric, written comm., 1992) within the highly fractured upper mud unit of the Calvert. The top surface of the upper mud unit is an unconformity, and the mineralization and fracturing are most intense close to this surface. As such, sulfate mineralization observed in the upper mud unit of the Calvert is likely to be a weathering phenomenon. Acid-sulfate soils commonly form on sulfide mineral-bearing deposits in oxidizing, wet and dry tropical, sub-tropical (Moormann, 1963), and temperate to cool-temperate climates (Postma, 1983). Pyrite is commonly observed in the lower half of the Calvert Formation (Spoljaric, 1988, 1996), the unit present at the Pollack Farm Site. The upper mud unit is interpreted to have been deposited in a tidal flat environment (Ramsey, 1998). The origin of some joints and fractures and the sulfate minerals in the upper mud of the Calvert could be related to cycles of wetting and drying typical of tidal flat deposits, or post-depositional weathering. It is possible that some of the intense fracturing could have been caused by desiccation during cold, dry periods; however, it is unlikely that these processes also caused the vertical fractures in the tidal-channel sands of the Calvert and fluvial sands of the Columbia and the horizontal fractures in the upper mud of the Calvert. Given the proximity of the mineralized fractures to land surface and the highly oxidized Calvert-Columbia or Calvert-Scotts Corners contacts it does not seem likely that the mineralized fractures were caused by hydrothermal processes, a possibility suggested by Spoljaric (1996).

Dissolution-Related Structures

The style of deformation, proximity to the shelly beds, and obvious dissolution front on the shelly beds documents that these features are collapse structures. The facts that the deformation associated with these features was restricted to within a few feet of the shelly beds and that the upper shell beds are not very thick (<3 ft) indicate that this process would not allow significant development of karst topography.

CONCLUSIONS

Several types of deformation features were observed in the Scotts Corners, Columbia, and Calvert formations at the Pollack Farm Site. Contorted, folded, and disrupted bedding; wedge-cast structures; and faults, fractures, and joints were observed. Several mechanisms are responsible for these features:

- (1) It appears that cold-climate (near periglacial) processes had a strong effect on the near-surface sediments. Contorted, folded, and disrupted bedding was likely caused

by cryoturbation processes that occurred in seasonally frozen ground. The wedge-cast features have many similarities to fossil frost wedges that are interpreted to have formed in seasonally frozen ground. There is no clear evidence for the existence of permafrost.

(2) Some of the fractures and joints appear to have formed in an extensional stress field, possibly related to movement along the Smyrna fault zone, the border fault zone associated with an inferred buried Mesozoic rift basin.

(3) Some of the joints may have formed in response to erosional unloading forces or desiccation, weathering, and mineralization processes.

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PALYNOMORPHS FROM THE LOWER MIOCENE POLLACK FARM SITE, DELAWARE¹

Johan J. Groot²

INTRODUCTION

The excavation that exposed a portion of the lower Miocene Cheswold sands of the Calvert Formation at the Pollack Farm Site near Cheswold, Delaware, afforded an opportunity to obtain two samples for palynological analyses and to compare their palynomorph assemblages with those of 44 other samples described previously from the Calvert (Groot, 1992). The age, stratigraphy, and depositional environments of the Miocene sediments at the site are discussed by Benson (1998) and Ramsey (1998).

Sample 41701 is from a muddy unit within the lower shell bed (just above the pumped water level shown in figure 2 of Benson, 1998). Sample 41620 is from a mud bed above the lower shelly sand bed exposed at the site (from near the base of the parallel-bedded sand unit shown in figure 2 of Benson, 1998).

RESULTS

Table 1 summarizes the pollen assemblages of the two samples. Plates 1 and 2 illustrate selected taxa.

Wetland genera are only 2 and 3 percent, respectively, of the total number of pollen. Exotic taxa (taxa no longer present in the eastern United States) are present but rare in both samples. Sample 41701 has 7 percent marine dinocysts plus "microforams," a high percentage of *Quercus*, and a low *Pinus* frequency compared with sample 41620. Similar assemblages occur elsewhere in the Calvert formation of Delaware; for instance, sample 41701 is quite similar to core sample 20587 (-180 ft msl) from well Je32-04 at the Dover Air Force Base (Groot, 1992, fig. 2).

DISCUSSION

The pollen assemblages of the samples from the Pollack Farm Site are characterized by high percentages of temperate or warm-temperate taxa and low frequencies of exotic subtropical or tropical taxa. This indicates a climate that now prevails in the coastal region of Georgia or northern Florida. The diversity and abundance of the palynoflora representing trees and shrubs and the near absence of herbaceous pollen indicate a dense forest growing right up to the coast. The decrease in marine palynomorphs from sample 41701 below to sample 41620 above may indicate a slight regression or a change from an open marine to an estuarine environment.

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Table 1

Pollen assemblages expressed as percentages of the pollen sum.

TAXON	SAMPLE	
	41620	41701
Conifers		
<i>Pinus</i>	35	12
*TCT	2	4
<i>Podocarpus</i>	**P	-
<i>Sequoia</i> type	-	1
Swamp or wetland taxa		
<i>Alnus</i>	-	P
<i>Ilex</i>	P	P
<i>Liquidambar</i>	1	2
<i>Nyssa</i>	P	-
<i>Planera</i>	P	P
<i>Cyrilla</i>	P	-
<i>Gordonia</i>	P	-
<i>Taxodium</i>	-	P
Other angiosperm taxa		
<i>Betula</i>	P	P
<i>Carya</i>	10	11
<i>Quercus</i>	48	64
<i>Tilia</i>	P	-
<i>Ulmus</i>	-	2
<i>Momipites</i> (<i>Engelhardia</i> type)	P	P
<i>Alangium</i>	P	-
Palmae	-	P
Herbs	P	P
Ferns	P	P
Dinocysts and "microforams"	1(?)	7

*Taxaceae, Cupressaceae-Taxodiaceae (except *Taxodium*)

**P=<1%

¹ In Benson, R.N., ed., 1998, Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 55-57.

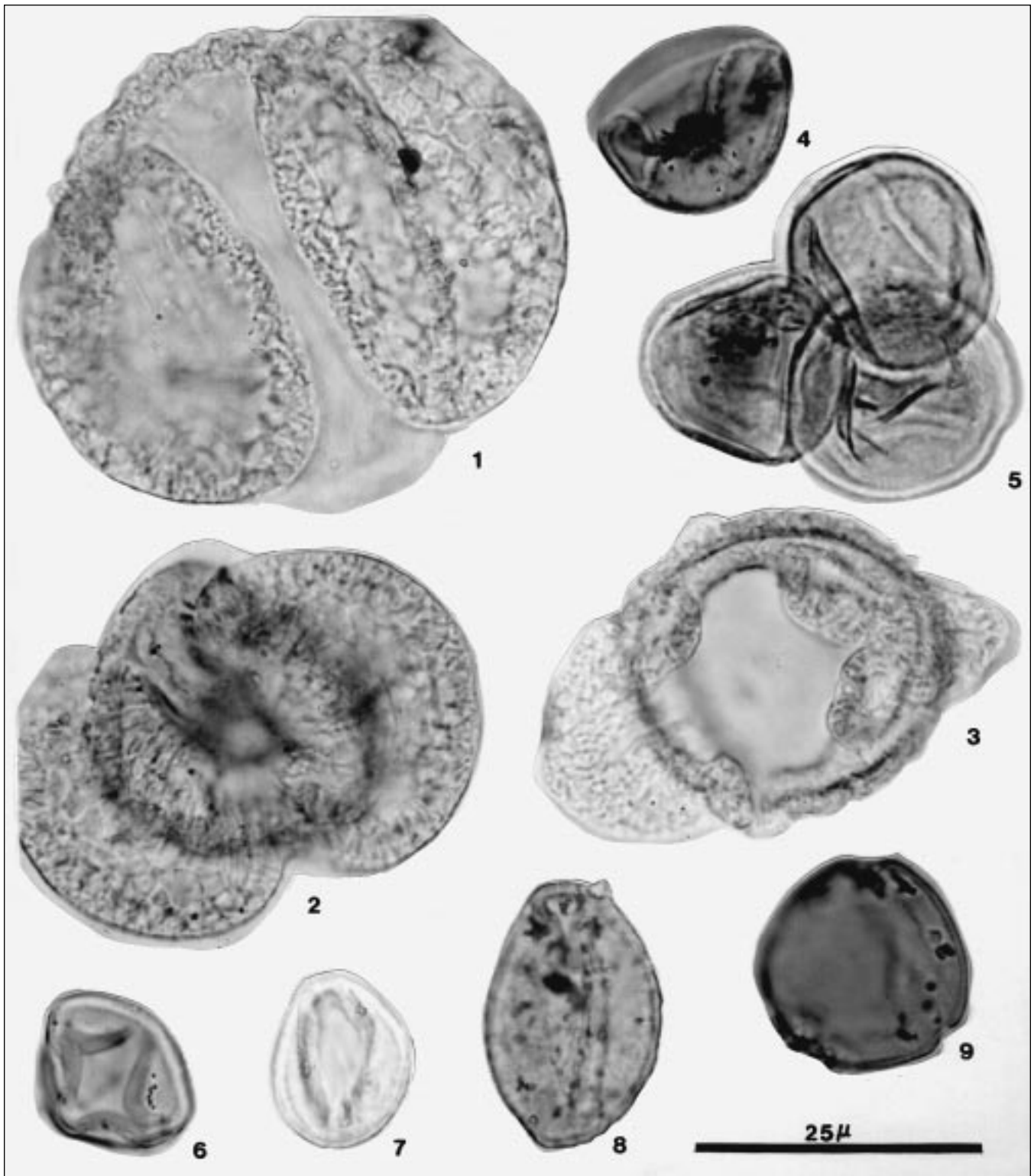


Plate 1. All from sample 41620. 1. *Pinus* type. 2. *Podocarpus*. 3. *Cedrus* (?). 4. TCT (Taxaceae, Cupressaceae-Taxodiaceae, except *Taxodium*). 5. TCT. 6. *Cyrilla*. 7. *Quercus*. 8. *Quercus*. 9. *Momipites*.

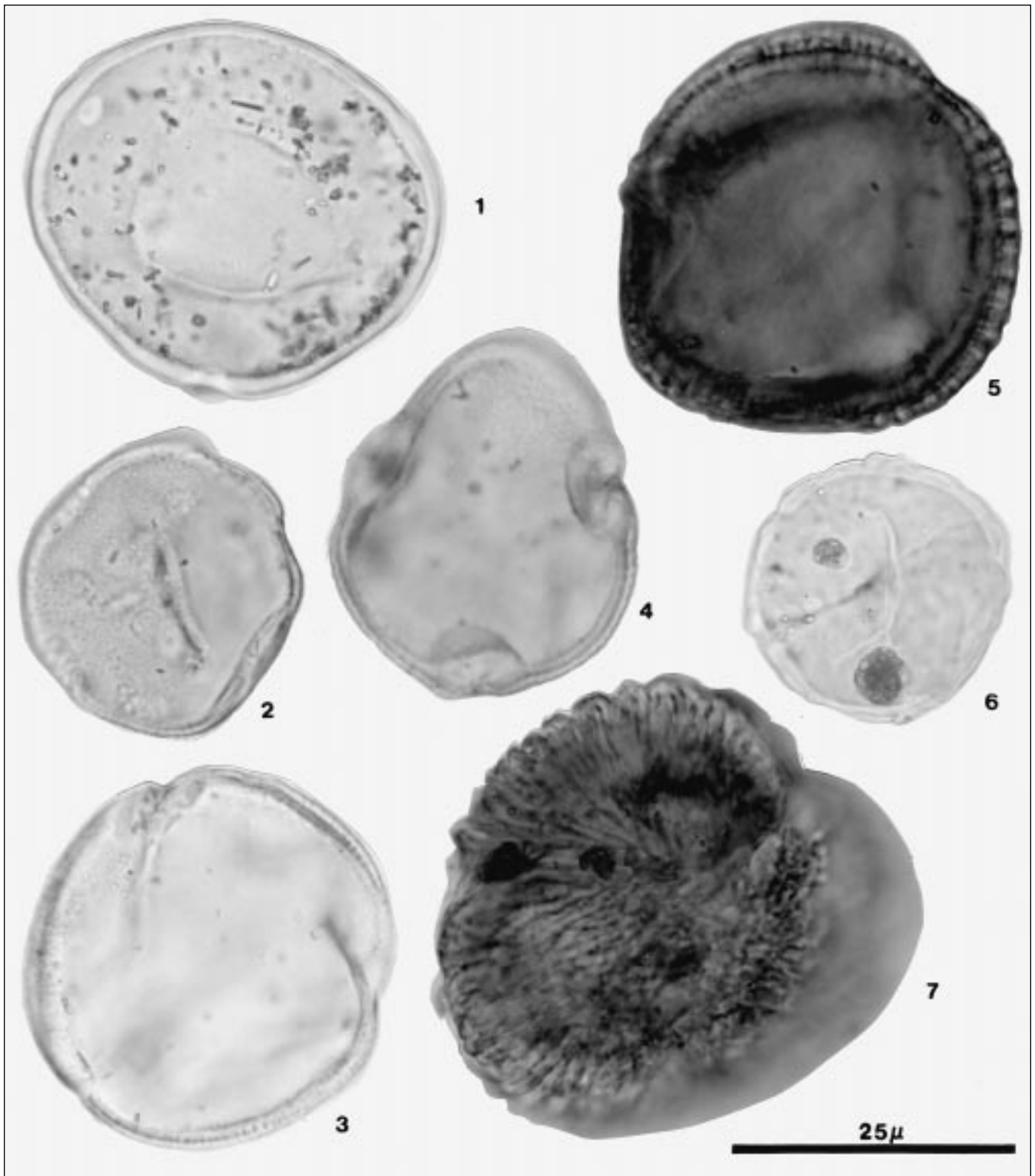


Plate 2. All from sample 41620. 1. *Carya*. 2. *Liquidambar*. 3. *Nyssa*. 4. *Tilia*. 5. *Gordonia*. 6. *Planera*. 7. *Alangium*.

MOLLUSKS FROM THE LOWER MIOCENE POLLACK FARM SITE, KENT COUNTY, DELAWARE: A PRELIMINARY ANALYSIS¹

Lauck W. Ward²

ABSTRACT

A previously undiscovered and undescribed assemblage of fossils was first exposed in a borrow pit for road construction near Cheswold, Delaware, in 1991. The assemblage, which consists principally of mollusks, is correlated with one from the Shiloh Marl Member of the Kirkwood Formation of New Jersey. The molluscan assemblage is analyzed, and 104 species are discussed and/or figured. The mollusks appear to have originated in a deltaic setting where fresh-water, brackish-water, and marine mollusks have been mixed and rapidly deposited in a channel.

The site is unique in that it exposes Miocene macrofossil-bearing beds that are only encountered in boreholes in Delaware. The molluscan assemblage is remarkable because of its excellent preservation, the vast numbers of specimens, the co-mingling of mollusks from varied habitats, and the presence of subtropical and tropical taxa so far north. This collection supplements those from the Kirkwood of New Jersey and helps to shed light on a period important in the transition from the climates and molluscan assemblages of the Oligocene to the early Miocene.

INTRODUCTION

In November 1991, personnel at the Delaware Geological Survey requested my help in identifying an assemblage of molluscan fossils from near Cheswold, Kent County, Delaware (Figs. 1 and 2). This collection was obtained from an excavation on the Pollack Farm Site exposed during the Delaware Route 1 road-building project that paralleled the existing U.S. Highway 13, a north-south road that extends the length of the state. In one area, on the Pollack Farm between Smyrna and Dover, 1.2 km (0.75 mi) north of Bishops Corner and just south of the Leipsic River (Little Duck Creek on earlier maps), construction crews had exposed a soft sandy bed packed with shells, the upper shell bed at the site (Benson, 1998, fig. 2). Excavation during the winter of 1991-92 exposed the more extensive and more richly fossiliferous lower shell bed.

A cursory, on-site examination of the shell bed in November indicated it represents a mixed assemblage containing, possibly, Miocene to Pleistocene fossils. Later study of the molluscan assemblage revealed the entire fauna is of early Miocene age, similar to fossils from the Shiloh marl beds exposed and described in Cumberland County, New Jersey. The New Jersey deposits, known principally from exposures on Stow Creek, pits at Jericho and Shiloh, and wells at Millville, Cape May, and Sea Isle City, have been referred to the Kirkwood Formation.

It was clear, early in the study, that the quantity and quality of the newly discovered Delaware fossil material far exceeded any collections from the Miocene of New Jersey and was the first significant Miocene material from Delaware. A study of the existing literature on the New Jersey Miocene mollusks (Heilprin, 1888; Whitfield, 1894; Dall and Harris, 1892; Pilsbry and Harbison, 1933; Richards and Harbison, 1942) made it clear that much of the material available to those early workers was fragmentary and sparse. On the other hand, descriptions of Miocene fossils from Delaware are nearly nonexistent. The only worker who mentioned Miocene mollusks was Booth (1841), who mentioned only molds and casts. Later workers who bothered to mention the Miocene of Delaware (Dall and Harris, 1892; Miller, 1906) merely referred to the observations of Booth. It also was clear that the Pollack Farm excavation was

one with an expected short life and needed intense study while it was still available. Accordingly, the site was visited and collected almost weekly from November 1991 until September 1992. Shortly thereafter, the fossiliferous portion of the pit was again covered. Because of this short life, collections from the pit were large and duplicative. Most of the molluscan material is housed at the Virginia Museum of Natural History. Duplicate material has been distributed to the Delaware Geological Survey and the National Museum of Natural History.

The relative rarity of available Miocene fossil material in New Jersey and especially Delaware made the discovery of the shell bed at the Pollack Farm Site very important. The collection will enable paleontologists to identify mollusks previously known only from fragments, and it has also provided a number of new taxa, previously unknown and unexpected, in so old a unit and so far north a location. Additionally, the knowledge of previously known taxa has been expanded by virtue of the large numbers of specimens collected.

This fossil deposit has provided a large array of data concerning the first appearances of various taxa and the last appearances of others. It contains a number of taxa that appear in Delaware in the early Miocene and do not reappear until the late Pliocene in Virginia or farther south. The assemblage has a number of species that are clearly European emigrants and others that only could have arrived from a southern route. It contains a surprising mixture of temperate, subtropical, and tropical taxa as well as brackish, back-barrier, shallow shoreface, and open-marine taxa.

Because of its large size and diversity, the molluscan collection from the Pollack Farm Site is invaluable. It is probably most important because it helps to fill a gap in our knowledge of the period after deposition of the upper Oligocene/lower Miocene Belgrade Formation in North Carolina and before deposition of the Plum Point Marl Member (Bed 10) of the Calvert Formation in Maryland. The Delaware fossils record the transitional event when the middle Atlantic continental margin changed from a tropical setting to a temperate one. This temperate environment, with thriving molluscan populations, persisted until the late Pliocene when a severe cooling event caused the extinction of many of the taxa.

¹ In Benson, R.N., ed., 1998, *Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware*: Delaware Geological Survey Special Publication No. 21, p. 59-131.

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TIM O'BRIAN

Figure 1. Aerial view of the Pollack Farm Site excavation (looking east) in 1992. The upper reaches of the Leisic River are in the upper left. New highway construction (Delaware Route 1) runs from left to right in the lower part of the view.

Acknowledgments

A number of people aided in the various aspects of this study. Dr. Thomas E. Pickett and Dr. Kelvin W. Ramsey, both of the Delaware Geological Survey, first called my attention to the excavation and asked for my help in identifying the mollusks in November 1991. Gordon (“Gordy”) Simonson, a foreman on the site, was the single, most instrumental person in aiding the various aspects of the investigation. Gordy spent numerous weekends, with his family, collecting the mollusks described in

this paper. He also helped in operating backhoes to dig out fresh material and gained the cooperation and enthusiasm of his crews in helping our work. Also, Debbie Paruszewski of the Iron Hill Museum in Newark, Delaware, spent a number of days helping me collect specimens for this study.

Personnel from the Virginia Museum of Natural History who helped collect were Cheryl Anthony, Patty Day, Wendy Hester, Karen Tunnell, and James Beard. A number of individuals from the National Museum of Natural History (Smithsonian Institution) helped to collect, and these collections were provided to me through David Bohaska. To all these workers and others who had any participation in the collection of the molluscan material I express my thanks.

Christa Hampton and Ellen Compton-Gooding helped pick and sort the collection and assisted with the photography of the specimens; Ellen also prepared the figures and tables and performed most of the duties associated with manuscript preparation. I thank Emily H. Vokes and Joseph G. Carter for their critical reviews of the manuscript.

STRATIGRAPHY

The stratigraphy of the Miocene deposits in Delaware is only briefly touched upon in the early literature. James C. Booth, Delaware’s first state geologist, made the first mention of that state’s Miocene strata in his “Memoir of the Geological Survey of the State of Delaware” (1841). That report includes the results of a geological survey done in 1837–1838. In his report, Booth describes the beds on Old Duck Creek in Kent County. This locality is immediately adjacent to the Pollack Farm Site and was said to have a

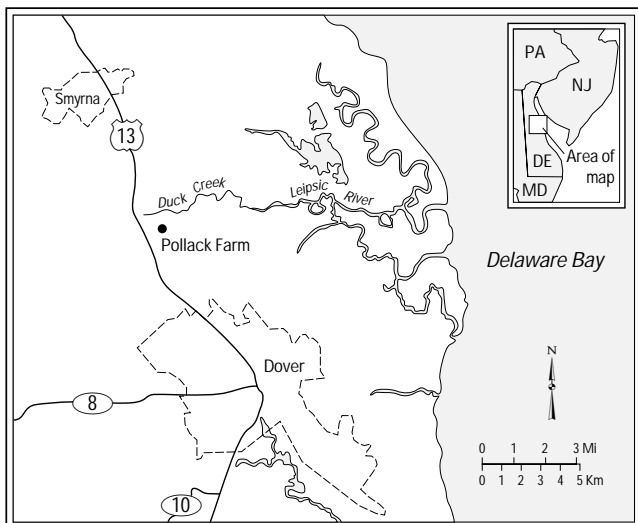


Figure 2. Map showing the location of the Pollack Farm Site, Kent County, Delaware.

lower blue clay overlain by a ferruginous sandstone with molds of mollusks. At “Wales’ mill-dam” Booth (1841) reports the presence of the following fossils (molds):

<i>Mactra</i> sp.	<i>Venus alveata</i>
<i>Balanus</i> sp.	<i>Venus inoceroides</i>
<i>Serpula</i> sp.	<i>Nucula laevis</i>
<i>Cardium</i> sp.	<i>Myoconcha</i> sp.

This is the first and only list of Miocene molluscan fossils from Delaware, unless those from the borehole at Brandywine lighthouse in Delaware Bay are included, said by Richards and Harbison (1942) to come from a few hundred yards inside New Jersey.

Later descriptions of Tertiary deposits in Delaware have been brief and based mainly on the comments of Booth (1841). Some of these papers are by F. D. Chester (1884) and Dall and Harris (1892). Shattuck (1904) concluded that Delaware was so covered by Pleistocene sands and gravels that the underlying formations were obscured and difficult to determine. Miller (1906) mapped the 30-minute Dover quadrangle in the U.S. Geological Survey’s Geologic Atlas–Folio Series. In the accompanying text, he repeated much of the data from Booth but included a well log from Dover. Miller (1906) also referred the Miocene beds on the Dover sheet to the Calvert Formation, which had recently been described by Shattuck (1902, 1904). The present practice of the Delaware Geological Survey is to include those beds in the Calvert (Benson et al., 1985; Benson and Spoljaric, 1996).

Another name, the Kirkwood Formation, was proposed for correlative Miocene beds of similar lithology and molluscan composition just to the northeast across Delaware Bay in New Jersey. The Kirkwood appeared in Knapp’s (1904) description of the beds in the Coastal Plain Province section. The description was enlarged upon by Kummel (1909); two members, the Alloway Clay and the Shiloh Marl, were named by Ries et al. (1904). These names are approved for use as mappable units by the Geologic Names Committee of the U. S. Geological Survey (Swanson et al., 1981), though they are rarely used.

Jordan (1962) reviewed the nomenclature of the Miocene stratigraphy in Delaware and assigned those strata to the Chesapeake Group, undifferentiated. Owing to the lack of well developed control by deep wells at that time, Jordan did not recognize the formations of the Chesapeake Group of Maryland. It was clear to him that the Kirkwood lithologies should interfinger with the Maryland ones, but lacking stratigraphic precision, the name Chesapeake Group was preferred. Jordan (1962) did recognize informal aquifer units within the Chesapeake Group, however, one of which is the Cheswold. The sands exposed at the Pollack Farm Site are the Cheswold sands, an informal unit of the Calvert in Delaware (Benson, 1998). Benson (1990), in a study of a borehole near Lewes, Delaware, described the Miocene beds and subdivided them into the Calvert, Choptank, and St. Marys formations on the basis of geophysical log correlation to Maryland Eastern Shore boreholes where the formations are recognized in the subsurface.

It appears, after studying the sediments from the type locality of the Calvert Formation in Maryland and those of the type locality of the Kirkwood Formation in New Jersey, that the two units interfinger in the area of Delaware (Fig. 3; see also Benson, 1998). The New Jersey type area of the Kirkwood and the area around Kent County, Delaware,

clearly were sites of deltaic accumulation, where large amounts of coarse clastic material were prograding basinward toward the southwest where finer sediments, typical of the type Calvert, were being deposited.

The beds exposed in the type area of the Kirkwood are lithologically similar to, and contain many of the same fossils as, those at the Pollack Farm Site in Delaware. The mollusks, most of which depended on a clayey-silty-sand substrate to support life and growth, apparently could not survive on silty or clayey bottoms. The result was mollusks abundant in the sandy facies of the beds but become rare to absent in the regions where soft, soupy bottom conditions prevailed, remote from areas of coarser sediment deposition. For this reason the abundantly shelly sands found in New Jersey and Delaware can be traced only as far as the Eastern Shore of Maryland. Equivalent beds that appear on the western shore of Chesapeake Bay are silts and clayey silts, which have only fragile poor molds in them.

All of these facies, however, contain a key diatom that allows correlation from Maryland to New Jersey. *Actinoptychus heliopelta* is abundant in the Kirkwood of New Jersey, is present at the Pollack Farm Site in Delaware, and is found in only one of Shattuck’s (1904) “zones” (beds). Andrews (1978, 1988) based his East Coast Diatom Zone (ECDZ) 1 on the appearance of *A. heliopelta* and found it only in the lower 3 m (10 ft) of Shattuck’s (1904) Bed 3. This bed is exposed along the Patuxent River (see Shattuck, 1904, p. LXXXVI, section 1; Ward, 1992, p. 47, fig. 31) where it consists of a diatom-rich silty clay. An indurated sand (Bed 2) at its base, containing molds of mollusks, probably represents the basal transgressive facies of this unit. The diatom bed, termed Bed 3-A by Andrews (1988) and Ward (1992), can be traced across Maryland, Delaware, and New Jersey in the subsurface. Benson (1990, 1998), however, shows that in subsurface rocks of Delaware, *A. heliopelta* has a long stratigraphic range, almost the entire lower Miocene, and although not useful for high resolution biostratigraphy, it is a good marker for recognition of the lower part of the Calvert Formation and its equivalents in New Jersey.

The molluscan assemblage in the Kirkwood Formation also contains a number of marker species that help to correlate that unit with the Calvert in Delaware and Maryland. Those taxa from the Delaware site are the main topic of this paper, but species listed and figured by Shattuck (1904) from Centerville, Church Hill, and Tilghman Station made it possible to trace the Kirkwood-equivalent beds across the Eastern Shore of Maryland. Those equivalents are present across Chesapeake Bay, but their sediments are finer as they were deposited distally from the deltas in New Jersey and Delaware, and they no longer could support a well developed benthic molluscan population.

The coarse to fine shelly sands exposed at the Pollack Farm Site are most similar to the Shiloh Marl Member of the Kirkwood Formation, but the muddy units above the sands are much more like the finer-grained Calvert Formation. The sandy beds of the Kirkwood, which thin and finally pinch out to the southwest, might best be termed tongues of the Kirkwood that extend deep into the Calvert Formation. Until these relationships are resolved using various subsurface stratigraphic techniques, the shelly sands at the Pollack Farm Site are considered to be an exposure of the informal unit, the Cheswold sands, of the lower Calvert Formation (Benson, 1998).

MOLLUSCAN BIOSTRATIGRAPHY AND CORRELATION

The molluscan assemblages of the Kirkwood Formation and the Pollack Farm Site are clearly intermediate in stratigraphic position between the well-known Calvert Formation, Plum Point Marl Member, Bed 10 assemblage (above), and that of the Haywood Landing Member of the Belgrade Formation in North Carolina (below). It falls within Ward's (1992) Interval-zone M13. The lower boundary of M13 is marked by the appearance of *Pecten humphreysii* (appears first in Calvert Bed 2) and the upper boundary by the appearance of *Marvaccrassatella turgidula* (appears first in Calvert Bed 14). It is here proposed that the lower portion of Interval-Zone M13 be called Subzone M13-A (Fig. 3). This subzone is characterized by the presence of *Astarte distans* Conrad; this species is common in the type Kirkwood in New Jersey, abundant in the Pollack Farm beds in Delaware, and present in the G.D. Harris collections from Tilghman Station (USGS 2361, 2362, 2363) and Centerville, Maryland (USGS 2360), at the National Museum of Natural History.

Tables 1 and 2 show the distribution of the molluscan taxa from the Pollack Farm Site in the Oligocene, Miocene, and Pliocene beds of the middle Atlantic Coastal Plain. The Pollack Farm species are plotted in the Fairhaven Member, Beds 2-3A, and are annotated according to their abundance. Several of the taxa also occur in the older Oligocene unit, the Haywood Landing Member of the Belgrade Formation.

Some of these taxa are:

- Mytilus incurva* Conrad
- Stewartia anodonta* (Say)
- Tagelus plebeius* ssp.
- Semele subovata* (Say)
- Leptomactra marylandica* (Dall)
- Mya producta* Conrad
- Bicorbula idonea* (Conrad)
- Turritella tampae* Heilprin
- Calyptrea aperta* (Solander)

The Pollack Farm assemblage has its clearest affinities to the "Plum Point" fauna of Glenn (1904) and Martin (1904) (=Bed 10 of the Plum Point Marl Member of the Calvert Formation). The two units share over 50 species, but the beds in Delaware contain a number of stratigraphically confined taxa that should facilitate their recognition in field and subsurface work. Some of the more notable include:

Bivalves

- Dallarca* sp.
- Astarte distans* Conrad
- Astarte* sp.
- Cyclocardia castrana* (Glenn)
- Glossus* sp.
- Iphigenia* sp.
- Caryocorbula subcontracta* (Whitfield)

Gastropods

- Turritella cumberlandia* Conrad
- Diastoma insulaemaris* (Pilsbry and Harbison)
- Epitonium charlestonensis* Johnson
- Urosalpinx cumberlandianus* (Gabb)
- Tritonopsis ecclesiastica* (Dall)
- Nassarius sopora* (Pilsbry and Harbison)
- Oliva simonsoni* new species
- Inodrillia whitfieldi* (Martin)

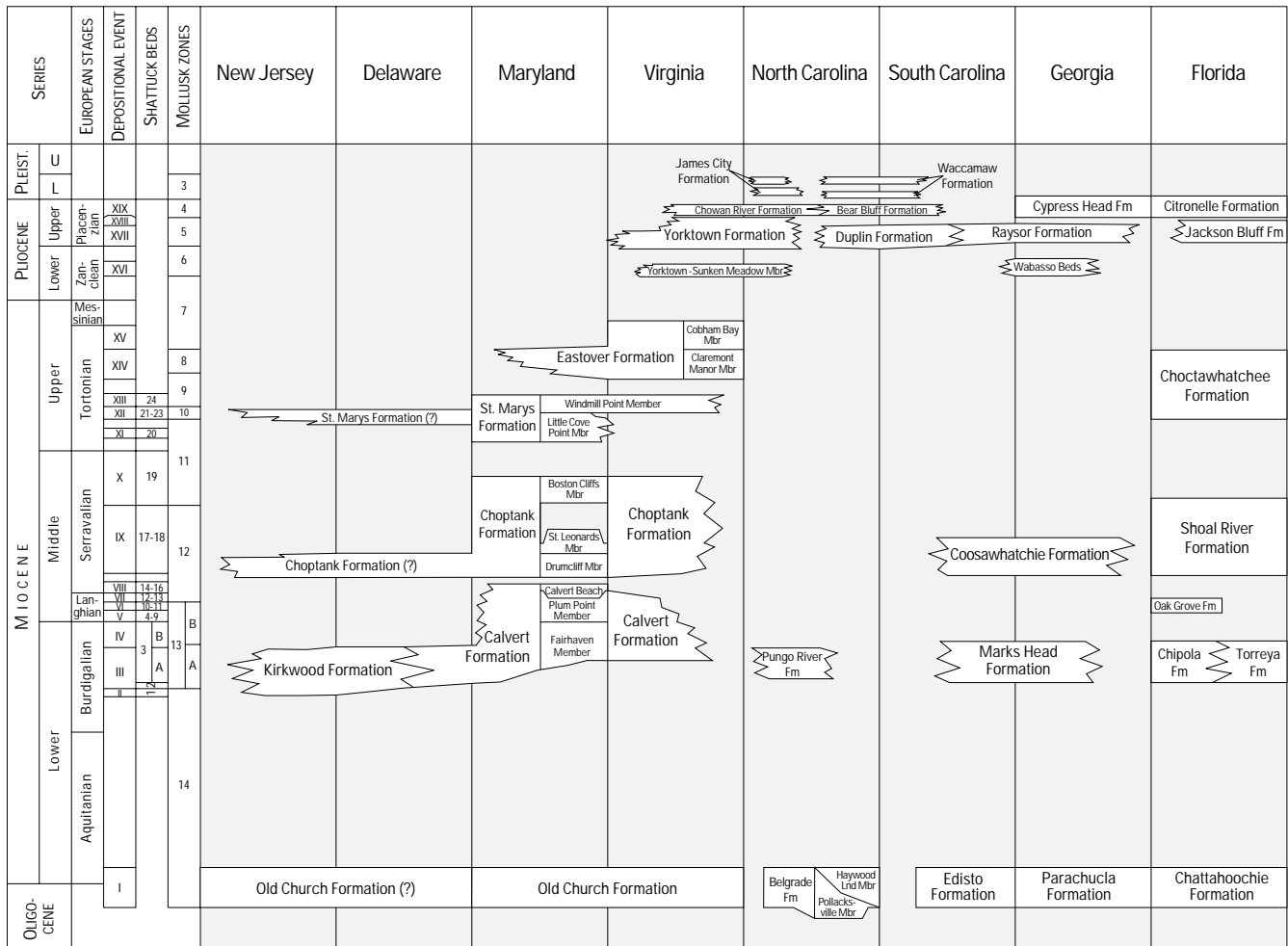


Figure 3. Correlation chart showing stratigraphic relations, based on molluscan biostratigraphy, of the outcropping geologic units referred to in this study.

Table 1.—Gastropod and scaphopod occurrences. Data for Bed 2–3A includes the taxa found at the Pollack Farm site.

Gastropoda & Scaphopoda	STRATIGRAPHY		Calvert Formation				Choptank Formation			St. Marys Formation			Eastover Formation		Yorktown Formation			
	Belgrade Formation	Haywood Landing Mbr.	Fairhaven Member			Plum Pt. Mbr.		17	18	19	20	21–23	24	Clare. Mbr.	Cob. Mbr.	S. M. Mbr.	R./M.B. Mbrs.	M. H. Mbr.
			1	2–3A	4–9	10–11	12–13	14–16										
GASTROPODA																		
<i>Diadora griscomi</i> (Conrad)	G		R															
<i>Tegula marylandicum</i> (Martin)			C		R													
<i>Calliostoma eboreus</i> (Wagner)			C		X													
<i>Littorina</i> sp.			U															
<i>Caecum calvertense</i> Martin			R		X													
<i>Solariorbis lipara</i> (H. C. Lea)			R		X				X		X	X	X	X	X	X	X	X
<i>Teinostoma nana</i> (I. Lea)			R								X	X	X		X	X	X	X
<i>Diastoma insulaemaris</i> (Pilsbry & Harbison)			A															
<i>Carinorbis dalli</i> (Whitfield)			A			C												
<i>Turritella cumberlandia</i> Conrad			C		?													
<i>Turritella tampae</i> Heilprin	X		C															
<i>Turritella plebeia</i> subspecies			R															
<i>Serpulorbis granifera</i> (Say)			C		X							X	X	X	X	X	X	X
<i>Crepidula fornicata</i> Linné			A		X				X		X	X	X				X	X
<i>Crepidula plana</i> Say			R		X				X			X	X				X	X
<i>Calyptrea centralis</i> (Conrad)			R										C					X
<i>Calyptrea aperta</i> (Solander)	X		A		X		?											
<i>Crucibulum costatum</i> (Say)			U		C		X		X		X	X	X	X	X			
<i>Polinices duplicatus</i> (Say)			A		X		X		X		X	X	X	X	X	X	X	X
<i>Lunatia hemicypta</i> (Gabb)			P		X													
<i>Lunatia heros</i> (Say)			A		X		X		X		X	X	X	X	X	X	X	X
<i>Sinum chesapeakeensis</i> Campbell			P		P			X			X	X	X				X	X
<i>Ficus harrisi</i> (Martin)			R		P													
<i>Seila adamsii</i> (H. C. Lea)			U		X				X		X	X	X		X	X	X	X
<i>Epitonium charlestonensis</i> Johnson			R															
<i>Melanella migrans</i> (Conrad)			R		X													
<i>Melanella eborea</i> (Conrad)			R		X				X		X	X	X				X	X
<i>Murexiella cumberlandiana</i> (Gabb)			R			P												
<i>Urosalpinx subrusticus</i> (d'Orbigny)			C								X	X	X					
<i>Typhis acuticosta</i> (Conrad)			R		X						X	X	X					
<i>Cymia woodii</i> (Gabb)	G		A		R													
<i>Tritonopsis ecclesiastica</i> (Dall)			U															
<i>Ecphora tricostata</i> Martin	G		C	P	C													
<i>Chrysodomus patuxentensis</i> Martin			R		X													
<i>Siphonalia devexa</i> (Conrad)			C		X													
<i>Ptychosalpinx</i> sp.			R															
<i>Mitrella c. mediocris</i> Pilsbry & Harbison			P															
<i>Nassarius trivittatoides</i> (Whitfield)			C		X													
<i>Nassarius trivittatoides elongata</i> (Whitfield)			P		X													
<i>Nassarius spopora</i> (Pilsbry & Harbison)			A															
<i>Metula</i> sp.			R															
<i>Busycotypus scalarispira</i> (Conrad)	G		C		X													
<i>Scaphella virginiana</i> Dall			P		P				P									
<i>Scaphella solitaria</i> (Conrad)			C		X							X						
<i>Oliva simonsoni</i> Ward			A															
<i>Trigonostoma biplicifera</i> (Conrad)	G		P		P													
<i>Cancellaria alternata</i> Conrad			C		P													
<i>Cymatosyrinx limatula</i> (Conrad)			P		X						A	A						
<i>Polystira communis</i> (Conrad)			C		?						A	A						
<i>Leucosyrinx rugata</i> (Conrad)			P		X													
<i>Inodrillia whitfieldi</i> (Martin)			C															
<i>Terebra inornata</i> Whitfield			C									X						
SCAPHAPODA																		
<i>Cadulus conradi</i> Pilsbry & Harbison			R		G		G	G	G		G	G	G	G	G	G	G	G

KEY: U—uncommon; P—present; C—common; R—rare; A—abundant; E—exists at this horizon in equivalent formations; ?—species closely resembles; G—genus present.

Table 1. Occurrence chart for the Gastropoda recovered from the Pollack site.

Table 2.—Bivalve occurrences. Data for Bed 2–3A includes the taxa found at the Pollack Farm site.

STRATIGRAPHY BIVALVIA	Belgrade Formation	Calvert Formation					Choptank Formation			St. Marys Formation			Eastover Formation		Yorktown Formation		
	Haywood Landing Mbr.	Fairhaven Member			Plum Pt. Mbr.		17	18	19	20	21–23	24	Clare. Mbr.	Cob. Mbr.	S. M. Mbr.	R./M.B. Mbrs.	M. H. Mbr.
		1	2–3A	4–9	10–11	12–13											
<i>Nucula prunicola</i> Dall			C		X												
<i>Nucula taphria</i> Dall			R						X				X			X	X
<i>Nuculana</i> sp.			R														
<i>Nuculana liciata</i> (Conrad)			R		X												
<i>Yoldia</i> sp.			C														
<i>Dallarca</i> (?) <i>subrostrata</i> Conrad			A		X												
<i>Dallarca</i> sp.			A														
<i>Glycymeris parilis</i> (Conrad)			A		X												
<i>Mytilus</i> (<i>Mytiloconcha</i>) <i>incurva</i> Conrad	C		A		C			P	P							E	
<i>Modiolus ducateilli</i> (Conrad)			P		P			P	P	P	P	P	P	P		P	P
<i>Isognomon</i> (<i>Hippochaeta</i>) sp.			P		P			C	A	A	P	P	P	A			
<i>Crassostrea virginica</i> (Gmelin)			A														
<i>Pecten humphreysii woolmani</i> Heilprin			P	P	C												
<i>Chesapecten coccymelus</i> (Dall)			C	P	A												
<i>Chesapecten sayanus</i> (Dall)			A		R												
<i>Parvalucina crenulata</i> (Conrad)	A		U		C			P	C	C	C	C	C	C	P	C	C
<i>Stewartia anodonta</i> (Say)			A		A				C	C	C	C		C	A	C	C
<i>Carditamera aculeata</i> Conrad			C														
<i>Cyclocardia castrana</i> (Glenn)			A														
<i>Marvacrassatella melinus</i> Conrad			A		A												
<i>Astarte distans</i> Conrad			A														
<i>Astarte</i> sp.			A														
<i>Dinocardium</i> sp.	G		A														
<i>Chesacardium craticuloides</i> (Conrad)			A		A												
" <i>Cardium</i> " <i>calvertensium</i> Glenn			P		U			C									
<i>Leptomacra marylandica</i> (Dall)	?		P														
" <i>Macra</i> " sp.			A														
<i>Ensis directus</i> Conrad			P		X			X	X	X	X	X	X	X	X	X	X
<i>Strigilla</i> sp. cf. <i>S. georgiana</i> ? Gardner			P														
<i>Florimetus buplicata</i> (Conrad)			P														
<i>Semele subovata</i> (Say)			P					X	X	X	X						
<i>Tagelus plebeius</i> subspecies	X		C														
<i>Donax idoneus</i> subspecies	X		P														
<i>Donax</i> sp.	?		P														
<i>Iphigenia</i> sp.			C														
<i>Mytilopsis erimocenicus</i> Vokes			A														
<i>Glossus</i> sp.			R														
<i>Lirophora latilirata</i> (Conrad)			A		A	G	G				G	G	G		G	G	
<i>Mercenaria ducateilli</i> (Conrad)	G		A														
<i>Dosinia acetabulum blackwelderi</i> Ward			A		C		C	C	C								
<i>Macrocallista marylandica</i> (Conrad)	G		A		C		X	A	A		R?						
<i>Clementia grayi</i> Dall			P		G				G	G	G	G					
<i>Mya producta</i> Conrad	X		C					X									
<i>Caryocorbula cuneata</i> (Say)			P		X		X	X	X	X	X	X	X	X	X	X	X
<i>Caryocorbula subcontracta</i> (Whitfield)			P														
<i>Varicorbula elevata</i> (Conrad)			R	A	C												
<i>Bicorbula idonea</i> (Conrad)	X		R		X			A	C			R					
<i>Panopea americana</i> Conrad			P		X			C	C								
<i>Panopea whitfieldi</i> Dall	?		P		?												
<i>Thovana</i> sp.			R														
<i>Martesia ovalis</i> (Say)			P					X									
<i>Periploma peralta</i> Conrad			C								X						

KEY: U—uncommon; P—present; C—common; R—rare; A—abundant; E—exists at this horizon in equivalent formations; ?—species closely resembles; G—genus present.

Table 2. Occurrence chart for the Bivalvia recovered from the Pollack site.

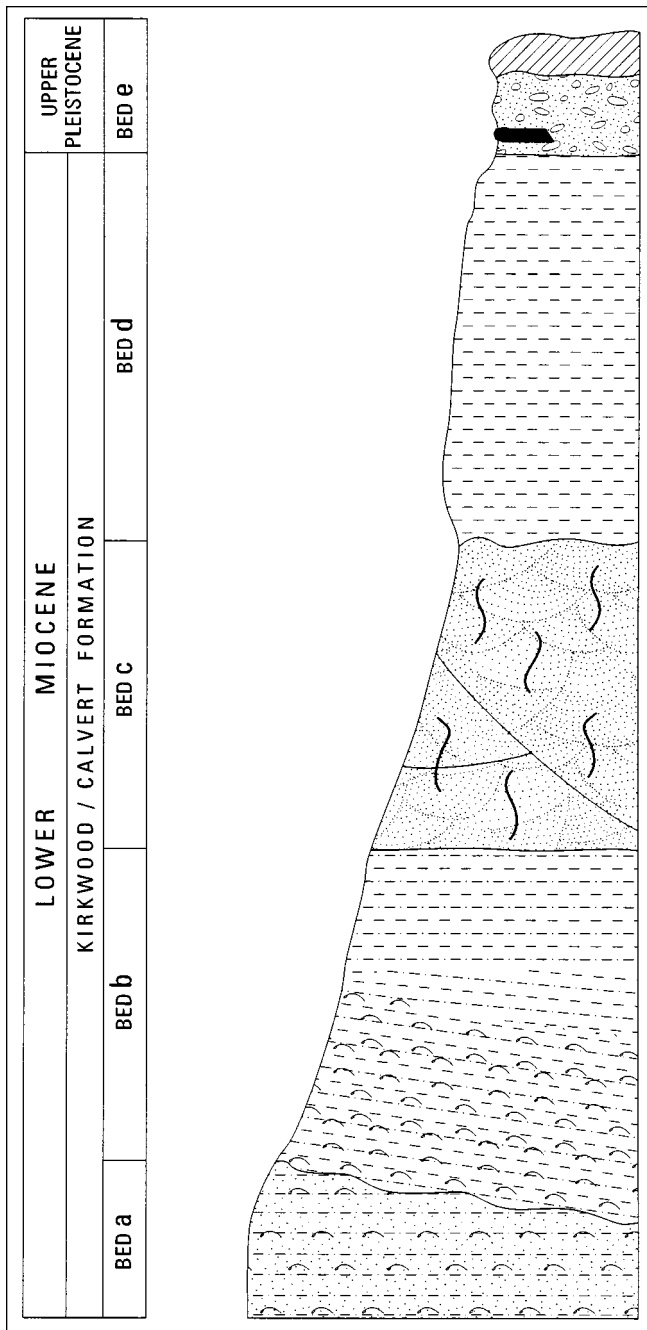


Figure 4. Composite stratigraphic section exposed at the Pollack Farm site and referred to in this study. For comparison with the composite section of (1) Benson (1998, fig. 2), bed a=shelly mud bed; bed b=lower shell bed, lower sand, and parallel-bedded sand including sandy silts with radiolarians and diatoms; bed c=cross-bedded sand, including upper shell beds; bed d=upper mud; and bed e=Columbia Formation; with (2) Ramsey's (1998, fig. 9) lithologic units, bed a=shelly mud; bed b=lower shell, lower sand, and interbedded sand and mud; bed c=cross-bedded sand; bed d=upper mud; and bed e=Columbia Formation.

It can be seen from tables 1 and 2 that the Pollack Farm collection contains a number of taxa best known from the St. Marys or other formations. The appearance of these taxa gave early workers the impression the Shiloh, New Jersey, assemblage was mixed with younger species and was reworked. The Pollack Farm collection helps to make clear the origin and stratigraphic position of the assemblage. No taxa are suspected of being reworked from older or younger beds.

On the basis of its molluscan and diatom assemblages, the Kirkwood and its Delaware equivalent are correlative with a number of stratigraphic units from New Jersey to Florida. In addition $^{87}\text{Sr}/^{86}\text{Sr}$ data have helped to corroborate these correlations (see Jones et al., 1998). In the Pungo River Formation, northeastern North Carolina, the presence of the Pollack Farm *Chesapecten sayanus* (Plate 11, Figure 5), and the diatom *Actinoptychus heliopelta* indicates with certainty the Kirkwood is stratigraphically equivalent with that unit. In southeastern South Carolina and northeastern Georgia, the Marks Head Formation, as described by Huddleston (1988), is also a stratigraphic equivalent of the Kirkwood. In addition, the Torreya Formation and Chipola Formation of western Florida are equivalents (Huddleston, 1988; Bryant et al., 1992).

PALEOENVIRONMENTAL SETTING

The entire molluscan assemblage reflects a number of environments, all consistent with deltaic and marginal marine settings. The abundance of *Crassostrea virginica* and *Mytilopsis* indicate brackish water conditions. The overwhelmingly marine fauna, however, indicates normal marine conditions. A number of the snails are usually found in intertidal, mudflat environments, while some of the clams, such as *Donax*, suggest high-energy, shoreface settings.

The general stratigraphic sequence was well exposed in the sides of the Pollack Farm borrow pit (Fig. 4). The excavation bottomed in a dark gray, silty sand (Bed a) with scattered *in situ* mollusks, many in living position (Fig. 5). At one time, over 2 m of Bed a were exposed. The upper surface of this sand (Bed a) is somewhat uneven, and, in one area, a shallow channel was cut into it. In this channel, a steeply cross-bedded, well-sorted array of clean sand and shells (Bed b) was deposited. At the deepest part of the channel, Bed b is approximately 4 m thick (Fig. 6). Most of the shell consists of broken and rolled fragments, but many whole and a few very fragile mollusks are buried in this coarse matrix. No specimens were found as paired valves or in living position in the channel deposit. The molluscan diversity is greatest in this bed, and it is clear that all of the taxa had been transported at least a short distance and rapidly buried in the channel. At various locations, thin strata of



Figure 5. Beds exposed in the lowest part of the excavation at the Pollack Farm Site. Bed a, a dark grayish green, silty sand, occupies the lowest 1.0 m in the photograph. The very shelly sands of bed b are in sharp contact with the underlying bed a. Within bed b, a thin discontinuous bed of blue-green clay is exposed (arrow) that may have originated when the channel was cut off for a short period.



Figure 6A. Bed b showing the cross-bedded, size-sorted nature of the principal mollusk-producing unit.

blue-green clay are present in the shelly sands. These clay stringers are somewhat lensoid and discontinuous (Fig. 5). Bed b fines abruptly upward into a cross-bedded, clean, fine sand (Bed c). This sand exhibits delicately preserved flaser bedding and trace fossils (Fig. 7) and is about 4 m thick. Most of the trace fossils appear to be *Ophiomorpha* burrows, but a number of smaller, worm-like tubes are also preserved. Within the sand body, a few small, scattered, lens-shaped channels were cut and filled with a laminated clayey silt (Fig. 8). Above the fine burrowed sands, a laminated silty



Figure 7A. Bed c, a fine, cross-bedded sand overlying bed b.

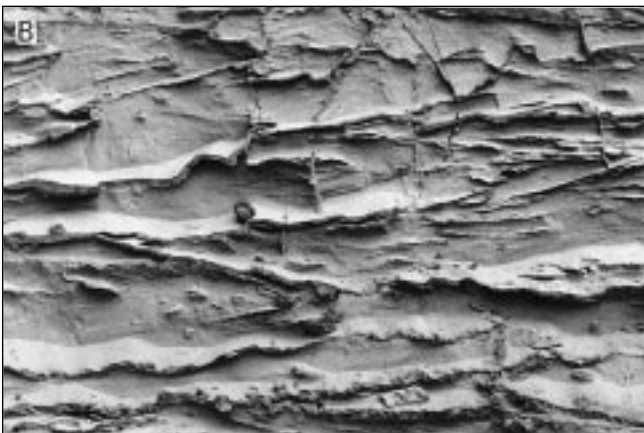


Figure 7B. A closeup of bed c showing the flaser-like bedding of the clean fine sand and the *Ophiomorpha* burrows that run vertically and horizontally in the bed.

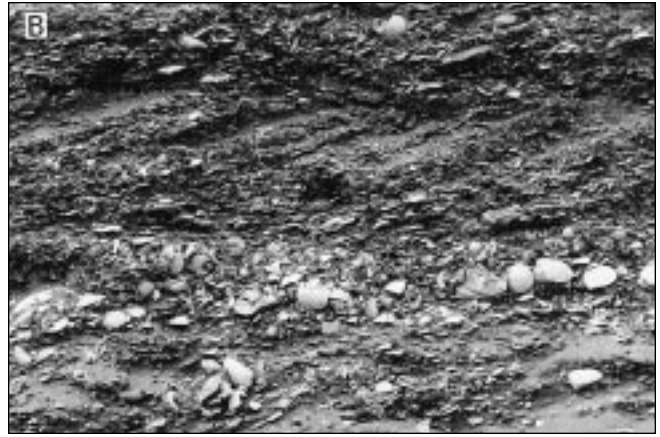


Figure 6B. Bed b showing the cross-bedded, imbricated nature of the shell accumulation.

clay (Bed d) was exposed, which is as much as five meters thick (Fig. 9). This clay has some small molds of mollusks in the lower portions, but these are indeterminate. The contact between the cross-bedded sand (Bed c) and the clay (Bed d) is sharp and abrupt, but there is no lag deposit or other indication of a diastem. Rather, it appears to be an abrupt transition between environmental regimes. The laminated clay is overlain by a 1.5-m-thick, gravelly, cobbly sand containing rare, large, silicified tree trunks (Bed e; Fig. 9).

The sequence of the lower four units is interpreted to be a series of beds deposited in a prograding deltaic setting. Bed a appears to be a nearshore, open-marine, quiet water setting. *Mytilus*, *Mercenaria*, *Panopea*, *Astarte*, and *Clementia* all occur scattered throughout the bed, in living position, and are not concentrated in any one horizon. The channel cut into the upper surface of Bed a could be the result of tidal scour or it could be the channel cut by an outflowing river at the mouth of a delta. The entire extent of the channel was not fully exposed in the small excavation at the Pollack Farm. The amount of coarse material in Bed b that infilled the channel indicates strong currents and a nearby sediment source. The interpretation is that most of the mollusks were shallow-water, near-shore in origin, and were swept into the channel and preserved. The presence of brackish-water and mud-flat dwelling taxa in an otherwise marine shelf assemblage could be explained by the cutting of a channel through a barrier or by the migration of a barrier island shoreward, during which the transgressive beach erosion incorporated older, back-barrier



Figure 7C. Detail of one of the exposed *Ophiomorpha* burrows to the left of the lens cap.

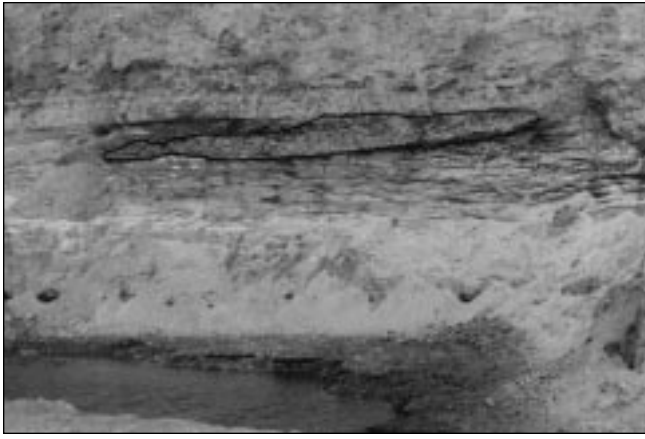


Figure 8. Bed c, with a small channel filled with a lens-shaped bed of laminated clay. Such clay bodies are believed to represent intermittent closures of active channels. The resulting quiet conditions allowed the fine sediments to settle before the channel was reopened.

taxa in the marine fauna. Rare fresh-water snails are believed to have been derived from fresh water ponds on the barrier islands or deltaic lobes. The fine blue clays that appear as very thin lenses in otherwise coarse shelly sand may reflect periods when the channel became blocked and the ensuing very quiet water allowed silts and clays to settle out. The channel then reopened, and coarse sedimentation resumed. Bed b generally fines upward and the shell content decreases dramatically. This may be partly due to dissolution. The fine cross-bedded sand (Bed c) that overlies the channel deposit still reflects marine influences but appears to be farther up-delta. Bed c contains abundant *Ophiomorpha* burrows probably built by callianassid types of crustaceans. These and other forms of burrows occur in fine, very well-sorted quartz sand and indicate high energy conditions where sediments bypassed. A few small lens-shaped channels within Bed c are filled with laminated clay. These probably represent short-lived cutoffs in which clays and silts could settle. The thick sequence of laminated clay, Bed d, that overlies the sands of Bed c may represent lagoonal deposits behind a barrier island. The poor molds of mollusks present in the unit make it difficult to interpret. It is part of the Kirkwood–Calvert sequence at the Pollack Farm Site. The overlying gravelly, cobbly sand, Bed e, is a Pleistocene fluvial deposit and is included in the Columbia Formation.

MOLLUSCAN COMPOSITION AND ANALYSIS

The molluscan composition at the Pollack Farm Site represents a mixed assemblage of brackish and normal-saline marine taxa. It also includes back-barrier, intertidal, shoreface, and shallow shelf forms. This mixture of environmental regimes has served to accumulate one of the most curious assemblages of the Atlantic Coastal Plain. Very near-shore, brackish water, and back-barrier settings are rarely preserved in the stratigraphic record on the Atlantic Coastal Plain as the later transgressions tend to bevel off the regressive sediments of the previous depositional sequence. For this reason the Pollack Farm assemblage is very important, because it gives us access to a part of the fauna that is usually lost.

It is also clear that this assemblage contains a mixture of tropical, subtropical, and temperate taxa that probably has no Holocene counterpart. Subsequent Calvert, Choptank, St. Marys, and Eastover transgressive events apparently never



Figure 9. Southwest corner of the pit showing the light-colored sands of bed c overlain by the laminated clays of bed d and the gravelly, cobbly sands of bed e. Bed d may represent back-barrier, quiet water conditions. It contains only a few poor molds of mollusks.

reached the warm water conditions present in the middle-late early Miocene. Not until the late Pliocene did some of the taxa common in the Pollack Farm beds reappear in the middle Atlantic. Some of these taxa are *Strigilla* and *Dinocardium*. Others have never been recorded at all, such as *Iphigenia* and *Mytilopsis*.

The specifics on each of the molluscan taxa are discussed in the systematics section. It is clear that the Pollack Farm assemblage reflects a tropical to subtropical, shallow-shelf assemblage, situated near a freshwater, deltaic influence. A number of taxa made their first appearance in the western Atlantic at that time after being present in the eastern Atlantic during the Oligocene. A number of taxa are subtropical to tropical forms that made their last appearance until conditions warmed up again in the late Pliocene. The bulk of the assemblage consists of taxa, arriving just before a period of cooling, that continued to thrive in the Miocene and Pliocene in the Salisbury Embayment and characterized the temperate environment for millions of years. Some of these taxa are *Isognomon*, *Glossus*, *Dallarca*, *Chesapecten*, *Marvacrassatella*, *Chesacardium*, *Leptomactra*, and *Ecphora*.

A number of individual taxa present add significantly to our knowledge of Coastal Plain mollusks. The presence of *Crassostrea virginica* was a surprise and is the only known occurrence of that species stratigraphically below the upper Pliocene in North Carolina. The same is true of *Dinocardium*, a subtropical to tropical genus. It is not seen again until the late Pliocene in North and South Carolina. *Strigilla* follows this same pattern, emerging in the late Pliocene. I can find no record of *Iphigenia* on the Atlantic Coastal Plain. *Crepidula fornicata* made its first appearance in the Delaware Miocene and was as large then as Holocene individuals of the species. *Polinices duplicatus* and *Lunatia heros* first appeared and are also as large as their Holocene counterparts. Some specimens of *Urosalpinx* exceed in size any known species of the genus. The *Busycon* are nearly as big as the largest specimens found today. It could be expected that genera such as *Urosalpinx* and *Busycon*, and species such as *C. fornicata*, *P. duplicatus*, and *L. heros* might have made their first appearances in the Tertiary as relatively small individuals, with a trend towards increasing size with time. These taxa, however, appeared first as large as Holocene specimens.



Figure 10. Gordy Simonson (site foreman) at work with backhoe at the Pollack Farm Site. Simonson stacked piles of material from bed b and then washed them down with bucket loads of water from the containment pond. Since the matrix in bed b consists of soft, unconsolidated, clean sand, the contained shell material was immediately exposed.

PREVIOUS WORK ON KIRKWOOD AND EQUIVALENT MOLLUSKS

Previous work on the Kirkwood mollusks involves only a few authors. T.A. Conrad named several species in the early 1800s, Gabb named a few in the middle 1800s, and Heilprin named a few more in the late 1800s. The first comprehensive study on the Miocene mollusks of New Jersey was that of Whitfield (1894), who monographed the fauna based on existing collections. Dall (1898) made some corrections and additions to this work and in 1903 discussed the origin of the Miocene fauna in New Jersey.

Martin (1904) and Glenn (1904) named several species from Church Hill and Centerville, Maryland, that occur in the bed (Shattuck's Bed 3-A) stratigraphically equivalent to the Kirkwood and might be considered a tongue of that formation. In addition, many of the species that they treated from the Calvert, Choptank, and St. Marys also occur in the Kirkwood. Pilsbry and Harbison (1933) had material from a number of cores in the New Jersey Coastal Plain available to them, and they named several new taxa. The last comprehensive report on the New Jersey Miocene was that of Richards and Harbison (1942). They figured all of the taxa previously named and also named several new ones. Stratigraphically equivalent strata in Florida received much attention from Dall (1890–1903), Maury (1902, 1910), and Gardner (1926–1950) who studied the Chipola Formation. Several taxa from the Chipola also occur in the Kirkwood.

In Whitfield's (1894) and Richards and Harbison's (1942) monographs, a puzzling array of mollusks are illustrated, which at a glance appear to be anomalous associations. The presence, for instance, of *Dallarca idonea* (known to this author to occur only in the St. Marys Formation) and *Sectiarca lienosa* (known to this author to occur only in the Yorktown Formation and equivalent and later beds) in a lower Miocene unit was disturbing indeed. In fact, identifications such as these have made authors, such as Dall (1903), believe that the Kirkwood, as it has come to be known, was a mixed assemblage of several different ages.

A closer look at the material that was available to the

early authors shows that, in many cases, they were working with fragments and made their identifications based on that imperfect material. For purposes of illustration they would then figure the species they believed the fragment to represent. This involved specimens from other formations and other states.

The large suites of specimens available from the Pollack Farm Site helped to decide the authenticity or correctness of many of these early identifications. Where the early workers had fragments or a single specimen, in many cases the Pollack Farm material affords access to thousands of individuals.

SUMMARY

This study has led to the following observations:

1. The Miocene deposits of Delaware are rich in fossil remains, though most remain unexposed.
2. The prolific fauna uncovered at the Pollack Farm Site is the equivalent of that collected from the Kirkwood Formation near Shiloh, New Jersey.
3. The Pollack Farm molluscan assemblage contains many of the previously known Kirkwood species, but also consists of a number of new species, first occurrences, last occurrences, subtropical and tropical species, and taxa not previously reported from North America.
4. The assemblage reflects deposition in a deltaic environment where brackish-water and marine mollusks are mixed.
5. The preservation of this fossil material and its abundance were made possible by its being swept into a channel and buried rapidly.

SYSTEMATICS

Gastropoda

Diadora griscomi (Conrad)

Plate 1, Figures 1, 3

Fissurella griscomi Conrad, 1834, p. 143.

Fissurella griscomi Conrad. Whitfield, 1894, p. 136–137, Pl. XXIV, figs. 11–14.

Fissurella griscomi Conrad. Richards and Harbison, 1942, p. 203, Pl. 21, fig. 9.

Discussion.—Conrad (1834) named this species from Stow Creek, New Jersey, and Whitfield (1894) reported it as abundant in the New Jersey Miocene. At the Pollack Farm Site the species is rare with only six specimens collected. Whitfield (1894, p. 136) described the species as being variable in its morphologic features, and the specimens from the Pollack Farm Site show some of that variability. Several specimens have coarse radial ribs while others have much finer ribs.

The species was reported by Martin (1904) from the Choptank Formation, and the specimen figured by him (pl. LXIII, fig. 5) as *Fissuridea nassula* from Jones Wharf looks very much like one of the Delaware specimens.

Geologic range.—Kirkwood, Calvert, and Choptank (?) formations.

Tegula marylandicum (Martin)

Plate 1, Figures 2, 5

Calliostoma marylandicum Martin, 1904, p. 263, Pl. LXI, figs. 15a, b.

Discussion.—This species, although represented by more than 100 individuals at the Pollack Farm Site, has not been reported from the Kirkwood of New Jersey. A single,

imperfect specimen was described by Martin (1904) as a species of *Calliostoma*. This specimen, as described, has the same color patterns as the Delaware specimens and came from Bed 10 of the Plum Point Marl Member, Calvert Formation. The color consists of mottled or striped patterns of reddish brown, much like that of *T. fasciata* (Born) from south Florida, a species that it resembles in overall form and sculpture. Recent species of *Tegula* from the Atlantic are all found in tropical settings.

³Geologic range.—Kirkwood Formation and Bed 10 of Plum Point Marl Member, Calvert Formation.

Calliostoma eboreus (Wagner)

Plate 1, Figures 4, 6

Trochus eboreus Wagner, 1839, p. 52–53, Pl. 1, fig. 5.

Monilia (Leiotrochus) eborea Wagner. Whitfield, 1894, p. 135, Pl. XXIV, figs. 7–10.

Calliostoma eboreum (Conrad). Richards and Harbison, 1942, p. 203, Pl. 18, fig. 3.

Discussion.—*Calliostoma eboreus* was reported as moderately common by Whitfield (1894), but Richards and Harbison (1942) indicated that it was rare. Wagner's (1839) type came from the lower Choptank Formation at Jones Wharf on the Patuxent River, but specimens from the Pollack Farm Site seem to be identical with that species. Seventy-five individuals were collected that exhibit a fair degree of variation in the shape and ornamentation of the whorls and the apical angle. The most obvious variation is the outline of the whorls. Some specimens have well-rounded, globose whorls while others, at the opposite end of the scale, have a well-defined carina at the edge of the whorl. Specimens in the Delaware collections exhibit all of the gradations between rounded and keeled. Several specimens have two carinae that form a shallow peripheral canal. Only a few have the "raised spiral lines" referred to by Whitfield (1894, p. 135) and figured by Richards and Harbison (1942, p. 203, pl. 18, fig. 3).

With this large suite of specimens, it may be possible to evaluate the validity of several named species of *Calliostoma* from the Calvert and Choptank Formations. *Calliostoma aphelium* Dall (1892) seems to be a *C. eboreus* with rounded, non-keeled whorls. *Calliostoma calvertanum* Martin (1904) appears to be a well-carinated *C. eboreus*, but its large, open umbilicus probably rules that out.

Geologic range.—Kirkwood, Calvert, and Choptank formations.

Littorina sp.

Discussion.—A minute species of *Littorina* is present at the Pollack Farm Site in small numbers, with over 50 specimens collected. It may be more common than is apparent, but its small size (adults are about 4 mm) makes detection difficult. The species is notable for its sharp shoulder, which is noticeably angular. This keel marks the position of the future, shallow suture between the whorls.

A living species, *L. angustior* (Mörch), has much the same overall shape as the Delaware taxon and is similarly carinate. It also is small, but ranges up to 9 mm.

Except for this Delaware taxon, there are only a few

references to the genus *Littorina* in the Tertiary of the Atlantic Coastal Plain. The only reference in the Miocene is to a single specimen from the upper Choptank on the Choptank River (Martin, 1904, p. 240). No later collections have confirmed this occurrence. The only other reported occurrences are in the upper Pliocene of Virginia (Gardner, 1948) and South Carolina (Tuomey and Holmes, 1856).

Geologic range.—Kirkwood Formation.

Caecum calvertense Martin

Caecum calvertense Martin, 1904, p. 231, Pl. LV, fig. 10.

Discussion.—No taxa assignable to the Caecidae have been reported from the Kirkwood Formation of New Jersey. Only five specimens have been found at the Pollack Farm Site. The specimens appear to be the same species described by Martin (1904) as *C. calvertense*, though that description is very brief. The beds at Martin's locality, Church Hill, Maryland, are stratigraphically equivalent with the Shiloh Marl in New Jersey.

The species has very fine, closely set annulations, except near the anterior aperture where several annulations are somewhat stronger and wider. *Caecum greensboroense* Martin is probably synonymous with *C. calvertense*.

Geologic range.—Kirkwood and Calvert formations. Lower Choptank Formation if *C. greensboroense* = *C. calvertense*.

Solariorbis lipara (H.C. Lea)

Delphinua lipara H.C. Lea, 1843, p. 261, Pl. 36, fig. 71.

Discussion.—A single specimen of *Solariorbis lipara* was found at the Pollack Farm Site. No mention is made in the literature of any specimens of that species, or even that genus, in the Kirkwood of New Jersey. The species was reported by Martin (1904, p. 264–265) in the Calvert, Choptank, and St. Marys Formations of Maryland.

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, Eastover, and Yorktown formations.

Teinostoma nana (I. Lea)

Rotella nana I. Lea, 1833, p. 214, Pl. VI, fig. 225.

Discussion.—Lea's specimen was collected by John Finch at Yorktown, Virginia, (probably in the Yorktown Formation) and not at "St. Mary's, Maryland" as reported by Lea (1833, p. 214; see Ward and Blackwelder, 1975, for details). The six specimens from the Pollack Farm Site are very small compared to the later St. Marys and Yorktown specimens, but they exhibit the nearly concealed spire and the heavy callus in the umbilicus. The species from the Calvert Formation, named *T. calvertense* by Martin (1904, p. 264, pl. LXII, fig. 3), has a lower spire and lacks the heavy callus in the umbilicus.

No specimens of *Teinostoma* have been reported from the Kirkwood of New Jersey. *Teinostoma calvertense* was reported by Martin (1904) from Church Hill, Maryland, in beds stratigraphically equivalent to the Shiloh Marl.

Geologic range.—Kirkwood and Calvert formations.

Diastoma insulaemaris (Pilsbry and Harbison)

³ Although the author refers to Kirkwood for the geologic range and occurrence of taxa from the Pollack Farm Site, the Delaware Geological Survey recognizes the Calvert Formation in Delaware and at the site instead of the Kirkwood Formation. ED.

Plate 1, Figures 7–9

Cerithidea insulaemaris Pilsbry and Harbison, 1933, p. 115, Pl. 4, figs. 20, 21.

Cerithidea insulaemaris Pilsbry and Harbison. Richards and Harbison, 1942, p. 206, Pl. 21, fig. 18.

Discussion.—The type lot of *Diastoma insulaemaris* was obtained from a well at Sea Isle City, New Jersey, at 600–700 ft. The taxon has not been reported by previous or subsequent authors in the Kirkwood Formation. Over 2500 specimens have been recovered from the Pollack Farm Site, making it one of the more common taxon at that locality.

Diastoma insulaemaris was originally assigned to the genus *Cerithidea*, but that genus has rounded whorls with strong axial ribs; spiral ornamentation is very faint. In *Diastoma* the whorls are flatter sided, the axial ribs are less prominent, and they are crossed by somewhat weaker spiral riblets. This gives a cancellate appearance with small nodes where the ribs cross. Adults of *Diastoma* exhibit a slight tendency towards pupaeform growth.

The Delaware species is similar in appearance to the living *Diastoma alternatum* (Say) but is much larger than that species, with adults commonly 20 mm in height. It is roughly similar to a late Oligocene/early Miocene species named *Cerithium insulatum* by Dall (1916) but has finer ribs than that taxon. No other occurrence of *Diastoma* has been reported from the Miocene of the Atlantic Coastal Plain.

Geologic range.—Kirkwood Formation.

***Carinorbis dalli* (Whitfield)**

Plate 1, Figures 10, 13

Trichotropis Dalli Whitfield, 1894, p. 127, Pl. XXIII, figs. 1–4.

Fossarus dalli (Whitfield). Richards and Harbison, 1942, p. 207, Pl. 18, fig. 16.

Discussion.—*Carinorbis dalli* is an abundant element of the molluscan assemblage at the Pollack Farm Site with some 600 specimens collected. Whitfield listed the species from Shiloh and Jericho, New Jersey, but Richards and Harbison (1942) noted that it is rare from those localities.

Geologic range.—Kirkwood and Calvert formations (Bed 10 of the Plum Point Marl Member).

***Turritella cumberlandia* Conrad**

Plate 1, Figures 11, 12; Plate 2, Figure 1

Turritella cumberlandia Conrad, 1863b, p. 584.

Turritella cumberlandia Conrad. Whitfield, 1894, p. 129, Pl. XXIII, figs. 9–11.

Turritella cumberlandia Conrad. Richards and Harbison, 1942, p. 203–204, Pl. 18, figs. 5, 6.

Discussion.—*Turritella cumberlandia* is the most abundant species of the genus with over 200 specimens collected from the Pollack Farm Site. They are variable in ornamentation, but most possess two prominent revolving ribs near the base of the whorl and another, less prominent rib at the top of the whorl. In the young stages the suture is hardly impressed, but in later whorls it is profoundly excavated, giving the whorls a rounded appearance. *Turritella secta* Conrad (1855) is similar in appearance to *T. cumberlandia* and may be the same species. In that case the name *T. secta* would have priority. At this time it is preferable to keep them separate as several problems concern *T. secta*. The principal problem is the locality information given by Conrad as

“Mullica Hill,” [New Jersey]. According to Richards and Harbison (1942), “there are no Miocene deposits in that vicinity.” Conrad’s (1863b) description of *T. cumberlandia* sounds very much like that of *T. secta*, but he fails to compare the two. It is possible that Conrad failed to remember his earlier name.

Geologic range.—Kirkwood and Calvert formations.

***Turritella tampae* Heilprin**

Plate 2, Figures 2, 3

Turritella tampae Heilprin, 1886, p. 113.

Turritella tampae Heilprin. Ward, 1992, p. 119–120, Pl. 26, fig. 3.

Discussion.—The *Turritella tampae*–*T. identa* lineage is clearly represented by the 55 specimens of that group found at the Pollack Farm Site. Neither species has been previously reported in the Kirkwood of New Jersey. *Turritella tampae* and *T. identa* are very similar in appearance and may prove to be the same species. Of the comparative material available from Maryland and North Carolina, the Delaware specimens are more like *T. tampae* in their large size. The smaller size of *T. identa* may be a product of environmental conditions, but the Delaware specimens are consistently larger than those from the Calvert Formation in Maryland. The specimens rival the size of the neotype of *T. tampae* (see Ward, 1992, p. 119) and specimens of that taxon from the Haywood Landing Member of the Belgrade Formation.

Geologic range.—Belgrade and Kirkwood formations; Tampa Member of the Arcadia Formation.

***Turritella plebeia* subspecies**

Plate 2, Figure 4

Turritella plebeia Say, 1824, p. 125, Pl. VII, fig. 1.

Turritella (Mesalia?) plebeia Say. Whitfield, 1894, Pl. XXIII, figs. 6–8.

Turritella plebeia Say. Richards and Harbison, 1942, p. 204, Pl. 18, figs. 4, 9.

Discussion.—Twenty specimens of this early representative of the *Turritella plebeia* lineage were collected at the Pollack Farm Site. They mark the first appearance of that lineage and exhibit the finely striate, rounded whorls that are so characteristic. They also show the single revolving rib that is present on the center of the whorl for the first eight volutions. The specimens, however, are very small, very high for their size, and very well-rounded after the initial eight whorls. Specimens of the lineage in Bed 10 of the Calvert approach the form of the Delaware specimens but have finer spiral ornamentation, a greater width-to-height ratio, and flatter whorls in the adult stages. The specimens figured by Whitfield (1894) are fragmentary but appear to be *T. plebeia*. It is unclear that they are the same as the taxon found in Delaware. The specimens figured by Richards and Harbison are also a stouter taxon than the Delaware specimens.

Geologic range.—Kirkwood Formation.

***Serpulorbis granifera* (Say)**

Plate 2, Figure 5

Serpula granifera Say, 1824, p. 154, Pl. 8, fig. 4.

Anguinella Virginiana Whitfield, 1894, p. 132–133, Pl. XXIV, figs. 1–5. [Not *Serpula Virginica* of Conrad, 1839; Not *Anguinella virginiana* of Conrad, 1845]

Vermetus graniferus (Say). Richards and Harbison, 1942, p.

205, Pl. 18, figs. 12, 13.

Discussion.—Whitfield (1894) reported the presence of *Anguinella virginiana* in the Kirkwood of New Jersey, but the specimens on which his identifications were based were very small (10 mm and less). Richards and Harbison (1942) later referred Whitfield's specimens and additional material from wells in New Jersey to *Vermetus graniferus*. In this assignment, they are probably correct. *Serpulorbis*, where unworn, has numerous, small rows of very fine striae, which are made up of individual stubby spines. *Anguinella* lacks the striae and instead, has an angular tube with transverse wrinkles.

It is difficult to get an accurate count on the specimens from the Pollack Farm Site due to the fragmentary nature of the fossils, but in excess of 40 individuals were recovered. The diameter of the broken tubes of some specimens (13 mm) is larger than any specimens I have seen in later deposits. Most of the specimens have been worn by reworking so that only a trace of the striae remain. The specimen illustrated by Martin (1904, pl. LV, fig. 14) from Church Hill, Maryland is *S. granifera* and is from beds stratigraphically equivalent to the Delaware and Shiloh, New Jersey, beds.

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, Eastover, and Yorktown formations.

***Crepidula fornicata* Linné**

Plate 2, Figures 6, 7

Patella fornicata Linnaeus, 1758, p. 781.

Crepidula fornicata Say?. Whitfield, 1894, p. 123.

Crepidula fornicata (Linné). Richards and Harbison, 1942, p. 208, Pl. 18, fig. 17.

Discussion.—Whitfield (1894) reported only a single cast of *Crepidula fornicata* from the Miocene of New Jersey. Richards and Harbison (1942) mentioned specimens from Shiloh and Bridgeton, but queried those localities. They also mentioned specimens from a well at Cape May Court House, but seemed unsure whether the specimens came from the Pleistocene or Miocene.

Crepidula fornicata is abundant at the Pollack Farm Site with over 700 specimens collected. Its occurrence in the Kirkwood marks the first known appearance of this long-lived species. Specimens found there are as large as Recent specimens (50 mm), whereas those in the Calvert, Choptank, and St. Marys are much smaller. The species is not known to reattain this size until the late Pliocene and Pleistocene.

Geologic range.—Kirkwood Formation—Recent.

***Crepidula plana* Say**

Plate 2, Figures 8, 9

Crepidula plana Say, 1822, p. 226.

Crepidula plana? Say. Whitfield, 1894, p. 124

Crepidula plana Say. Richards and Harbison, 1942, p. 208, Pl. 18, figs. 18–20.

Discussion.—*Crepidula plana* is rare in the Kirkwood of New Jersey, Whitfield (1894) having only one broken specimen and Richards and Harbison (1942) having only a few. The species is also rare at the Pollack Farm Site with only two specimens recovered.

The species is present in all of the stratigraphic units in the Chesapeake Group, but it is never common.

Geologic range.—Kirkwood, Calvert, Choptank, St.

Marys, Eastover, Yorktown, and Chowan River formations. Recent.

***Calyptraea centralis* (Conrad)**

Plate 2, Figure 10

Infundibulum centralis Conrad, 1841b, p. 348.

Calyptraea centralis (Conrad). Martin, 1904, p. 248, Pl. LIX, figs. 2a, 2b, 2c.

Discussion.—*Calyptraea centralis* is present, but not common, at the Pollack Farm Site with 15 specimens collected. The species was not reported by Whitfield (1894) or Richards and Harbison (1942), and it has not been reported stratigraphically below the St. Marys Formation. It was originally named from the Duplin Formation (upper Pliocene) at Natural Well, North Carolina. That assemblage is subtropical in nature. Today *Calyptraea centralis* is found from North Carolina to Brazil.

Geologic range.—Kirkwood, St. Marys, Yorktown, and Duplin formations and numerous other stratigraphic equivalents. Recent.

***Calyptraea aperta* (Solander)**

Plate 2, Figures 11–15

Trochus apertus Solander, 1766, p. 9, figs. 1, 2.

Infundibulum perarmatum Conrad, 1841a, p. 31.

Trochita perarmata Conrad. Whitfield, 1894, p. 124–125.

Trochus apertus Solander. Martin, 1904, p. 247, 248, Pl. LIX, fig. 1.

Calyptraea aperta (Solander). Richards and Harbison, 1942, p. 207–208, Pl. 18, figs. 23, 24.

Discussion.—*Calyptraea aperta* is common at the Pollack Farm Site with over 400 specimens collected. It was reported by Whitfield (1894) and Richards and Harbison (1942) to be common in the Kirkwood of New Jersey. Martin (1904) listed the species from beds equivalent to the Kirkwood (Church Hill, Centerville) and from Bed 10 at Plum Point. The species is known in North America from the Eocene to the Miocene (Harris and Palmer, 1946) and in Europe from the upper Paleocene to the upper Eocene. It appears that the last occurrence of *C. aperta* is in Bed 10 of the Calvert Formation. Smooth-sided specimens of *Calyptraea*, such as *C. centralis*, are present in beds higher than the Calvert, but they are smaller and never develop the rows of foliated spines.

Geologic range.—North America: lower Eocene to Miocene. Europe: upper Paleocene to upper Eocene. Kirkwood, Calvert, Belgrade, and Old Church formations.

***Crucibulum costatum* (Say)**

Plate 3, Figures 1, 4

Calyptraea costata Say, 1820, p. 40.

Crucibulum costatum Say. Whitfield, 1894, p. 122–123, Pl. XXII, figs. 11–14.

Crucibulum costatum (Say). Richards and Harbison, 1942, p. 208, Pl. 18, figs. 21, 22.

Discussion.—Whitfield (1894) and Richards and Harbison (1942) mentioned *Crucibulum costatum* as common in the Kirkwood deposits of New Jersey. The taxon is present in the Delaware exposure but is not abundant, with only 15 specimens collected. The specimens vary in external sculpture from having a number of strong raised ribs to being

nearly smooth. Some specimens are strongly ribbed in young stages and become smoother in later stages.

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, and Eastover formations and a number of other stratigraphic equivalents.

***Polinices duplicatus* (Say)**

Plate 3, Figure 7

Natica duplicata Say, 1822, p. 247.

Neverita duplicata Say. Whitfield, 1894, p. 121–122, Pl. XXI, figs. 13–16.

Polinices duplicatus (Say). Richards and Harbison, 1942, p. 209–210, Pl. 19, figs. 3, 4.

Discussion.—*Polinices duplicatus* was reported from the Miocene of New Jersey by Whitfield (1894), but only as juveniles (largest 15.9 mm). Richards and Harbison (1942) described the species as uncommon in the Kirkwood, but it is abundant at the Pollack Farm Site with over 200 specimens collected. Individual specimens range up to 45 mm in height, which is nearly the size of a large Recent specimen. The presence of the species in the Kirkwood marks the first known appearance of the taxon.

Geologic range.—Kirkwood Formation–Recent.

***Lunatia hemicypta* (Gabb)**

Plate 3, Figures 2, 3

Natica hemicypta Gabb, 1860, p. 375, Pl. 67, fig. 5.

Natica (Lunatia) hemicypta Gabb. Whitfield, 1894, p. 118–119, Pl. XXII, figs. 1–5.

Polinices hemicypta (Gabb). Richards and Harbison, 1942, p. 210, Pl. 19, figs. 8, 9.

Discussion.—The presence of *Lunatia hemicypta* in the Kirkwood of New Jersey was noted by Whitfield (1894) and by Richards and Harbison (1942). The species is small, but present at the Pollack Farm Site. It is clearly different from the young of the more globose *Lunatia heros* and the umbilically plugged *Polinices duplicatus*. About 20 individuals have been found.

Geologic range.—Kirkwood, Calvert, and Choptank formations.

***Lunatia heros* (Say)**

Plate 3, Figure 5

Natica heros Say, 1822, p. 248.

Natica (Lunatia) heros Say. Whitfield, 1894, p. 119–120.

Polinices heros (Say). Richards and Harbison, 1942, p. 209, Pl. 19, fig. 6.

Discussion.—Whitfield (1894) listed *Lunatia heros* from the New Jersey Miocene only as immature specimens. Richards and Harbison (1942) described the species as uncommon in the Kirkwood. The species is abundant at the Pollack Farm Site with over 200 specimens collected. The specimens here range up to 45 mm in height, a size which rivals Recent forms. The presence of *Lunatia heros* in the Kirkwood marks the first known appearance of that long-lived taxon.

Geologic range.—Kirkwood Formation–Recent.

***Sinum chesapeakeensis* Campbell**

Plate 3, Figures 6, 9

Natica fragilis Conrad, 1830, p. 222, Pl. IX, fig. 3. [Not of Leach, 1819]

Sinum fragile (Conrad). Richards and Harbison, 1942, p.

210, Pl. 19, fig. 13.

Sinum chesapeakeensis Campbell, 1993, p. 73, Pl. 32, fig. 353.

Discussion.—*Sinum fragilis* [renamed *S. chesapeakeensis* by Campbell (1993) because the name was preoccupied] did not appear in Whitfield's (1894) monograph on the New Jersey Miocene, but it was listed as "very rare" by Richards and Harbison (1942, p. 210) who had two specimens. The species is also rare at the Pollack Farm Site with only five specimens collected. Several individuals are complete, however, making sure its identification. The taxon, which is present in Miocene and Pliocene beds of the Atlantic Coastal Plain, is somewhat more globose than its Oligocene predecessors. The genus is somewhat conservative in its evolutionary changes making it difficult to easily discern species or morphologic trends. The presence of *S. chesapeakeensis* in the Kirkwood marks the first appearance of that long-lived taxon.

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, Eastover, and Yorktown formations.

***Ficus harrisi* (Martin)**

Plate 3, Figures 8, 10

Pyrula harrisi Martin, 1904, p. 226, Pl. LV, fig. 3.

Discussion.—*Ficus harrisi* has not previously been reported from the Kirkwood Formation of New Jersey and is represented by only one specimen at the Pollack Farm Site. Except for this occurrence, it is known only from Bed 10 of the Plum Point Marl Member. In that unit, Martin (1904) reported it to be common, though usually fragmentary.

Geologic range.—Kirkwood Formation and Bed 10 of the Plum Point Marl Member of the Calvert Formation.

***Seila adamsii* (H.C. Lea)**

Cerithium Adamsii H.C. Lea, 1845, p. 268.

Seila adamsii (H.C. Lea). Martin, 1904, p. 228–229, Pl. LV, fig. 6.

Seila clavulus (Lea). Richards and Harbison, 1942, p. 206, Pl. 18, fig. 15.

Discussion.—H.C. Lea (1845, p. 268) proposed the name *Cerithium clavulus* for a species of *Seila* in the upper Yorktown Formation (upper Pliocene). In the same paper, on the same page in a footnote, he proposed the name *C. adamsii* for *C. terebrale* Adams because the name was preoccupied. *Seila adamsii* appears to be the same species as *S. clavulus*, and as such, the renamed species should take priority; however, if the comments by Martin (1904, p. 170–171, footnote) are correct, then the publication date of *S. clavulus* is 1843, giving it priority. Until the validity of Lea's preprint dates are decided, I will use *S. adamsii*.

Seila adamsii is an element of the molluscan assemblages of the Atlantic Coastal Plain during the Miocene and Pliocene and is common today from Massachusetts to Brazil. At the Pollack Farm Site it is rare and only 10 specimens have been recovered. Previously it had been mentioned from the Kirkwood in equivalent strata by Richards and Harbison (1942) and Martin (1904).

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, Eastover, and Yorktown formations and Recent.

***Epitonium charlestonensis* Johnson**

Plate 3, Figure 11

Epitonium charlestonensis Johnson, 1931, p. 8, Pl. 1, fig. 4.

Discussion.—Whitfield (1894, p. 126, pl. XXIII, fig. 5) and Richards and Harbison (1942, p. 206, pl. 18, fig. 14) both figured specimens of *Epitonium* from the Kirkwood of New Jersey, but their specimens were very worn and very young, making certain identification impossible. Whitfield (1894) used the name *Scalaria multistriata* of Say (1830), but that species is smaller and living on the southeast shelf. Say described the species as having “numerous, approximate, equidistant, impressed lines” between the costae. The Delaware specimens have raised spiral riblets. Richards and Harbison (1942) used the name *Scala marylandica* of Martin, 1904, but that species has no spiral sculpture.

Four specimens were collected from the Pollack Farm Site that should allow identification. They are large, high-spired, have strong axials (~12 per whorl), have fairly strong spiral, raised riblets seen between the axials, and have a strong spiral cord near the base, upon which succeeding whorls attach at the point of suture.

In all these characters, the Delaware specimens are identical to specimens collected from the Cooper River at Charleston, South Carolina. The species was reported as late Eocene, but is probably from the late Oligocene Edisto Formation (stratigraphically equivalent to the Belgrade Formation).

Epitonium charlestonensis is much larger (30+ mm) than, but similar in general form to, *E. marylandica* of the Calvert Formation. It differs from *E. marylandica* in having spiral riblets. *Epitonium calvertensis*, also from the Calvert Formation and also much smaller, has spiral riblets, but the axial ribs are stronger, wider, and closer together, nearly hiding the spiral ornamentation from view.

***Melanella eborea* (Conrad)**

Eulima eborea Conrad, 1846, p. 20, Pl. 1, fig. 21.

Eulima eborea Conrad. Martin, 1904, p. 216–217, Pl. LIII, figs. 9, 10.

Discussion.—Martin (1904) was the first to report the presence of the genus *Eulima*, now known as *Melanella*, in beds equivalent to those at the Pollack Farm Site and to the Kirkwood Formation, when he listed *M. eborea* from Church Hill, Maryland. Pilsbry and Harbison (1933) were the first to identify the genus *Melanella* from the Kirkwood of New Jersey. Their species, *M. retrocita*, may be the same as *M. eborea*, but is somewhat atypical in its somewhat bulbous final whorl. *Melanella eborea* is rare at the Pollack Farm Site, with only four specimens collected.

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, Yorktown, Chowan River, and James City formations.

***Melanella migrans* (Conrad)**

Eulima migrans Conrad, 1846, p. 20, Pl. 1, fig. 22.

Eulima migrans Conrad. Martin, 1904, p. 217–218, Pl. LIII, fig. 12.

Discussion.—*Melanella migrans*, a thinner more elongate species than *M. eborea*, is represented by a single specimen at the Pollack Farm Site and is the first report of the taxon in the Kirkwood Formation or its equivalents.

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, and Yorktown formations.

***Murexiella cumberlandiana* (Gabb)**

Plate 3, Figure 12

Cantharus Cumberlandiana Gabb, 1860, p. 375, Pl. 67, fig. 6.

Cantharus Cumberlandianus Gabb. Whitfield, 1894, p. 103–104, Pl. XVII, figs. 3–6.

Coralliophila cumberlandia (Gabb). Richards and Harbison, 1942, p. 213, Pl. 19, fig. 18.

Discussion.—*Murexiella cumberlandiana* is present but rare at the Pollack Farm Site, with only one specimen recovered. It is rare in the Kirkwood of New Jersey, also, with only a few specimens available to Whitfield (1894) or Richards and Harbison (1942).

Geologic range.—Kirkwood Formation.

***Urosalpinx subrusticus* (d’Orbigny)**

Plate 3, Figures 13, 14

Fusus rusticus Conrad, 1830, p. 230, Pl. IX, fig. 2.

Fusus subrusticus d’Orbigny, 1852, p. 69.

Discussion.—The specimens from the Pollack Farm Site, which number over 100, look very much like *U. subrusticus* (d’Orbigny, 1852) [= *U. rusticus* (Conrad, 1830)]. It is noteworthy that, in spite of the abundance of *Urosalpinx* at the Pollack Farm Site, it is not reported from the Kirkwood and Calvert formations, and only a single occurrence is noted by Martin (1904) in the Choptank Formation. The taxon reappears in the late Miocene and commonly occurs in the St. Marys and higher units.

The occurrence of *Urosalpinx* in the lower Miocene appears to be the first appearance of that taxon. *Murex veatchi* from the Chipola, named by Maury (1910), was later referred to *Urosalpinx* by Gardner (1948) but does not belong to that genus (see Vokes, 1968, p. 101). The specimen, named by Mansfield (1937, p. 134) *Urosalpinx? hillsboroensis*, is incomplete, hence that author’s query about its generic placement. Two taxa, *Urosalpinx xustris* and *U. tribaka*, were named by Gardner (1947) from the Oak Grove of western Florida, a slightly higher unit.

Geologic range.—Kirkwood, Calvert, Choptank, and St. Marys formations.

***Typhis acuticosta* (Conrad)**

Plate 4, Figure 1

Murex acuticosta Conrad, 1830, p. 211, 217, Pl. IX, fig. 1.

Typhis acuticosta Conrad. Martin, 1904, p. 201, Pl. LI, figs. 1–3.

Discussion.—*Typhis acuticosta* is rare at the Pollack Farm Site, with only four specimens collected, and is previously unreported from the Kirkwood. The species is known from the Calvert, Choptank, and St. Marys formations.

Geologic range.—Kirkwood, Calvert, Choptank, and St. Marys formations.

***Cymia woodii* (Gabb)**

Plate 4, Figures 2–6

Fasciolaria Woodii Gabb, 1860, p. 375, Pl. LXVII, fig. 7.

Fasciolaria Woodi Gabb. Whitfield, 1894, p. 98, Pl. XVII, figs. 7, 8.

Fasciolaria woodi Gabb. Richards and Harbison, 1942, p. 216, Pl. 19, fig. 17.

Cymia woodii (Gabb). E.H. Vokes, 1989, p. 92, Pl. 12, fig. 12.

Discussion.—Whitfield (1894) and Richards and Harbison (1942) noted that this species is rare in the Miocene in New Jersey; however, it is common to abundant at the Pollack Farm Site with over 1000 specimens collected. This large suite shows a fair amount of variability within the species. Some specimens have fine spiral ribs and smooth whorls, others have strong spiral riblets, and still others develop strong nodes on the shoulders of the whorls. In this regard the species has many of the same growth characteristics as *Cymia henekeni* Maury, from the Dominican Republic (see Vokes, 1989, pl. 12, figs. 3–11). Except for the specimens from the Kirkwood Formation, only a single specimen has been found in Bed 10 of the Plum Point Marl Member of the Calvert Formation. Members of the genus are found in subtropical to tropical water, some in intertidal settings.

Geologic range.—Kirkwood and Calvert (Plum Point Marl Member, Bed 10) formations.

***Tritonopsis ecclesiastica* (Dall)**

Plate 4, Figure 7

Fasciolaria (Lyrosoma) sulcosa Conrad. Whitfield, 1894, p. 100, Pl. XVII, figs. 9, 10.

Rapana tampaënsis Dall, 1890, p. 153.

Rapana tampaënsis var.? Dall, 1892, p. 244, Pl. XX, fig. 14.

Ephora tampaënsis (Dall). Martin, 1904, p. 210–211, Pl. LII, figs. 9, 10.

Rapana ecclesiastica Dall, 1915, p. 78. [Not *Rapana ecclesiastica* Dall. Richards and Harbison, 1942, p. 211, Pl. 19, fig. 19].

Discussion.—Whitfield (1894, pl. XVII, figs. 9, 10) had a single specimen that is probably *Tritonopsis ecclesiastica*, but he called it *Fasciolaria (Lyrosoma) sulcosa*. Dall (1890) figured a specimen from Church Hill, Maryland, but called it *Rapana tampaënsis*. This identification was followed by Martin (1904, pl. 52, fig. 9), but was corrected by Dall (1915, p. 78) who gave it the name *Rapana ecclesiastica*. Richards and Harbison (1942) could not find Whitfield's specimen, but had an additional specimen from a well that they identified as *Rapana ecclesiastica*. Seven specimens from the Pollack Farm Site are referred to *Tritonopsis ecclesiastica*.

Geologic range.—Kirkwood Formation; Bed 3-A of the Calvert Formation.

***Ephora tricostata* Martin**

Plate 4, Figures 8–10

Ephora tricostata Martin, 1904, p. 209–210, Pl. LII, figs. 5–8.

Ephora tricostata Martin. Richards and Harbison, 1942, p. 211, Pl. 17, fig. 15.

Discussion.—The only record of *Ephora tricostata* in the Miocene of New Jersey is that of Richards and Harbison (1942), who reported several specimens from two wells near the coast. The species is fairly common at the Pollack Farm Site with over 80 specimens collected. The specimens there, as a whole, tend to be less variable in their ornamentation than those in Bed 10 of the Plum Point Marl Member. In addition, the Delaware specimens tend to uncoil less and at a later stage of growth.

Geologic range.—Kirkwood Formation. Calvert Formation, Fairhaven Member and Plum Point Marl Member (up to and including Bed 10).

***Chrysodomus patuxentensis* Martin**

Plate 4, Figure 11

Chrysodomus patuxentensis Martin, 1904, p. 184, Pl. XLVII, figs. 2, 3.

Discussion.—*Chrysodomus patuxentensis* was named by Martin (1904) and reported from Bed 10 of the Plum Point Marl Member and Bed 17 or the Drumcliff Member. There has been no mention of the taxon in the Kirkwood. It is rare at the Pollack Farm Site with only five specimens collected. I am unable to confirm the generic placement of the taxon. The only other species that resembles this form is *Lirofusus thoracicus* (Conrad, 1833a) from the middle Eocene of Alabama. The two are similar in exterior form, rib configuration, and even have a subsutural channel. The Miocene species, however, shows no sign of nodes on the ribs where the incremental growth lines intersect them as is common in the Eocene species. Palmer (1937, p. 348) mentions that specimens from the middle Eocene at Orangeburg, South Carolina, lack the nodes, and the channel is less pronounced, both characteristics more like the Kirkwood species.

Geologic range.—Kirkwood, Calvert, and Choptank formations.

***Siphonalia devexa* (Conrad)**

Plate 5, Figure 1

Fusus devexus Conrad, 1843a, p. 309.

Siphonalia devexa (Conrad). Martin, 1904, p. 185–186, Pl. XLVII, figs. 5, 6.

Siphonalia devexa (Conrad). Richards and Harbison, 1942, p. 213, Pl. 20, fig. 1.

Discussion.—No specimens of *Siphonalia devexa* have been obtained from surface exposures in the Miocene beds of New Jersey, but several were reported from wells by Richards and Harbison (1942). Specimens of this species are fairly common at the Pollack Farm Site with over 40 collected.

Geologic range.—Kirkwood, Calvert, and Choptank formations.

***Ptychosalpinx* sp.**

Discussion.—The single specimen found at the Pollack Farm Site is possibly the earliest occurrence of that taxon. There is no report of *Ptychosalpinx* in units below Bed 10 of the Plum Point Marl Member. The specimen, somewhat broken, looks similar to *Ptychosalpinx pustulosus* Petuch, but lacks the nodes on the ribs that species exhibits. It may be a smooth variety of that taxon or a new subspecies.

Geologic range.—Kirkwood Formation.

***Mitrella communis mediocris* Pilsbry and Harbison**

Mitrella communis mediocris Pilsbry and Harbison, 1933, p. 114, Pl. 4, fig. 16.

Mitrella communis mediocris Pilsbry and Harbison. Richards and Harbison, 1942, p. 213, Pl. 19, fig. 20.

Discussion.—Whitfield (1894) reported this taxon as *Amycla communis*. Pilsbry and Harbison (1933) recognized it as distinct from the larger St. Marys form, *M. communis*, and gave it a subspecific name. Richards and Harbison (1942) followed this assignment and found it abundant at Shiloh, New Jersey, in the Kirkwood. Specimens are present at the Pollack Farm Site, but they are not common, with only 30 individuals collected.

Geologic range.—Kirkwood Formation.

***Nassarius trivittatoides* (Whitfield)**

Plate 5, Figure 3

Tritia trivittatoides Whitfield, 1894, p. 104–105, Pl. XIX, figs. 1–3.

Nassarius trivittatoides (Whitfield). Richards and Harbison, 1942, p. 214, Pl. 20, figs. 7, 11.

Discussion.—Previously reported from the Miocene of New Jersey, *Nassarius trivittatoides* is present but not common at the Pollack Farm Site with less than 100 specimens collected. It is also reported from Bed 10 of the Calvert Formation and the Drumcliff Member of the Choptank Formation.

Geologic range.—Kirkwood, Calvert, and Choptank formations.

***Nassarius trivittatoides elongata* (Whitfield)**

Plate 5, Figure 2

Tritia trivittatoides var. *elongata* Whitfield, 1894, p. 105–106, Pl. XIX, figs. 4–6.

Nassarius trivittatoides elongata (Whitfield). Richards and Harbison, 1942, p. 214, Pl. 20, fig. 10.

Discussion.—Whitfield (1894) had a number of specimens that were markedly more slender than *N. trivittatoides* and placed them in *N. t. elongata*. Martin (1904) reunited the two under *N. trivittatoides*, considering the differences to be slight. Richards and Harbison (1942) figured *N. t. elongata* but repeated Martin's comments.

The specimens from the Pollack Farm Site, about 50 in number, are clearly smaller and more elongate than *Nassarius trivittatoides* and are here considered a valid subspecies.

Geologic range.—Kirkwood Formation. Martin (1904) lists the species from Bed 10 of the Calvert Formation and Bed 17 (Drumcliff Member) of the Choptank Formation.

***Nassarius sopora* (Pilsbry and Harbison)**

Plate 5, Figures 4–6

Nassa sopora Pilsbry and Harbison, 1933, p. 114–115, Pl. 3, figs. 9, 10.

Nassarius sopora (Pilsbry and Harbison). Richards and Harbison, 1942, p. 215, Pl. 20, figs. 8, 9.

Discussion.—This species, if my identification is correct, is the most abundant gastropod taxon in the sands at the Pollack Farm Site with over 7000 specimens collected. The specimens, on which the description of *Nassarius sopora* is based, appear to be immature. The description of the early whorls is identical to that of the Delaware specimens, but in the later whorls, growth stages not exhibited on the type material, the axial ribs and the spiral ornamentation becomes progressively less prominent until, in many specimens, the last whorls are nearly smooth. This feature is apparently the adult condition.

Geologic range.—Kirkwood Formation.

***Metula* sp.**

Plate 5, Figures 7, 9

Discussion.—Two specimens that appear to belong to the genus *Metula* were found at the Pollack Farm Site. *Metulas* commonly have sculpture consisting of very fine longitudinal riblets and very fine spiral riblets that, together, give a finely cancellate appearance. The Delaware species has longitudinal striae that are extremely fine, giving it a

much less cancellate look.

Metula is present in the Paleocene, Eocene, and lower Oligocene of the Gulf Coast and, except for the Delaware species, does not reappear until the late Pliocene in Florida. The genus is known only from tropical to subtropical settings.

Geologic range.—Kirkwood Formation.

***Busycotypus scalarispira* (Conrad)**

Plate 5, Figures 8, 10; Plate 6, Figures 1, 3, 4, 6

Busycon scalarispira Conrad, 1863b, p. 584.

Busycon scalarispira Conrad. Whitfield, 1894, p. 102–103, Pl. XVII, figs. 11, 12.

Busycon carica Linn. Whitfield, 1894, p. 101–102, Pl. XVIII, fig. 1.

Busycon tuberculatum (Conrad). Richards and Harbison, 1942, p. 214, Pl. 20, figs. 2, 3.

Busycon scalarispira Conrad. Richards and Harbison, 1942, p. 214, Pl. 20, figs. 4–6.

Busycotypus calvertensis Petuch, 1989, p. 74–75, Pl. 1, figs. 6, 7.

Discussion.—There are over 1000 specimens of the Busyconidae from the Pollack Farm Site in Delaware. Previously, reports of members of the family in the Kirkwood were few. The suite of specimens available from this site, many longer than 130 mm, makes it possible to evaluate the considerable variation in form and conclude which characters distinguish species. That variation is partially demonstrated in the figures on Plates 5 and 6. Possibly as many as three busyconids occur in the beds at the Pollack Farm, but only *B. scalarispira*, the most abundant species, will be considered in the present report. Specimens assigned by Whitfield (1894) to *B. carica* and *B. scalarispira* both belong to this species. The specimens assigned to *B. tuberculatum* and *B. scalarispira* by Richards and Harbison (1942) both belong to the latter. *Busycotypus calvertensis* Petuch (1989) is identical to *B. scalarispira*. The majority of the specimens are weakly canaliculate. This condition is most noticeable in the adult shells, but can be traced along the suture on most of the whorls in the spire. The various morphologies present in the Kirkwood have their beginnings in the Oligocene Belgrade Formation and older units.

***Scaphella virginiana* Dall**

Plate 6, Figure 2

Scaphella (*Aurinia*) *virginiana* Dall, 1890, p. 80.

Scaphella (*Aurinia*) *typus* Martin, 1904, p. 175, Pl. XLIV, fig. 10. [Not *Volutifusus typus* Conrad, 1866].

Scaphella virginiana Dall. Ward, 1992, p. 135–136, Pl. 19, fig. 9.

Discussion.—There is no previous record of *Scaphella virginiana* in the Kirkwood or its equivalents. The species has been reported from the Calvert Formation (Bed 10) and the Choptank Formation (Bed 17) (Martin, 1904; Ward, 1992). At the Pollack Farm Site ten specimens assignable to this species were found. The Delaware specimens represent the earliest known appearance of the taxon. Several early authors used the name "*Scaphella typus*" for this species, but this is a late Pliocene–Pleistocene species from North Carolina. See Ward (1992) for the derivation of this name.

Geologic range.—Kirkwood, Calvert, and Choptank formations.

Scaphella solitaria (Conrad)

Plate 6, Figure 5

Voluta solitaria Conrad, 1830, p. 218, Pl. IX, fig. 7.

Scaphella solitaria (Conrad). Martin, 1904, p. 173, Pl. XLIV, fig. 7.

Scaphella coronaspira Petuch, 1989, p. 76, Pl. 1, figs. 13, 14.

Scaphella sanctaemariae Petuch, 1989, pl. 76–77, Pl. 2, figs. 7, 8.

Discussion.—There is no mention of *Scaphella solitaria* in the Kirkwood or its equivalents in the literature. It is fairly well-represented at the Pollack Farm Site with 38 individuals collected. The sharpness of the shoulders and the strength of the tubercles on the shoulder, as well as misinformation on the type locality of *S. solitaria*, have spawned two junior synonyms for this species, *S. sanctaemariae* and *S. coronaspira* (see Petuch, 1989, p. 76). Conrad (1830, p. 210–212) explicitly described the type locality of *S. solitaria* as being on the western shore of the St. Marys River (upriver of Windmill Point). There and elsewhere the species is variable in ornamentation, but the specimens from the Kirkwood, Calvert, and St. Mary formations have numerous small tubercles in the early whorls and, as adults, usually lack these tubercles. The shoulder varies from slightly rounded to sharply keeled. The Pliocene species, with fewer heavier tubercles, has recently been named *S. s. ricei* by Campbell (1993, p. 87). The Pollack Farm specimens mark the earliest known occurrence of *Scaphella solitaria*.

Geologic range.—Kirkwood, Calvert, and St. Mary formations.

Oliva simonsoni new species

Plate 7, Figures 1–3

Oliva Carolinensis Whitfield, 1894, p. 109–110. [Not *O. carolinensis* of Conrad, 1862]

Oliva sayana Richards and Harbison, 1942, p. 216, Pl. 17, fig. 20, Pl. 21, fig. 6. [Not *O. sayana* of Ravenel, 1834]

Oliva litterata Martin, 1904, p. 169, Pl. XLIV, figs. 1a, b. [Not *O. litterata* of Lamarck, 1810]

Diagnosis.—Shell small, ovoid, with low spire, on which sutural channel is covered by parietal material on all but last whorl.

Description.—Shell of moderate size for group, moderately thick and heavy, smooth and polished, ovoid in outline, with low spire; spire covered by callus, 5 mm in height, rounding broadly with greatest width approximately mid-length. Sutural channel narrow, sharply defined, covered by posterior parietal callus, except on last whorl. Incremental growth lines visible in late stages of shell, causing slight undulation in area just posterior to aperture. Aperture narrow, outer lip thickened, parietal callus thick and wide anteriorly, marked by raised transverse corrugations. Base of columella thickened by several overlapping folds. Parietal callus posteriorly becomes narrow and obsolete below suture; above suture, callus thickened to form continuous slope with outer lip; callus obscuring sutural channel in all but last whorl.

Measurements.—Holotype (VMNH I 595): height 36.8 mm; length 17.2 mm.

Discussion.—Fragments of *Oliva* have been reported in the Miocene of New Jersey for a number of years (Whitfield, 1894; Richards and Harbison, 1942) but were

assigned to various non-related species, probably because of their condition. Martin (1904) figured a specimen of the new species from the stratigraphically equivalent beds at Church Hill, Maryland, but incorrectly assigned it to a Recent species. The specimens at the Pollack Farm Site in Delaware afford a better chance at describing this new species, as over 900 specimens were collected.

Oliva simonsoni is a much larger species than *O. har-risi* Martin and has a much more rounded, heavy outline than that high-spined, elongate taxon. *Oliva sayana* Ravenel is a much more elongate species, that is more cylindrical in outline and has a higher spire. *Oliva litterata* Lamarck is the same species as *O. sayana*.

The only other *Oliva* with a rounded outline even close to that of *O. simonsoni* is *O. idonea* (Conrad, 1839) from the Eastover Formation (upper Miocene) of Virginia. That species is much shorter, thicker, and does not obscure the sutural channel with parietal material (see Ward, 1992, pl. 4, fig. 5).

Etymology.—Named in honor of Gordon Simonson, who was instrumental in helping me gain access to the excavation, and who, with his family, helped me collect much of the material used in this report (see Figure 10).

Type information.—Holotype, VMNH I 595. Paratypes: VMNH I 594, 596–610. Type locality: Pollack Farm, just south of the Leipsic River, 0.8 km (0.5 mi) southeast of the spillway at Garrisons Lake, Kent County, Delaware, in the Calvert Formation.

Figured specimens.—Holotype VMNH I 595 and Paratype VMNH I 594.

Geologic range.—Kirkwood and Calvert formations, New Jersey and Delaware.

Trigonostoma biplicifera (Conrad)

Plate 7, Figures 5–7

Cancellaria biplicifera Conrad, 1841a, p. 31.

Discussion.—Pilsbry and Harbison (1933) and Richards and Harbison (1942) have named species of *Trigonostoma* from the Miocene of New Jersey and they may be valid, but my feeling at this time is that they, and the 20 specimens from the Pollack Farm Site, belong in the taxon *Trigonostoma biplicifera*. A number of the Delaware specimens are over 40 mm in height and look identical to specimens from Bed 10 of the Plum Point Marl Member (probably Conrad's type locality).

Geologic range.—Kirkwood, Calvert, and Choptank formations.

Cancellaria alternata Conrad

Plate 7, Figure 4

Cancellaria alternata Conrad, 1834, p. 155.

Cancellaria alternata Conrad. Whitfield, 1894, p. 112–113, Pl. XX, figs. 5–10.

Cancellaria alternata Conrad. Pilsbry and Harbison, 1933, p. 108, Pl. 3, figs. 2, 3.

Cancellaria alternata Conrad. Richards and Harbison, 1942, p. 216, Pl. 21, fig. 1.

Discussion.—*Cancellaria alternata* was reported in the New Jersey Miocene by Whitfield (1894), Pilsbry and Harbison (1933), and Richards and Harbison (1942). The species is fairly common at the Pollack Farm Site with over

30 specimens collected. The species is reported stratigraphically as high as the St. Marys Formation, but apparently makes its first appearance in the Kirkwood.

Geologic range.—Kirkwood, Calvert, Choptank, and St. Marys formations.

***Cymatosyrinx limatula* (Conrad)**

Plate 7, Figure 8

Pleurotoma limatula Conrad, 1830, p. 224, Pl. 9, fig. 12.

Drillia limatula Conrad. Martin, 1904, p. 158–159, Pl. XLII, figs. 12, 13.

Discussion.—A number of taxa of the genus *Cymatosyrinx* have been reported from the Miocene of New Jersey. Ten specimens of that genus have been found at the Pollack Farm Site, but I find them closer in form to the species *C. limatula*, abundant in the St. Marys Formation. Several other forms are present in the sample that may represent different species, but they appear unnamed.

Geologic range.—Kirkwood, Calvert, Choptank, and St. Marys formations.

***Polystira communis* (Conrad)**

Plate 7, Figure 9

Pleurotoma communis Conrad, 1830, p. 224, Pl. 9, fig. 23.

Pleurotoma (Hemipleurotoma) communis Conrad. Martin, 1904, p. 147, Pl. XLI, figs. 2, 3.

Discussion.—*Polystira communis* is common at the Pollack Farm Site with over 40 specimens collected. It appears identical with the species from the type locality in the St. Marys Formation on the St. Marys River, Maryland. Specimens are present, though rare, that may be the more ribbed species *P. protocommunis* (Martin). Living *Polystira* are subtropical to tropical in habitat.

Geologic range.—Kirkwood, Calvert (?), and St. Marys formations.

***Leucosyrinx rugata* (Conrad)**

Plate 7, Figures 10, 11

Surcula rugata Conrad, 1862, p. 285.

Surcula rugata Conrad. Martin, 1904, p. 149, Pl. XLI, figs. 12a, b.

Discussion.—A number of large turrids, over 25, were collected from the Pollack Farm Site and apparently are previously unrecorded from the Kirkwood. They are provisionally assigned to the genus *Leucosyrinx* and the species *L. rugata*. Some specimens measure over 50 mm in height. The species has been previously reported from Jones Wharf (Choptank Formation, Bed 17) and Plum Point (Calvert Formation, Bed 10) (Martin, 1904).

Geologic range.—Kirkwood, Calvert, and Choptank formations.

***Inodrillia whitfieldi* (Martin)**

Plate 7, Figures 12, 13

Drillia elegans Whitfield, 1894, p. 115, Pl. XXI, figs. 2–4. [Not *Drillia elegans* of Emmons, 1858].

Drillia whitfieldi Martin, 1904, p. 157–158.

Discussion.—The most abundant turrid present at the Pollack Farm Site, with over 100 specimens collected, is *Inodrillia whitfieldi*. That taxon was first identified as *Drillia elegans* by Whitfield (1894) from the Miocene of New Jersey. It was reported by Martin (1904, p. 158) from Church

Hill, Maryland, from beds stratigraphically equivalent to those in Delaware.

Geologic range.—Kirkwood and Calvert (Fairhaven Member, Bed 3A) formations.

***Terebra inornata* Whitfield**

Plate 7, Figure 14

Terebra inornata Whitfield, 1894, p. 114, Pl. 20, figs. 11–13.

Terebra (Hastula) inornata Whitfield. Martin, 1904, p. 144, Pl. XL, figs. 12, 13.

Terebra inornata Whitfield. Richards and Harbison, 1942, p. 220, Pl. 21, figs. 31, 32.

Discussion.—Whitfield's (1894) specimens came from a well at Cape May, and Martin (1904) thought that they occurred there in a St. Marys assemblage. *Terebra inornata* is common at the Pollack Farm Site with over 200 specimens collected. The species is variable in its ornamentation, with some specimens possessing fine axial riblets well into the adult stages, while the majority are smooth. Some individuals have slightly rounded whorls while others are flat-sided. All of the specimens from Delaware have a smaller apical angle than *Terebra simplex* from the St. Marys and accordingly are more slender in outline.

Geologic range.—Kirkwood Formation. Choptank and St. Marys formations, fide Martin, 1904.

Bivalvia

***Nucula prunicola* Dall**

Nucula proxima Say. Whitfield, 1894, p. 50, Pl. VII, figs. 7–10. [Not *Nucula proxima* of Say, 1822].

Nucula prunicola Dall, 1898, p. 576, Pl. XXXII, fig. 9.

Discussion.—This species was listed as *Nucula proxima* by Whitfield (1894, p. 50–51) and Richards and Harbison (1942, p. 180). These authors described it as being common at Shiloh, Jericho, and Bridgeton, New Jersey. *Nucula prunicola* is a well-characterized species with a general outline and form like *Nucula proxima*, but with noticeable concentric lamellae as described by Dall (1898, p. 576):

. . . on the anterior third sculpture of moderately elevated concentric lamellae separated by wider radially grooved interspaces; these lamellae break off abruptly anteriorly, and posteriorly become gradually obsolete in front of the middle of the shell . . .

At the Pollack Farm Site 310 specimens were collected, most in excellent condition.

Geologic range.—Kirkwood Formation and Calvert Formation (Fairhaven and Plum Point Marl members).

***Nucula taphria* Dall**

Nucula taphria Dall, 1898, p. 576, Pl. XXXII, fig. 14.

Nucula taphria Dall. Glenn, 1904, pl. 400–401, Pl. CVIII, figs. 9–11.

Discussion.—*Nucula taphria* has not previously been recorded in any units stratigraphically below the Choptank Formation. The species is rare at the Pollack Farm Site, where only three specimens were recovered.

Geologic range.—Kirkwood Formation (Calvert in Delaware); Choptank Formation, Drum Cliff Member; St. Marys Formation, Windmill Point Member; Yorktown Formation, Rushmere and Moore House members; Chowan River Formation; James City Formation.

***Nuculana* sp.**

Discussion.—Known only from a single specimen. This could be *Nuculana leioryncha* (Gardner, 1926) or *N. diphya* (Gardner, 1926), both of which come from age-equivalent units in Florida.

Geologic range.—Kirkwood Formation.

***Nuculana liciata* (Conrad)**

Nucula liciata Conrad, 1843a, p. 305.

Nuculana liciata (Conrad). Glenn, 1904, p. 395–396, Pl. CVII, figs. 5–8.

Nuculana liciata (Conrad). Richards and Harbison, 1942, p. 180, Pl. 7, fig. 3.

Discussion.—Richards and Harbison (1942) list this species as rare and only three specimens were recovered at the Pollack Farm Site.

Geologic range.—Kirkwood Formation, Shiloh Marl Member; Calvert Formation, Plum Point Marl Member; lower Choptank Formation (fide Glenn, 1904).

***Yoldia* sp.**

Plate 8, Figures 1–4

Yoldia limatula Say. Whitfield, 1894, p. 51, Pl. VII, figs. 11, 12 [Not *Yoldia limatula* of Say, 1831].

Yoldia laevis (Say). Richards and Harbison, 1942, p. 181, Pl. 7, figs. 5, 6. [Not *Yoldia laevis* of Say, 1824].

Discussion.—This apparently unnamed taxon is similar to *Yoldia soror* (Gardner, 1926) but is thicker shelled and deeper valved than that species. It seems to be similarly distinct from *Yoldia laevis* (Say, 1824), which is present in much of the Miocene and Pliocene, and from *Yoldia limatula* (Say), which is a Recent form that ranges from Labrador to off North Carolina (Abbott, 1974). *Yoldia* sp., at the Pollack Farm Site, is fairly common; over 100 specimens were recovered.

Geologic range.—Kirkwood Formation.

***Dallarca subrostrata* (Conrad)**

Plate 8, Figures 5–7

Arca subrostrata Conrad, 1841a, p. 30.

Arca (Scapharca) subrostrata Conrad. Whitfield, 1894, p. 45, Pl. VI, figs. 11–13.

Arca subrostrata Conrad. Richards and Harbison, 1942, p. 181, Pl. 7, fig. 13.

Discussion.—*Dallarca subrostrata* (Conrad) is one of the well-represented taxa recovered from the Pollack Farm Site with over 2000 specimens collected. The species was not reported from New Jersey by Conrad and was represented only by fragments in the Whitfield (1894) and Richards and Harbison (1942) study material. Because of the fragmentary condition of the Shiloh Marl arcids, those authors admittedly guessed at the identity of those specimens and incorrectly reported the presence of a number of species in the Kirkwood. They include the following:

Arca callipleura Conrad [= *Dallarca elevata* (Conrad)], Boston Cliffs Member, Choptank Formation

Arca lienosa Say [= *Sectiarca lienosa* (Say)], Rushmere and Moore House members, Yorktown Formation

Arca idonea Conrad [= *Dallarca idonea* (Conrad)], Windmill Point Member, St. Marys Formation

Arca staminea Say [= *Dallarca staminea* (Say)], Duplin and Raysor formations

These taxa range in age from the middle Miocene to the late Pliocene and were not present in the well-preserved mollusks at the Pollack Farm Site.

Specimens of *Dallarca subrostrata* from Delaware are larger, on average, than those found in Bed 10 of the Plum Point Marl Member, the only other unit in which they are common to abundant.

Geologic range.—Kirkwood Formation; Calvert Formation, Plum Point Marl Member (Bed 10); Pungo River Formation.

***Dallarca* sp.**

Plate 8, Figures 8–10

Discussion.—One of the most abundant taxa at the Pollack Farm Site is an unidentified species of *Dallarca*. Represented by over 2500 valves, the species resembles *Dallarca staminata* (Dall, 1898) but seems to be more elongate and rounded posteriorly than that species. The abundant material should make final identification of the Pollack species possible. The species is known only from that site and was not represented in the material from New Jersey studied by Whitfield (1894) or Richards and Harbison (1942) and has not been reported from the Calvert Formation.

Geologic range.—Kirkwood [Calvert] Formation in Delaware.

***Glycymeris parilis* (Conrad)**

Plate 9, Figures 1, 3, 7, 9

Pectunculus parilis Conrad, 1843a, p. 306.

Axinea lentiformis? Whitfield, 1894, p. 49–50, Pl. VII, figs. 5, 6.

Glycymeris parilis (Conrad). Richards and Harbison, 1942, p. 183, Pl. 7, figs. 16, 17.

Discussion.—Whitfield (1894) had only small, young specimens available to him and was uncertain as to the exact identity of the material. Richards and Harbison (1942) reported only young specimens from the pits near Shiloh, New Jersey, but illustrated a young adult from a borehole at Sea Isle City, New Jersey. The material at the Pollack Farm Site consists of numerous large valves, many of which are larger than any found in Bed 10 of the Plum Point Marl Member (Calvert Formation). Bed 10 contains the only other large accumulation of *G. parilis*. Approximately 650 complete specimens were obtained from the Pollack Farm Site.

Geologic range.—Kirkwood Formation; Calvert Formation, Fairhaven Member, Plum Point Marl Member (Bed 10).

***Mytilus (Mytiloconcha) incurva* Conrad**

Plate 9, Figures 4, 5

Myoconcha incurva Conrad, 1839, inside new back cover, Pl. XXVIII, fig. 1.

Mytiloconcha incrassata Conrad. Whitfield, 1894, p. 38, Pl. V, figs. 10, 11, Pl. VI, figs. 1, 2.

?*Mytilus incurvus* (Conrad). Richards and Harbison, 1942, p. 184, Pl. 7, fig. 18.

Discussion.—Numerous large fragments consisting principally of beaks are present at the Pollack Farm Site; however, several whole individuals were obtained in the lower, finer-grained portions of the exposure. Glenn (1904) reported and figured specimens that he named *M. incurvus* and *M. conradinus* (= *M. incrassata*). The two taxa co-occur

at most of the localities mentioned. The differences mentioned by Glenn can be resolved with large numbers of specimens. There seems to be no significant difference between the Miocene specimens referred to *M. incurva* and those from the late Pliocene of North Carolina (Duplin Formation), South Carolina (Raysor Formation), and Florida (Pinecrest Formation); in that case *Mytilus incurva* would be the appropriate name.

Geologic range.—Appears to range from the early Miocene to the late Pliocene, but it is not known to occur higher than the Choptank Formation in the Chesapeake Group.

***Modiolus ducatellii* (Conrad)**

Plate 9, Figure 2

- Modiola Ducatellii* Conrad, 1840, p. 53, Pl. XXVIII, fig. 2.
Modiola inflata Tuomey and Holmes. Whitfield, 1894, p. 39, Pl. VI, figs. 3, 4.
Modiolus ducatellii Conrad. Glenn, 1904, p. 366, Pl. XCVII, figs. 6, 7.
Modiola inflata Tuomey and Holmes. Richards and Harbison, 1942, p. 183, Pl. 7, fig. 15.

Discussion.—Only a single, imperfect valve of this very delicate species was found. *Modiola inflata* appears to be a junior synonym of *M. ducatellii*. The elongate adult form illustrated by Conrad (1840) can be united with the small, wide juvenile form illustrated by Tuomey and Holmes (1856) by a continual growth series where large collections are available.

Geologic range.—Ranges from the early Miocene to the late Pliocene in all of the stratigraphic units of the Chesapeake Group.

Isognomon (Hippochaeta) sp.

Plate 9, Figures 6, 8

- Perna torta* Say, 1820, p. 38.
Perna torta Say. Whitfield, 1894, p. 36, Pl. V, figs. 12, 13.
Perna maxillata Lam. Heilprin, 1888, p. 402 [list only].
Perna maxillata Lamarck. Conrad, 1840, p. 52, Pl. 27.
Perna conradii d'Orbigny, 1852, p. 127.
Melina maxillata (Deshayes). Glenn, 1904, p. 383–384, Pl. CII, fig. 3, Pl. CIII, fig. 1.
Melina maxillata (Deshayes). Richards and Harbison, 1942, p. 184, Pl. 8, fig. 1.

Discussion.—Heilprin (1888), Whitfield (1894), and Richards and Harbison (1942) all described the abundant though fragmentary specimens of *Isognomon (Hippochaeta)*. Only three very worn beaks of this taxon were recovered from the shell hashes at the Pollack Farm Site. The obviously high-energy environment was probably not conducive to the preservation of these massive, but fragile, bivalves.

A number of names have been used in describing and illustrating the Miocene *Isognomon (Hippochaeta)*, including European ones, but the most likely to be correct is *Perna torta* (Say, 1820) [*Isognomon (Hippochaeta) torta* (Say, 1820)]. A species name is not employed here because of the fragmentary condition of the specimens.

Isognomon (Hippochaeta) was abundant on the Atlantic Coastal Plain during the Cretaceous, but became very rare in the Paleocene and is not known to occur in any units above the Paleocene until the upper Oligocene. It reap-

pears on the Atlantic Coastal Plain in the Old Church Formation in Virginia, after an absence of approximately 45 million years. In the Miocene, the genus reestablishes itself as a dominant form, but then disappears at the end of the Miocene in North America, and during the Pliocene in Europe. It is now believed to be extinct.

Geologic range.—The genus ranges from the Cretaceous to the Pliocene.

***Crassostrea virginica* (Gmelin)**

Plate 10, Figures 1, 2, 5–8

- Ostrea virginica* Gmelin, 1791, p. 3336.
Ostrea mauricensis Gabb, 1860, p. 376, Pl. 67, fig. 26.
Ostrea Virginiana (Gmelin). Whitfield, 1894, p. 27–28, Pl. II, figs. 1–7.
Ostrea virginiana var. *procyon* Tuomey and Holmes. Whitfield, 1894, p. 28–29, Pl. I, figs. 4–6.
Ostrea virginica Gmelin. Richards and Harbison, 1942, p. 187, Pl. 9, fig. 4.

Discussion.—The Pollack Farm Site yielded large numbers of *Crassostrea virginica*, apparently the earliest appearance of the species. More than 1600 specimens were collected. Many attain large size and massive thickness but are obviously much smaller than their predecessor *C. gigantissima*, from the Haywood Landing Member of the Belgrade Formation (upper Oligocene/lower Miocene). The specimens of *C. virginica* from the Pollack Farm Site fall fully within the size range of *C. virginica* described by Galtsoff (1964). Many of the specimens are very elongate forms, a shape that is commonly found associated with tidal channels and high-energy, fast-flowing currents near inlets. Such a form is the synonymous species *Ostrea virginiana* var. *procyon* (attributed to Tuomey and Holmes, 1855, by Whitfield but is actually Holmes, 1858). This taxon is usually associated with brackish water, marginal marine settings. These peripheral and usually thin deposits are generally eroded and destroyed during subsequent marine transgressions. As a result, the record of such settings is poor and accounts for the lack of *C. virginica* in most of the Miocene and much of the Pliocene.

Geologic range.—Kirkwood, Yorktown, Chowan River, and James City formations and Recent.

***Pecten humphreysii woolmani* Heilprin**

Plate 10, Figures 3, 4

- Pecten humphreysii* Conrad, 1842, p. 194, Pl. 2, fig. 2.
Pecten humphreysii var. *woolmani* Heilprin, 1888, p. 405.
Vola humphreysii Conrad. Whitfield, 1894, p. 32–34, Pl. IV, figs. 6–9.
Pecten humphreysii Conrad. Richards and Harbison, 1942, p. 186, Pl. 8, fig. 45.
Pecten humphreysii woolmani Heilprin. Richards and Harbison, 1942, p. 186, Pl. 8, figs. 12, 13, Pl. 9, fig. 2.

Discussion.—The material from New Jersey available to Whitfield (1894) and Richards and Harbison (1942) was mainly fragmentary, as is the present material from the Pollack Farm Site. Those authors concluded that their material agreed well with Conrad's (1842) description and figure. They admitted, however, that their specimens had very square ribs as described by Heilprin (1888). Gibson (1987) figured a number of specimens of *P. humphreysii humphreysii*, *P. humphreysii woolmani*, and *P. mclellani*, and it appears to this author that they may all be variants of the same species. It seems safe at

this time to treat the Delaware material as a distinct subspecies; however, because of the fragmentary material this distinction is uncertain. Apparently the forms with the very squared ribs occur only in the lower Calvert (Bed 3A), the Shiloh Marl of the Kirkwood, and the Pungo River Formation, all stratigraphically equivalent units.

Geologic range.—Kirkwood Formation; Calvert Formation, Fairhaven Member (Bed 3A); Pungo River Formation.

***Chesapecten coccymelus* (Dall)**

Plate 11, Figures 1, 2, 6

Pecten (Chlamys) coccymelus Dall, 1898, p. 741–742, Pl. 34, fig. 1.

Pecten Madisonius Say. Whitfield, 1894, p. 30, Pl. IV, figs. 1–4.

Pecten madisonius Say. Richards and Harbison, 1942, p. 185, Pl. 8, fig. 11.

Discussion.—Specimens available to Whitfield (1894) and Richards and Harbison (1942) were all juveniles or fragments and were identified as “*Pecten madisonius*” by those authors. That species occurs only in the upper Pliocene strata of the Yorktown Formation and its stratigraphic equivalents to the south (Ward and Blackwelder, 1975). Gibson (1987) and Ward (1992) have more recently described and illustrated *Chesapecten coccymelus*. The specimens from Delaware are typical of the species, but none exhibit the extreme development of the center row of scales on the ribs that was described by Dall (1898). The material recovered consists of more than 20 nearly complete valves and numerous fragments. The species is relatively small with adults averaging 40 mm. It is also abundant in Bed 10 of the Plum Point Marl Member.

Geologic range.—Kirkwood Formation; Calvert Formation, Fairhaven Member (Bed 3A), Plum Point Marl Member (Beds 4 and 10).

***Chesapecten sayanus* (Dall)**

Plate 11, Figures 3–5

Pecten Madisonius Sayanus Dall, 1898, p. 725, Pl. 26, fig. 6.
?Pecten Madisonius Say. Whitfield, 1894, p. 30, Pl. II, fig. 8.

Discussion.—The most abundant species of pectinids at the Pollack Farm Site is a fairly large *Chesapecten* that is characterized by numerous scaly ribs that are prominent during the early stages of development, but gradually become less elevated in the adults to the point that the disk is nearly flat in many specimens. The entire disk is covered by rows of very fine scales. In this regard, the species closely resembles “*Pecten madisonius sayanus*,” described by Dall (1898) from the Oak Grove in western Florida and is here considered to be that species. A single valve of *C. sayanus* was found by the author in Bed 10 of the Plum Point Marl at Camp Roosevelt, Calvert County, Maryland. The only other specimens known to the author are several collected by Julia Gardner from Wye Island, Maryland, and a number of individuals collected by the author from the Pungo River Formation at the Lee Creek Mine, Aurora, North Carolina.

This appearance of *Chesapecten* in the early Miocene marks the first known occurrence of that taxon.

Geologic range.—Kirkwood Formation; Calvert Formation, Plum Point Marl Member (Bed 10); Pungo River Formation.

***Parvalucina crenulata* (Conrad)**

Plate 12, Figures 5–7

Lucina crenulate Conrad, 1840, p. 39, Pl. XX, fig. 2.

Lucina crenulata Conrad. Whitfield, 1894, p. 63, Pl. X, figs. 7–15.

Phacoides crenulatus (Conrad). Richards and Harbison, 1942, p. 192, Pl. 11, figs. 11, 12.

Discussion.—This species, rather small and almost ubiquitous in the Chesapeake Group, is rather uncommon at the Pollack Farm Site with only 25 specimens collected. Richards and Harbison (1942) list the taxon as common in the Kirkwood of New Jersey.

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, Eastover, Yorktown, and Chowan River formations.

***Stewartia anodonta* (Say)**

Plate 12, Figures 1–3

Lucina anodonta Say, 1824, p. 146, Pl. X, fig. 9.

Phacoides anodonta (Say). Richards and Harbison, 1942, p. 192, Pl. 11, figs. 11, 12.

Discussion.—*Stewartia anodonta* is known from the Kirkwood of New Jersey only by specimens from deep wells at Sea Isle City, New Jersey (Richards and Harbison, 1942). There is no record of the species from Shiloh, but it is common to abundant in the stratigraphically equivalent beds in Delaware with over 500 specimens collected. It is equally abundant in Bed 10 of the Plum Point Marl Member of the Calvert Formation and in the Choptank Formation.

Geologic range.—Belgrade, Kirkwood, Calvert, Choptank, St. Marys, Eastover, Yorktown, Chowan River, and James City formations.

***Carditamera aculeata* Conrad**

Plate 12, Figures 4, 8, 9

Carditamera aculeata Conrad, 1863b, p. 585.

Cardita arata (Conrad). Whitfield, 1894, p. 57, Pl. IX, figs. 5, 6.

Carditamera aculeata Conrad. Whitfield, 1894, p. 58, Pl. IX, figs. 7, 8.

Discussion.—Whitfield (1894) and Richards and Harbison (1942) both listed and figured specimens that they identified as *C. arata* (a species that first appears in the late Pliocene), but in their discussions they compare their material favorably with the smaller and more elongate species *C. protracta* Conrad. The specimens of *C. protracta* available to me have a pronounced keel on the posterior slope and fewer ribs than the Kirkwood specimens. I believe the Delaware specimens belong in *C. aculeata*, the type of which was collected at Shiloh, New Jersey. The material available included 60 single valves.

Geologic range.—Known only from the Kirkwood Formation, Shiloh Marl Member.

***Cyclocardia castrana* (Glenn)**

Plate 12, Figures 10, 12

Cardita granulata Say. Whitfield, 1894, p. 56, Pl. IX, figs. 1–4.

Venericardia castrana Glenn, 1904, p. 345, Pl. XCI, figs. 11, 12.

Venericardia granulata (Say). Richards and Harbison, 1942, p. 141, Pl. 11, figs. 1, 2.

Discussion.—Whitfield (1894) and Richards and Harbison (1942) mentioned specimens of *Cyclocardia* only from deep wells along the New Jersey coast; apparently none had been collected in the pits at Shiloh. By contrast, *Cyclocardia* is abundant in Delaware at the Pollack Farm Site with over 1400 specimens collected. The juvenile specimens available to previous authors caused them to assign the Kirkwood specimens to *C. granulata*, a much larger, robust species with beaded ribs that first appears in the Pliocene. Martin (1904) first described the Kirkwood species from Church Hill, Maryland, a locality that clearly has beds stratigraphically equivalent to those at Shiloh and the Pollack Farm Site.

Geologic range.—Kirkwood Formation, Shiloh Marl Member.

***Marvacrassatella melinus* (Conrad)**

Plate 12, Figures 11, 13, 14

Crassatella melina Conrad, 1832, p. 23–24, Pl. 9, fig. 2.

Crassatella melina Conrad. Whitfield, 1894, p. 60, Pl. VIII, figs. 11–13.

Eucrassatella melina (Conrad). Richards and Harbison, 1942, p. 190, Pl. 10, figs. 14, 15.

Discussion.—Whitfield (1894) and Richards and Harbison (1942) both found *Marvacrassatella melinus* to be a common species in the Kirkwood Formation in New Jersey. Whitfield (1894) knew of only the Shiloh occurrences, but Richards and Harbison (1942) mentioned a number of localities and wells where specimens had been obtained. The species was common to abundant at the Pollack Farm Site; 320 valves were obtained. The species is equally abundant in the Calvert Formation, Plum Point Marl Member, Bed 10, in Calvert County, Maryland.

Geologic range.—Kirkwood Formation; Calvert Formation, Fairhaven Member (Bed 2), Plum Point Marl Member (Bed 10).

***Astarte distans* Conrad**

Plate 13, Figures 1, 2, 4, 5

Astarte distans Conrad 1862, p. 288.

Astarte distans Conrad. Whitfield, 1894, p. 53, Pl. VII, figs. 13–17.

Astarte castrana Glenn, 1904, p. 353–354, Pl. XCIII, figs. 7–9.

Astarte distans Conrad. Richards and Harbison, 1942, p. 188, Pl. 10, figs. 1, 2.

Discussion.—Specimens of *Astarte distans* are extremely abundant at the Pollack Farm Site with over 1500 specimens collected. They resemble *A. undulata*, but are different in the profound, large undulations that extend over the entire disk. *Astarte castrana* Glenn (1904) is probably an ecophenotypic variation of this species. *Astarte* responds to substrate conditions with higher energy, sandy substrates by producing thicker shelled, well-ribbed specimens, while thinner valved, ribless specimens occur in finer, silty sediments. This condition was reported by Ward (1992, p. 84) relative to *Astarte thisphila* Glenn.

Geologic range.—Kirkwood Formation, Shiloh Marl Member.

***Astarte* sp.**

Plate 13, Figures 3, 6

Astarte symmetrica Conrad. Whitfield, 1894, p. 54, Pl. VIII, figs. 1, 2.

Discussion.—A small, very triangular species of *Astarte* occurs at the Pollack Farm Site in large numbers. The taxon has only two to three small undulations on its beak and, otherwise, its disk is smooth except for irregularly spaced growth interruptions. It appears that the specimens figured by Whitfield (1894, pl. VIII, figs. 1, 2) belong to this species and not *A. symmetrica* or *A. cuneiformis*. The specimen wrongly figured as *Astarte vicina* Say by Glenn (1904, pl. XCIII, figs. 10, 11) has a similar exterior sculpture pattern, but is much more profoundly prosocline and deeper valved. The material collected from Delaware consists of 2500 valves.

Geologic range.—Known only from the Kirkwood [Calvert] at the Pollack Farm Site and the questionable New Jersey material from wells at Atlantic City.

***Dinocardium* sp.**

Plate 13, Figures 7, 8

Discussion.—Specimens of an early form of *Dinocardium* are abundant at the Pollack Farm Site with over 116 specimens collected. Less abundant, but well-represented, is the cardiid species *Chesacardium craticuloides* (Conrad). Cardiids were found only as juveniles or fragments in the Kirkwood by Whitfield (1894) and Richards and Harbison (1942). This species of *Dinocardium* has the discerning characteristics of the genus, including the very tumid umbones and the wide, low ribs with prominent crescent-shaped cross-threads; but it has only a trace of the later hinge modification, in which the hinge plate is reflected upward and attaches to the beaks (see Ward, 1992, p. 89 for further discussion of this feature). Glenn (1904, pl. LXXXVI, fig. 5) figured a specimen obtained from external molds in Bed 2 of the Fairhaven Member that appears to be a *Dinocardium*, but it has considerably more ribs than the Delaware specimens (52 versus 35). That species, named *Cardium* (*Cerastoderma*) *patuxentium* by Glenn, occurs at the same stratigraphic level as the Delaware beds, but the significantly different rib counts suggest the Delaware taxon is a different species. Comparison of the Pollack Farm material with other species of *Dinocardium* suggests that the species is new. *Dinocardium* has not been reported in other beds in the Chesapeake Group and apparently did not inhabit the Salisbury Embayment. It is reported from the Chowan River Formation by Campbell (1993); however, it occurs in older Pliocene units in North Carolina, South Carolina, Georgia, and in the Miocene and Pliocene of Florida. *Dinocardium* is today a subtropical to tropical bivalve, and the evidence in the earlier occurrences of the genus indicates that it occupied similar settings in the Oligocene and Miocene.

Geologic range.—Kirkwood Formation, Shiloh Marl Member.

***Chesacardium craticuloides* (Conrad)**

Plate 13, Figure 10

Cardium craticuloides Conrad, 1845, p. 66, Pl. 37, fig. 3.

Cardium (*Cerastoderma*) *craticuloides* Conrad. Whitfield, 1894, p. 66, Pl. X, figs. 16–19.

Cardium laqueatum Conrad. Richards and Harbison, 1942, p. 193, Pl. 12, fig. 6.

Cardium patuxentium Glenn. Richards and Harbison, 1942, p. 193, Pl. 12, fig. 4.

Discussion.—*Chesacardium craticuloides* is common to abundant at the Pollack Farm Site with 58 specimens and a large number of fragments collected. This occurrence marks the first known appearance of *Chesacardium*, a temperate-water taxon. The co-occurrence of *Dinocardium* and *Chesacardium* in the Kirkwood is the only known appearance of these two genera together until the late Pliocene (3.5 Ma.). At that time their geographic ranges overlapped in the Duplin Formation of North and South Carolina and Raysor Formation of South Carolina.

Geologic range.—Kirkwood Formation, Shiloh Marl Member; Calvert Formation, Plum Point Marl Member (Bed 10).

“*Cardium*” *calvertensium* Glenn

Plate 13, Figures 9, 11

Cardium (*Cerastoderma*) *calvertensium* Glenn, 1904, p. 321, Pl. LXXXVI, fig. 4.

Discussion.—“*Cardium*” *calvertensium* is present but never common in the beds at the Pollack Farm Site with 18 specimens collected. The species was not mentioned by Whitfield (1894) or Richards and Harbison (1942). Two species resemble “*Cardium*” *calvertensium* in terms of number of ribs, but their ribs are V-shaped. The two, *Cardium ctenolium* Dall (1900) and *Cardium panastrum* Dall (1900) both occur in the Oak Grove of Florida, a stratigraphic equivalent of the upper Calvert Formation.

Geologic range.—Kirkwood Formation, Shiloh Marl Member; Calvert Formation, Fairhaven Member, Plum Point Marl Member, Calvert Beach Member.

***Leptomacra marylandica* (Dall)**

Plate 14, Figures 1, 2

Spisula (*Hemimacra*) *marylandica* Dall, 1898, p. 897, Pl. XXVIII, fig. 5.

Spisula (*Hemimacra*) *marylandica* Dall. Glenn, 1904, p. 287, Pl. LXIX, fig. 11.

Leptomacra marylandica (Dall). Ward, 1992, p. 94–95, Pl. 17, figs. 3, 5.

Discussion.—A number of mactrids were mentioned by Whitfield (1894) and Richards and Harbison (1942) as occurring in the Miocene of New Jersey. The specimen (fragment) identified as *Mactra delumbis* by Whitfield (1894, p. 82–83) may be a *L. marylandica* and not a *L. delumbis* as he concluded. The specimens identified by Richards and Harbison (1942, pl. 15, figs. 16, 17) as *Mactra delumbis* are not that species, which ranges from the St. Marys to the Yorktown Formation, nor is it *L. marylandica*, but rather it probably is a specimen of “*Mactra*” sp. described below and figured on Plate 14, figures 3–6.

The specimens found in Delaware are large (eight specimens are 75+ mm) and nearly complete making their identification certain. Rare specimens from the Haywood Landing Member of the Belgrade Formation appear to be identical to the Delaware specimens. This would extend the range of the genus *Leptomacra* back into the late Oligocene and indicate that *L. marylandica* lived from the late Oligocene until the late Miocene.

Geologic range.—Belgrade (Haywood Landing Member), Kirkwood, Calvert, Choptank, and St. Marys formations.

“*Mactra*” sp.

Plate 14, Figures 3–6

Discussion.—Whitfield’s (1894, pl. XV, figs. 1–6) specimens may be identical to the mactrid species so common at the Pollack Farm Site in Delaware. It is clear that his identifications, *Mactra lateralis* for figures 1–3 and *Rangia* (*Perissodon*) *minor* for figures 4–6, are incorrect. *Mulinia lateralis* is a Pleistocene to Recent species and *Rangia minor* (which is probably not a *Rangia*) is known only from the upper Pliocene Duplin Formation in North Carolina.

Pilsbry and Harbison (1933) named and figured a mactrid, *Mactra insulaeamaris*, that is similar in form and size to the Delaware species, but it was described as having strongly crenulated lateral teeth. The species at the Pollack Farm Site, which numbers in excess of 500 specimens, shows no trace of the striations on the lateral teeth. “*Spisula*” *subcuneata* (Conrad) figured by Glenn (1904, pl. LXIX, figs. 7–9) and Ward (1992, pl. 11, fig. 4) is shaped much like the Delaware species, but it too has crenulated lateral teeth.

A specimen figured by Glenn from Plum Point, Maryland (probably Bed 10 of the Calvert Formation) resembles the Delaware specimens, but it was identified as *Spisula subparilis*, an upper Pliocene species from the Duplin Formation in North Carolina. The specimens figured by Richards and Harbison (1942, pl. 15, figs. 1, 2–4, 8, 20) may be identical to the Delaware species, but they were called *Mulinia lateralis* and *Mactra clathrodon* by the authors. The poor figures and inadequate species descriptions make identification difficult.

The Delaware species, therefore, seems undescribed. It is thin, almost equilateral, with the beaks slightly prosocline. Specimens are most numerous in the 20 mm range, but some specimens are as large as 60 mm. In general form, it resembles the Recent *Hemimacra solidissima*. That species exhibits very fine striations on the lateral teeth, a condition not observed in the lower Miocene taxon. The Delaware species is also not nearly as deep-valved as *Leptomacra marylandica*.

Geologic range.—Kirkwood Formation; possibly Bed 10 of the Plum Point Marl Member of the Calvert Formation.

***Ensis directus* Conrad**

Plate 14, Figures 7, 8

Ensis directus Conrad, 1843b, p. 325.

Ensis directus Conrad. Richards and Harbison, 1942, p. 200, Pl. 16, figs. 7, 8.

Discussion.—Broken valves of *Ensis* are common at the Pollack Farm Site, and over 100 specimens were collected, though none were even half complete. Specimens from the St. Marys River (where the type of *E. ensiformis* Conrad, 1843, originates) and the Neuse River below New Bern, North Carolina (type locality of *E. directus*) were compared with the specimens from Delaware, and no important differences were noted. Thus, the name *E. directus* is used as it appeared first in Conrad’s 1843b paper.

Whitfield (1894) did not mention the presence of *Ensis* in the New Jersey Miocene, but Richards and Harbison (1942) report fragments in several deep wells. The material from Delaware, though fragmentary, is sufficient to make comparisons with specimens from younger units. *Ensis* occurs in European beds as old as the Eocene, but the presence of that taxon in the Kirkwood beds marks its first

known appearance on the Atlantic Coastal Plain. *Ensis directus* occurs in the Recent in shallow shelf conditions from Labrador to Florida.

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, Eastover, Yorktown, Chowan River, James City formations, and younger units to the Recent.

***Strigilla* sp. cf. *S. georgiana?* Gardner**

Plate 14, Figures 9–11

Strigilla georgiana Gardner, 1928, p. 199, Pl. XXX, figs. 12, 13.

Discussion.—*Strigilla* is fairly common in the Pollack Farm collection with some 200 valves collected. The valves average 17–20 mm in length. The exterior V- or W-shaped divaricate sculpture is very weak, even in the best preserved specimens, and can scarcely be seen without magnification. In this way it seems to differ from *S. georgiana*, which has much stronger sculpture. The Delaware species also resembles the Recent taxon, *S. pisiformis* (Linné).

Strigilla was not reported by Whitfield (1894) or Richards and Harbison (1942). In addition, there is no report of the taxon in any stratigraphic unit in the Chesapeake Group, except the Chowan River Formation, an upper Pliocene unit, which is essentially subtropical in nature. There is, therefore, an approximately 16 million year absence of *Strigilla* in the mid-Atlantic region. The genus today is characterized by Abbott (1974) as “worldwide and tropical.” Its presence in Delaware is strong evidence of tropical influences during the early Miocene at least as far north as the 39°30' north latitude.

Geologic range.—Not known outside of the Kirkwood [Calvert] Formation of Delaware and the Oak Grove Sand of Florida and Georgia.

***Florimetus biplicata* (Conrad)**

Plate 15, Figure 1

Tellina biplicata Conrad, 1834, p. 152.

Metis biplicata (Conrad). Richards and Harbison, 1942, p. 196, Pl. 12, figs. 2, 3.

Discussion.—The only record of this taxon in the Kirkwood Formation is that of Richards and Harbison (1942), who, besides fragments, record only one specimen at 310 ft in a core from a well at Millville, New Jersey. *Florimetus biplicata* is represented at the Pollack Farm Site by at least 10 specimens, four of which are essentially complete. The species is present during most of the Miocene, but is common only during the early middle Miocene in the Drumcliff Member of the Choptank Formation. The occurrence of this taxon in the Kirkwood marks its earliest known appearance on the Atlantic Coastal Plain. A species of *Metis*, *Metis chipolana*, was described by Dall (1900) from the Chipola Formation in Florida, a stratigraphic equivalent of the Kirkwood Formation in New Jersey.

The large, thin valves of *Florimetus* are fragile and easily broken, hence the few preserved specimens at the Delaware site.

Geologic range.—Kirkwood, Calvert, Choptank, St. Marys, and Eastover formations.

***Semele subovata* (Say)**

Plate 15, Figure 2

Amphidesma subovata Say, 1824, p. 152, Pl. X, fig. 10.

Amphidesma Burnsii Whitfield, 1894, p. 79, Pl. XIV, figs. 16–18.

Abra aequalis Conrad. Whitfield, 1894, p. 80, Pl. XIV, figs. 11–15.

Semele johnsoniana Pilsbry and Harbison, 1933, p. 18, Pl. 5, figs. 4–6.

Semele burnsi (Whitfield). Richards and Harbison, 1942, p. 199, Pl. 15, figs. 18, 19.

Semele johnsoniana Pilsbry and Harbison. Richards and Harbison, 1942, p. 199, Pl. 15, figs. 11, 12.

Discussion.—Specimens of *Semele subovata* were named *Amphidesma burnsi* and also identified as *Abra aequalis* by Whitfield (1894) who reported the species to be common at Shiloh, New Jersey. Pilsbry and Harbison (1933) described and named another species of *Semele* from the Kirkwood, *S. johnsoniana*. Examination of specimens present in the stratigraphic units from the Belgrade Formation (upper Oligocene/lower Miocene) to the Yorktown Formation (upper Pliocene) shows only very minor differences between the populations over this geologic interval. For this reason I have included all of these specimens in *Semele subovata*, a species whose type came from the upper Yorktown Formation. Young specimens tend to be noticeably longer than high, but later growth changes their outlines to make adult specimens nearly as high as they are long. This species was present, but never common, at the Delaware site with 13 valves collected.

Geologic range.—Belgrade (Haywood Landing Member), Kirkwood, Calvert, Choptank, St. Marys, Eastover, and Yorktown formations.

***Tagelus plebeius* subspecies**

Plate 15, Figure 3, 5

Solen plebeius [Lightfoot], 1786, p. 42.

Discussion.—*Tagelus* is common at the Pollack Farm Site, though most specimens are broken and incomplete due to their fragility. Whole individuals suggest that the Delaware taxon is somewhat more elongate than the Recent *T. plebeius* (Lightfoot). Specimens collected by the author from the upper Oligocene Haywood Landing Member of the Belgrade Formation in North Carolina are probably the same species as the Delaware taxon. Some 55 specimens were collected at the Pollack Farm Site. In the Atlantic Coastal Plain the genus is not known to reappear until the late Pliocene in the Moore House Member of the Yorktown Formation. *Tagelus* becomes common in the late Pliocene and Pleistocene of the Atlantic Coastal Plain.

Geologic range.—Belgrade and Kirkwood formations.

***Donax idoneus* subspecies?**

Plate 15, Figures 4, 6, 9

Donax idoneus Conrad, 1872, p. 216, Pl. 7, fig. 2.

?*Donax variabilis* Say. Whitfield, 1894, p. 79, Pl. XIV, figs. 19, 20. [Not *Donax variabilis* of Say, 1822].

?*Donax abseconi* Richards and Harbison, 1942, p. 197–198, Pl. 15, figs. 5, 6.

Discussion.—*Donax idoneus* is common in the Haywood Landing Member of the Belgrade Formation (upper Oligocene/lower Miocene) in North Carolina. It is a very large species for the genus with specimens commonly exceeding 40 mm in length. The Pollack Farm specimens are fairly common with 35 specimens collected, and they average approximately the same length as *D. idoneus*, except one

incomplete valve that suggests a length of about 60 mm. There are several significant differences between the Delaware and North Carolina forms that may indicate they are different subspecies. The Delaware form has a smaller hinge plate and teeth, a very sharply angled and straight posterior slope, and finer crenulations along the basal margin. The North Carolina form is deeper valved, and its posterior slope is more rounded and slightly curved. Whitfield (1894) and Richards and Harbison (1942) each figured a single specimen of a *Donax* from a well at Atlantic City, New Jersey. Richards and Harbison (1942, p. 197–198) named their specimen *D. abseconi*. It appears this specimen, an incomplete valve, could be the young of *D. idoneus* subspecies as could the juvenile specimen illustrated by Whitfield (1894). Further study may help to determine if *D. abseconi* is the proper name for this remarkable taxon.

Donax striatus Linné, a living West Indian species, approaches the shape and size of the Delaware species but is smaller. *Donax peruvianus* Deshayes, a living West Coast species, is very near the shape of the Delaware form and nearly as big. *Donax* lives in high-energy environments, typically near sandy beaches and is strong evidence that dynamic currents were present during the development of the beds at the Pollack Farm Site. Most species are subtropical to tropical.

Geologic range.—*Donax* ranges from the early Eocene to the Recent; *D. idoneus* is known from the Belgrade Formation in North Carolina, and *D. idoneus* subspecies is known only from the Kirkwood [Calvert] in Delaware.

***Donax* sp.**

Plate 15, Figures 11–14

Discussion.—A small, very elongate species of *Donax* is sparingly present in the beds at the Pollack Farm Site. Twenty-five specimens have been collected, the longest of which is about 12 mm. An imperfect specimen described by Richards and Harbison (1942) from a well at Atlantic City at an unknown depth appears to be distinct from the Delaware species. That taxon, *Donax abseconi*, based on a single incomplete specimen, may be the young of *Donax idoneus* subspecies? and is much more triangular in shape than the elongate species under consideration here. A very similar, but much larger species of *Donax* is present in the Belgrade Formation in North Carolina. *Donax aldrichi* Gardner, based on a single specimen from the Oak Grove Sand on the Yellow River in Florida, is similarly shaped and nearly the same size, but the very obvious radial lines developed on the type cannot be seen on the Delaware specimens.

Except for the Kirkwood occurrence, no other species of this genus is known to occur in Chesapeake Group sediments until the late Pliocene, in the upper beds of the Yorktown Formation, an approximately 15 million year absence.

Geologic range.—Kirkwood [Calvert] Formation in Delaware. Possibly Belgrade Formation in North Carolina, and possibly the Oak Grove Sand in Florida.

***Iphigenia* sp.**

Plate 15, Figures 7, 8, 10

Discussion.—An unnamed species of *Iphigenia* is common at the Delaware site. It was not reported by Whitfield (1894) or by Richards and Harbison (1942), but is

represented by over 2000 specimens at the Pollack Farm Site. I can find no reference to the genus in the literature on the Atlantic and Gulf Coasts, but it is represented in the Recent by *I. brasiliiana* (Lamarck). That taxon occurs in subtropical to tropical settings from south Florida to Brazil. The genus is reported from the Miocene to the Recent in West Africa and Central and South America (Cox and others, 1969).

The Delaware species is broadly trigonal in outline but does not exhibit the broad medial fold that flexes the margin of *I. brasiliiana*. It is also smaller than that species with the largest individuals slightly larger than 40 mm.

Geologic range.—Kirkwood [Calvert] Formation in Delaware.

***Mytilopsis erimiocenicus* Vokes**

Plate 16, Figures 1–3

Mytilopsis erimiocenicus Vokes, 1985, p. 163–165, figs. 1–3.

Discussion.—*Mytilopsis erimiocenicus* is common to abundant at the Pollack Farm Site with over 2100 specimens collected. The taxon was not mentioned by Whitfield (1894) or Richards and Harbison (1942) in their studies on the New Jersey early Miocene. There is no record of the genus on the Atlantic Coastal Plain except in the Chipola Formation (lower Miocene) of west Florida and in the late Pliocene of south Florida (Dall, 1898). Cox and others (1969) give the range of the genus from the late Oligocene to the Recent in western South America, Africa, and the East Indies. Presently, there is a single species on the North American Atlantic Coast, *M. leucophaeata*, which first appeared in the late Pleistocene. That species occurs from New York to Mexico and is found in brackish water where rivers run into the sea. Except for this species, the others mentioned in the literature occur in subtropical and tropical environments.

The specimens from Delaware closely resemble *M. leucophaeata* in shape and size, but for the present, I am placing the species in *Mytilopsis erimiocenicus* of Vokes. The Florida Pliocene species, *M. lamellata* (Dall), is much heavier and has a more triangular shell.

Geologic range.—Kirkwood [Calvert] Formation in Delaware, Chipola Formation in Florida, and possibly Recent, if this species is identical to *M. leucophaeata*.

***Glossus* sp.**

Plate 16, Figure 4

?*Isocardia fraterna* Say var. *marylandica*? Schoonover, 1941, Pl. 9, fig. 5.

Discussion.—No species of *Glossus* has been reported from the Kirkwood of New Jersey nor has a specific species been reported in the Calvert Formation below Bed 10 of the Plum Point Marl Member. A possible exception is *Glossus ignolea*, based on a single specimen (both valves), from an uncertain locality, either the lower St. Marys Formation or Plum Point (=Bed 10). The author, Glenn (1904), was inclined to believe the Plum Point *Glossus*, similar to *G. ignolea*, was present in Beds 4–9 of the Calvert. A species of *Glossus* does occur in those beds, in vast numbers, along single bedding planes, but they exist only as molds and casts or poorly preserved, eroded specimens. A specimen called "*Isocardia fraterna* var. *marylandica*?" by Schoonover, and illustrated by her, came from Bed 5 of the Calvert and may be the same species as the Delaware taxon. However, that

specimen (pl. 9, fig. 5) is not Schoonover's *I. f.* var. *marylandica* (= *Glossus marylandica* [Schoonover])

The specimens from the Pollack Farm Site differ from the stratigraphically higher Maryland forms in being less elongate and lacking the more pronounced ridge on the posterior slope. The Delaware species is rare, with only one whole individual and two partial specimens collected. The material, however scant, marks the first known appearance of the genus in North America. Some species, belonging to the family Glossidae, have been reported from the Paleocene and Eocene in North America, but the earliest appearance of true *Glossus* was in northern Europe in the early Oligocene.

Geologic range.—Kirkwood Formation, Shiloh Marl Member.

***Lirophora latilirata* (Conrad)**

Plate 16, Figures 5, 6

Venus latilirata Conrad, 1841a, p. 28.

Chione latilirata (Conrad). Glenn, 1904, p. 309–310, Pl. LXXVII, figs. 3, 4, 6.

Discussion.—*Lirophora latilirata* is common to abundant in the beds at the Pollack Farm Site with 350 specimens collected. The species is equally abundant in the Plum Point Marl Member (Bed 10) of the Calvert Formation. The name "*L. latilirata*" has been applied to species in the Pliocene, Pleistocene, and Recent, but it is properly only applied to the Kirkwood and Calvert species. Recent taxa referred to *Lirophora* live in subtropical and tropical settings. There is no mention of this species in the Kirkwood of New Jersey by either Whitfield (1894) or Richards and Harbison (1942).

Geologic range.—Kirkwood and Calvert (Plum Point Marl Member, Bed 10) formations.

***Mercenaria ducatelli* (Conrad)**

Plate 16, Figures 7, 8; Plate 17, Figures 1–3

Venus Ducatelli Conrad, 1838, p. 8, Pl. IV, fig. 2.

Mercenaria Ducatelli Conrad. Whitfield, 1894, p. 67, Pl. XI, figs. 1–7.

Venus ducatelli Conrad. Glenn, 1904, p. 304, Pl. LXXV, figs. 7, 8.

Venus ducatelli Conrad. Palmer, 1927, p. 192–193, Pl. XXXV, figs. 5, 9.

Venus ducatelli Conrad. Richards and Harbison, 1942, p. 194–195, Pl. 13, fig. 5.

Discussion.—*Mercenaria ducatelli* is extremely abundant at the Pollack Farm Site, with over 1200 specimens collected. Only a meager number of specimens were available to Whitfield (1894) from New Jersey, and Richards and Harbison (1942, p. 194) reported the species to be "Rare and usually broken." The forms figured by Whitfield (1894, pl. XI, figs. 1–7) are typical of the species. Other ecophenotypic varieties are present in the Pollack Farm collections. Those specimens have their lamella fused together, or nearly so, as is typical of back-barrier or quiet water, lagoonal-living *Mercenaria*. To see the several morphs mixed together is no surprise as the entire Pollack Farm collection shows the mixing of brackish, back-barrier mollusks with normal-salinity, open-shelf taxa. The species named "*M. cancellata*" Gabb (figured by Whitfield, 1894, pl. XII, figs. 2, 3) may be merely a variety of *M. ducatelli* that grew in a lagoonal, muddy setting. *Mercenaria plena* Conrad (figured by Whitfield, 1894, pl. XII, figs. 4–6) may also be referable to

M. ducatelli. *Mercenaria langdoni* (Dall, 1900), which lived in the stratigraphically equivalent Chipola Formation in Florida, is also probably the same species as the Delaware form.

Geologic range.—Kirkwood Formation, Shiloh Marl Member.

***Dosinia acetabulum blackwelderi* Ward**

Plate 17, Figure 4

Dosinia acetabulum blackwelderi Ward, 1992, p. 102–103, Pl. 18, fig. 2.

Dosinia acetabulum Conrad. Whitfield, 1894, p. 73. [Not Plate XIII, fig. 2].

Dosinia acetabulum (Conrad). Richards and Harbison, 1942, p. 194, Pl. 12, fig. 5. [Not Plate 12, fig. 1].

Discussion.—This taxon is common to abundant at the Pollack Farm Site with more than 100 whole or nearly whole individuals collected. By contrast, Whitfield (1894) and Richards and Harbison (1942) reported only a few fragments from deep wells in New Jersey. Whitfield figured Conrad's (1832) type of *Dosinia acetabulum acetabulum* from the Yorktown Formation (upper Pliocene) of Virginia, and Richards and Harbison figured Ward's (1992) *Dosinia acetabulum thori* from the St. Marys Formation (late Miocene) of Maryland. Neither of these taxa occur in the Kirkwood. The occurrence of *Dosinia* in the Kirkwood marks the first known appearance of that genus on the North American Atlantic Coastal Plain. The *D. acetabulum* lineage is represented through the entire Chesapeake Group, apparently becoming extinct during the cooling event after the deposition of the Yorktown Formation and before the deposition of the Chowan River Formation. The *D. acetabulum* lineage clearly prefers temperate habitats, and it is replaced in subtropical and tropical settings by the *D. concentrica* lineage. That lineage survived the cooling event and is extant.

Geologic range.—Kirkwood Formation; Calvert Formation, Plum Point Marl Member, Calvert Beach Member; Choptank Formation.

***Macrocallista marylandica* (Conrad)**

Plate 17, Figures 5–7

Cytherea marylandica Conrad, 1833b, p. 343.

Dione marylandica Conrad. Whitfield, 1894, p. 74. [Plate XIII, fig. 1 is a copy of Conrad's (1838) figure, probably from the Choptank Formation].

Macrocallista marylandica (Conrad). Richards and Harbison, 1942, p. 193, Pl. 10, fig. 13.

Discussion.—*Macrocallista marylandica* is very abundant at the Pollack Farm Site with at least 800 whole valves collected. Whitfield (1894) had only two fragments of a hinge and Richards and Harbison (1942) had only fragments, all of which came from deep wells in the Kirkwood of New Jersey. The large suite of specimens exhibits a fair amount of variation in shape that involves a number of very short, stout individuals, as well as very elongate ones. This author believes that the Delaware specimens are all the same species and that they seem identical to *M. marylandica* from the type locality on the Choptank River. Ward (1992) was unsure about the identity of the *Macrocallista* specimens from Bed 10 of the Plum Point Marl Member because of their small size and corresponding thinness, but it seems clear, with the Delaware material in hand, that *M. mary-*

landica was present in the Kirkwood, Calvert, and Choptank formations. Specimens present in the Belgrade Formation, Haywood Landing Member (upper Oligocene/lower Miocene) of North Carolina would be difficult to differentiate from *M. marylandica*, though other distinctly different species of *Macrocallista* are also present in that unit. The genus is clearly a slowly evolving one, which, because of its conservative morphologic changes, is difficult to determine to the specific level.

Geologic range.—Kirkwood Formation, Calvert Formation, and Choptank Formation.

***Clementia grayi* Dall**

Plate 18, Figures 1, 4

Clementia grayi Dall, 1890, p. 193, Pl. 37, fig. 12.

Clementia (Egesta) grayi Dall. Woodring, 1926, p. 37, Pl. 15, fig. 4.

Clementia (Egesta) inoceriformis (Wagner). Woodring, 1926, Pl. 15, fig. 6. [Only hinges of specimens labeled "Shiloh, N. J." glued to holotype of *C. inoceriformis*].

Clementia inoceriformis (Wagner). Richards and Harbison, 1942, p. 175, fig. 4. [Only hinges of specimens labeled "Shiloh, N. J." (ANSP 4303)].

Discussion.—The Pollack Farm specimens are provisionally placed in *Clementia grayi*. This species has a posterior slope more flattened than that of *C. inoceriformis*. In addition, the concentric undulations extend farther down the shell in *C. inoceriformis* than in *C. grayi*. The specific determination, in this case, is based principally on the only complete specimen, a double-valved individual. The remaining 20 specimens consist of the beak and hinge portion of the taxon, the only thick part of the shell. Using only broken specimens, I would have concluded that the species was *C. inoceriformis* because the concentric undulations on the beak are regular and strong. The whole specimen, however, shows that the undulations become irregular in the lower two-thirds of the disk and are replaced by numerous, closely placed, fine, concentric growth lines. This is a characteristic described by Dall (1900) and Woodring (1926) in their description of *C. grayi*. The species is known from a number of lower Miocene localities in Florida, including the stratigraphically equivalent Chipola Formation. Richards and Harbison (1942, p. 175) and Woodring (1926) both figured *Clementia* hinges collected by Conrad and said to come from Shiloh, New Jersey. The Delaware material leaves little doubt that the genus was present in the Kirkwood Formation in New Jersey as well as Delaware.

Geologic range.—Kirkwood Formation, Shiloh Marl Member; Oak Grove Sand and Chipola Formation in Florida.

***Mya producta* Conrad**

Plate 18, Figures 2, 5

Mya producta Conrad, 1838, p. 1, Pl. 1, fig. 1.

Mya producta Conrad. Glenn, 1904, p. 283, Pl. LXVIII, figs. 1, 2.

Mya producta Conrad. Richards and Harbison, 1942, p. 202, Pl. 16, fig. 11. [Fig. 12 is from the Choptank Formation in Maryland].

Discussion.—The first report of *Mya producta* in the Kirkwood Formation in New Jersey was that of Richards and Harbison (1942), but that report was based on "fragments only." Glenn (1904) reported the species only from Jones

Wharf, St. Marys County, Maryland (= Bed 17 of the Choptank Formation), and there this author has found it rather common. I can find no evidence of the species in Bed 10 of the Plum Point Marl Member, but it is fairly common at the Pollack Farm Site in Delaware, where over 130 valves have been recovered, mostly broken, but many nearly whole. The adult specimens commonly range from 90–100 mm in length, are relatively thick-valved, and have a prominent medial fold. Young specimens do not exhibit this fold. Several young specimens found in the Haywood Landing Member of the Belgrade Formation in North Carolina look identical to the Delaware material and may indicate that this species was present from the late Oligocene to the middle Miocene.

Geologic range.—Belgrade Formation (Haywood Landing Member), Kirkwood Formation, Choptank Formation (Drumcliff Member).

***Caryocorbula cuneata* (Say)**

Plate 18, Figures 13, 14

Corbula cuneata Say, 1824, p. 152, Pl. XIII, fig. 3.

Corbula cuneata Say. Glenn, 1904, p. 282, Pl. LXVII, figs. 15–19.

Discussion.—The most common corbulid species present in the Pollack Farm assemblage is *Caryocorbula cuneata*, which is common from the Miocene to the Pliocene. It is most readily identified by its exterior sculpture of fine, equally spaced, close-set, concentric ribs. The other corbulid species, which commonly co-occurs with *C. cuneata*, is *C. inaequalis* Say, but that taxon has very unequal, irregular ribs, and is more rounded. *Caryocorbula cuneata* is represented by over 1000 specimens from Delaware, though it has not been previously reported from the Kirkwood Formation of New Jersey. The species is not particularly abundant, despite the numbers, as similar volumes of sediment in the other beds of the Chesapeake Group commonly would yield many times more individuals.

The specimens from Delaware identified by myself as *C. cuneata* are similar to, and may be identical with, specimens from the Chipola Formation that Dall named *Corbula (Cuneocorbula) sarda* (Dall, 1898).

***Caryocorbula subcontracta* (Whitfield)**

Plate 18, Figures 3, 6

Corbula subcontracta Whitfield, 1894, p. 88–89, Pl. XV, figs. 11–14.

Corbula inaequalis Say. Glenn, 1904, p. 281–282, Pl. LXVII, figs. 6, 10. [Not *C. inaequalis* of Say, 1824].

Corbula inaequalis Say. Richards and Harbison, 1942, p. 198, Pl. 15, figs. 13, 14. [Not *C. inaequalis* of Say, 1824].

Discussion.—*Caryocorbula subcontracta* is present in small numbers in the molluscan material from Delaware. It was named by Whitfield (1894) based on specimens from Shiloh, New Jersey. Glenn (1904) and Richards and Harbison (1942) considered *C. subcontracta* to be a junior synonym of *C. inaequalis* (Say, 1824), but *C. subcontracta* has strong, equal-sized, equidistant, concentric ribs (fewer and stronger than in *C. cuneata*) and not the "rough, unequal coarse wrinkles" described by Say (1824, p. 153) for *C. inaequalis*.

Over 100 specimens have been obtained from the

Pollack Farm material, but considering the large amount of material picked, this species is somewhat uncommon. Several of the specimens figured by Glenn (1904, pl. LXVII, figs. 6, 10, 12) appear to be *C. subcontracta*. The specimen in his figure 6 comes from Church Hill, Maryland, in a bed stratigraphically equivalent to the Shiloh Marl and the beds at the Pollack Farm Site. The specimen shown in his figure 12, if it is properly a *C. subcontracta*, extends the range of that species up to Bed 10 of the Plum Point Marl Member.

Geologic range.—Kirkwood Formation; possibly Bed 10 of Plum Point Marl Member, Calvert Formation.

***Varicorbula elevata* (Conrad)**

Plate 18, Figures 9, 12

Corbula elevata Conrad, 1838, p. 7, Pl. IV, fig. 3.

Corbula elevata Conrad. Whitfield, 1894, p. 86–87, Pl. XV, figs. 15–19.

Corbula elevata Conrad. Richards and Harbison, 1942, p. 198, Pl. 15, figs. 9, 10.

Varicorbula elevata (Conrad). Ward, 1992, p. 113, Pl. 21, fig. 2.

Discussion.—*Varicorbula elevata* is comparatively rare at the Pollack Farm Site with only 20 valves recovered. Conrad's type came from Stow Creek, near Shiloh, New Jersey, and both Whitfield (1894) and Richards and Harbison (1942) mention that locality. The heaviest concentration of the taxon is in the bottom beds of the Plum Point Marl Member, Bed 4–9 and Bed 10, where they are extremely abundant and dominate the fauna.

Geologic range.—Kirkwood and Calvert (Beds 2–10) formations.

***Bicorbula idonea* (Conrad)**

Plate 18, Figures 7, 8, 10, 11

Corbula idonea Conrad, 1833b, p. 341.

Corbula idonea Conrad. Whitfield, 1894, p. 88, Pl. XV, fig. 20.

Corbula idonea Conrad. Richards and Harbison, 1942, p. 198, Pl. 15, figs. 7, 15.

Bicorbula idonea (Conrad). Ward, 1992, p. 112–113, Pl. 21, fig. 1.

Discussion.—*Bicorbula idonea* is reported from the Kirkwood Formation of New Jersey, based only on a small fragment found in a well at Atlantic City and listed by Heilprin (1888). Whitfield (1894, pl. XV, fig. 20) refers to this citation and reproduces Conrad's (1838, pl. 10, fig. 6) figure. Richards and Harbison (1942) also cite the Atlantic City well specimen and figure the fragment.

The 26 specimens from the Pollack Farm Site are adults as large as 30 mm in length. Ward (1992) reported *B. idonea* from the Belgrade Formation (Haywood Landing Member, upper Oligocene). The specimens from that unit are generally small and have a noticeably produced posterior in both valves, apparently to accommodate the siphons. Immature specimens from the Choptank Formation, in which the species is common, exhibit the same condition, but the valves become increasingly less produced in the adults. Ward and Blackwelder (1990) reported *B. idonea* from the Edisto Formation in South Carolina, a unit stratigraphically equivalent to the Haywood Landing Member. Also, Ward (1985) reported the species from the Old Church Formation in Virginia, also an upper Oligocene/lower

Miocene unit.

Geologic range.—Old Church, Belgrade, Edisto, Kirkwood, Calvert, Choptank, St. Marys (rare), and Eastover (rare) formations.

***Panopea americana* Conrad**

Plate 18, Figure 16

Panopaea Americana Conrad, 1838, p. 4, Pl. II.

Panopaea americana Conrad. Glenn, 1904, p. 278, Pl. LXVI, fig. 2.

Discussion.—There is no report on the presence of *Panopea americana* in the Kirkwood Formation, or any older units, in the literature. Glenn did report the taxon from Wye Mills, Queen Anne County, Maryland, where it probably was found in beds equivalent to those in Delaware and the Kirkwood of New Jersey. The species is not known to occur stratigraphically higher than the Choptank Formation. *Panopaea americana* is present in relatively small numbers and fragmentary condition at the Pollack Farm Site. More than 30 fragments and one nearly complete valve are available for study. The thickness, size, and reflected nature of the anterior and posterior margins of the valves make the identification of this species certain. The Delaware specimens mark the first known appearance of this species. The taxon occurs in sediment that indicates fairly high-energy conditions. Another species, *P. whitfieldi*, and the stratigraphically higher *P. goldfussi*, occur in finer, more silty beds that reflect quieter conditions. *Panopea reflexa* Say, a Pliocene species, may be a representative of the same lineage as *P. americana*. It also has heavy, thick valves, but it is a smaller taxon with a much more rounded anterior margin, lacking the extreme anterior gape of *P. americana*.

Geologic range.—Kirkwood, Calvert, and Choptank formations.

***Panopea whitfieldi* Dall**

Plate 18, Figure 15

Panopea goldfussi Wagner. Whitfield, 1894, p. 89–90, Pl. XVI, figs. 9–13.

Panopea whitfieldi Dall, 1898, p. 829.

Panopea whitfieldi Dall. Glenn, 1904, p. 276–277, Pl. LXV, fig. 10.

Panopea whitfieldi Dall. Ward, 1992, p. 114, Pl. 21, fig. 4.

Discussion.—Whitfield (1894) figured and described a specimen from Shiloh, New Jersey, that is roughly rectangular in shape, and assigned it to *Panopea goldfussi*. Dall (1898) recognized differences in the New Jersey species and named it *P. whitfieldi*. Specimens from Bed 10 of the Plum Point Marl Member figured by Glenn (1904, pl. LXV, fig. 10) and Ward (1992, pl. 21, fig. 4) both appear to be *P. whitfieldi* as does Gardner's (1928, p. 237–238, pl. XXXVI, figs. 11, 12) *P. parawhitfieldi* and Mansfield's (1940, p. 200–201, pl. 25, fig. 49) *P. taylorensis* from the Chickasawhay Marl of Mississippi.

The seven specimens found at the Pollack Farm Site are mostly incomplete single valves. Whitfield (1894, p. 90) mentioned its occurrence in the "gray marly beds" at Shiloh. Richards and Harbison (1942) reiterated this locality information. The species appears to be a thin-valved, quiet-water form like the stratigraphically higher *P. goldfussii*, and it occurs in living position only in the silty, finer sediments.

Geologic range.—Kirkwood and Calvert (Bed 10 of

Plum Point Marl Member) formations. Possibly Belgrade Formation (Haywood Landing Member). Edisto and Arcadia (Tampa Member) Formations. Probably the Oak Grove Formation of Florida and Chickasawhay Marl of Mississippi.

***Thovana* sp.**

Plate 19, Figure 1

Discussion.—Broken specimens of a species of *Thovana* are present, though rare, at the Pollack Farm Site. The specimens are all less than 25 mm long and resemble the Recent species *T. campechiensis*. That species, however, is 75–100 mm long. It ranges from North Carolina to Brazil (subtropical and tropical) and is probably evidence of those climates during the lower Miocene.

Geologic range.—Kirkwood Formation.

***Martesia ovalis* (Say)**

Plate 19, Figures 2–8

Pholas ovalis Say, 1820, p. 39.

Martesia? ovalis Dall, 1898, p. 820, 821.

Martesia (Aspidopholas) ovalis Say, Dall, 1900, Pl. XXXVI, fig. 5.

Martesia ovalis (Say). Glenn, 1904, p. 275–276, Pl. LXV, figs. 4–9.

Discussion.—Specimens of *Martesia* are relatively common at the Pollack Farm Site, although they have not been previously reported in the Kirkwood of New Jersey. Most specimens are found in the valves of *Mercenaria* and *Crassostrea*, from which they are difficult to obtain whole. Those taxa apparently become a desirable substrate after death, disarticulation, and reworking of the valves because of their thickness. Some valves are thoroughly riddled with the borings made by *Martesia*.

Glenn (1904) reported *Martesia ovalis* from the Calvert, Choptank, and St. Marys Formations, but most of his specimens came from the Choptank, where they occupied the valves of *Isognomon*.

Geologic range.—Kirkwood, Calvert, Choptank, and St. Marys formations.

***Periploma peralta* Conrad**

Periploma alta Conrad, 1863a, p. 572, 585. [Not *Anatina alta* C. B. Adams, 1852].

Periploma peralta Conrad, 1867, p. 188.

Periploma (?) alta Whitfield, 1894, Pl. XVI, figs. 7, 8.

Periploma peralta Conrad. Glenn, 1904, p. 359, Pl. XCV, fig. 3.

Periploma peralta Conrad. Richards and Harbison, 1942, p. 202, Pl. 17, fig. 2.

Discussion.—*Periploma* is common at the Pollack Farm Site, but is known only from fragments of beaks containing the spoon-like chondrophore. The shell fragments have a pearly sheen characteristic of the genus.

Geologic range.—Kirkwood Formation; Calvert Formation, Fairhaven Member (Bed 3A); St. Marys Formation.

Scaphapoda

***Cadulus conradi* Pilsbry and Harbison**

Cadulus conradi Pilsbry and Harbison, 1933, p. 117, Pl. 4, figs. 18, 19.

Cadulus conradi Pilsbry and Harbison. Richards and

Harbison, 1942, p. 222, Pl. 22, figs. 18, 19.

Discussion.—Pilsbry and Harbison's (1933) name for this species of *Cadulus*, "*C. conradi*," is used here provisionally. The nine specimens from the Pollack Farm Site are worn and small, but seem to fall within the description of *C. conradi* rather than the larger and more compressed species *C. thallus* (Conrad).

Geologic range.—Kirkwood Formation.

Miscellaneous Taxa

A number of small species occur in the fines from the Pollack Farm Site. These taxa are only partially studied at this time but include the following genera: *Odostomia*, *Actaeon*, *Cylichna*, *Turbonilla*, *Strombiformis*, *Aligena*, and *Geukensia*. It is expected that further study will allow determination of these species as well as others in the fine fraction.

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PLATES

(Unless otherwise indicated, all specimens are from the Pollack Farm Site, Delaware)

PLATE 1

- 1, 3. *Diadora griscomi* (Conrad)
 1. Lateral view; VMNH I 533; l. 43.7 mm; ht. 19.2 mm.
 3. Apical view of same specimen.
- 2, 5. *Tegula marylandicum* (Martin)
 2. Apertural view of coated specimen; VMNH I 534; ht. 13.5 mm; w. 19.0 mm.
 5. Apertural view of same specimen, uncoated, showing color on primary spiral ribs.
- 4, 6. *Calliostoma eboreus* (Wagner)
 4. Apertural view of specimen with single carina; VMNH I 535; ht. 15.9 mm; w. 12.5 mm.
 6. Apertural view of specimen with two carinae; VMNH I 536; ht. 11.2 mm; w. 11.7 mm.
- 7–9. *Diastoma insulaeamaris* (Pilsbry and Harbison)
 7. Apertural view; VMNH I 537; ht. 20.5 mm; w. 7.0 mm.
 8. Apertural view; VMNH I 538; ht. 20.5 mm; w. 7.3 mm.
 9. Apertural view; VMNH I 539; ht. 23.4 mm; w. 7.3 mm.
- 10, 13. *Carinorbis dalli* (Whitfield)
 10. Apertural view; VMNH I 540; ht. 12.5 mm; w. 8.9 mm.
 13. Dorsal view; VMNH I 541; ht. 15.6 mm; w. 8.0 mm.
- 11, 12. *Turritella cumberlandia* Conrad
 11. Apertural view; VMNH I 542; ht. 61.0 mm; w. 15.5 mm.
 12. Apertural view; VMNH I 543; ht. 29.4 mm; w. 6.2 mm.

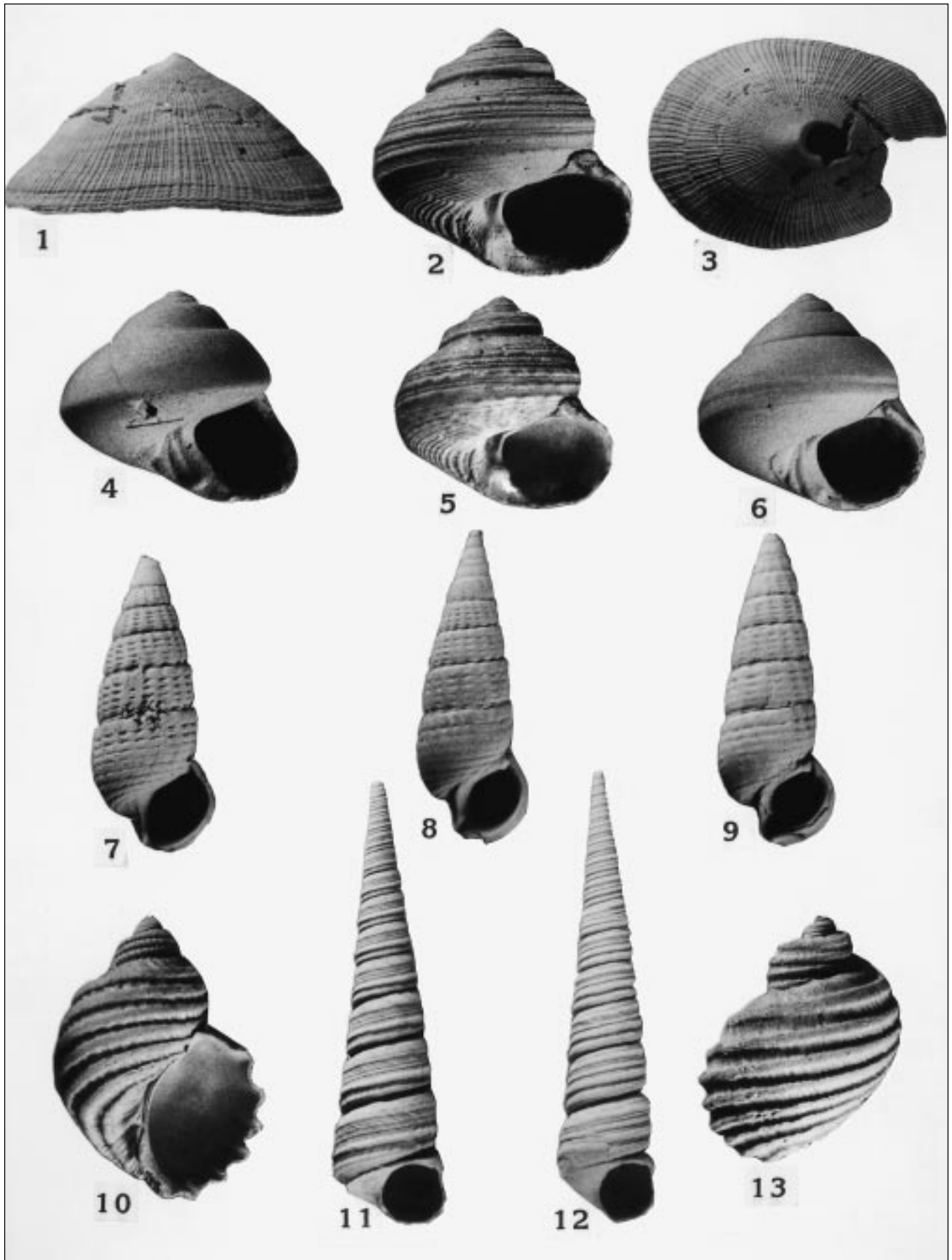


PLATE 2

1. *Turritella cumberlandia* Conrad
Apertural view of an immature specimen; VMNH I 544; ht. 23.3 mm; w. 9.9 mm.
- 2, 3. *Turritella tampae* Dall
 2. Apertural view; VMNH I 545; ht. 41.8 mm; w. 11.9 mm.
 3. Apertural view; VMNH I 546; ht. 77.0 mm; w. 21.9 mm.
4. *Turritella plebia* ssp.
Apertural view; VMNH I 547; ht. 24.4 mm; w. 5.7 mm.
5. *Serpulorbis granifera* (Say)
View of a number of individual with uncoiled whorls intertwined; VMNH I 548. One relatively regularly whorled specimen appears just above center. Height of illustrated specimen group 90.0 mm. Collected by G. Simonson.
- 6, 7. *Crepidula fornicata* Linné
 6. Dorsal view of specimen exhibiting exposed tube-burrows probably of the marine worm *Polydora*; VMNH I 549; ht. 47.9 mm; w. 35.0 mm.
 7. Dorsal view; VMNH I 550; ht. 46.0 mm; w. 33.1 mm.
- 8, 9. *Crepidula plana* Say
 8. Dorsal view of immature specimen; VMNH I 551; ht. 15.9 mm; w. 7.9 mm.
 9. Dorsal view; VMNH I 552; ht. 38.1 mm; w. 31.0 mm.
10. *Calyptraea centralis* (Conrad)
Dorsal view; VMNH I 553; ht. 9.7 mm; w. 21.9 mm.
- 11–15. *Calyptraea aperta* (Solander)
 11. Dorsal view of large specimen; VMNH I 554; ht. 21.0 mm; w. 41.7 mm.
 12. Apertural view of same specimen.
 13. Side view of same specimen.
 14. Dorsal view of incomplete specimen with strongly developed spines; VMNH I 555; ht. 18.0 mm.
 15. Side view of specimen with high spire; VMNH I 556; ht. 16.1 mm; w. 24.1 mm.

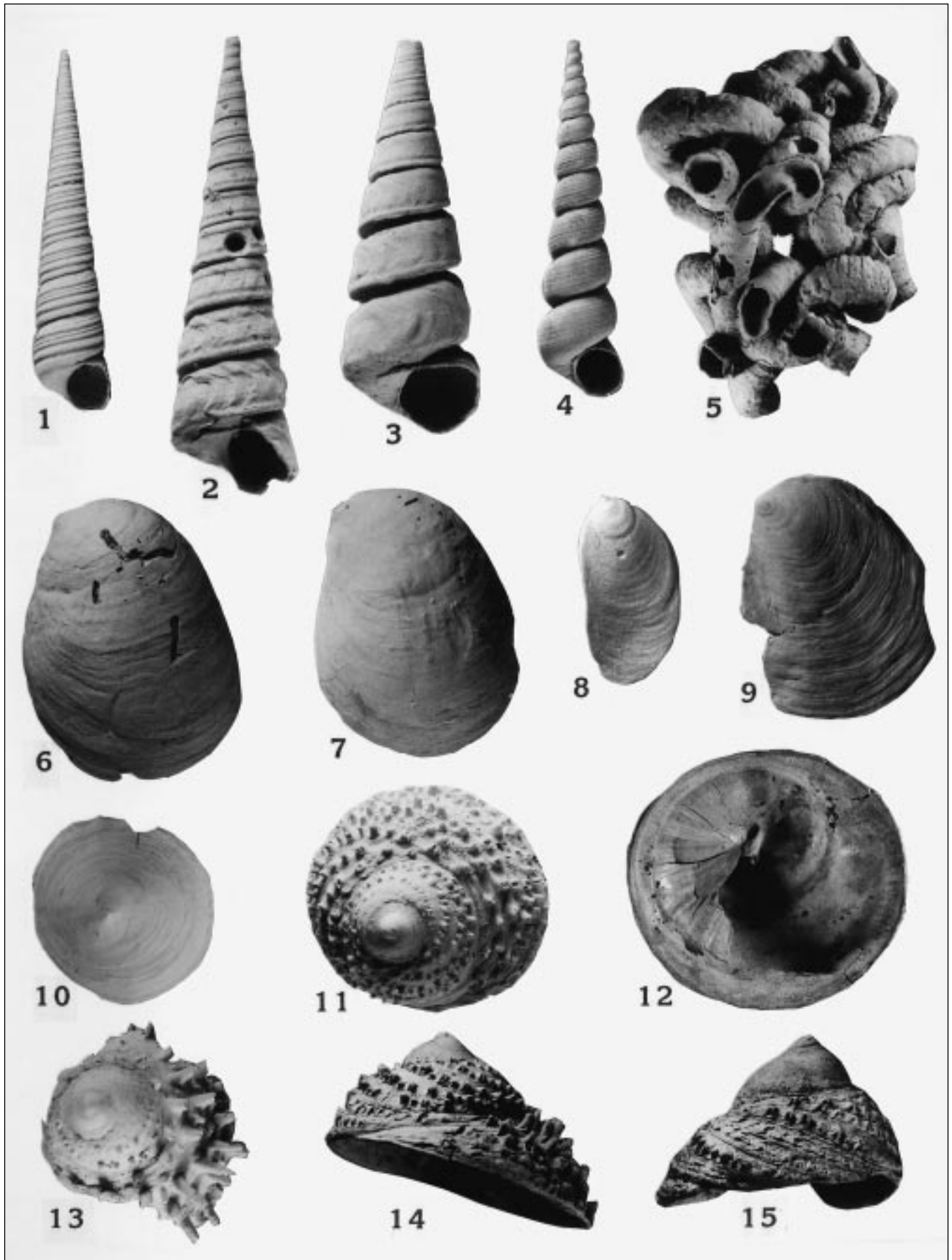


PLATE 3

- 1, 4. *Crucibulum costatum* (Say)
 1. Dorsal view of a weakly ribbed, incomplete, specimen; VMNH I 557; ht. 7.4 mm; w. 21.6 mm.
 4. Dorsal view of a strongly ribbed specimen; VMNH I 558; ht. 6.4 mm; w. 26.1 mm. Collected by G. Simonson.
- 2, 3. *Lunatia hemicrypta* (Gabb)
 2. Apertural view; VMNH I 559; ht. 4.0 mm; w. 3.3 mm.
 3. Apertural view; VMNH I 560; ht. 5.0 mm; w. 4.3 mm.
5. *Lunatia heros* (Say)

Apertural view; VMNH I 561; ht. 48.1 mm; w. 42.8 mm.
- 6, 9. *Sinum chesapeakensis* Campbell
 6. Dorsal view; VMNH I 562; ht. 20.4 mm; w. 18.6 mm.
 9. Apertural view of same specimen.
7. *Polinices duplicatus* (Say)

Apertural view; VMNH I 563; ht. 44.3 mm; w. 43.9 mm.
- 8, 10. *Ficus harrisi* (Martin)
 8. Apertural view of an incomplete specimen; VMNH I 564; ht. 19.5 mm; w. 18.1 mm.
 10. Dorsal view of same specimen.
11. *Epitonium charlestonensis* Johnson

Apertural view of a nearly complete specimen; VMNH I 565; ht. 31.1 mm; w. 17.5 mm.
12. *Murexiella cumberlandiana* (Gabb)

Apertural view; VMNH I 566; ht. 19.1 mm; w. 11.5 mm.
- 13, 14. *Urosalpinx subrusticus* (d'Orbigny)
 13. Apertural view; VMNH I 567; ht. 46.1 mm; w. 31.5 mm.
 14. Apertural view; VMNH I 568; ht. 28.8 mm; w. 16.0 mm.

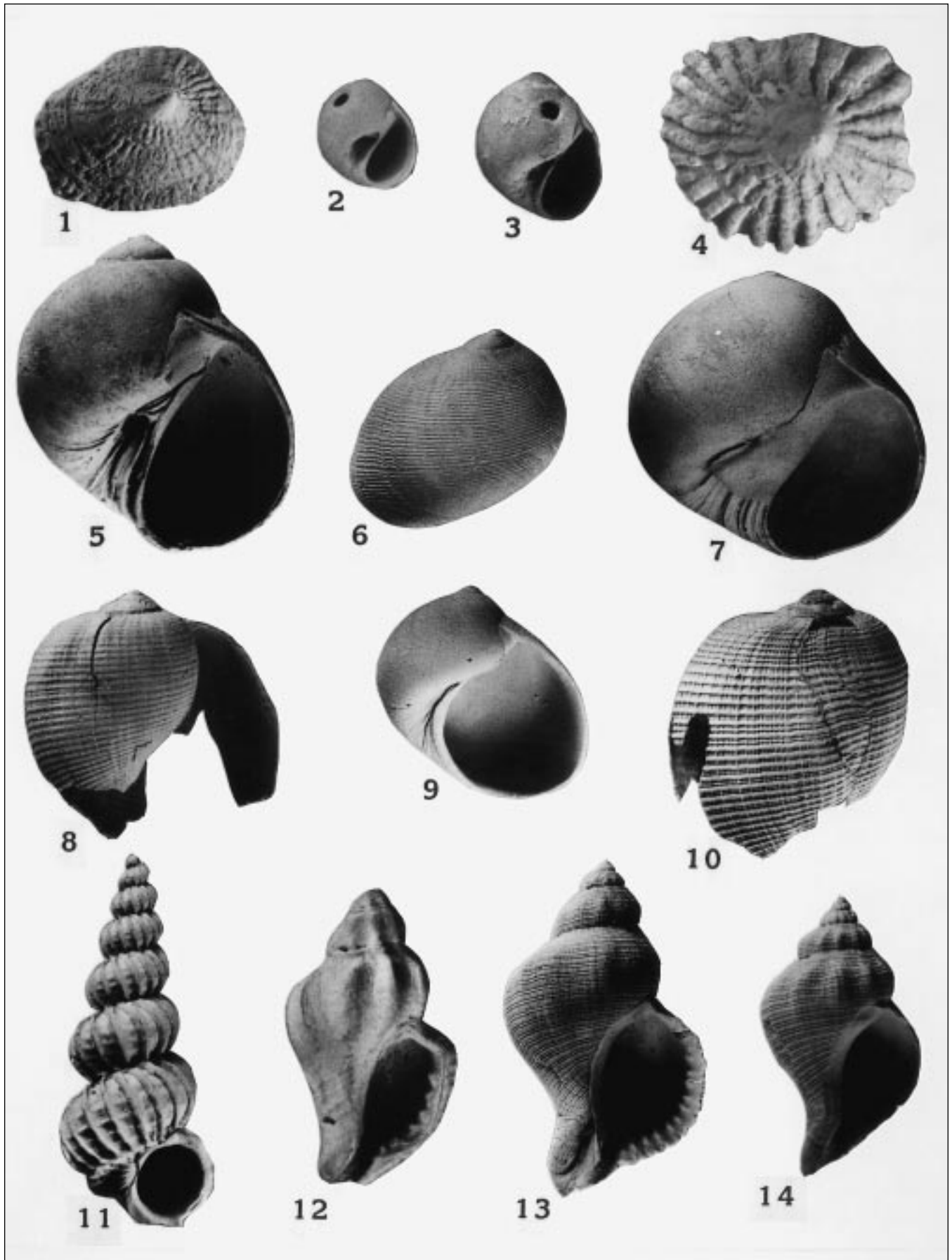


PLATE 4

1. *Typhis acuticosta* (Conrad)
Apertural view of an incomplete specimen; VMNH I 569; ht. 20.4 mm; w. 12.3 mm.
- 2–6. *Cymia woodi* (Gabb)
 2. Apertural view of specimen with strong shoulder and well-developed tubercles; VMNH I 570; ht. 28.8 mm; w. 18.2.
 3. Apertural view of specimen with moderately developed shoulder and weakly defined tubercles; VMNH I 571; ht. 28.2 mm; w. 14.9 mm.
 4. Apertural view of specimen with very weak shoulder and numerous, very weak tubercles; VMNH I 572; ht. 26.0 mm; w. 15.7 mm.
 5. Apertural view of specimen with smooth shoulder and finely reticulate sculpture; VMNH I 573; ht. 27.8 mm; w. 15.7 mm.
 6. Dorsal view of specimen with smooth shoulder and only spiral sculpture in the late whorls; VMNH I 574; ht. 34.5 mm; w. 21.5 mm. This specimen is close in appearance to Gabb's type.
7. *Tritonopsis ecclesiastica* (Dall)
Apertural view of an incomplete specimen; VMNH I 575; ht. 21.3 mm; w. 15.9 mm.
- 8–10. *Ecphora tricostata* Martin
 8. Apertural view; VMNH I 576; ht. 72.0 mm; w. 60.2 mm.
 9. Apertural view; VMNH I 577; ht. 54.4 mm; w. 40.7 mm.
 10. Dorsal view of same specimen.
11. *Chrysodomus patuxentensis* Martin
Apertural view; VMNH I 578; ht. 13.6 mm; w. 8.0 mm.

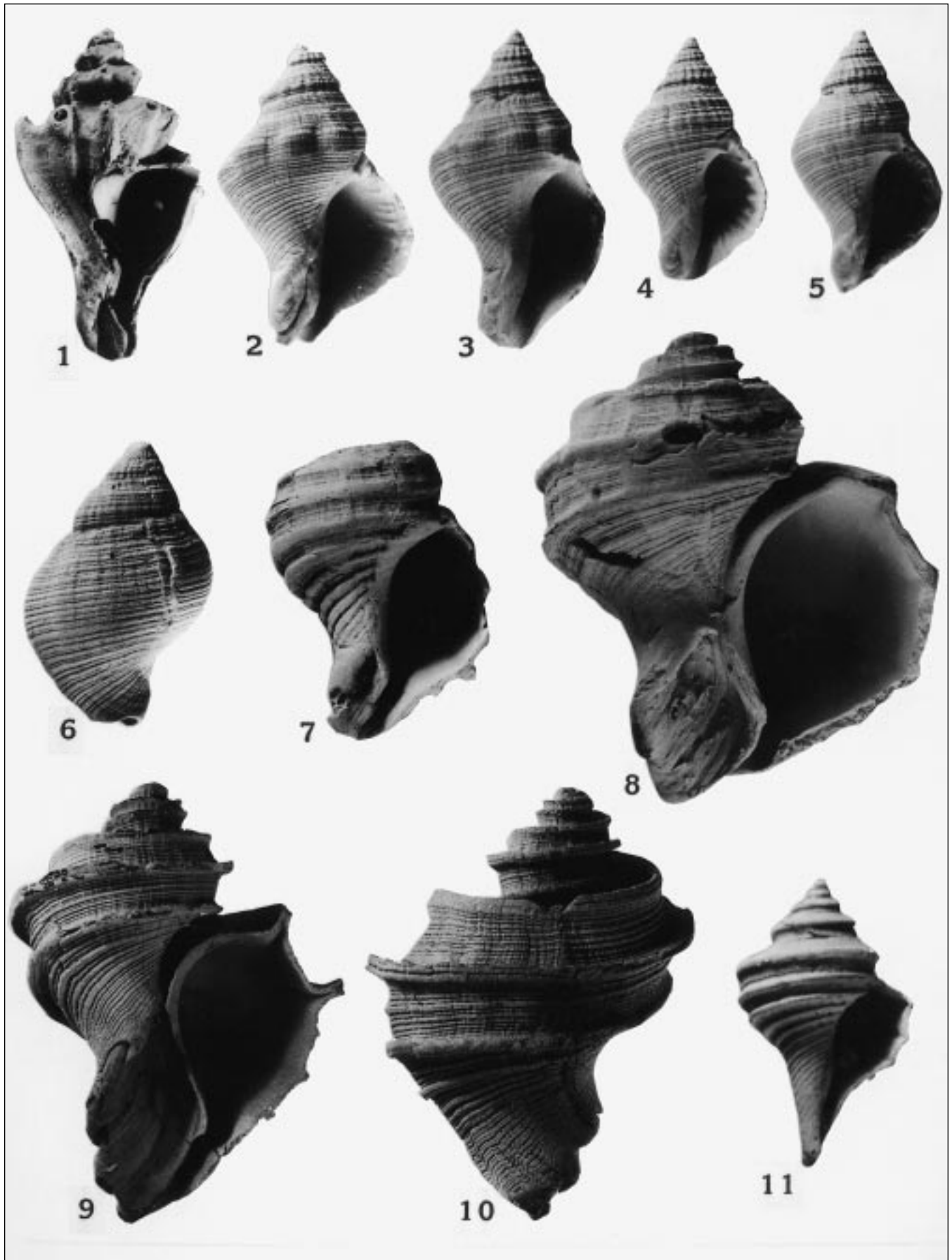


PLATE 5

1. *Siphonalia devexa* (Conrad)
Apertural view; VMNH I 579; ht. 55.6 mm; w. 24.0 mm.
2. *Nassarius trivitattoides elongata* (Whitfield)
Apertural view; VMNH I 580; ht. 11.0 mm; w. 4.5 mm.
3. *Nassarius trivitattoides* (Whitfield)
Apertural view; VMNH I 581; ht. 16.0 mm; w. 8.0 mm.
- 4–6. *Nassarius sopora* (Pilsbry and Harbison)
 4. Apertural view; VMNH I 582; ht. 12.1 mm; w. 6.8 mm.
 5. Apertural view; VMNH I 583; ht. 11.0 mm; w. 6.9 mm.
 6. Apertural view; VMNH I 584; ht. 10.0 mm; w. 5.6 mm.
- 7, 9. *Metula* sp.
 7. Apertural view; VMNH I 585; ht. 30.0 mm; w. 12.9 mm.
 9. Apertural view; VMNH I 586; ht. 34.9 mm; w. 16.1 mm.
- 8, 10. *Busycotypus scalarispira* (Conrad)
 8. Apertural view of specimen with high spire and strong tubercles; VMNH I 587; ht. 140.1 mm; w. 87.1 mm.
 10. Apertural view of specimen with high spire and strong tubercles along a persistent shoulder ridge; VMNH I 588; ht. 133.1 mm; w. 85.7 mm.

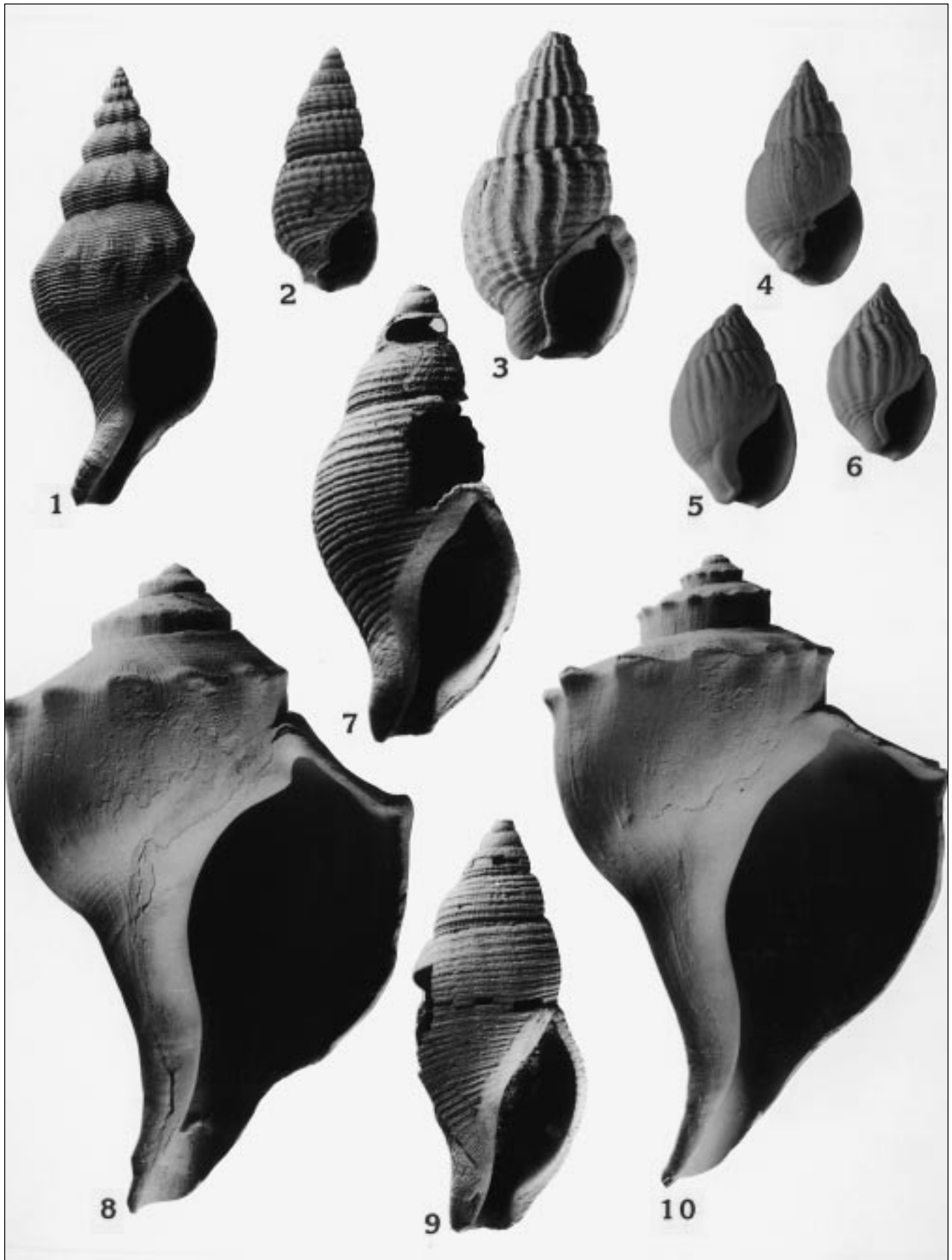


PLATE 6

- 1, 3, 4, 6. *Busycotypus scalarispira* (Conrad)
 1. Apertural view of specimen with low spire and moderately strong tubercles along a weaker shoulder; VMNH I 589; ht. 125.2 mm; w. 81.0 mm.
 3. Dorsal view of same specimen.
 4. Apertural view of specimen with low spire and weak tubercles becoming obsolete along a rounded shoulder; VMNH I 590; ht. 100.6 mm; w. 63.0 mm.
 6. Apertural view of specimen with low spire and devoid of tubercles on a rounded shoulder; VMNH I 591; ht. 70.6 mm; w. 44.4 mm.
2. *Scaphella virginiana* Dall
Apertural view; VMNH I 592; ht. 73.1 mm; w. 37.5 mm.
5. *Scaphella solitaria* (Conrad)
Apertural view; VMNH I 593; ht. 36.1 mm; w. 17.7 mm.

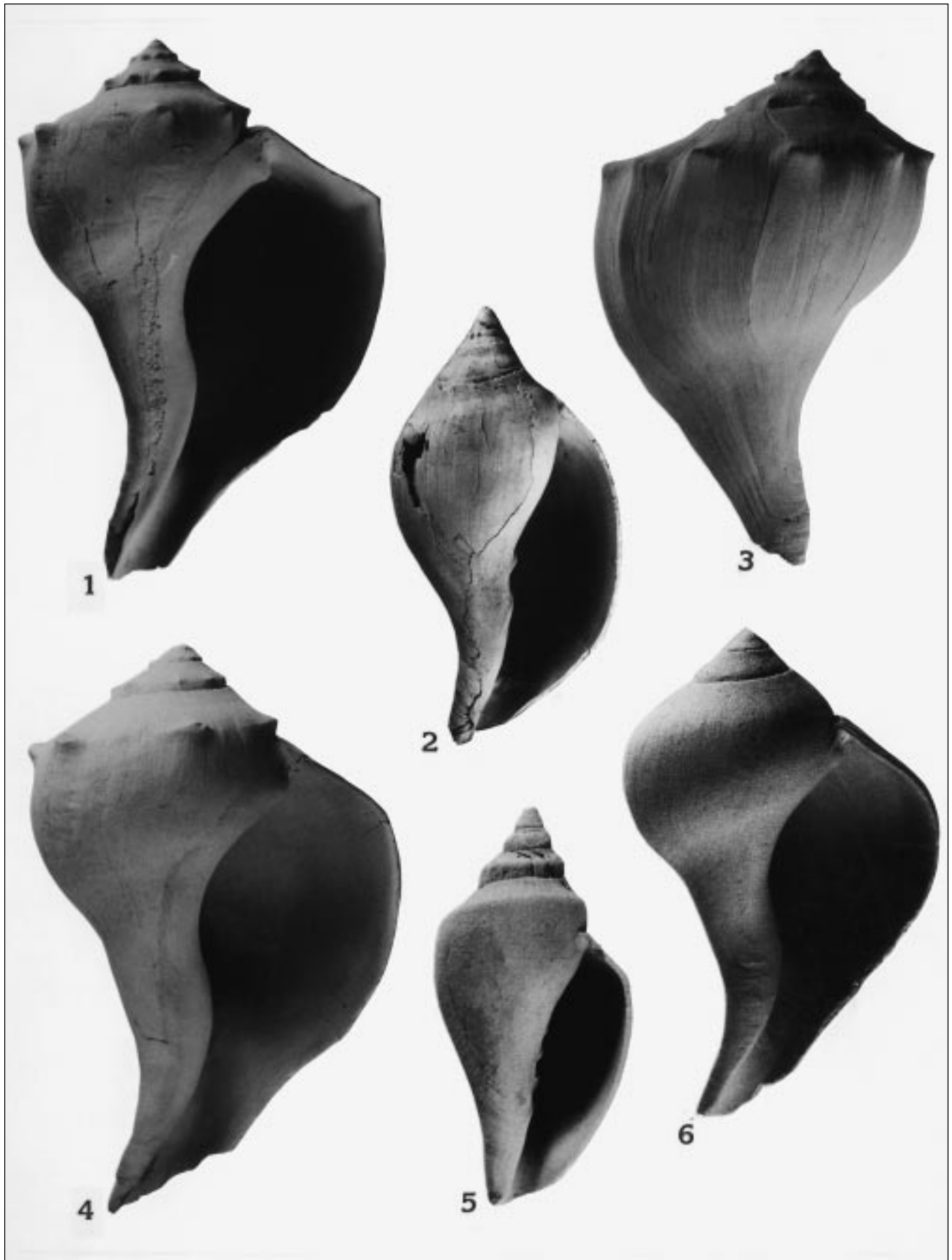


PLATE 7

- 1–3. *Oliva simonsoni* Ward, new species
 1. Apertural view; Paratype VMNH I 594; ht. 37.9 mm; w. 17.2 mm.
 2. Apertural view; Holotype VMNH I 595; ht. 36.8 mm; w. 17.9 mm.
 3. Dorsal view of holotype.
4. *Cancellaria alternata* Conrad
Apertural view; VMNH I 611; ht. 24.8 mm; w. 14.3 mm.
- 5–7. *Trigonostoma biplicifera* (Conrad)
 5. Apertural view; VMNH I 612; ht. 47.3 mm; w. 31.5 mm.
 6. Dorsal view of same specimen.
 7. Apertural view; VMNH I 613; ht. 31.2 mm; w. 22.5 mm.
8. *Cymatosyrinx limatula* (Conrad)
Apertural view; VMNH I 614; ht. 20.0 mm; w. 7.2 mm.
9. *Polystira communis* (Conrad)
Apertural view; VMNH I 615; ht. 28.0 mm; w. 9.5 mm.
- 10, 11. *Leucosyrinx rugata* (Conrad)
 10. Apertural view; VMNH I 616; ht. 30.1 mm; w. 12.1 mm.
 11. Apertural view; VMNH I 617; ht. 32.1 mm; w. 11.6 mm.
- 12, 13. *Inodrillia whitfieldi* (Martin)
 12. Apertural view; VMNH I 618; ht. 23.4 mm; w. 8.8 mm.
 13. Apertural view; VMNH I 619; ht. 23.0 mm; w. 8.6 mm.
14. *Terebra inornata* Whitfield
Apertural view; VMNH I 620; ht. 36.5 mm; w. 9.0 mm.

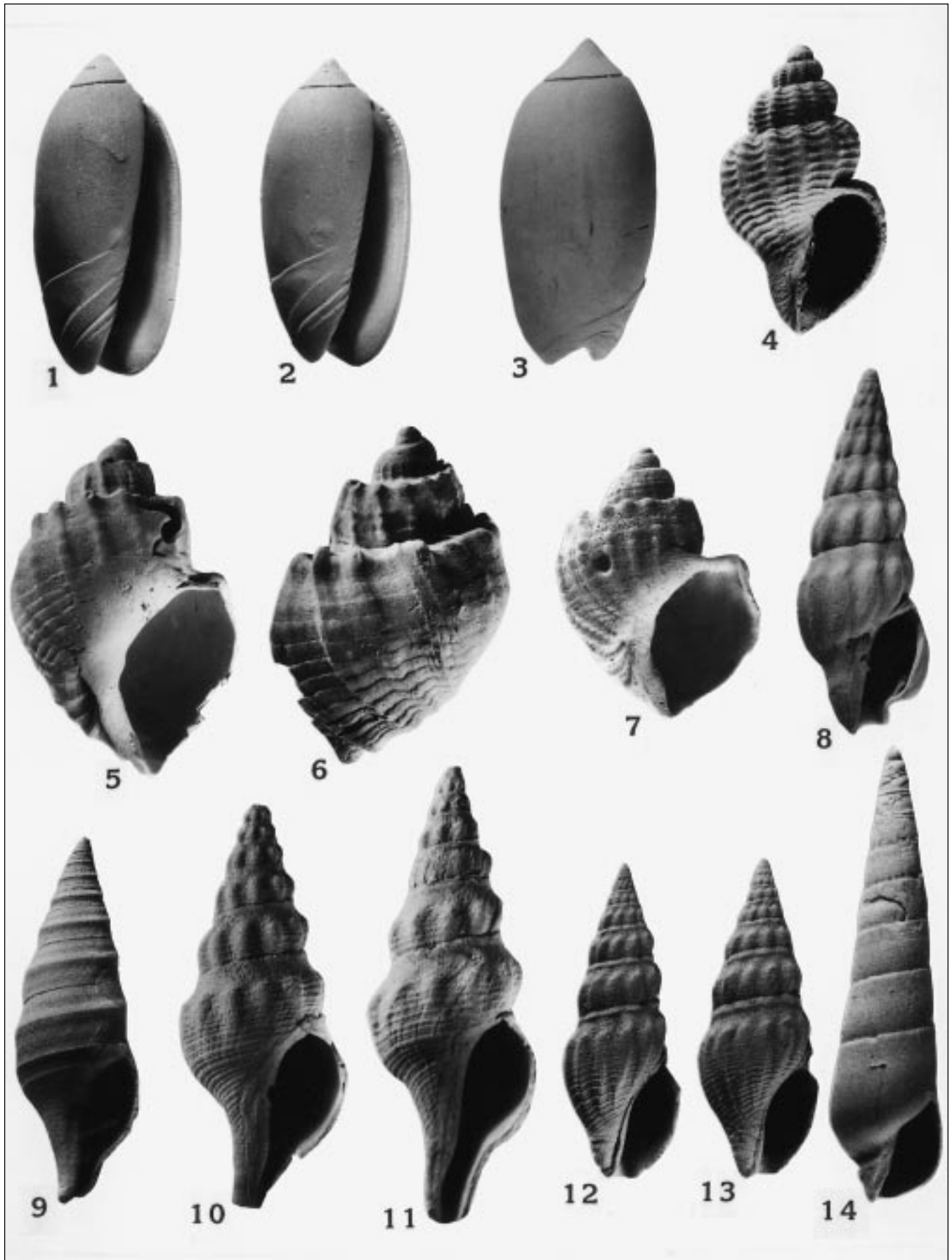


PLATE 8

- 1, 3. *Yoldia* sp.
 1. Exterior view right valve; VMNH I 621; ht. 18.5 mm; l. 42.0 mm.
 3. Interior view of the same specimen.
- 2, 4. *Yoldia* sp.
 2. Exterior view right valve; VMNH I 622; ht. 15.2 mm; l. 34.6 mm.
 4. Interior view of the same specimen.
- 5–7. *Dallarca* (?) *subrostrata*
 5. Exterior view left valve; VMNH I 623; ht. 39.1 mm; l. 52.0 mm. Collected by G. Simonson.
 6. Exterior view left valve; VMNH I 624; ht. 37.2 mm; l. 49.1 mm. Collected by G. Simonson.
 7. Exterior view left valve; VMNH I 625; ht. 33.5 mm; l. 44.9 mm.
- 8–10. *Dallarca* sp.
 8. Exterior view left valve; VMNH I 626; ht. 24.1 mm; l. 34.1 mm.
 9. Exterior view right valve; VMNH I 627; ht. 34.6 mm; l. 48.0 mm.
 10. Exterior view right valve; VMNH I 628; ht. 33.2 mm; l. 45.5 mm.

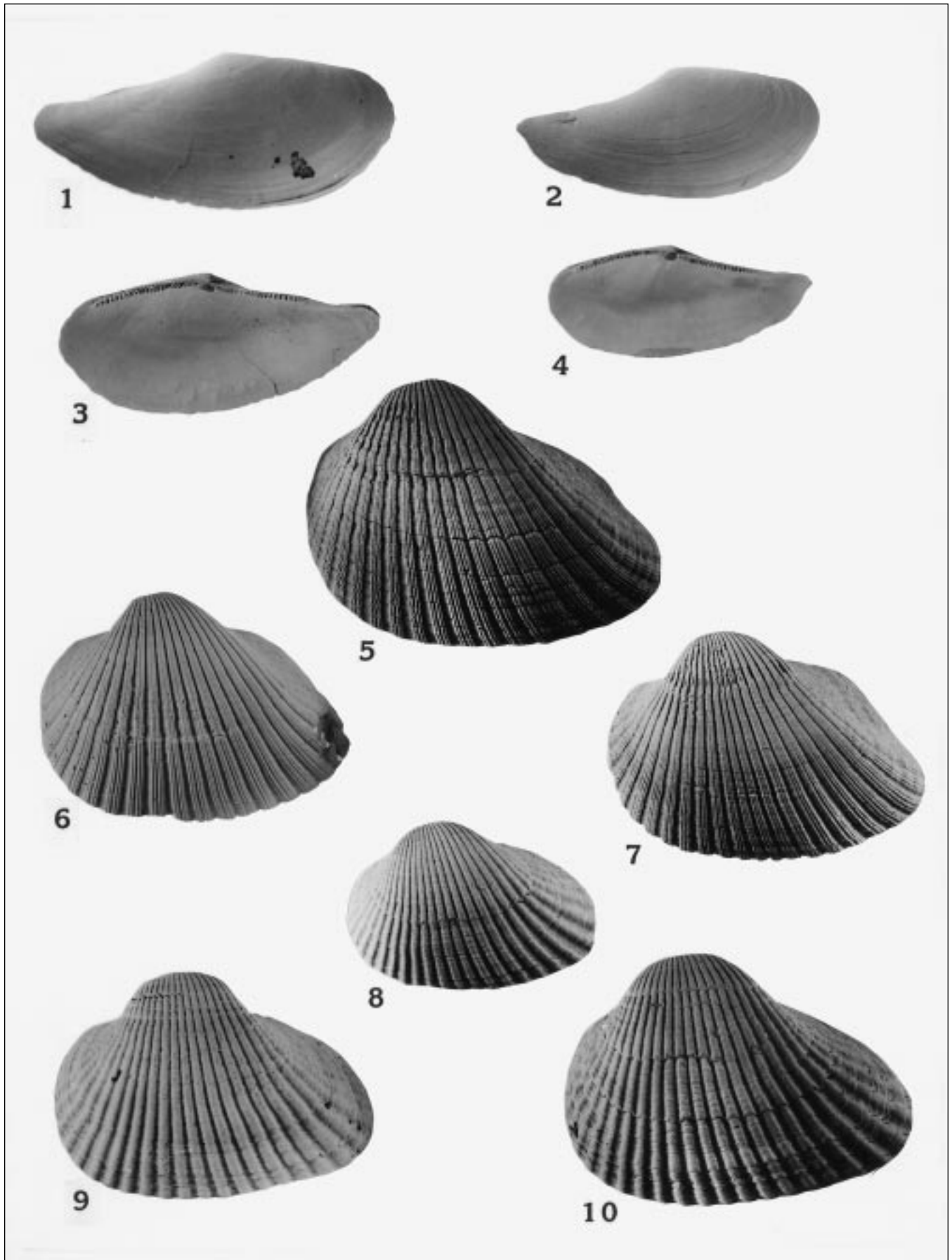


PLATE 9

1, 3. *Glycymeris parilis* (Conrad)

1. Exterior view left valve; VMNH I 629; ht. 75.1 mm; l. 74.3 mm.

3. Interior view of the same specimen.

2. *Modiolus ducatellii* Conrad

Exterior view incomplete left valve; VMNH I 630; l. 52.9 mm. Specimen was photographed uncoated to show characteristic brown discoloration of the shell due to its periostracum.

4, 5. *Mytilus (Mytiloconcha) incurva* Conrad

4. Exterior view left valve of a nearly complete specimen; VMNH I 631; l. 155.0 mm.

5. Exterior view incomplete right valve; VMNH I 632; l. 84.0 mm.

6, 8. *Isognomon (Hippochaeta)* sp.

6. Exterior view of a worn beak; VMNH I 633; ht. 63.2 mm.

8. Interior view of the same specimen.

7, 9. *Glycymeris parilis* (Conrad)

7. Exterior view right valve; VMNH I 634; ht. 44.7 mm; l. 46.0 mm. This specimen has fewer ribs than average specimens but in all other respects appears typical.

9. Interior view of the same specimen.

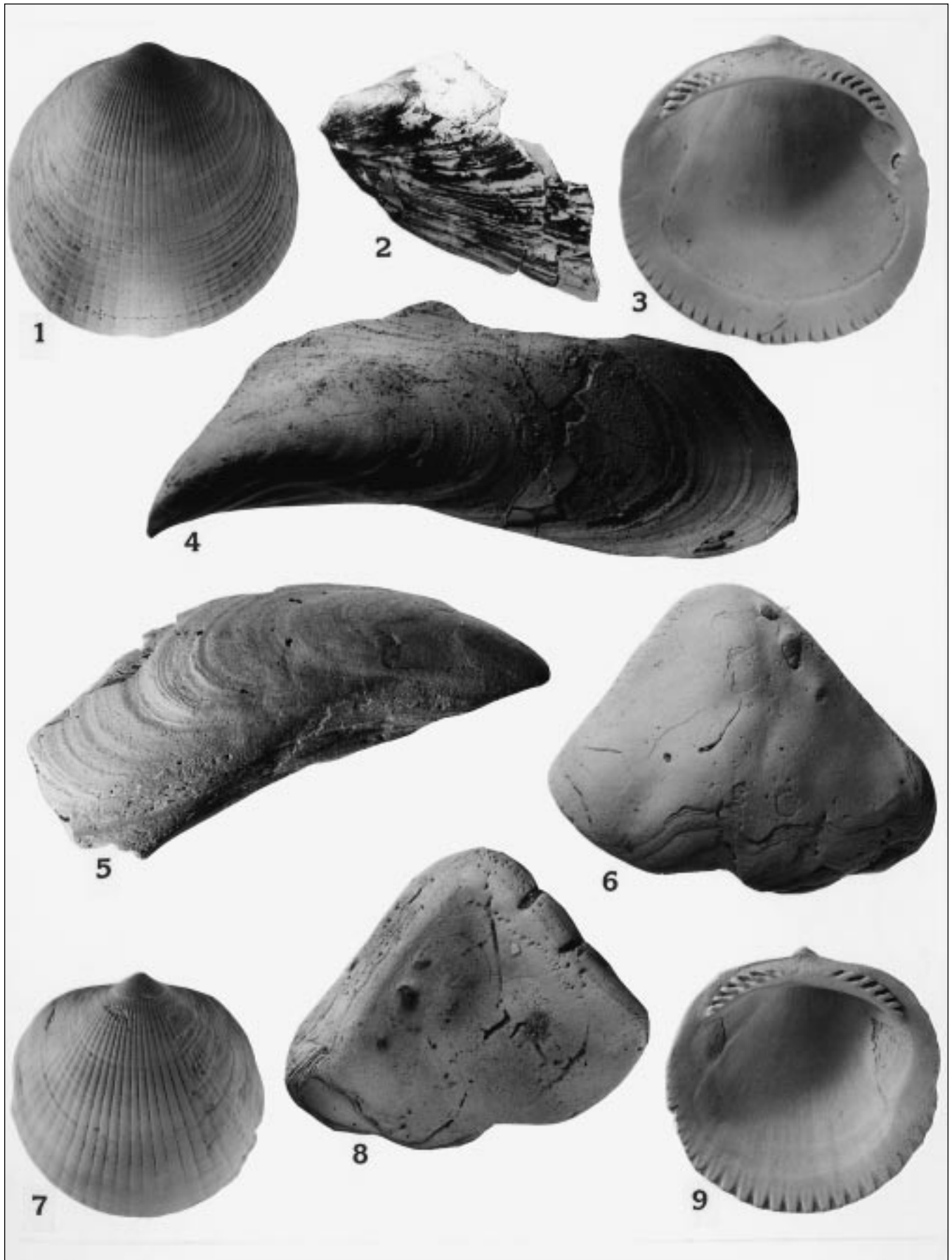


PLATE 10

- 1, 2. *Crassostrea virginica* (Gmelin)
 1. Exterior view right valve; VMNH I 635; ht. 142.0 mm; l. 53.0 mm.
 2. Exterior view left valve; VMNH I 636; ht. 183.9 mm; l. 53.0 mm.
- 3, 4. *Pecten humphreysii woolmani* Heilprin
 3. Exterior view incomplete right valve; VMNH I 637; ht. of fragment 53.8 mm. Collected by G. Simonson.
 4. Exterior view incomplete left valve; VMNH I 638; ht. of fragment 58.0 mm. Collected by G. Simonson.
- 5–8. *Crassostrea virginica* (Gmelin)
 5. Exterior view left valve; VMNH I 639; ht. 115.6 mm; l. 52.7 mm.
 6. Exterior view left valve; VMNH I 640; ht. 149.0 mm; l. 69.0 mm.
 7. Interior view right valve. The same specimen as figure 1.
 8. Interior view left valve. The same specimen as figure 6.

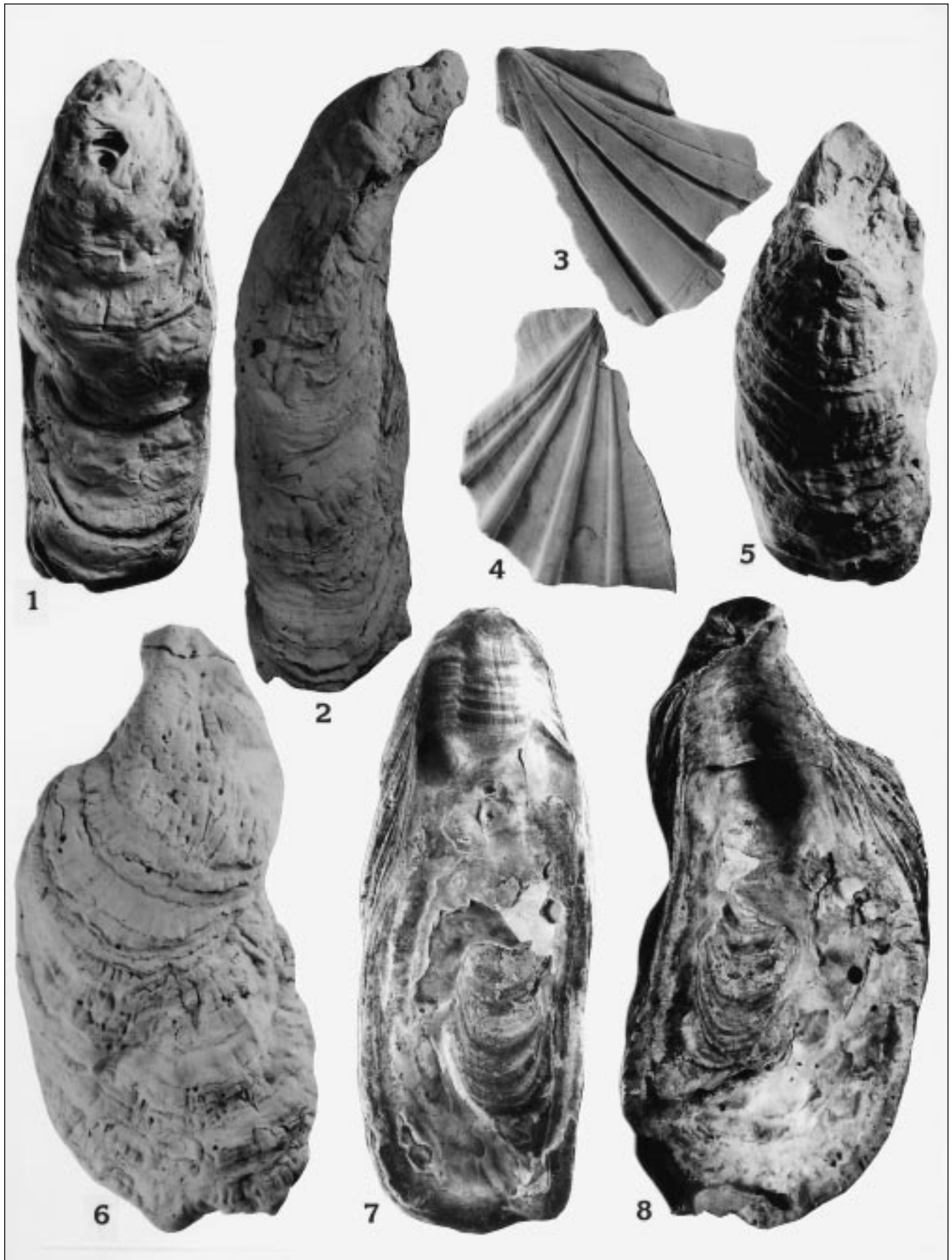


PLATE 11

- 1, 2. *Chesapecten coccymelus* (Dall)
 1. Exterior view left valve; VMNH I 641; ht. 43.4 mm; l. 41.0 mm.
 2. Exterior view right valve; VMNH I 642; ht. 44.3 mm; l. 44.0 mm.
- 3, 4. *Chesapecten sayanus* (Dall)
 3. Exterior view right valve; VMNH I 643; ht. 62.0 mm; l. 60.5 mm.
 4. Exterior view right valve; VMNH I 644; ht. 85.3 mm; l. 84.2 mm.
5. *Chesapecten sayanus* (Dall)

Exterior view right valve; VMNH I 645; ht. 116.7 mm; approximate l. 119.5 mm. Pungo River Formation (lower Miocene) at the Texas Gulf Sulphur phosphate mine, Aurora, N. C.
6. *Chesapecten coccymelus* (Dall)

Exterior view right valve; VMNH I 646; ht. 67.1 mm; l. 68.7 mm. Pungo River Formation (lower Miocene) at the Texas Gulf Sulphur phosphate mine, Aurora, N. C.

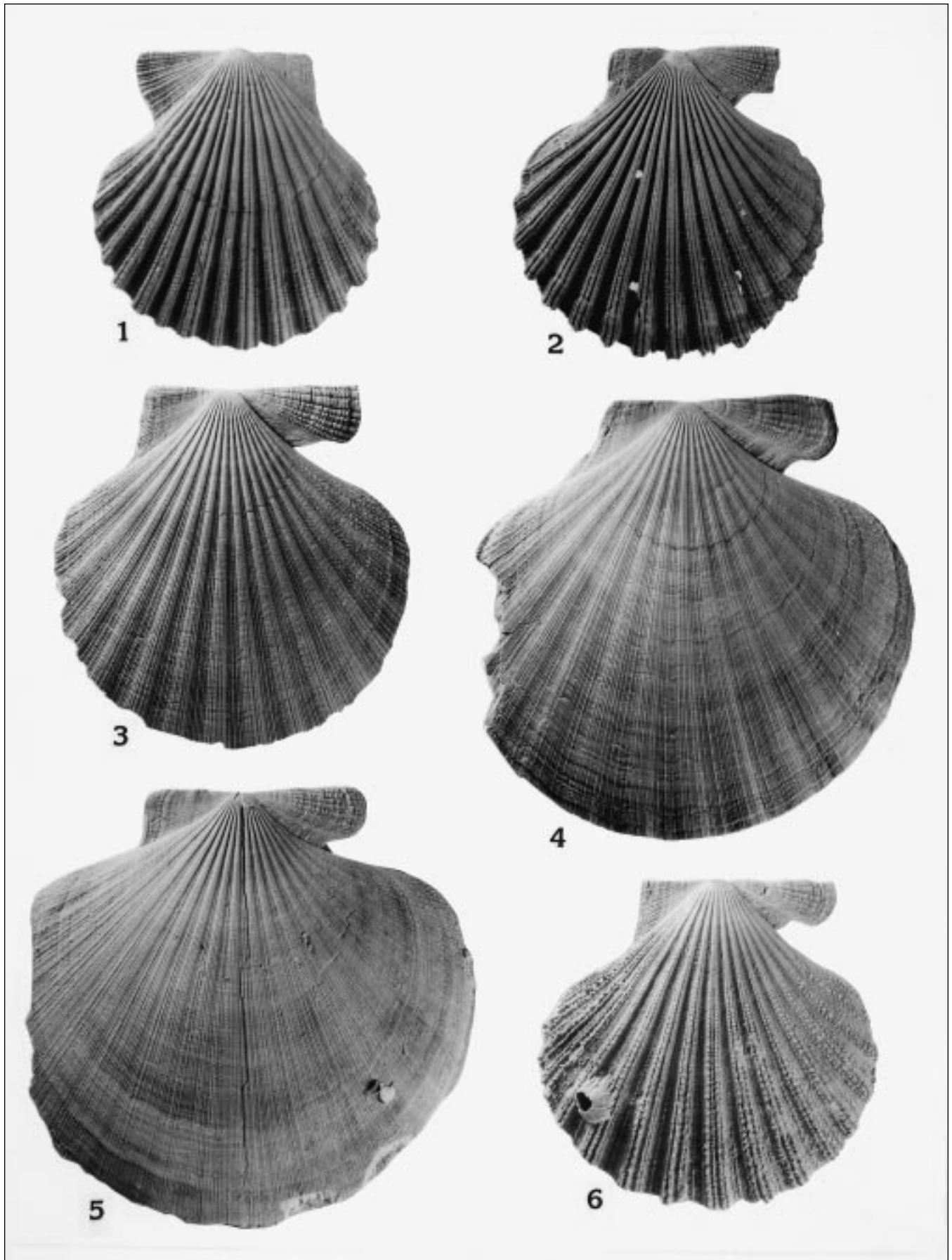


PLATE 12

1–3. *Stewartia anodonta* (Say)

1. Exterior view right valve; VMNH I 647; ht. 45.0 mm; l. 46.1 mm.
2. Interior view left valve; VMNH I 648; ht. 44.8 mm; l. 47.2 mm.
3. Exterior view of the same specimen.

4, 8, 9. *Carditamera aculeata* Conrad

4. Exterior view left valve; VMNH I 649; ht. 27.9 mm; l. 51.0 mm.
8. Interior view of the same specimen.
9. Exterior view right valve; VMNH I 650; ht. 31.1 mm; l. 53.9 mm.

5–7. *Parvalucina crenulata* (Conrad)

5. Exterior view right valve; VMNH I 651; ht. 5.1 mm; l. 5.1 mm.
6. Exterior view right valve; VMNH I 652; ht. 4.7 mm; l. 4.8 mm.
7. Exterior view left valve; VMNH I 653; ht. 4.2 mm; l. 4.6 mm.

10, 12. *Cyclocardia castrana* (Glenn)

10. Exterior view left valve; VMNH I 654; ht. 19.5 mm; l. 20.1 mm.
12. Interior view right valve; VMNH I 655; ht. 21.5 mm; l. 22.1 mm.

11, 13, 14. *Marvacrassatella melinus* (Conrad)

11. Exterior view right valve; VMNH I 656; ht. 40.1 mm; l. 61.2 mm.
13. Exterior view left valve; VMNH I 657; ht. 48.8 mm; l. 76.0 mm.
14. Interior view of the same specimen.

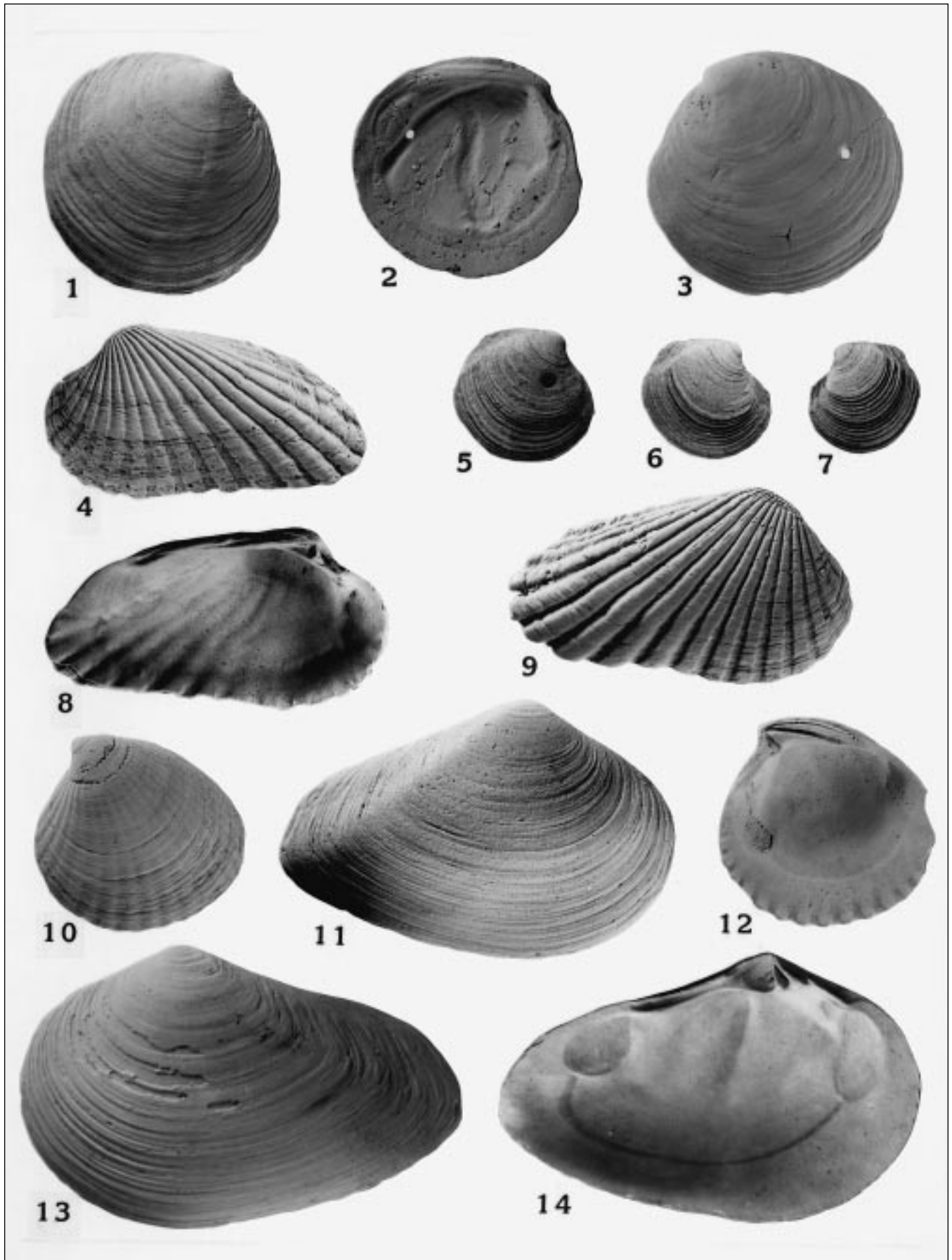


PLATE 13

- 1, 2. *Astarte distans* Conrad
 1. Exterior view left valve; VMNH I 658; ht. 24.0 mm; l. 29.6 mm. Specimen shows well-developed concentric undulations on exterior associated with higher energy, sandy matrix.
 2. Exterior view right valve; VMNH I 659; ht. 24.2 mm; l. 28.9 mm. Specimen with rugose sculpture as in figure 1.
- 3, 6. *Astarte* sp.
 3. Exterior view right valve; VMNH I 660; ht. 18.9 mm; l. 20.0 mm.
 6. Exterior view left valve; VMNH I 661; ht. 18.6 mm; l. 20.8 mm.
- 4, 5. *Astarte distans* Conrad
 4. Exterior view right valve; VMNH I 662; ht. 23.4 mm; l. 28.0 mm. Specimen shows the lower, more rounded, less rugose concentric sculpture associated with finer, more silty sands. Martin (1904) named this morphotype *Astarte castrana*. This specimen came from Bed a at the Pollack Farm Site.
 5. Exterior view left valve; VMNH I 663; ht. 27.0 mm; l. 30.8 mm. Specimen with subdued sculpture as in figure 4.
- 7, 8. *Dinocardium* sp.
 7. Exterior view left valve; VMNH I 664; ht. 63.0 mm; l. 65.3 mm. Collected by J. Beard.
 8. Interior view of the same specimen.
- 9, 11. "*Cardium*" *calvertensium* Glenn
 9. Exterior view left valve; VMNH I 665; ht. 20.4 mm; l. 21.5 mm.
 11. Exterior view left valve; VMNH I 666; ht. 17.0 mm; l. 18.8 mm.
10. *Chesacardium craticuloides* (Conrad)
Exterior view right valve; VMNH I 667; ht. 32.1 mm; l. 37.1 mm.

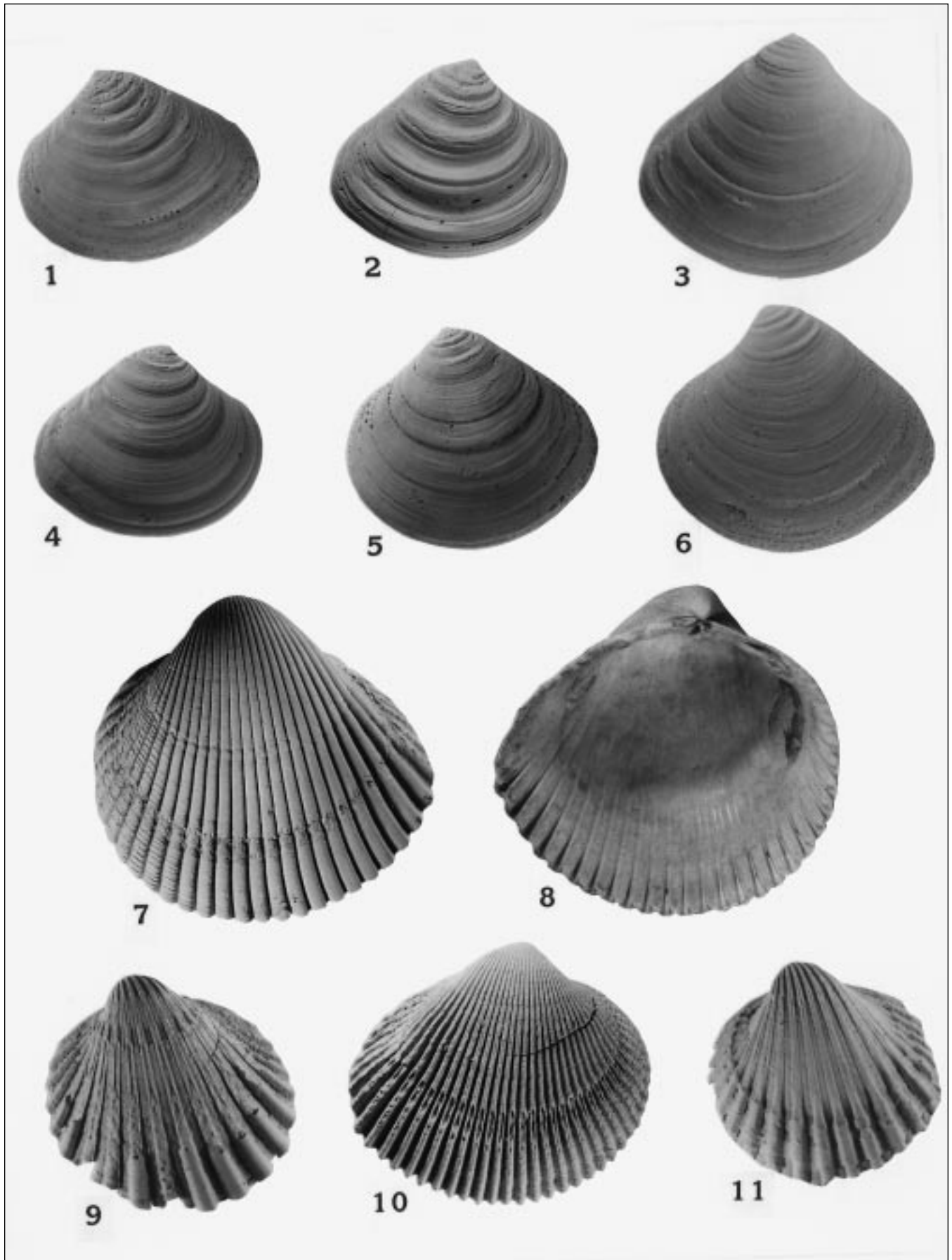


PLATE 14

- 1, 2. *Leptomactra marylandica* (Dall)
 1. Exterior view left valve; VMNH I 668; ht. 51.4 mm; l. 75.8 mm. Collected by G. Simonson.
 2. Interior view of the same specimen.
- 3–6. “*Mactra*” sp.
 3. Exterior view right valve; VMNH I 669; ht. 47.1 mm; l. 63.2 mm.
 4. Interior view of the same specimen.
 5. Exterior view left valve; VMNH I 670; ht. 40.4 mm; l. 63.1 mm.
 6. Interior view of the same specimen.
- 7, 8. *Ensis directus* Conrad
 7. Exterior view incomplete left valve; VMNH I 671; approximate ht. 8.0 mm; l. of fragment 32.6 mm.
 8. Interior view of the same specimen.
- 9–11. *Strigilla* sp.
 9. Exterior view left valve; VMNH I 672; ht. 16.6 mm; l. 17.0 mm.
 10. Interior view of the same specimen.
 11. Interior view right valve; VMNH I 673; ht. 17.0 mm; l. 17.5 mm.

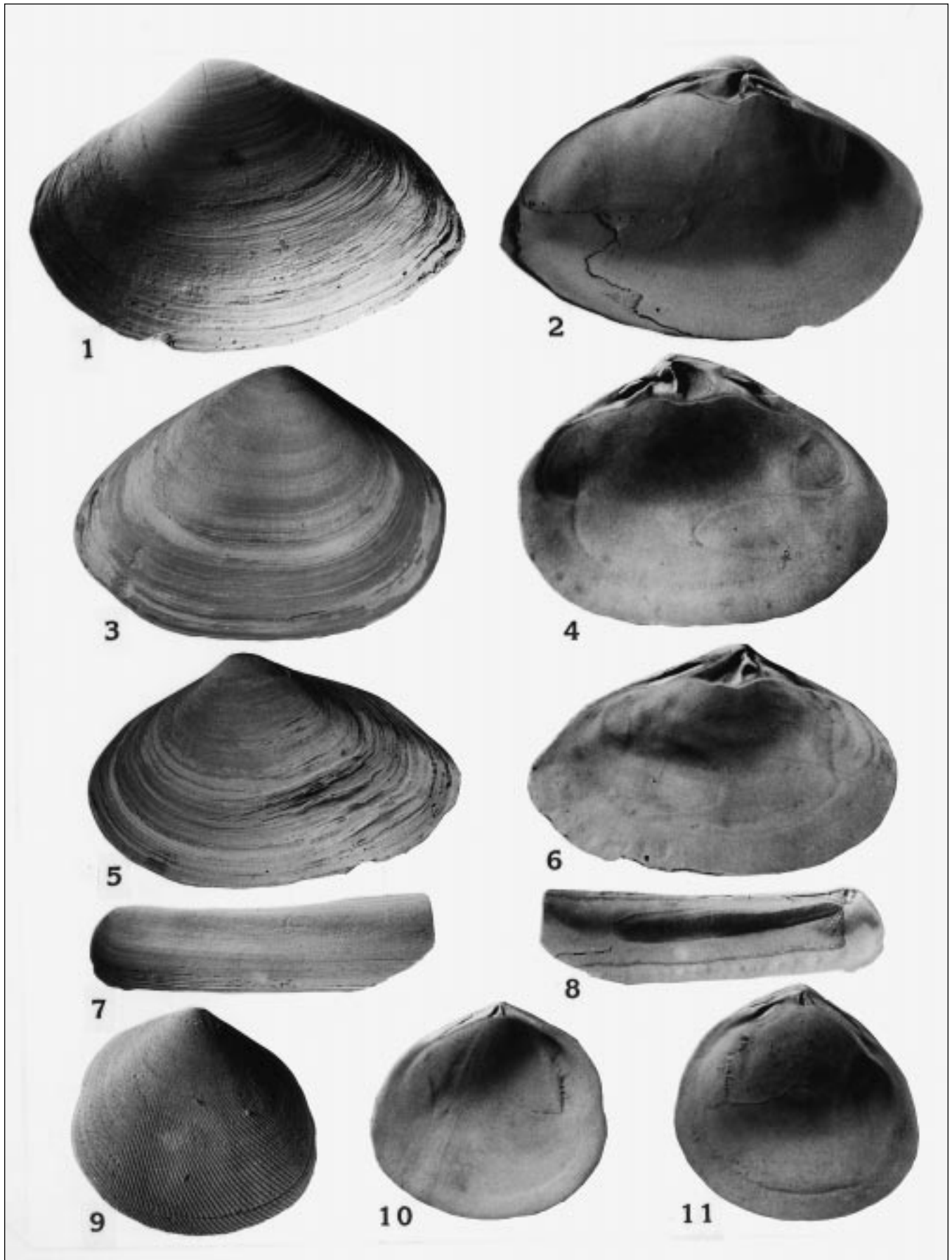


PLATE 15

1. *Florimetis biplicata* (Conrad)
Exterior view left valve; VMNH I 674; ht. 47.3 mm; l. 59.4 mm.
2. *Semele subovata* (Say)
Exterior view right valve; VMNH I 675; ht. 16.1 mm; l. 21.0 mm.
- 3, 5. *Tagelus plebeius* ssp.
3. Exterior view left valve; VMNH I 676; ht. 22.1 mm; l. 66.7 mm.
5. Interior view of the same specimen.
- 4, 6, 9. *Donax idoneus* ssp.
4. Exterior view left valve; VMNH I 677; ht. 17.5 mm; l. 29.9 mm.
6. Exterior view right valve; VMNH I 678; ht. 25.5 mm; l. 43.9 mm.
9. Exterior view right valve; VMNH I 679; ht. 26.8 mm; l. 43.1 mm.
- 7, 8, 10. *Iphigenia* sp.
7. Exterior view left valve; VMNH I 680; ht. 26.7 mm; l. 41.0 mm.
8. Interior view right valve; VMNH I 681; ht. 21.5 mm; l. 36.1 mm.
10. Exterior view of the same specimen.
- 11–14. *Donax* sp.
11. Interior view right valve; VMNH I 682; ht. 9.0 mm; l. 16.1 mm.
12. Exterior view left valve; VMNH I 683; ht. 10.2 mm; l. 18.5 mm.
13. Interior view left valve. The same specimen as figure 12.
14. Exterior view right valve. The same specimen as figure 11.

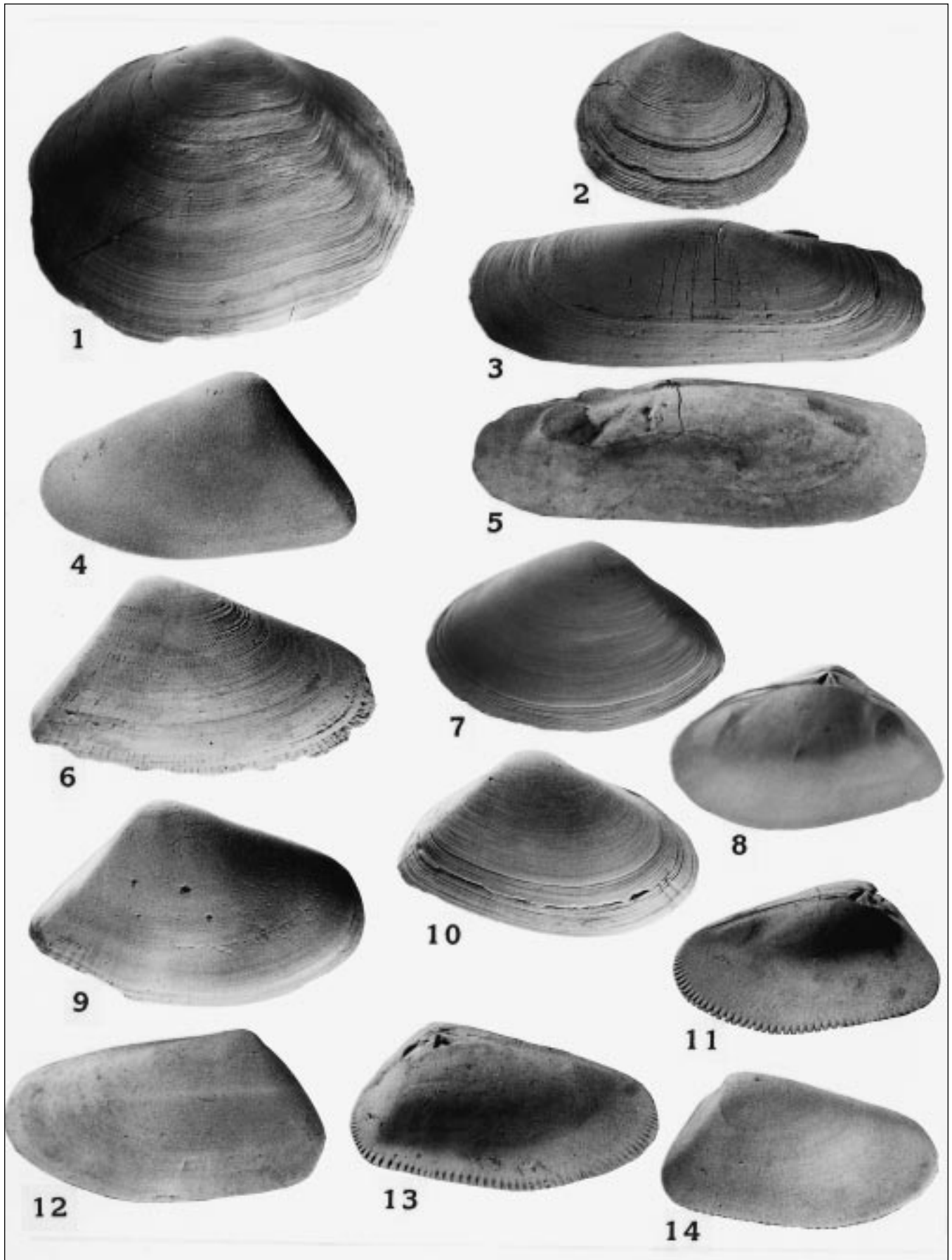


PLATE 16

1–3. *Mytilopsis erimiocenicus* Vokes

1. Exterior view right valve; VMNH I 684; approximate ht. 10.5 mm; l. 26.1 mm.
2. Interior view right valve; VMNH I 685; ht. 9.3 mm; l. 18.9 mm.
3. Exterior view left valve; VMNH I 686; ht. 9.0 mm; l. 21.1 mm.

4. *Glossus* sp.

Exterior view right valve; VMNH I 687; ht. 34.9 mm; l. 45.0 mm.

5, 6. *Lirophora latilirata* (Conrad)

5. Exterior view right valve; VMNH I 688; ht. 16.0 mm; l. 18.0 mm.
6. Exterior view left valve; VMNH I 689; ht. 16.2 mm; l. 18.9 mm.

7, 8. *Mercenaria ducatellii* (Conrad)

7. Exterior view right valve; VMNH I 690; ht. 65.0 mm; l. 81.0 mm.
8. Exterior view left valve; VMNH I 691; ht. 78.0 mm; l. 96.7 mm.

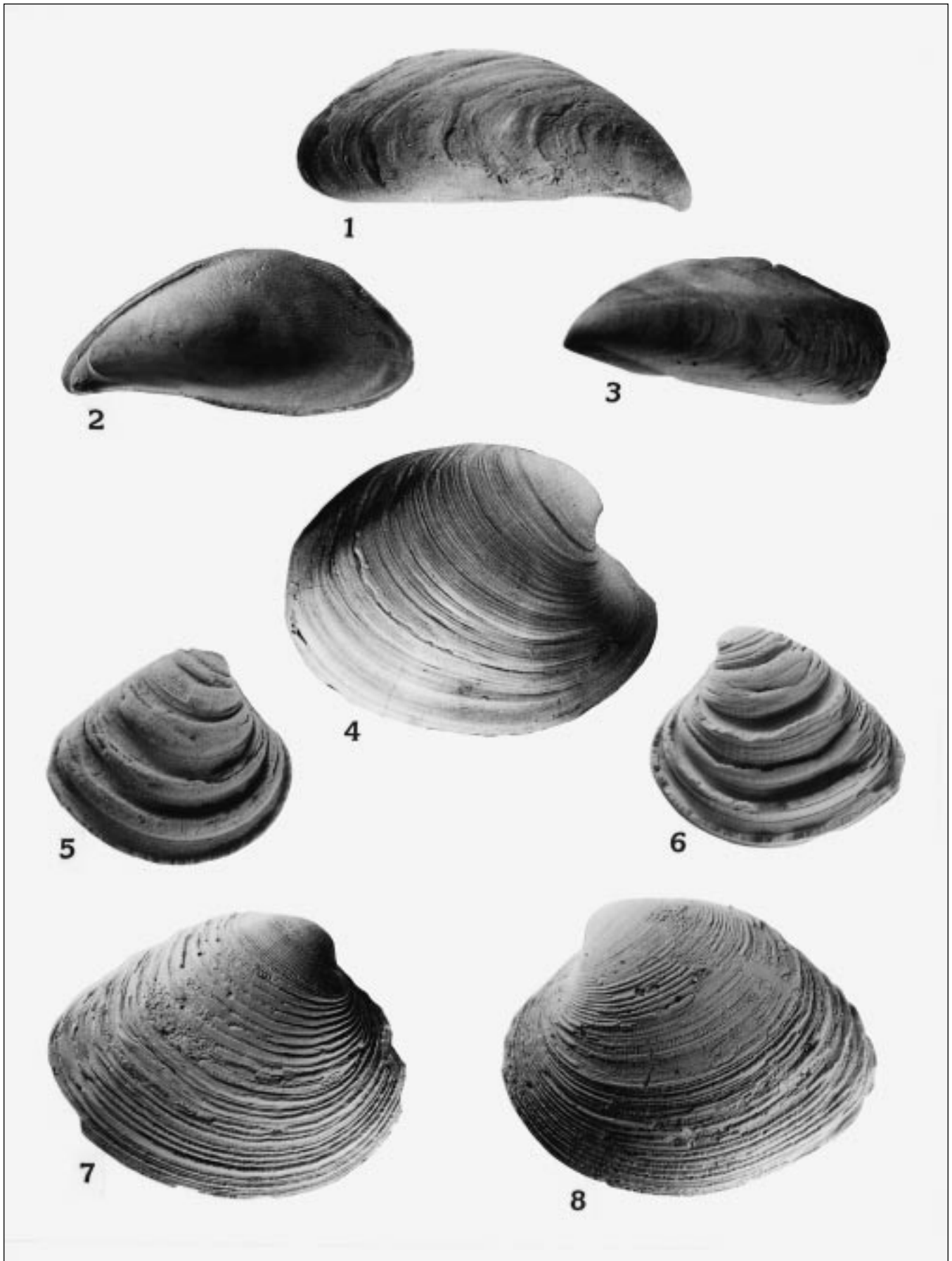


PLATE 17

- 1-3. *Mercenaria ducatellii* (Conrad)
 1. Exterior view right valve; VMNH I 692; ht. 76.6 mm; l. 93.5 mm. *Martesia* are visible in several of the holes bored into the shell.
 2. Interior view right valve; VMNH I 690; ht. 65.0 mm; l. 81.0 mm.
 3. Exterior view right valve; VMNH I 693; ht. 44.1 mm; l. 52.9 mm.
4. *Dosinia acetabulum blackwelderi* Ward
Exterior view right valve; VMNH I 694; ht. 58.1 mm; l. 57.8 mm.
- 5-7. *Macrocallista marylandica* (Conrad)
 5. Interior view right valve; VMNH I 695; ht. 54.0 mm; l. 78.5 mm.
 6. Exterior view left valve; VMNH I 696; ht. 40.0 mm; l. 51.2 mm.
 7. Exterior view right valve; VMNH I 697; ht. 57.1 mm; l. 82.5 mm.

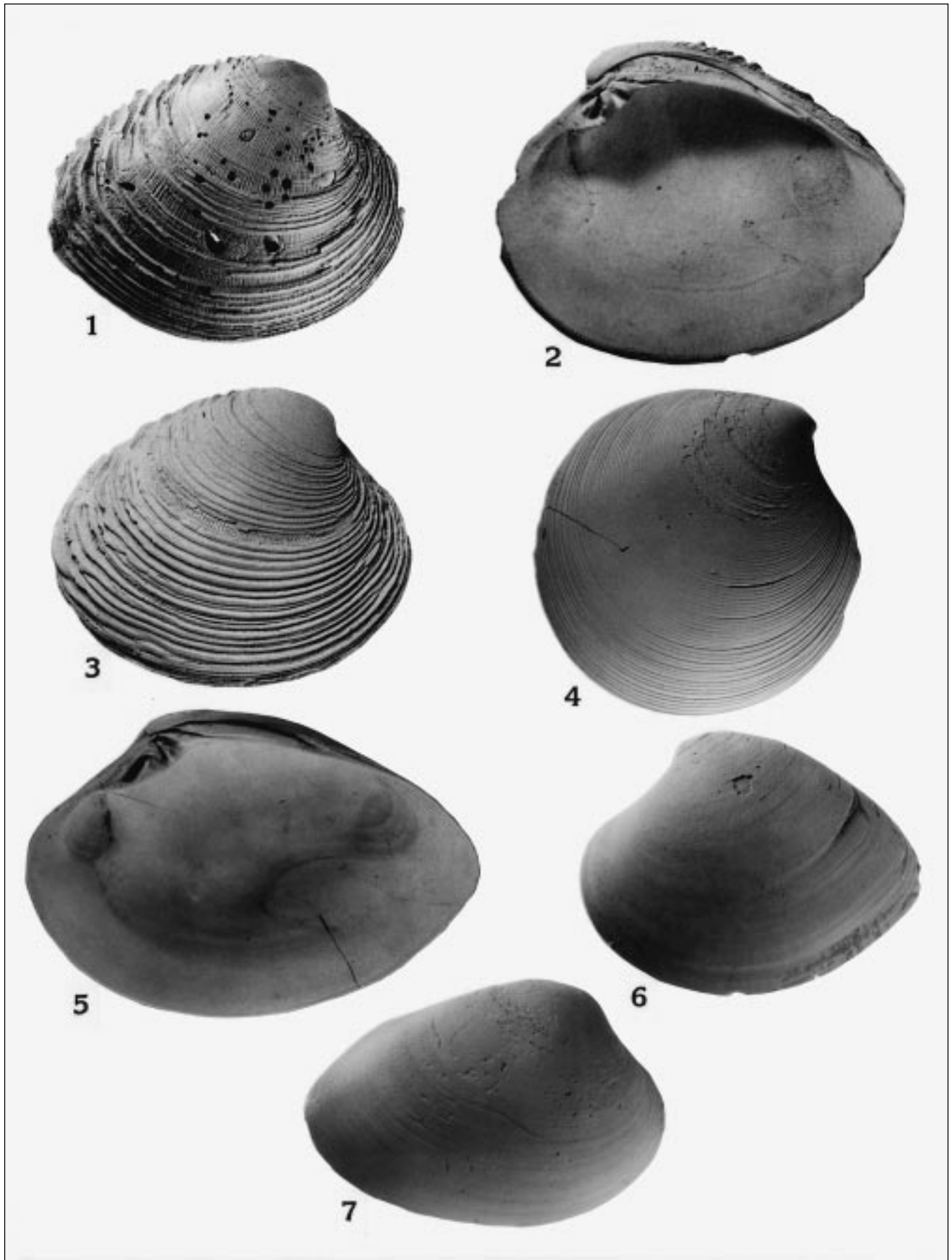


PLATE 18

- 1, 4. *Clementia grayi* Dall
 1. Exterior view left valve of a paired individual; VMNH I 698; ht. 56.5 mm; l. 62.9 mm.
 4. Exterior view of beak of a left valve; VMNH I 699; l. of fragment 42.0 mm. Most of the specimens from the Pollack Farm Site are fragmentary, consisting mainly of the hinge area. They look very similar to one found at Shiloh, New Jersey and illustrated by Richards and Harbison (1942, p. 175, fig. 4).
- 2, 5. *Mya producta* Conrad
 2. Exterior view right valve; VMNH I 700; ht. 52.5 mm; l. 102.0 mm.
 5. Exterior view left valve; VMNH I 701; ht. 36.1 mm; l. 76.0 mm. Collected by G. Simonson.
- 3, 6. *Caryocorbula subcontracta* (Whitfield)
 3. Exterior view right valve; VMNH I 702; ht. 4.9 mm; l. 6.1 mm.
 6. Interior view right valve; VMNH I 703; ht. 4.7 mm; l. 6.0 mm.
- 7, 8, 10, 11. *Bicorbula idonea* (Conrad)
 7. Exterior view right valve; VMNH I 704; ht. 25.8 mm; l. 30.0 mm.
 8. Exterior view left valve; VMNH I 705; ht. 17.9 mm; l. 23.8 mm.
 10. Interior view right valve. The same specimen as figure 7.
 11. Interior view left valve. The same specimen as figure 8.
- 9, 12. *Varicorbula elevata* (Conrad)
 9. Exterior view right valve; VMNH I 706; ht. 8.9 mm; l. 8.8 mm.
 12. Interior view of the same specimen.
- 13, 14. *Caryocorbula cuneata* (Say)
 13. Exterior view left valve; VMNH I 707; ht. 5.5 mm; l. 9.5 mm.
 14. Interior view left valve; VMNH I 708; ht. 5.7 mm; l. 9.5 mm.
15. *Panopea whitfieldi* Dall
Exterior view right valve of a paired individual; VMNH I 709; ht. 53.1 mm; l. 95.5 mm. This specimen was found in living position in Bed a. Collected by J. Beard.
16. *Panopea americana* Conrad
Exterior view incomplete right valve; VMNH I 710; ht. 77.5 mm; l. of fragment 115.0 mm.

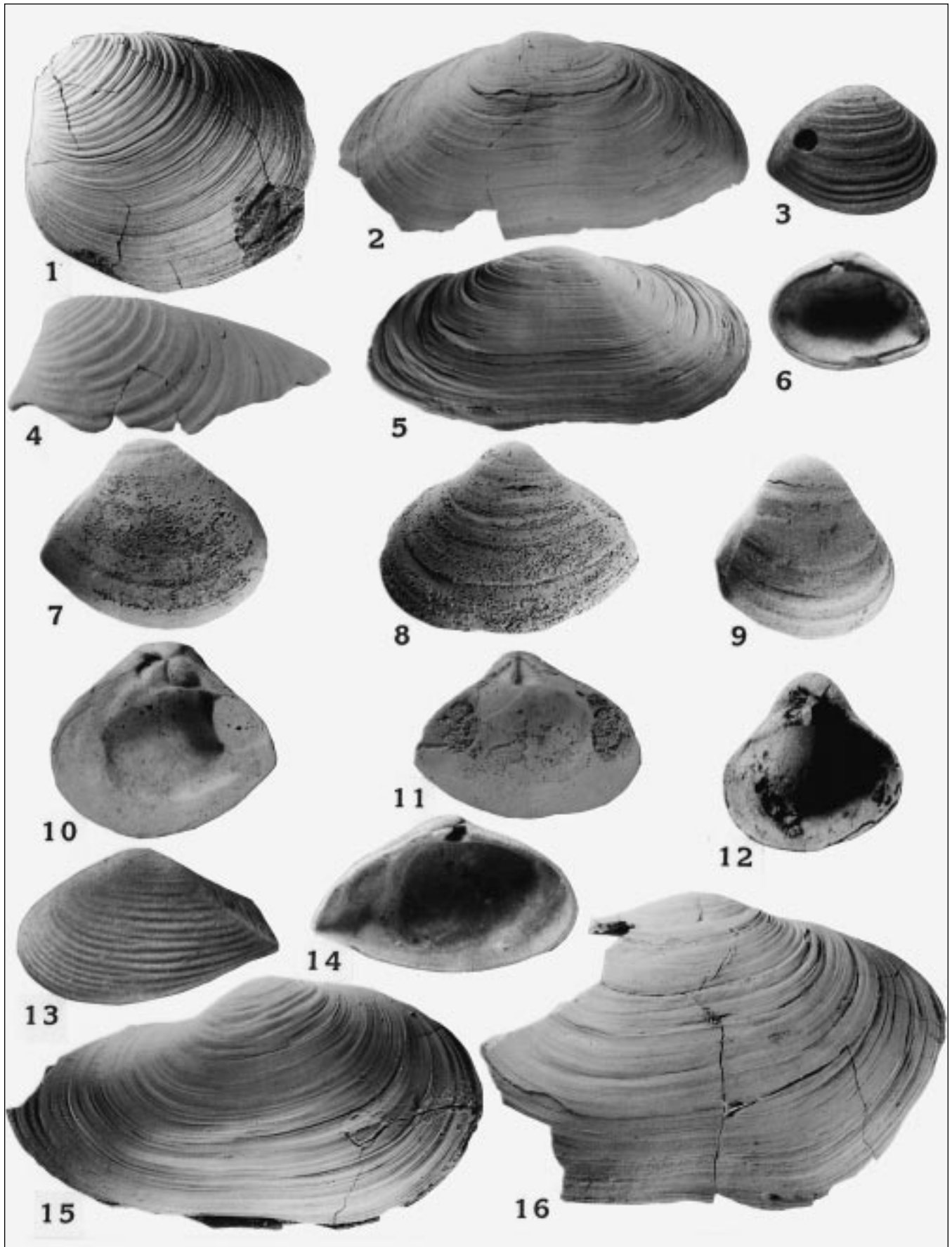
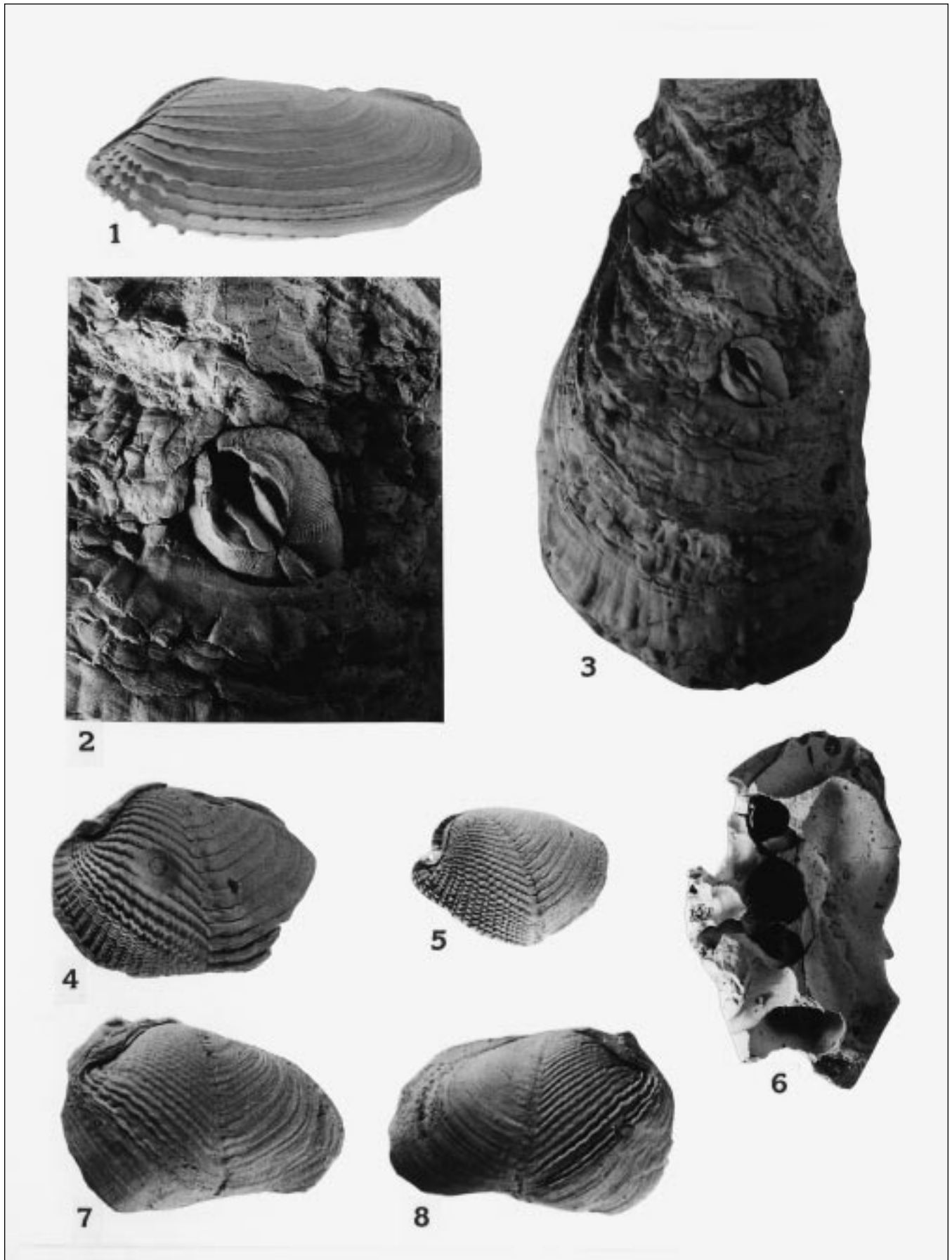


PLATE 19

1. *Thovana* sp.
Exterior view left valve; VMNH I 711; ht. 10.7 mm; l. 25.9 mm.
- 2–8. *Martesia ovalis* (Say)
 2. Exposed hinge of a complete specimen in place in a boring into *Crassostrea virginica*; VMNH I 712. Length of specimen as exposed in boring 22.7 mm.
 3. Close-up view of same specimen in figure 2.
 4. Exterior view incomplete left valve; VMNH I 713; ht. 13.0 mm; l. 18.0 mm.
 5. Exterior view left valve; VMNH I 714; ht. 7.4 mm; l. 9.5 mm.
 6. *Martesia ovalis* borings into a broken *Mercenaria* shell; VMNH I 715. Some valves still remain in place. The heavy infestation probably contributed to the destruction of the host shell. Length of shell fragment 53 mm.
 7. Exterior view left valve; VMNH I 716; ht. 9.5 mm; l. 13.7 mm.
 8. Exterior view right valve; VMNH I 716; ht. 10.0 mm; l. 14.6 mm.



THE EARLY MIOCENE FISH FAUNA FROM THE POLLACK FARM SITE, DELAWARE¹

Robert W. Purdy²

INTRODUCTION

The Pollack Farm Site, a large borrow pit excavated during 1991–1992 for highway construction near Cheswold, Delaware, exposed two stratigraphically separated shelly beds of the Cheswold sands of the lower Miocene Calvert Formation. The lower shell bed was bulk sampled, yielding 30 fossil fish taxa, consisting of 24 cartilaginous and 6 bony fishes. This fauna is almost identical to those found in sediments of equivalent age to the south of Delaware; it suggests that deposition occurred in a subtropical, shallow-water, nearshore environment.

Acknowledgments

I thank Michael D. Gottfried and David J. Bohaska who reviewed this manuscript and Shelton P. Applegate who reviewed my identifications of the sharks.

FAUNAL ASSEMBLAGE

With the exception of the relative abundances of the taxa as given in the list that follows, the Pollack Farm fish fauna is identical to those of the Calvert and Pungo River formations of Maryland and North Carolina, respectively. Unlike the more southern fossil fish faunas, bony fish remains, with the exception of juvenile *Pogonias* teeth, are uncommon. No new species were found.

Except for *Carcharhinus limbatus*, *Dasyatis* sp., *?Raja* sp., *Lepisosteus* sp., and *Lagodon* sp., the Pollack Farm fish taxa are illustrated in Plates 1 and 2. The taxa are being described more fully in a paper by Purdy et al. (in press) on the fossil fishes of the Pungo River and Yorktown Formations from the Lee Creek Mine, Aurora, North Carolina.

Chondrichthyes

<i>Notorynchus</i> sp.	Uncommon
<i>Squalus</i> sp.	Rare
<i>Squatina</i> sp.	Rare
Orectolobid	Rare
<i>Rhincodon</i> sp.	Rare
<i>Carcharias cuspidata</i> (Agassiz)	Common
<i>Carcharodon subauriculatus</i> (Agassiz)	Rare
<i>Isurus hastalis</i> (Agassiz)	Uncommon
<i>I. oxyrinchus</i> (Rafinesque)	Uncommon
<i>Hemipristis serra</i> Agassiz	Very common
<i>Galeocerdo contortus</i> Gibbes	Common
<i>G. aduncus</i> Agassiz	Common
<i>Carcharhinus brachyurus</i> (Günther)	Common
<i>C. limbatus</i> (Valenciennes)	Common
<i>C. perezii</i> (Poey)	Common

<i>Negaprion</i> sp.	Very common
<i>Rhizoprionodon</i> sp.	Uncommon
<i>Sphyrna</i> sp.	Uncommon
<i>Aetobatis</i> sp.	Common
<i>Dasyatis</i> sp.	Common
<i>?Raja</i> sp.	Rare
<i>Rhinoptera</i> sp.	Uncommon
<i>Alopias</i> sp.	
<i>Paragaleus</i> sp.	

Osteichthyes

<i>Acipenser</i> sp.	Uncommon
<i>Lepisosteus</i> sp.	Uncommon
<i>Ictalurus</i> sp.	Uncommon
<i>Pogonias</i> sp.	Common
<i>Lagodon</i> sp.	Rare
<i>Sphyrnaena</i> sp.	Rare

AGE OF THE FAUNA

With the exception of *Galeocerdo contortus* and *G. aduncus*, the identified fish taxa range stratigraphically from the early Miocene to the Holocene. The two species of *Galeocerdo*, however, range from the late Oligocene to the middle Miocene. The fish fauna, then, indicates an age of early Miocene to middle Miocene. On the bases of microfossils (Benson, 1998), mollusks (Ward, 1998), land mammals (Emry and Eshelman, 1998), and strontium-isotope dating (Jones et al., 1998) the age of the sediments, thus the fish fauna, at the Pollack Farm Site is early Miocene.

PALEOECOLOGY

Among the Pollack Farm sharks, the now shallow-water species *Carcharias taurus* and *Negaprion* sp. are more abundant here than in the other two faunas to the south. The three species of *Carcharhinus* also represent inshore, shallow-water sharks. *Isurus* spp. and *Notorynchus* sp. (now deep-water species), which are relatively common at localities to the south, are rare at the Pollack Farm Site. These differences in relative abundances suggest that the Pollack Farm fish fauna lived in shallow inshore waters.

Concerning climate, *Isurus* spp., *Rhincodon* sp., *Hemipristis serra*, *Galeocerdo* spp., *Carcharhinus* spp., *Negaprion* sp., *Rhizoprionodon* sp., *Sphyrna* sp., and *Sphyrnaena* sp. are all warm-water taxa. These taxa are common today south of Cape Hatteras, North Carolina, except for *Hemipristis*, which is restricted to the tropical eastern Pacific and Indian oceans, and *Carcharhinus perezii*, which is not found north of Florida (Compagno, 1984). The presence of *C. perezii* at the Pollack Farm Site suggests that the water temperature was warmer than that found in the Carolina Bight today.

¹ In Benson, R.N., ed., 1998, Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 133–139.

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PLATES

PLATE 1

All figures are 1X unless otherwise noted.

1. *Carcharias cuspidata* (Agassiz), composite dentition, lingual view, USNM 474258, collectors: Bohaska et al.
2. *Notorynchus* sp., lower anterolateral tooth, lingual view, USNM 474226, collector & donor: T.R. O'Hagan.
3. *Notorynchus* sp., upper anterolateral tooth, lingual view, USNM 474227, collectors: Bohaska & Purdy.
4. *Notorynchus* sp., median tooth, lingual view, USNM 474225, collectors: Bohaska et al.
5. *Squatina* sp., tooth, labial view, USNM 474486, collector: R. Eshelman.
6. *Squatina* sp., tooth, labial view, USNM 474487, collector: R. Eshelman.
7. Orectolobid, tooth, labial view, USNM 474539, collector: R. Eshelman.
8. *Rhincodon* sp., tooth, lateral view, USNM 474505, collector: Bohaska et al.
9. *Isurus hastalis* (Agassiz), lower lateral tooth, lingual view, USNM 474247, collector and donor: G. Simonson.
10. *Isurus hastalis* (Agassiz), upper, second anterior tooth, lingual view, USNM 474239, collectors: Bohaska & Simonson.
11. *Isurus oxyrinchus* (Rafinesque), lower, second anterior tooth, lingual view, USNM 474504, collectors: Bohaska & Purdy.
12. *Carcharodon subauriculatus* (Agassiz), lower lateral tooth, lingual view, USNM 474246, collector: R. Eshelman.
13. *Carcharodon subauriculatus* (Agassiz), upper, second anterior tooth, lingual view, USNM 474344, collector: R. Eshelman.
14. *Galeocerdo aduncus* Agassiz, anterolateral tooth, lingual view, USNM 474540, photo is reversed, collector and donor: G. Simonson.
15. *Galeocerdo aduncus* Agassiz, upper anterolateral tooth, lingual view, USNM 474277, photo is reversed, collector: R. Eshelman.
16. *Alopias* sp., lower tooth, lingual view, USNM 474236, collector and donor: K.A. Glunt.
17. *Galeocerdo contortus* Gibbes, upper anterolateral tooth, lingual view, USNM 474354, photo is reversed, collector and donor: G. Simonson.
18. *Galeocerdo contortus* Gibbes, lower anterolateral tooth, lingual view, USNM 474361, photo is reversed, collector and donor: G. Simonson.
19. *Hemipristis serra* Agassiz, lower symphyseal tooth, lingual view, USNM 474263, photo is reversed, collector: R. Eshelman.
20. *Hemipristis serra* Agassiz, lower lateral tooth, lingual view, USNM 474292, photo is reversed, collector: R. Eshelman.
21. *Hemipristis serra* Agassiz, upper lateral tooth, lingual view, USNM 474570, photo is reversed, collectors: Bohaska and Purdy.
22. *Hemipristis serra* Agassiz, upper lateral tooth, lingual view, USNM 474262, photo is reversed, collector: R. Eshelman.
23. *Hemipristis serra* Agassiz, upper lateral tooth, lingual view, USNM 474286, photo is reversed, collector: R. Eshelman.
24. *Hemipristis serra* Agassiz, lower anterior tooth, lingual view, USNM 474518, photo is reversed, collectors: Bohaska and Purdy.

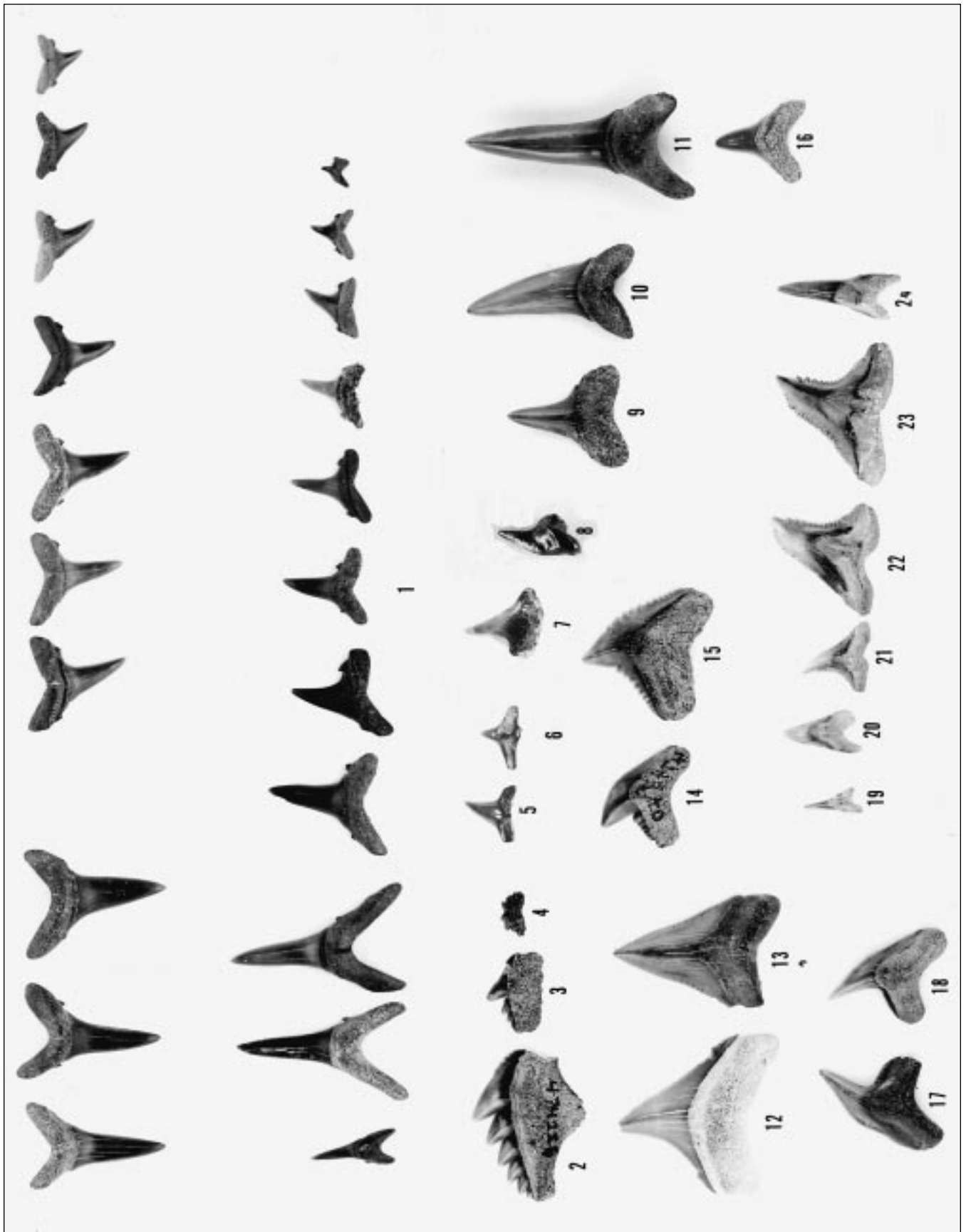
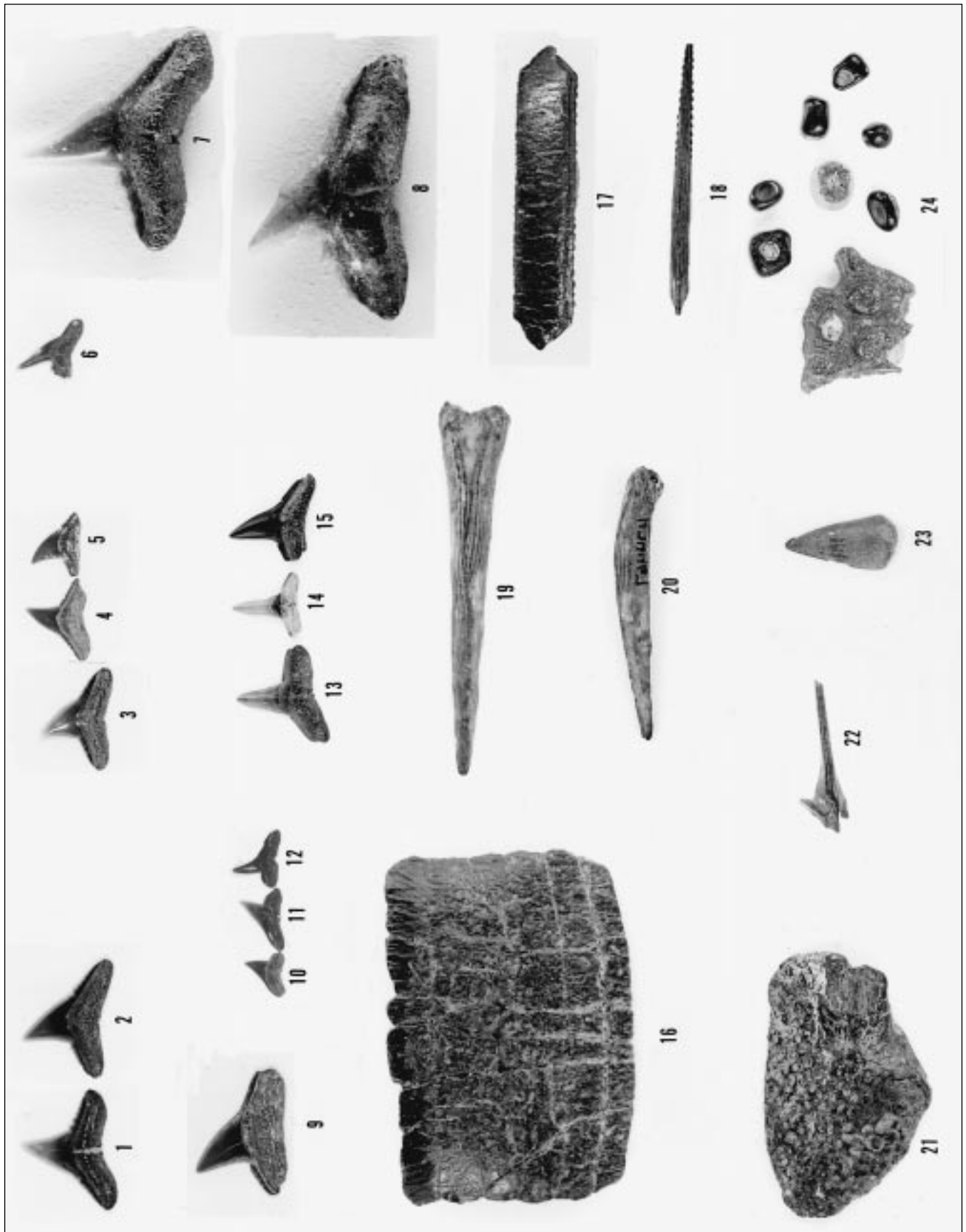


PLATE 2

All figures are 1X unless otherwise noted.

1. *Carcharhinus perezii* (Poey), upper anterolateral tooth, lingual view, 2X, USNM 494363, collector: G. Simonson.
2. *Carcharhinus perezii* (Poey), upper anterolateral tooth, lingual view, 2X, USNM 494364, collector: G. Simonson.
3. *Carcharhinus brachyurus* (Günther), upper anterolateral tooth, lingual view, 1.5X, USNM 494365, collector: G. Simonson.
4. *Carcharhinus brachyurus* (Günther), upper anterolateral tooth, lingual view, USNM 494366, collectors: Bohaska & Purdy.
5. *Carcharhinus brachyurus* (Günther), upper lateral tooth, lingual view, USNM 494367, collectors: Bohaska & Purdy.
6. *Paragaleus* sp., lower tooth, lingual view, USNM 474356, collectors: Bohaska and Purdy.
7. *Paragaleus* sp., lower tooth, lingual view, 3X, USNM 474338, collector and donor, G. Simonson.
8. *Paragaleus* sp., lower tooth, lingual view, 3X, USNM 474231, collectors: Bohaska et al.
9. *Sphyrna* sp., upper tooth, lingual view, 2X, USNM 474357, collectors: Bohaska and Purdy.
10. *Rhizoprionodon* sp., upper tooth, female, lingual view, USNM 474329, collectors, Bohaska and Purdy.
11. *Rhizoprionodon* sp., upper tooth, female, lingual view, USNM 474333, collectors: Bohaska and Purdy.
12. *Rhizoprionodon* sp., lower tooth, lingual view, USNM 474333 collectors: Bohaska and Purdy.
13. *Negaprion* sp., upper tooth, lingual view, USNM 474399, collectors: Bohaska and Purdy.
14. *Negaprion* sp., lower tooth, lingual view, USNM 474420, collector: G. Simonson.
15. *Negaprion* sp., upper anterolateral tooth, lingual view, USNM 494362, collector: D. J. Bohaska.
16. *Aetobatis* sp., upper dental battery, occlusal view, in the collection of Michael Miskofsky.
17. *Rhinoptera* sp., isolated tooth, occlusal view, USNM 494361, collector: G. Simonson.
18. Sting ray tail spine, USNM 494360, collector: D. J. Bohaska.
19. *Ictalurus* sp., dorsal spine, anterior view, 1.5X, USNM 474467, collector and donor: G. Simonson.
20. Same specimen, lateral view, 1X.
21. *Acipenser* sp., dermal scute, external view, USNM 474457, collector: R. Eshelman.
22. *Ictalurus* sp., pectoral spine, ventral view, USNM 474481, collector and donor: D. B. Duke.
23. *Sphyrna* sp., tooth, lateral view, USNM 474448, collector and donor: G. Simonson.
24. *Pogonias* sp., fragment of pharyngeal with isolated teeth, USNM 474470, collector: R. Eshelman.



REPTILES OF THE LOWER MIOCENE (HEMINGFORDIAN) POLLACK FARM FOSSIL SITE, DELAWARE¹

J. Alan Holman²

ABSTRACT

The Pollack Farm Fossil Site near Cheswold, Kent County, Delaware has yielded a unique early Miocene (Hemingfordian) reptile fauna that, among other species, has yielded the first North American remains of small Miocene lizards and snakes east of the Great Plains and north of Florida. This fauna includes a thick-shelled kinosternid turtle (*Kinosternon* sp.), an emydid turtle (“*Chrysemys* group”), a very large land tortoise (*Geochelone* sp.), a very large crocodylian (cf. *Crocodylus* sp.), a glass lizard (*Ophisaurus* sp. indet.), a new species of the unique extinct boid genus *Pterygoboa* (*Pterygoboa delawarensis*), the extinct boid genus *Calamagras* (*Calamagras* sp. indet.), the extinct colubrid snake genus *Ameiseophis* (*Ameiseophis robinsoni*), a distinct new genus of colubrid snake (*Pollackophis depressus*), and an indeterminate (probably extinct) viperid snake (cf. *Crotalinae* gen. et sp. indet.).

Pterygoboa and *Ameiseophis* have never been recorded from eastern North America, both of these snakes being characteristic of Miocene assemblages in the northern High Plains (e.g., Nebraska, Wyoming, and South Dakota). The crocodylians and aquatic turtles indicate a large, sluggish, permanent body of water. The remainder of the reptile species probably preferred open brushy or grassy habitats with loose or sandy soil.

INTRODUCTION

Records of small Miocene lizards and snakes are non-existent in a vast area of North America east of the Great Plains and north of Florida. Thus, the recovery of small fossil squamates from the lower Miocene Pollack Farm Site near Cheswold, Kent County, Delaware, is of considerable paleoherpetological importance. Moreover, records of aquatic turtles, a giant land tortoise, and a very large crocodylian from this site are of additional interest.

The fauna came from a borrow pit used for new highway construction that was located near Cheswold, Kent County, Delaware. During excavation the pit was referred to as the Pollack Farm Site. The Delaware Geological Survey (DGS) identifier for the site is Id11-a (39°14'08"N, 75°34'36"W). The fossils described here were recovered from the lower shell bed at the site (see Benson, 1998, fig. 2). The excavation exposed some of the Cheswold sands (DGS informal designation) of the Calvert Formation that are of early Miocene (Hemingfordian) age. The geological features of the site as well as the other faunal remains are detailed in other reports in this DGS Special Publication No. 21.

Acknowledgments

I wish to thank Robert Purdy and Robert Emry of the National Museum of Natural History for allowing me to examine the Miocene reptiles from Delaware. Teresa Petersen made the figures. The manuscript was reviewed by Zbigniew Szyndlar and Dennis Parmley.

CHECKLIST OF THE HERPETOFAUNA FROM THE POLLACK FARM SITE

Kinosternon sp. indet. Mud turtle.
“*Chrysemys* group” turtle. Painted turtle, cooter, slider group.
Geochelone sp. indet. Very large land tortoise.
cf. *Crocodylus* sp. indet. Very large crocodile.
Ophisaurus sp. indet. Legless lizard.
Pterygoboa delawarensis. New species of distinctive small boid genus.

Calamagras sp. indet. Small boid.

Ameiseophis robinsoni. Extinct genus and species of small colubrid snake.

Pollackophis depressus. Distinctive new genus and species of small colubrid snake.

cf. *Crotalinae* gen. et sp. indet. Viperid snake.

ANNOTATED LIST

Numbers are of the National Museum of Natural History (USNM) and measurements are in millimeters (mm). MSUVP refers to the Michigan State University Vertebrate Paleontology collection. The classification used here follows King and Burke (1989) for turtles and crocodylians, Estes (1983) for lizards, and Rage (1984) for snakes.

Class REPTILIA Laurenti, 1768
Order TESTUDINES Batsch, 1788
Family KINOSTERNIDAE Baur, 1893
Genus *Kinosternon* Spix, 1824
***Kinosternon* sp. indet.**

Material.—Two fragmentary costals, three peripherals, one left and two right hyoplastra, two left and one right hypoplastra; USNM 483389, collected March through August 1992. In addition, a pygal is from the private collection of John Ricard.

Remarks.—The genus *Kinosternon*, which presently ranges from Long Island to Argentina (Conant and Collins, 1991), may be osteologically distinguished from the similar kinosternid genus *Sternotherus* on the basis that *Kinosternon* has two transverse plastral hinges that allow upward movement of both the anterior and posterior plastral lobes. Well-developed hinge line grooves are present on two of the three Miocene hyoplastra (the third is so worn that this character cannot be identified) as in skeletons of modern *Kinosternon*. The three fossil hypoplastra are either too worn or incomplete to show this character.

Some *Kinosternon* species such as the North American *Kinosternon bauri* and the Mexican *Kinosternon herrerae*

¹ In Benson, R.N., ed., 1998, Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 141–147.

cannot close the shell completely, but others such as the Mexican and Central American *Kinosternon leucostomum* and *Kinosternon scorpioides* have the ability to close up the shell completely in the manner of North American box turtles (*Terrapene*), although with two hinges rather than one.

In my examination of modern skeletons of *Kinosternon* (*Kinosternon acutum*, *K. bauri*, *K. flavescens*, *K. herrerae*, *K. hirtipes*, *K. integrum*, *K. leucostomum*, *K. scorpioides*, *K. sonoriense*, and *K. subrubrum*) I discovered that the species that were able to close the shell tightly (e.g., *K. leucostomum* and *K. scorpioides*) have much thicker shell bones than those species with limited shell-closing ability (e.g., *K. bauri* and *K. herrerae*). It would seem that having a thick as well as a tightly closable shell would offer greater protection against predators.

It is then of considerable interest that the Pollack Farm Site Miocene *Kinosternon* fossils have very thick shell bones as in *K. leucostomum* and *K. scorpioides*, thus differing from the *Kinosternon* that presently occur on the east coast of North America (*Kinosternon bauri* and *K. subrubrum*) that are thin-shelled forms that cannot close the shell completely.

The scute impressions on the hyo- and hypoplastral bones of the Pollack Farm fossils differ from those of modern *Kinosternon* that I have studied; thus, I strongly suspect that the Miocene fossils represent an undescribed species. More complete material from the Pollack Farm Site might confirm this suggestion.

Family EMYDIDAE Lydekker, 1889

In Nicholson and Lydekker

“*Chrysemys* group”

Material.—One fragmentary nuchal, two fragmentary costals, and one posterior peripheral; USNM 483390, collected in April and August 1992.

Remarks.—These bones closely resemble the “*Chrysemys* group” of emydid turtles which includes *Chrysemys*, *Pseudemys*, and *Trachemys*. This is a New World group that presently ranges from southern Canada to Brazil (Ernst and Barbour, 1989). The nuchal is from a small, probably immature specimen. The posterior peripheral is from a large turtle of the size of modern *Pseudemys* or *Trachemys* species. All of the species in the three modern genera prefer permanent, rather quiet bodies of water and some forms of *Pseudemys* inhabit brackish coastal rivers in Florida.

Family TESTUDINIDAE Gray, 1825

Genus *Geochelone* Fitzinger, 1835

***Geochelone* sp. indet.**

Material.—Entoplastron, posterior portion of left hypoplastron, three plastral fragments, two costal fragments, and one peripheral fragment; USNM 483391 collected from March to August 1992. In addition, a peripheral fragment is from the private collection of Tom Voss and a costal fragment is from the private collection of G. Simonson.

Remarks.—These are the remains of a very large tortoise. The left hypoplastron especially resembles that of the presently pantropical genus *Geochelone* in having a very thick posterior portion with a thick, triangular xiphiplastral articular surface. The scute impressions on the posterior part of the hypoplastron closely resemble those of *Geochelone wilsoni* (Auffenberg, 1964, fig. 1), a close relative of *Geochelone*

ducatelli (Collins and Lynn 1936) of the Barstovian Calvert Formation of Maryland, Zone A (Auffenberg, 1974), and it seems that the Pollack Farm Site tortoise material might belong to that species. The other large land tortoise elements from the Pollack Farm locality are indistinguishable from those of fossil *Geochelone* in the MSUVP collections but do not appear to be specifically diagnostic.

Order CROCODYLIA (Gmelin, 1789)

Family CROCODYLIDAE (Cuvier, 1807)

cf. *Crocodylus* sp. indet.

Material.—A very large mandibular tooth from the private collection of Robert D. Bowes.

Remarks.—The name *Thecachampsa* has sometimes been applied to crocodylian material from the Miocene of the eastern United States (*Thecachampsa contusa* Cope 1867 and *Thecachampsa sericodon* Cope 1867), but *Thecachampsa* is currently considered a synonym of *Crocodylus* Laurenti 1768 (Steel, 1973). The tooth from the Pollack Farm Site represents a very large specimen of Crocodylia. The tip of the tooth is striated as in many *Crocodylus* species rather than smooth as in *Alligator*. I am therefore tentatively referring the above Miocene tooth to the pantropical genus *Crocodylus*. The presence of very large crocodiles in Delaware in the Miocene is of great paleontological importance.

Order SAURIA McCartney, 1802

Family ANGUIDAE Gray, 1825

***Ophisaurus* Daudin, 1803**

The genus *Ophisaurus* occurs today in eastern United States south to Veracruz, Mexico, Morocco, southeastern Europe into Afghanistan, southeastern Asia, Borneo and Sumatra, and fossil *Ophisaurus* species are known from the Miocene to the Pleistocene of Europe and North America (Estes, 1983). The trunk vertebrae of *Ophisaurus* are easily identified based on the structure of the centrum, which has its ventral surface very smooth with no trace of a keel, and with two distinct anterior foramina, one usually larger than the other. The condyle on the centrum is very flattened. Dentary teeth of *Ophisaurus* are simple and unicuspid; some of them are slightly recurved and their tips are weakly striated.

***Ophisaurus* sp. indet.**

Material.—Trunk vertebra and a part of a right dentary with a single tooth; USNM 483392.

Remarks.—This vertebra is very worn, and I am unable to identify it to the specific level. It differs from *Ophisaurus canadensis* Holman 1970 from the medial Miocene Wood Mountain Formation of Saskatchewan and from *Ophisaurus ventralis* Linnaeus 1758 from the Miocene (Barstovian) of Nebraska in that, in dorsal view, the anterior edge of the neural arch ends well behind the anterior edges of the prezygapophyseal facets.

It is possible that this character might indicate that the specimen is from an undescribed species, but it does not seem wise to describe a new species on a single, worn vertebra.

Measurements.—The greatest length of the vertebra through the prezygapophyses and condyle is 3.7. The greatest width of the vertebra through the prezygapophyses is 3.9.

A very small fragment of a right dentary bone of an anguid lizard is also identified as *Ophisaurus* sp. indet. The

single tooth is similar to those that occur on the anterior part of the dentary bone in modern *Ophisaurus* in that it is unicuspid, slightly recurved, and has its tip weakly striated.

Ophisaurus does not presently occur in the fauna of Delaware, but *Ophisaurus ventralis* ranges as close as the southeastern tip of Virginia (Conant and Collins, 1991).

Order SERPENTES Linnaeus, 1758
Family BOIDAE Gray, 1825

Several authors (e.g. Holman, 1979; Rage, 1984) have discussed the identification of the family Boidae on the basis of individual fossil vertebrae.

Subfamily ERYCINAE Bonaparte, 1831

Snakes of this boid subfamily are small semi-fossorial to fossorial forms many of which have unique, elaborated caudal vertebrae (Rage, 1984, fig. 15a). These vertebrae form the skeleton of the very blunt tail, that in outline, resembles the head of the snake. On the other hand, most fossil and modern Erycinae have rather simple trunk vertebrae. Erycinine boids were widely distributed in the Paleogene and Neogene of North America, but the only modern representatives are *Charina* and *Lichanura* of about the western one-fourth of the United States (Stebbins, 1985).

Only two erycine genera have elaborated trunk vertebrae. These are *Cadurceryx* Hoffstetter and Rage 1972 of the Eocene of France and *Pterygoboa* Holman 1976 of the Miocene of North America. Both have pterapophyses (wing-like processes) associated with the postzygapophyses (Rage, 1984), but they are structurally different in each of these genera (Holman, 1977; Rage, 1984).

***Pterygoboa* Holman, 1976**

This genus has been previously identified from only two Miocene localities of the northern High Plains of North America. The type material was collected from the Black Bear Quarry II of the Rosebud Formation (early Hemingfordian) of Bennett County, South Dakota (Holman, 1976a), and additional material was taken from the Myers Farm Site (Barstovian) of Webster County, Nebraska (Holman, 1977).

The trunk vertebrae of *Pterygoboa* are distinct from those of any other fossil snakes in North America in having pterapophyses associated with the postzygapophyses, coupled with having a very depressed neural arch. Two other North American genera, *Palaeophis* Marsh 1878 and *Pterosphenus* Lucas 1899 (Family Palaeopheididae) have pterapophyses, but they are very differently shaped than in *Pterygoboa*. Moreover, the vertebrae of *Palaeophis* and *Pterosphenus* have quite vaulted neural arches.

Only one species, *Pterygoboa miocenica* Holman 1976, has been described, and this species has been reported from both of the above localities. Among the herpetological material collected at the Pollack Farm Site is a single vertebra of *Pterygoboa* that is so different from that of *Pterygoboa miocenica* that it is described here as a new species.

***Pterygoboa delawarensis* sp. nov.**

Figure 1

Holotype.—Trunk vertebra; USNM 483393.

Type Locality and Horizon.—From the Pollack Farm

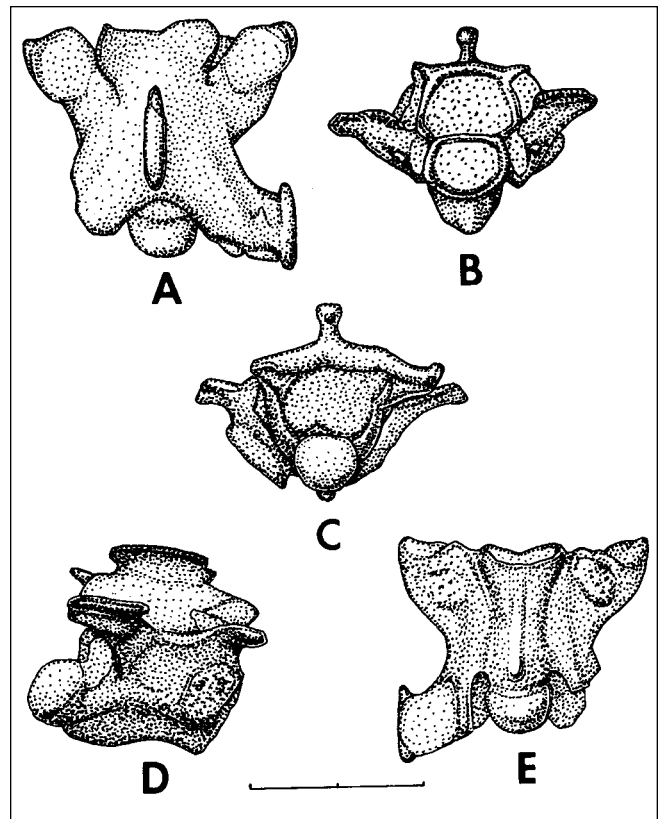


Figure 1. *Pterygoboa delawarensis* sp. nov., holotype trunk vertebra; USNM 483393. A, dorsal view; B, anterior view; C, posterior view; D, lateral view; E, ventral view. The line equals 2 mm and applies to all figures.

Site (Delaware Geological Survey site Id11-a), near Cheswold, Kent County, Delaware. Cheswold sands of the Calvert Formation; lower Miocene, Hemingfordian Age.

Etymology.—The specific name is for the state of Delaware where the type specimen was collected.

Diagnosis.—(1) Neural arch very depressed; (2) pterapophyses present on postzygapophyses; (3) pterapophyses pointed anteriorly and posteriorly; (4) neural spine low; (5) posterior neural arch flat across the top.

Description of the Holotype.—In dorsal view, the vertebra is moderately wider than long. The pterapophysis is slender and acutely pointed both anteriorly and posteriorly. The prezygapophyseal articular facets are round and have small, blunt prezygapophyseal accessory processes. The posterior border of the neural arch is broadly U-shaped. The anterior border of the neural arch is slightly concave. The neural spine is moderately swollen dorsally and extends from the posterior border of the neural arch to slightly beyond the posterior borders of the prezygapophyseal facets.

In anterior view, the neural spine is moderately high. The anterior neural arch is very slightly convex at the top. The prezygapophyses are slightly tilted upward. Pits occur on either side of the cotyle, but they are filled with matrix and it cannot be determined whether they contain foramina or not. The subrounded neural canal is about one-fourth larger than the round cotyle. The sides of the neural arch are bowed slightly outward.

In posterior view, the neural spine is low. The posterior neural arch is very flat across the top. The pterapophysis

appears rounded and delicate in this view. The rounded neural canal is about one-third larger than the round condyle. The sides of the neural arch are bowed outward.

In lateral view, the neural arch is very depressed. The pterapophyses are thin. The prezygapophyseal facets are slightly tilted upward. The hemal keel is well-developed and extends well below the level of the centrum. Both of the synapophyses are damaged so it is not possible to determine whether they have the divided or undivided condition.

In ventral view, the vertebra is wider than long. The hemal keel is moderately well-developed and moderately thick. Distinct subcentral ridges are present, and these have distinct valleys between themselves and the hemal keel. The postzygapophysis has an ovaloid face and the pterapophysis is acutely pointed both anteriorly and posteriorly. Both of the synapophyses are damaged, thus it is not possible to tell whether they have the divided or undivided condition.

Measurements.—The width of the vertebra through the prezygapophyses is 3.6. The length of the vertebra through the zygapophyses is 2.8. The length of the centrum through the cotyle and condyle is 2.3. The length of the pterapophysis is 1.0. The greatest width of the condyle is 0.8.

Remarks.—This record of the distinctive genus *Pterygoboa* from the eastern coastal state of Delaware is of special zoogeographic interest as the only previous records of the taxon are from isolated sites in Nebraska and South Dakota.

The new species differs from the only other species in the genus, *Pterygoboa miocenica* Holman as follows: (1) the vertebra is more lightly constructed; (2) the neural spine is lower; (3) the posterior neural arch is flatter across the top; (4) the pterapophyses are gracile and are more pointed anteriorly and posteriorly.

It would appear that the ancestral form of both species of *Pterygoboa* (*P. miocenica*, western form; and *P. delawarensis*, eastern form) must have lived in pre-Hemingfordian times, since the earliest records of both species are from the Hemingfordian (Holman, 1976a and this paper). It is difficult to speculate where the geographic location of this ancestor might have been.

***Calamagras* Cope, 1873**

Calamagras is an extinct genus of erycine boid that occurs from the lower Eocene of France to the middle Miocene of North America, where it has been recorded from Saskatchewan, Wyoming, Colorado, Nebraska, and Florida (Holman, 1979). On the basis of trunk vertebrae characters, *Calamagras* is distinguished from the related erycine genus *Ogmophis* mainly on the basis of its shorter, usually thicker neural spine.

***Calamagras* sp. indet.**

Material.—A fragmentary vertebra; USNM 483394.

Remarks.—This vertebra may be identified as *Calamagras* on the basis of its short, thick neural spine, but the specimen is too fragmentary to identify to the specific level. *Calamagras* represents a genus that is mainly western, except for its occurrence in Florida (Auffenberg, 1963).

cf. ERYCINAE gen. et sp. indet.

Material.—A fragmentary vertebra; USNM 483395.

Remarks.—On the basis of its short and wide vertebral form, its heavily-built construction, and its strong hemal

keel, this vertebra is tentatively referred to the boid subfamily Erycinae. The neural spine and other diagnostic characters are missing in this specimen.

Family COLUBRIDAE Opper, 1811

Several authors (e.g. Holman, 1979; Rage, 1984) have discussed the identification of taxa of the family Colubridae on the basis of individual vertebrae. The huge family Colubridae is a very derived one, and the first fossil colubrids occur in the late Eocene of Thailand (Rage et al., 1992). Fossil Colubridae are first known in Europe and North America in the early Oligocene. As far as I am aware, the accounts that follow represent the earliest records of colubrid snakes from eastern North America east of the Great Plains and north of Florida.

***Ameiseophis* Holman, 1976**

This genus has been previously identified from only two localities, both in the Miocene of the northern High Plains of North America. The type material was collected from the Miocene Split Rock Formation of central Wyoming (Holman, 1976b). This *Ameiseophis* material occurred both in the lower Split Rock beds that have a snake assemblage similar to that of the early Hemingfordian Black Bear Quarry II fauna of South Dakota, as well as from the upper beds that have a snake assemblage that is similar to Barstovian ones in Nebraska (Holman, 1976b). Additional material of *Ameiseophis* was collected from the Bijou Hills local fauna (Barstovian) of south-central South Dakota (Holman, 1978).

Ameiseophis is a distinctive colubrid genus with a very strong hemal keel and with deep grooves between the hemal keel and the subcentral ridges. *Ameiseophis* may be distinguished from *Texasophis*, the other extinct North American genus with a very strong hemal keel, on the basis of its shorter vertebral form and higher neural spine. Only one species, *Ameiseophis robinsoni*, has been named, and it occurs in both localities in Wyoming and South Dakota.

***Ameiseophis robinsoni* Holman, 1976**

Material.—Trunk vertebra; USNM 483396.

Remarks.—I cannot find any trenchant characters that separate the Pollack Farm vertebra from those of *Ameiseophis robinsoni* (see diagnosis of *A. robinsoni* in Holman, 1976b) except that the grooves between the hemal keel and the subcentral ridges are not quite as deep as in the holotype material. Measurements are as follow: the length of the vertebra through the zygapophyses is 4.8; the width through the prezygapophyses is 4.3 (but the tip of the left prezygapophysis is broken); the length of the centrum through the cotylar lip and the end of the condyle is 3.3.

This record of the distinctive *Ameiseophis robinsoni* in Delaware is of significant zoogeographic interest in that the only previous records of the taxon are from isolated localities in Wyoming and South Dakota. Holman (1976b) believes that *Ameiseophis* possibly represents an archaic colubrid line with no living descendants.

***Pollackophis* gen. nov.**

Type species.—*Pollackophis depressus*

Locality and Horizon.—From the Pollack Farm Site (Delaware Geological Survey Site Id11-a), near Cheswold, Kent County, Delaware. Cheswold sands of the Calvert Formation; lower Miocene, Hemingfordian Age.

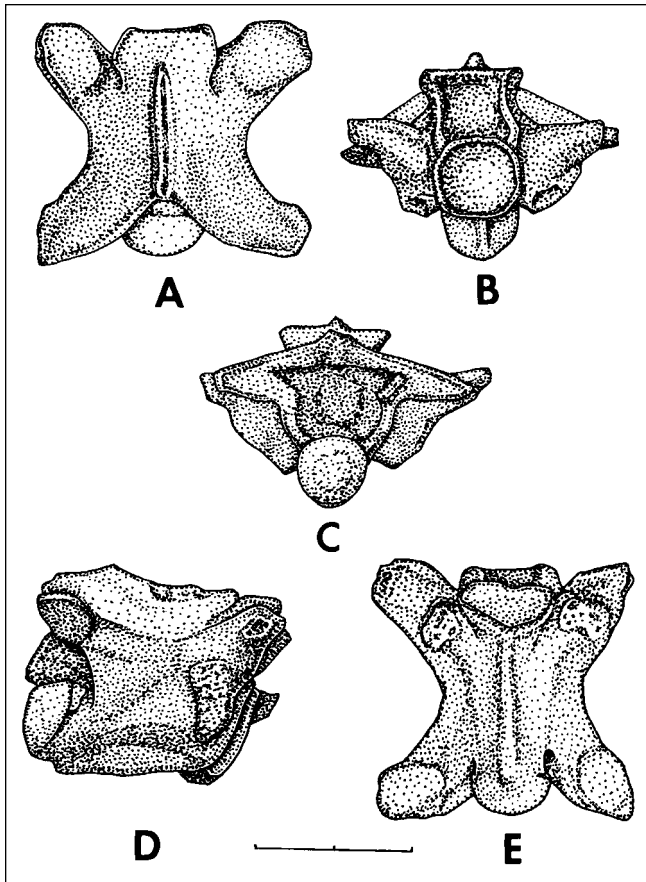


Figure 2. *Pollackophis depressus* gen. et sp. nov., holotype trunk vertebra; USNM 483397. A, dorsal view; B, anterior view; C, posterior view; D, lateral view; E, ventral view. The line equals 4 mm and applies to all figures.

Etymology.—The generic name is for the Pollack Farm Site where the type specimen was collected.

Diagnosis.—The diagnosis is the same as for the type and only known species.

***Pollackophis depressus* sp. nov.**

Figure 2

Holotype.—A single trunk vertebra; USNM 483397.

Etymology.—The name reflects the depressed shape of the vertebra.

Diagnosis.—(1) vertebra slightly wider than long; (2) neural spine long and thin; (3) neural arch depressed; (3) hemal keel well-developed, but narrow; (4) subcentral ridges weakly developed; epizygapophyseal spines absent.

Description of the Holotype.—In dorsal view, the vertebra is slightly wider than long. The left prezygapophysis is broken on its anterolateral edge and the right prezygapophyseal face is ovaloid. Prezygapophyseal processes are either lacking or have been eroded away. The anterior edge of the zygosphene is very slightly concave. The neural spine is broken, but the basal portion is long and thin. Epizygapophyseal spines are lacking.

In anterior view, the roof of the zygosphene is straight. The walls of the neural canal are slightly concave. The neural canal is slightly smaller than the rounded cotyle. The prezygapophyses are slightly tilted upward. In posterior view, the neural arch is depressed. The neural canal is about one-third larger than the round condyle. In lateral view, the vertebra is

moderately depressed. The borders of the subcentral ridges are moderately concave. The synapophyses are eroded.

In ventral view, the postzygapophyseal faces are subequal in shape and size; the right one is larger and has its apex directed medially; the left one is smaller and has its apex directed posteriorly. The hemal keel is well developed but thin. The subcentral ridges are weakly developed, and the synapophyses are eroded.

Measurements.—Greatest length through the zygapophyses 6.5. Greatest width through posterior zygapophyses 6.7.

Discussion.—*Pollackophis* is so distinct that I feel justified in naming a new genus on the basis of this single, well-preserved vertebra. The combination of a short, depressed vertebral form, with a well-developed, but thin hemal keel appears to be unique among fossil and modern Colubridae, thus it seems possible that *Pollackophis* is an archaic form that has left no modern descendants.

Family VIPERIDAE Oppel, 1811

The Viperidae is the most derived family of snakes and has evolved a very complex venom-injecting apparatus. This family is composed of 16 genera and is cosmopolitan in its distribution except for Madagascar and Australasia. The earliest viperid fossils are known from the lower Miocene both in Europe and North America (Rage, 1984).

Subfamily CROTALINAE Oppel, 1811

The Crotalinae (pit vipers) have the maxillary bone deeply excavated for a heat-sensitive loreal pit organ. This subfamily occurs only in the New World. In the United States there are 17 species in three genera: *Agkistrodon* Beauvois 1799; *Crotalus* Linnaeus 1758; and *Sistrurus* Garman 1883.

cf. CROTALINAE gen. et sp. indet.

Material.—Right compound bone and two vertebrae; USNM 483398.

Remarks.—The compound bone forms the posterior part of the lower jaw in snakes. It lacks teeth and has an inwardly directed retroarticular process on its posterior end. The compound bone is a very distinctive element in the Viperidae in that the distinct, deep groove on the dorsal part of the bone has a very low, almost obsolete lateral wall. Moreover, a deep, elongate fossa occurs just anterior to the retroarticular process.

The fossil compound bone appears to be somewhat closer to *Sistrurus* than to the other North American genera *Agkistrodon* and *Crotalus* in some features, but differs from all three of these genera in others. Comparisons with other New World and Old World viperid genera also indicate that the bone may represent a distinct genus or even a distinct subfamily. However, at present it seems best not to attempt a more specific identification of this specimen until more fossil and modern skeletal material becomes available for comparison.

Two very worn vertebrae also represent viperids in having the very thick hypapophyses that are characteristic of this family. These bones are assigned tentatively to the Crotalinae on the basis of zoogeographic grounds until more fossil and recent skeletal material becomes available.

The earliest record of the family Viperidae in North America is from the Harrison Formation in Nebraska which

represents the uppermost unit in the Arikareean Land Mammal Age (Holman, 1981), and hence the lowest part of the Miocene. Holman (1981) notes that the specimen, a vertebra, somewhat resembles the modern genus *Sistrurus*. As far as I can determine, this is the first published record of a Hemingfordian viperid snake, the first Miocene record of a viperid snake east of the Great Plains and north of Florida, and the oldest record of this family east of the Great Plains.

DISCUSSION

The Pollack Farm Site has given us the first good window of Miocene reptile life in North America east of the Great Plains and north of Florida. Probably the most striking aspect of this small reptile fauna is that three of the ten identified taxa, *Pterygoboa*, *Calamagras* and *Ameiseophis*, are forms that are characteristic of the Miocene of the North American northern High Plains (Holman, 1979). The wide east-west occurrence of herpetological genera in the Miocene of North America has previously led to the suggestion that east-west rainfall zonation was not as pronounced as it is in the present (Holman, 1970).

Moreover, herpetofaunas from Barstovian Miocene sites in the northern High Plains, from Nebraska to Saskatchewan, have often contained large reptiles such as giant tortoises (*Geochelone*) and crocodylians. These occurrences have been interpreted as indicating subtropical climates in these areas (Holman, 1970, 1977); thus, it seems that the climate in Delaware during the deposition of the Pollack Farm fauna was probably subtropical.

One may get some idea of the ecological setting in which the reptile fauna at the Pollack Farm Site lived by a consideration of habits and habitats of their modern analogs. Large modern crocodiles normally need large, permanent bodies of water in which to live. "*Chrysemys* group" turtles are also aquatic and prefer still rather than rapidly flowing water, as do mud turtles (*Kinosternon*). Considering these three taxa, one could picture a large shallow lake or a river oxbow setting.

The second part of the fauna, however, indicates terrestrial conditions. Large land tortoises (*Geochelone*) have often been depicted as being species that preferred grassy or open terrestrial habitats as do most of their recent congeners.

Species of *Ophisaurus* are legless, snakelike lizards that today eat insects, spiders, snails, birds eggs, and small snakes and lizards (Conant and Collins, 1991). Some of the large southern European forms eat small mice as well. These lizards are excellent burrowers and may spend much of their lives below the ground. Typically, ophisaurids prefer sandy soil with a brushy or grassy ground cover.

The two small erycine boas (*Pterygoboa* and *Calamagras*) are not represented by living genera. Nevertheless, most modern erycine boas are semifossorial or fossorial species, and many of them are partial to loose or sandy soil. In fact, the skulls of many of these modern snakes are blunt in shape for burrowing through sand or loose soil. It thus seems probable that the two fossil genera might have inhabited rather open, sandy habitats, similar to those of the ophisaur. Both *Pterygoboa* and *Calamagras* probably killed their prey by constriction as do the boids of today. Holman (1977) suggested that *Pterygoboa miocenica* ate rodent prey.

Ameiseophis robinsoni is believed to be from an archaic line with no living relatives (Holman, 1976b).

Nevertheless, one can speculate on some of its habits based on its vertebral characteristics. Modern colubrid snakes with heavily-constructed vertebrae and massive vertebral processes (e.g., *Lampropeltis getulus*) are usually relatively slow-moving species that kill their prey by constriction. On the other hand, modern colubrid snakes with lightly-constructed vertebrae with gracile vertebral processes (e.g., *Coluber constrictor*) are usually fast, non-constricting species. Since *Ameiseophis* has a heavily-constructed vertebral form with a massive hemal keel, it may have been a slow-moving, constricting snake that could have fed on small rodent prey. Its small size may indicate that it had secretive or fossorial habits.

It is difficult to suggest feeding habits or habitat preferences for the new genus and species *Pollackophis depressus* because it apparently has no modern analogs. Nevertheless, it lacks the vertebral hypapophyses that occur on several genera of aquatic colubrid snakes and thus may have been terrestrial. Moreover, considering its small size, it seems possible that it was secretive.

Other than the fact that the viperid snake certainly must have killed its prey by the injection of venom, it is difficult to suggest specific habits or habitats for this form. But together, the terrestrial reptile assemblage from the Smyrna fossil sites suggests a group of forms that probably occupied a rather open grassy or brushy habitat with loose or sandy soil. This habitat was probably near a large sluggish lake or oxbow.

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EARLY MIOCENE AVIFAUNA FROM THE POLLACK FARM SITE, DELAWARE¹

Pamela C. Rasmussen²

ABSTRACT

In contrast to the extensive fossil record of other vertebrate groups, such as fishes and mammals, only 11 specimens of avian fossils, all fragmentary and unassociated, have been recovered from the Pollack Farm Fossil Site near Cheswold, Delaware, a borrow pit during highway construction (now covered) that exposed lower Miocene shelly sands of the Calvert Formation. Taxa represented include *Gavia* small sp. (1 specimen and possibly another); *Morus* cf. *M. loxostylus* (5 specimens); and one large species of pseudodontorn (1 specimen). Other less diagnostic specimens appear to pertain to a rather larger, stockier species of loon (1 specimen) and one probable small gull (1 specimen); yet another avian specimen is unidentified to order. The five avian taxa identified are mostly or exclusively marine in distribution, in contrast to the situation with mammals from the site, in which the diversity of land mammals is higher than that for marine mammals. The avian fossils apparently all belong to species already known from the younger part of the Calvert Formation of the western shore of Chesapeake Bay in Maryland. The composition of the avifauna supports the depositional hypothesis of a nearshore area of a large embayment.

INTRODUCTION

The recently excavated (now covered) portion of the lower Miocene Cheswold sands (Delaware Geological Survey informal designation) of the lower Calvert Formation at the Pollack Farm Site near Cheswold, Delaware, has thus far yielded a sizeable vertebrate fauna of more than 70 species, mostly from the lower shell bed at the site (see Benson, 1998, fig. 2). Vertebrate fossils identified include 22 cartilaginous and 6 bony fish species (Purdy, 1998), 10 reptilian taxa (Holman, 1998), 8 marine mammal species (Bohaska, 1998), and at least 26 species of land mammals (Emry and Eshelman, 1998). The invertebrate fauna is also extensive, with 104 species of mollusks identified (Ward, 1998). Most of the mammalian species represented are terrestrial, and the site has produced the most diverse Miocene land vertebrate assemblage known from the northeastern United States. The extensive land vertebrate fauna, combined with a diverse marine vertebrate and invertebrate macro- and microfauna, provides an unusual opportunity for significant marine-terrestrial correlations (see Benson, 1998). The depositional environment has been interpreted as the sandy nearshore area of a large embayment, with a subtropical to tropical climate (Ramsey et al., 1992; Ramsey, 1998).

The site has thus far produced few avian fossils, however, all of which are isolated fragments, most poorly preserved. These bird fossils are nevertheless of interest as they comprise the only known sample of the Miocene avifauna of this area and are older (dated at 17.9 Ma; Jones et al., 1998) than are most of the bird fossils from the better-known exposures of the Calvert Formation along the western shore of Chesapeake Bay. The deposits at the Pollack Farm Site are approximately coeval with the "Popes Creek Sand" (Bed 3-A of Ward, 1993; see also Benson, 1998) at Popes Creek, Maryland, from which a number of bird bones are under study by Storrs L. Olson and the author. The upper Calvert Formation is partially coeval with the middle Miocene Pungo River Formation (see Gibson, 1983) of Lee Creek Mine, North Carolina, which has produced abundant avian specimens (Olson and Rasmussen, in press).

Acknowledgments

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SYSTEMATIC PALEONTOLOGY

Order GAVIIFORMES

Family GAVIIDAE

Gavia sp.

Figure 1A

Material.—Distal fourth of right ulna; USNM (United States National Museum) 476045, collected by R.E. Eshelman, 8 July 1992. Tentatively referred: scapular facet and glenoid facet region of left coracoid, USNM 476046; collected by Smithsonian Institution (SI) field crew.

Remarks.—A number of small loon elements from the Calvert Formation of Virginia and Maryland and the Pungo River Formation of North Carolina are apparently from an undescribed species (S.L. Olson, pers. comm., 1997). The Pollack Farm Site ulna is indistinguishable from a specimen of this species, USNM 460030, from the Calvert Formation of Popes Creek, Maryland. The referred coracoid specimen, however, is fragmentary and its assignment must be considered tentative.

cf. *Gavia* sp. indet.

Figure 1B

Material.—Worn fragment of cranial end of sternum, including base of carina, coracoidal sulcus, and manubrium; USNM 237288, collected by David B. Duke.

¹ In Benson, R.N., ed., 1998, Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 149–151.

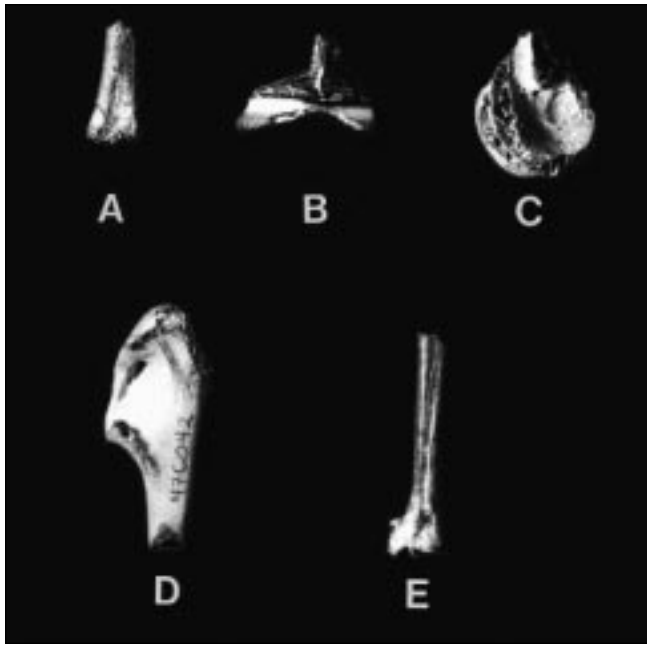


Figure 1. Fossil bird bones from the Pollack Farm Site, Delaware: A, right ulna of *Gavia* sp., USNM 476045 in internal view; B, fragment of cranial end of sternum of cf. *Gavia* sp. indet., USNM 237288 in cranial view; C, middle trochlea of left tarsometatarsus of pseudodontorn sp., USNM 476044 in lateral view; D, sternal half of left coracoid of *Morus* cf. *M. loxostyla* USNM 476042 in internal view; E, distal half of right carpometacarpus of *Morus* cf. *M. loxostyla*, USNM 476041 in external view.

Remarks.—This fragmentary, heavily worn specimen appears to be from a species of loon somewhat larger than the previous species; it is heavier than the well-preserved sternum of USNM 237137 from Popes Creek. If correctly assigned to Gaviidae, it may be from *Gavia* cf. *G. egeriana*, a small loon previously known only from the distal ends of humeri from the early Miocene (Ottangian) of Czechoslovakia (Svec, 1982), but specimens from the Calvert Formation of Virginia and Maryland, the St. Marys Formation of Maryland, and the Pungo River Formation of North Carolina have now been referred to this species on the basis of size and relative stoutness (S.L. Olson, pers. comm., 1997). The Pollack Farm Site specimen might well be assignable to the same species which is smaller than any Pliocene or later species of loon.

Order PELECANIFORMES
Family PELAGORNITHIDAE

Genus and species indet.

Figure 1C

Material.—Middle trochlea of left tarsometatarsus; USNM 476044, collected by G. Simonson, 4 June 1992.

Remarks.—This trochlea is slightly smaller than that of a specimen of *Pelagornis miocaenus* from Charleston, South Carolina (cast USNM 244174). Two or three specimens of pseudodontorns are thought to occur in the Pungo River Formation and the Calvert Formation of Maryland (Olson, 1984; Becker, 1987), and specimens have also been collected in Westmoreland County, Virginia (Olson, 1984). Several species of pseudodontorns occurred in the Miocene (Howard, 1957; Hopson, 1964, 1978; Scarlett,

1972). The systematics of pseudodontorns are poorly resolved (Olson, 1985) even though specimens are not uncommon and they are of nearly worldwide occurrence. This is primarily because pseudodontorn material is usually quite fragmentary, as is the Delaware specimen, and because no recent comprehensive treatment of the group has been produced.

Family SULIDAE

Morus* cf. *M. loxostylus

Figure 1D, E

Material.—Sternal half of left coracoid; USNM 476042, collected by David Crew. Distal half of major phalanx of right carpometacarpus; USNM 476041, collected by T. O'Hagan, 6 April 1992. Left phalanx 2 of pedal digit 3; USNM 476043, collected by G. Simonson, 12–13 March 1992. Tentatively referred: centrum of thoracic vertebra, USNM 476047, collected by G. Simonson, 18 May 1992; proximal end of left tibiotarsus, USNM 476049, collected by G. Simonson, 6 April 1992.

Measurements.—Coracoid, cranial width: 10.0 mm; cranial depth: 15.3 mm. Phalanx, length: 27.3 mm.

Remarks.—The first three specimens listed above are much better preserved than are the other specimens from the Pollack Farm Site. They are clearly referable to a relatively large sulid, probably *Morus loxostylus*, a common species in the Miocene Pungo River Formation of Lee Creek Mine, North Carolina, and the Calvert Formation of Maryland (Wetmore, 1926; Olson, 1984; S.L. Olson, pers. comm., 1992). One or two other species of sulids are also known from the Calvert Formation of Maryland (Wetmore, 1938; Becker, 1987) and the Kirkwood Formation of New Jersey (Olson, 1984).

Order CHARADRIIFORMES

Genus et sp. indet.

Material.—Proximal end of right scapula; USNM 446997, collected by D. Bohaska and crew, 27 April 1992.

Remarks.—This specimen is from a medium-sized charadriiform, and appears most likely to be from a rather small species of gull approximately the size of the Laughing Gull, *Larus atricilla*, although due to the fragmentary nature of the specimen its identification must be considered tentative. An unnamed species of gull of this size range occurs in the Calvert Formation (S.L. Olson, pers. comm., 1992).

Aves indet.

Material.—Proximal portion of alar phalanx 2 digit 2; USNM 476048.

Remarks.—This relatively well-preserved element is from an indeterminate bird roughly the size of a small gull, but it is not charadriiform and certainly represents yet another taxon for the Pollack Farm Site.

DISCUSSION

The lower Miocene Pollack Farm Fossil Site near Cheswold, Delaware, has yielded few bird fossils in comparison to other classes of vertebrates and invertebrates—only 11 isolated and fragmentary avian specimens assignable to at least 6 taxa are available to date. In contrast to the high diversity of terrestrial mammal species known from the site, all the bird species represented are from groups that are largely

or entirely marine. Marine mammal fossils are also common at the site but are less diverse than the land mammal assemblage.

The species composition of the avifauna from Smyrna lends support to the hypothesis that the Miocene depositional environment at this site was the nearshore area of an embayment (Ramsey et al., 1992; Ramsey, 1998). This is a typical habitat for modern loons and sulids, the two most common taxa at the site, and pseudodontorns which were strictly marine (Olson, 1984). Procellariiforms and alcids, which are relatively common groups represented by two or three species each in the Calvert Formation of Maryland (Becker, 1987), are surprisingly unrepresented in the Smyrna sample. These are generally among the most pelagic of birds, and the absence of these more highly pelagic groups (which could be due to sampling error) is the major difference seen between the avifaunas known from the lower Miocene of Delaware and Maryland.

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THE EARLY HEMINGFORDIAN (EARLY MIOCENE) POLLACK FARM LOCAL FAUNA: FIRST TERTIARY LAND MAMMALS DESCRIBED FROM DELAWARE¹

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ABSTRACT

Land mammal fossils were discovered in 1992 in the lower part of the Calvert Formation at the Pollack Farm Site, a temporary excavation for highway construction, between Smyrna and Dover, Delaware. During the short time the pit was open the collection grew to become the most diverse Tertiary land mammal fauna known in eastern North America north of Florida. The assemblage, termed the Pollack Farm Local Fauna, includes at least 26 species representing at least 17 families. The age established by the land mammals is early Hemingfordian (early Miocene), in good agreement with the mean strontium-isotope age estimate of 17.9 ± 0.5 Ma on mollusk shells. The fauna shares the greatest homotaxial similarity with the Thomas Farm Local Fauna of Florida, but also has several taxa in common with the classic early Hemingfordian faunas of the Great Plains, such as those from Quarry A of northeastern Colorado, the Runningwater Formation of western Nebraska, and the Flint Hill Quarry of southwestern South Dakota. The Pollack Farm Local Fauna provides a direct and unambiguous correlation between the North American Land Mammal Age system and marine biochronologies based on diatoms, radiolarians, foraminifers, and molluscs.

INTRODUCTION

Although terrestrial mammals of Tertiary age have been known from eastern North America for well over a century (e.g., Leidy, 1860), the eastern record has remained poor compared to the rich faunas known from western North America. In eastern North America, Tertiary land mammals are best represented in Florida, with faunas ranging from Arikareean (about 22 Ma) to Hemphillian (about 5 Ma) (MacFadden and Webb, 1982). North of Florida, Miocene land mammals are known only from a few specimens from each of a few localities: Ashley River in South Carolina (Leidy, 1860), the Kirkwood Formation in Monmouth County, eastern New Jersey (Marsh 1870a, 1870b, 1893; Wood 1939), the Chesapeake Group of Maryland (Gazin and Collins, 1950; Wright and Eshelman, 1987), and near Statenville in extreme southern Georgia (Voorhies, 1974). Only a few of these sites represent early Miocene. Recent discovery (Ramsey et al., 1992; Benson, 1993) near Smyrna, just north of Dover, Delaware, of the most diverse assemblage of Tertiary land mammals known from eastern North America north of Florida is therefore of special importance. The assemblage, described below as the Pollack Farm Local Fauna, is early Miocene; more precisely, it is early Hemingfordian in the system of North American Land Mammal Ages (Wood et al, 1941; Tedford et al, 1987). The land mammal fossils occur in nearshore marine deposits associated with rich marine faunas, vertebrate and invertebrate, thereby affording direct, unambiguous comparison of marine and nonmarine biochronologies.

The land mammals of the Pollack Farm Local Fauna are represented predominantly by single teeth and parts of postcranial elements. In just a few instances are more than one tooth associated in a single specimen. The land mammal fauna includes a minimum of 26 species representing at least 17 families in 7 orders, summarized as follows:

Order SORICOMORPHA

Family PLESIOSORICIDAE

Plesiosorex cf. *P. coloradensis*

Order ERINACEOMORPHA

Family ?ERINACEIDAE

Unidentified genus or genera

Order CHIROPTERA

Family VESPERTILIONIDAE

Unidentified genus

Order RODENTIA

Family CASTORIDAE

Anchitheriomys sp.

"*Monosaulax*" sp.

Family HETEROMYIDAE

Proheteromys magnus

Family ZAPODIDAE

Plesiosminthus sp.

Order CARNIVORA

Family URSIDAE

?*Hemicyon*

Family PROCYONIDAE

Unidentified genera

Family AMPHICYONIDAE

Amphicyon intermedius

Cynelos sp.

Family CANIDAE

Tomarctus cf. *T. thomsoni*

Tomarctus cf. *T. canavus*

Order PERISSODACTYLA

Family EQUIDAE

Archaeohippus cf. *A. blackbergi*

Anchitherium sp.

Parahippus leonensis

Family CHALICOTHERIIDAE

cf. *Tylocephalonyx* sp.

Family RHINOCEROTIDAE

Unidentified genus or genera

Order ARTIODACTYLA

Family TAYASSUIDAE

Cynorca sociale

¹ In Benson, R.N., ed., 1998, Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 153-173.

?*Desmathyus* or *Hesperhys*
?Family ANTHRACOTHERIIDAE
Family OREODONTIDAE
?Unidentified genus
Family MOSCHIDAE
Blastomeryx galushai
Family uncertain
Unidentified genera (probably 2)

Acknowledgments

From the first discovery of land mammal fossils at the Pollack Farm Site through the completion of this report, an unusually large number of people have made direct and important contributions. First and foremost were the special efforts of Gordon Simonson, supervisor at the site for Pierson Engineering. Clearly two-thirds of the terrestrial mammals known to us from the site are the direct result of his efforts. Not only did he personally find many of the specimens, but with his contagious enthusiasm and spirit of volunteerism, he encouraged his fellow workers at the site to either donate their finds to the National Museum of Natural History, or to loan them for making replicas.

The following persons donated land mammal fossils to the National Museum of Natural History: David Crew, John Danner, Mike Derieux, Stuart Derrow, David Duke, Evelyne Eshelman, Keith Glunt, Michael Miskofsky, Thomas O'Hagan, Mark Power, Deborah Paruszewski, Mark Rikerson, Sandy Roberts, Gordon Simonson, Grace Simonson, Albert Snelson, Cheryl Snelson, Scott Walters, and Kenneth Webb.

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In the field aspects of this study, Dave Bohaska deserves special mention; he made a number of collecting trips to the site, and was the National Museum's primary contact with Pierson Engineering and Century Engineering and their employees, and with the many amateurs who collected much of the material. The following people from various institutions assisted in collecting: Betty Ashby, Wally Ashby, George Fonger, Vivian Marsh, Sandy Roberts, Albert Snelson, Cheryl Snelson, Curry Snelson, and Verna Muir, all of the Calvert Marine Museum Fossil Club; Joann Austin, Ruth Bowman, Diane Crow, Stephen Curtis, Allison Elterich, Charles Fithian, Libby Gregg, Alice Guerrant, Ann Horsey, Clydia Melson, Heather Patton, and James Stewart, all associated with Delaware State Museums; Lauck Ward and Cheryl Anthony of the Virginia Museum of Natural History; Edwin Crow, Ryan Crow, and Debrah Parusewski, all of Iron Hill Museum of Natural History; William Gallagher of the New Jersey State Museum; Frederick Grady, Peter Kroehler, Robert Purdy, and Clayton Ray, all from the National Museum; and, of course, Gordon Simonson.

For permission to collect at the Pollack Farm Site, and for other courtesies and assistance that facilitated access to the site, we thank David Duke of the Department of Transportation of the State Of Delaware, Ed Adams of Century Engineering, and Gordon Simonson of Pierson Engineering.

Frederick Grady of the National Museum processed and picked the washed matrix to recover the micromammals, which added substantially to the diversity of the collection. Peter Kroehler did the photography for the plates and assisted with preparing and curating the material.

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METHODOLOGY

Though some of the vertebrate fossils reported herein were collected *in situ*, most were collected from the surface, either of freshly exposed *in situ* sediment, of stockpiled sediment at the site, or at places where the sediment had been used as road bed or embankment fill. We are confident that all of the specimens used in this study were derived from the lower shell bed of the Cheswold sands of the lower Calvert Formation (Benson, 1993, 1998; Ramsey, 1998). This conclusion is supported by the fact that all fossils that were discovered *in situ* were from this lower shell bed, all specimens have similar preservation, and all are consistent with a very restricted age assignment.³

Most of the material was recovered by walking or crawling over the exposed pit surfaces, spoil piles, and road bed fill surfaces. The best collecting conditions were after rains on newly stockpiled shell bed material. On some occasions buckets and shovels were used to toss water from the pit (constant pumping of the pit was necessary to keep it from filling with water) onto the outcrop faces or surfaces of spoil piles to wash matrix from fossils. Pumps with hoses, and even buckets of front end loaders, were similarly employed with good results. When a potentially good lens was encountered in place, a tool such as an oyster knife was used to carefully scrape away the surface a thin layer at a time to expose fossils.

Virtually all of the teeth of small mammals such as the heteromyid rodent and bat were recovered by screening and picking. Matrix was first screened through hardware cloth at the pit. The coarser material (about 1 cm and larger) that remained in the screen was sorted at the site; the finer material, representing about 20 percent of the original volume, was bagged and transported to the National Museum of Natural History for processing. Here the matrix was further graded

³ The lower shell bed was not unearthed until winter 1991–1992. Collections made before this time could only have been from the upper shell bed.—ED

using screen with approximately 3-mm openings, and the coarser fraction was picked with unaided eyes; the finer fraction was then first sorted under a magnifying light on black background to recover otoliths and whole small invertebrates. After this initial picking, it was placed in an acidic bath to remove the fragmentary shell material, reducing this fine fraction to about 10 percent of its original volume. The residue was then picked under a binocular microscope at 10 power and high intensity light on white background, as virtually all of the teeth and bones have a very dark color. This process, though tedious and time consuming, produced about 12–14 mammal teeth from an estimated 250 kg of sediment processed.

Abbreviations Used

When used with measurements, AP = anteroposterior, TR = transverse. In dental notations, L = left and R = right; upper case letters refer to upper teeth, and lower case letters refer to lower teeth (e.g., M1 is the upper first molar, p3 is the lower third premolar). Acronyms preceding specimen numbers refer to institutional collections: AMNH = The American Museum of Natural History, New York; F:AM, Frick Collection, American Museum of Natural History; LACM, Los Angeles County Museum of Natural History; UCMP, University of California Museum of Paleontology, Berkeley; UF, University of Florida; UNSM = University of Nebraska State Museum, Lincoln; USNM = National Museum of Natural History (United States National Museum), Washington.

SYSTEMATIC PALEONTOLOGY

Order SORICOMORPHA Gregory, 1910

Superfamily SORICOIDEA Fischer de Waldheim, 1817

Family PLESIOSORICIDAE Winge, 1917

Plesiosorex Pomel, 1848

Plesiosorex cf. *P. coloradensis* Wilson, 1960

Material.—USNM 475857, right m1.

Discussion.—This tooth (Fig. 1A–C) corresponds closely in size to m1 of *Plesiosorex coloradensis*, and differs only slightly in morphology. In the Pollack Farm tooth, the trigonid appears to be slightly longer anteroposteriorly, relative to the talonid, because of its longer and slightly more obliquely oriented paraconid blade. With a sample of one it cannot be determined whether this difference is individual variation or species distinction, so we assign the tooth provisionally to *P. coloradensis*. Measurements of comparable molars in the sample of *P. coloradensis* from Quarry A of northeastern Colorado range from 3.9 to 4.0 mm anteroposteriorly, and from 2.5 to 2.6 mm transversely (Wilson, 1960:24). The same measurements of USNM 475857 are 3.8 mm and 2.3 mm, respectively; the latter measurement, however, is a minimum because some enamel is broken from the buccal surface of the protoconid.

Order ERINACEOMORPHA Gregory, 1910

Family ?ERINACEIDAE Fischer de Waldheim, 1817

Material.—USNM 475854, left M2 or M3; USNM 475862, trigonid of left lower molar; USNM 475858, left lower molar.

Discussion.—USNM 475854 (Fig. 1D) most closely resembles M3 of the galericine hedgehog *Lanthanotherium* (see James, 1963, figs. 13 and 16, for example). It measures

2.15 mm transversely and 2.11 mm anteroposteriorly (along buccal margin), versus 1.82 mm and 1.94 for the same measurements of *Lanthanotherium sawini*, UCMP 54600 (James, 1963, table 8). Except for its smaller size, USNM 475854 also resembles M2 of the brachyericine hedgehogs such as *Brachyerix* and *Amphechinus* (Rich, 1981); in these brachyericines, M3 has been lost and M2 has been reduced so that it superficially resembles the M3 of some other hedgehogs such as *Lanthanotherium*.

USNM 475858 is a left lower molar (Fig. 1E), so abraded that identification is not possible beyond saying that it is clearly a lower molar of tribosphenic type with distinct trigonid and talonid. USNM 475862, not illustrated, is also not identifiable beyond saying that it is the trigonid of a lower molar of hedgehog size and has the reduced paraconid typical of hedgehogs. It is doubtful that these three specimens represent one genus, and is by no means certain that they represent hedgehogs.

Order CHIROPTERA

Suborder MICROCHIROPTERA

Family VESPERTILIONIDAE Gray, 1821

Material.—USNM 475856, right M1 or M2. USNM 475860, trigonid of left lower molar.

Discussion.—A very small bat is represented by the M1 or M2 (Figure 1F), which measures 1.68 mm anteroposteriorly by 1.93 mm transversely; the size is comparable to that of the smaller species of *Myotis*, but in this tooth the lingual margin is rounded rather than having the angular outline seen in *Myotis*. Bats are well represented in the Thomas Farm fauna of Florida, but this tooth appears to be unlike any of those. The lower molar talonid (USNM 475860, Fig. 1G) also represents a microchiropteran bat, but is probably not further identifiable, and does not necessarily represent the same taxon as the upper molar.

Order RODENTIA Bowdich, 1821

Family CASTORIDAE Hemprich, 1820

Anchitheriomys Roger, 1898

Anchitheriomys? sp.

Material.—USNM 475897, a fragment of incisor.

Discussion.—This specimen, which consists of a section of the anterior face of an incisor, indicates the presence in the fauna of a large rodent. The curvature, in cross section, of its anterior face and the prominent longitudinal corrugation of its enamel (Fig. 1H) are characteristic of *Anchitheriomys* (see Voorhies, 1990; Wilson, 1960). Furthermore, *Anchitheriomys* is the only rodent known from the North American early Miocene that is this large. The complete cross section of the incisor is not preserved in this specimen; the minimum transverse dimension is 8 mm.

“*Monosaulax*” Stirton, 1935

“*Monosaulax*” sp.

Material.—USNM 475818, partial left dentary with m1-m3; USNM 475836, right P4; USNM 475933, left P4 with damaged crown; USNM 475896, part of ?right m1 or m2; USNM 475863, part of incisor; 475934, cast of part of incisor in private collection.

Discussion.—Several characters of this small beaver (Figure 1I–L) place it in the “*Monosaulax*”/*Eucastor* group:

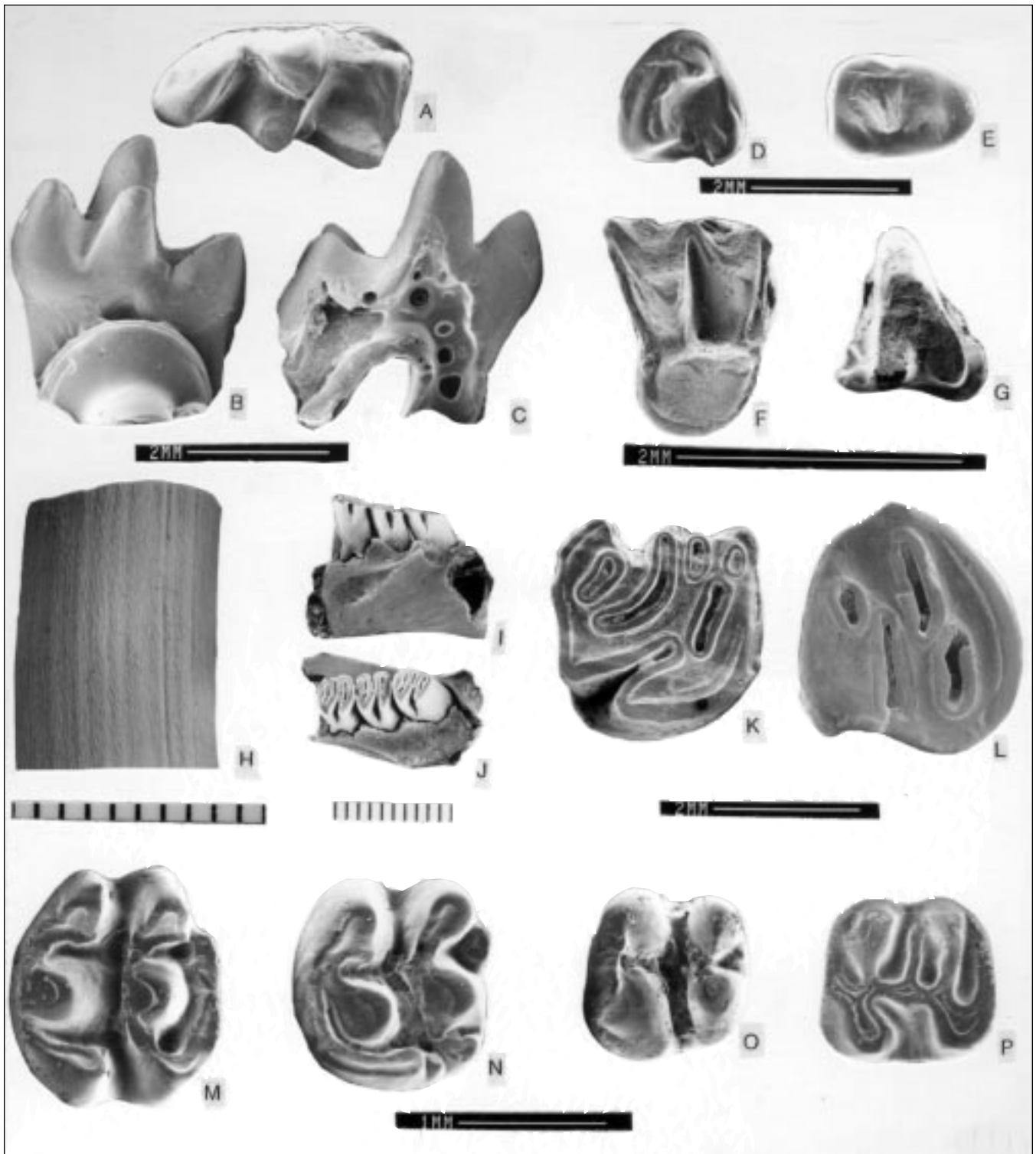


Figure 1. Insectivores (A–E), bats (F–G) and rodents (H–P) of Pollack Farm Local Fauna. A–C, USNM 475857, *Plesiosorex* cf. *P. coloradensis* in A, occlusal, B, lingual, and C, buccal views. D, USNM 475854, left M2 of brachyricine erinaceid or M3 of galericine erinaceid. E, USNM 475858, left molar of ?insectivore. F–G, Microchiroptera; F, USNM 475856, right M1 or M2, vesperilionid; G, USNM 475860, trigonid of left m1 or m2. H, USNM 475897, *Anchitheriomys*, fragment of incisor enamel. I–L, “*Monosaulax*” sp.; I–J, USNM 475818, left partial dentary with m1–m3, in I, buccal, and J, occlusal views; K, USNM 475836, right P4; L, USNM 475896, part of left m1 or m2. M–O, *Proheteromys magnus*; M, USNM 475855, right M1 or M2; N, USNM 475853, left m1 or m2; O, USNM 475852, right p4. P, *Plesiosminthus* sp, USNM 475851, left M2. All approximately X12.5 except for H, which is approximately X4.5 and I–J, which are approximately X2. Scales in millimeters.

in the lower cheek teeth, the protoconid and hypoconid pillars are quite angulate (Fig. 1I–J), suggesting the “rabbit pattern” that Stirton (1935) cited as characteristic of *Eucastor*; in USNM 475836, the P4 (Fig. 1K), the hypoflexus approximately equals the paraflexus, and these and the mesoflexus and metaflexus are arched anteriorly; the buccal end of the hypoflexus is opposite the lingual end of the paraflexus. This P4 (USNM 475836) has two additional fossettes, which Xiaofeng Xu (personal communication, 1993) considers a plesiomorphic character common in earlier beavers, including Arikareean forms such as *Palaeocastor* and *Capacikala*. The Pollack Farm beaver differs from typical *Palaeocastor*, however, in the other characters mentioned above, as well as in the cross sectional shape of its incisors, which have rounded anterior faces rather than flat.

Voorhies (1974) reported the first known Tertiary record of Castoridae in eastern North America, a single tooth from southern Georgia referred to cf. “*Monosaulax*” and dated as Barstovian by means of associated teeth of *Merychippus*. We follow Voorhies (1990) in placing the name “*Monosaulax*” within quotation marks, because of the uncertain status of its type species, *M. pansus* (Cope). Stout (in Skinner and Taylor, 1967), for example, offered an opinion, without the supporting justification, that *M. pansus* is a junior synonym of the type species of *Eucastor*, *E. tortus* Leidy, 1858. Xiaofeng Xu (personal communication, 1993) also considers *Monosaulax* a junior synonym of *Eucastor*.

Measurements of the cheek teeth of USNM 475818, taken at the occlusal surface are: m1, AP=3.3 mm, TR=3.7 mm; m2, AP=3.3 mm, TR=3.6 mm; m3, AP=3.6 mm, TR=3.6 mm. USNM 475836, a P4, is AP=3.1 mm, TR = approximately 3.2 mm (buccal edge is broken so this measurement is inexact) at the occlusal surface. These measurements indicate that this small beaver is within the size range of *Monosaulax* from Quarry A of northeastern Colorado, discussed by Galbreath (1953) and Wilson (1960). Wilson (1960) referred to the Quarry A material as “*Monosaulax* n. sp.” and provided a description and measurements, but refrained from naming the species “in deference to Thompson Stout’s forthcoming work on the Castoridae of the World,” which remains unpublished. Identification of the Delaware material to specific level, if indeed possible, should be done in the context of a broader study of the generic group. Suffice it to say here that it represents a small and relatively plesiomorphic species of “*Monosaulax*,” which is most likely a junior synonym of *Eucastor*.

Family HETEROMYIDAE Allen and Chapman, 1893

Proheteromys Wood, 1932

Proheteromys magnus Wood, 1932

Material.—USNM 475855, RM1 or M2; USNM 475853, Lm1 or m2; USNM 475852, Rp4.

Discussion.—The original material of *P. magnus*, including its holotype, is from the Thomas Farm Fauna of Florida (Wood, 1932). Several teeth from Quarry A of northeastern Colorado were referred to the same species by Wilson (1960). The three teeth from the Pollack Farm Site (Fig. 1M–O) are assigned to *Proheteromys magnus* primarily on the basis of size, but Black’s (1963) emended diagnosis for the species also includes several characters that apply here: “largest species of genus; central valley completely

bisects upper molars; p4 with median crest; anteroconid present on p4; stylids small on lower molars; posterior cingulum short but prominent on lower molars.”

The upper molar, USNM 475855, measures 1.44 mm anteroposterior, by 1.79 mm transversely; the upper molar of *P. magnus* from Thomas Farm measures, respectively, 1.5 mm, by 1.8 mm (Black, 1963:500). The M1 or M2 referred from Colorado is slightly smaller; the same measurements are, respectively, 1.25 mm and 1.60 mm (Wilson, 1960:80).

The lower molar, USNM 475853, measures 1.44 mm anteroposteriorly and 1.57 mm transversely. The sample of *P. magnus* from Thomas Farm is respectively, 1.53 mm (mean, N = 3) by 1.56 mm (mean, N = 3) (Black, 1963:500).

The p4, USNM 475852, measures 1.28 mm anteroposteriorly by 1.23 mm transversely. The same measurements of the Thomas Farm p4 are 1.4 mm by 1.4 mm (Black, 1963:500), and of a Colorado specimen are 1.4 mm by 1.2 mm (Wilson, 1960:80).

Though these three teeth from Delaware conform to the emended diagnosis of *P. magnus* given by Black (1963), there are some morphologic differences between them and the Florida and Colorado specimens that may be worth noting (see Lindsay, 1972:40, fig. 19 for heteromyid dental terminology). In the upper molar, USNM 475855 (Fig. 1M), the anterior cingulum is stronger, extending from the protostyle across the anterior margin of the tooth to meet the base of the paracone, enclosing two small basins between it and the protoloph (compare Fig. 1M with Black, 1963, fig. 5b, and with Wilson, 1960, fig. 123). In these characters, this upper molar bears considerable resemblance to *Proheteromys* sp. from the Harrison Formation of Nebraska (Korth, 1992, fig. 13A); the Nebraska specimen is substantially smaller, however. In the lower molar, USNM 475853 (Fig. 1N), the anterior cingulid, which ends in the protostylid, seems to extend slightly farther posteriad, and between the protostylid and hypostylid is a very small separate cusp; this more posteriorly placed protostylid, along with the small, separate cusp, block the transverse valley so that it does not open on the buccal side of the tooth, as it appears to do on the Florida specimen (compare Fig. 1N with Black, 1963, fig. 5e). The Pollack Farm tooth is suggestive of some specimens of *P. sulculus*, in which the anterior cingulid, protostylid and hypostylid appear to be connected in one continuous crest (see for example Wilson, 1960, fig. 108). These molars of *P. sulculus*, however are 25 to 30 percent smaller than the tooth from Delaware and others referred to *P. magnus*.

Family ZAPODIDAE Coues, 1875

Subfamily SICISTINAE Allen, 1901

Plesiosminthus Viret, 1926

Plesiosminthus sp.

Material.—USNM 475851, left M2.

Discussion.—One isolated but distinctive tooth (Fig. 1P) represents a small species of *Plesiosminthus*. The tooth is very low crowned; the slight wear has not obscured details of morphology. A species assignment is probably not possible on the basis of this single tooth. It is of appropriate size to be *P. galbreathi* Wilson, 1960, and, as in this species and also in *P. clivosus* Galbreath, 1953, the endoloph is connected to the protocone (see Green, 1977:997 for terminology); in other species, *P. grangeri* (Wood, 1935) and *P. sabrae* (Black, 1958), the endoloph normally stops short of

the protocone (see Green, 1977:1001, fig. 3, for example). In the Pollack Farm tooth the mesoloph is long, reaching nearly to the buccal margin of the tooth; its buccal end is associated more directly with the metacone than with the paracone.

USNM 475851 measures 1.27 mm anteroposteriorly and 1.18 mm transversely. No upper second molars of *P. clivus* were reported from Quarry A of northeastern Colorado, but Wilson (1960:85) gave mean measurements of 1.4 mm (anteroposterior) and 1.2 mm (transverse) for *P. galbreathi*. Green (1977) referred specimens from the Batesland Formation of South Dakota to *P. clivus*; he reported mean values of 1.04 mm and 0.89 mm for the same respective measurements, somewhat smaller than *P. galbreathi* and the Pollack Farm tooth. In summary, the Delaware tooth represents a small primitive *Plesiosminthus*, which in size and morphology is comparable to the species that occur in early Hemingfordian deposits of the western Great Plains and Rocky Mountain areas.

Order CARNIVORA Bowdich, 1821
Family URSIDAE Fischer de Waldheim, 1817
Subfamily HEMICYONINAE Frick, 1926

?*Hemicyon* Lartet 1851

Material.—USNM 475830, distal end of left radius.

Discussion.—The specimen (Fig. 2A–B) represents a relatively large carnivore. It is slightly abraded, but the measurements of 45 mm for the greatest width and 24 mm for the depth are close to its original size. It is about two-thirds the size of a radius of *Amphicyon* (UF 95032) from Thomas Farm, and differs in morphologic details, which are more suggestive of a bear. Our tentative referral of this distal radius to *Hemicyon* is circumstantial: it is of appropriate size to be a radius of the ursid *Hemicyon*; the Pollack Farm fauna and Thomas Farm fauna are otherwise largely homotaxial; *Hemicyon* occurs in the Thomas Farm fauna (Tedford and Frailey, 1976); so *Hemicyon* would not be unexpected in the Pollack Farm fauna.

Family PROCYONIDAE Gray, 1825
Subfamily PROCYONINAE Gray, 1825

Material.—USNM 475815, right M1.

Discussion.—The M1 (Fig. 2C) is reminiscent of that of *Edaphocyon*, but differs in having a more nearly isolated metaconule. Except for its much smaller size, it is most like an undescribed tooth from Sucker Creek, Oregon (comparison made with AMNH 105117, a cast of LACM 1771).

Subfamily BASSARISCINAE Gray, 1869

Material.—USNM 475814, posterior part of right mandibular ramus with alveoli for m2.

Discussion.—The jaw fragment (Fig. 2D–E), represents a smaller animal than the molar mentioned above. The posterior alveolus is anteroposteriorly elongate, indicating the presence of an elongate m2, which is characteristic of procyonids. This fragment is of similar size, and otherwise compares well with a small *Bassariscus*-like form represented by two partial jaws in the Frick Collection (AMNH) from Cottonwood Creek Quarry (Hemingfordian) in western Nebraska (the Frick specimens are not cataloged but have “Hay Springs” field numbers 396-2828 and 397-2930).

Family AMPHICYONIDAE Haeckel, 1866
***Amphicyon* Lartet, 1836**

***Amphicyon intermedius* White, 1940**

Material.—USNM 475816, left m1; USNM 475916, cast of right m2 in private collection; USNM 475917, cast of trigonid of right m1 in private collection; USNM 475829, left scapholunar.

Discussion.—Close correspondence is found between these teeth (Fig. 2F–H) and those of *Amphicyon intermedius* from the Thomas Farm of Florida. The m2 (USNM 475916, Fig. 2F), although well worn, nevertheless shows a distinct metaconid, as is also seen in the same tooth of MCZ 3631 (comparison with cast in AMNH), the type of *A. intermedius*, a left mandibular ramus with p3-m2 (White, 1940: pl. III). The width of the Pollack Farm m2 is 16.7 mm, versus 14.5 mm in MCZ 3631 (White, 1940:32).

The Pollack Farm m1 (USNM 475816, Fig. 2G–H) measures 27.8 mm anteroposteriorly and 13.9 mm transversely, very close to the size of m1 in the type of *A. intermedius*, MCZ 3631 (29 mm anteroposteriorly, 14 mm transversely), and also to m1 in MCZ 3630 (29 mm anteroposteriorly, 13.5 mm transversely), a right mandibular ramus with p3-m1. The Pollack Farm m1 appears to be equal in size to an unworn m1, UF 95013, and noticeably smaller than MCZ 5833, both of which are also from Thomas Farm. The entoconid of the Delaware m1 is slightly less distinct than on the Florida specimens, but the morphology is otherwise very similar. The size disparity (i.e., the m1 is equal to or slightly smaller than in Thomas Farm material, while the m2 is larger), is not great enough to suggest more than one species; sexually dimorphic size disparity in these larger amphicyonids is well documented (Ginsburg, 1961; Ginsburg and Telles Antunes, 1968; R. M. Hunt, personal communication, 1994).

The scapholunar, USNM 475829, is morphologically similar to several in the University of Florida collections (e.g., UF 95024, 95025, 67222), although it is substantially smaller. Its reference to *A. intermedius* is not certain, but it does seem to be too large to belong to the smaller amphicyonid *Cynelos* discussed below.

***Cynelos* Jourdan 1848**

***Cynelos* sp.**

Material.—USNM 475811, left jaw fragment with posterior half p4 and anterior half m1; tentatively referred, USNM 475918, cast of distal end of right humerus in private collection.

Discussion.—In USNM 475811 (Fig. 2I–J) the paraconid of m1 is shorter and oriented more obliquely than it is in *Amphicyon*, and the posterior surface of the trigonid is squared off and oriented more nearly transversely. Enough of the p4 remains to show that it had a distinct posterior accessory cuspid. In all parts remaining for comparison, the specimen corresponds very closely, both in size and morphology, to UNSM 25675 (comparisons with cast in AMNH), identified as *Cynelos* sp., from the lower part of the Marsland Formation of western Nebraska.

The distal portion of a right humerus (Fig. 2K) is clearly from an amphicyonid carnivore. The entepicondylar foramen is retained in amphicyonids, and although the medial and lateral epicondyles are broken and abraded in this spec-

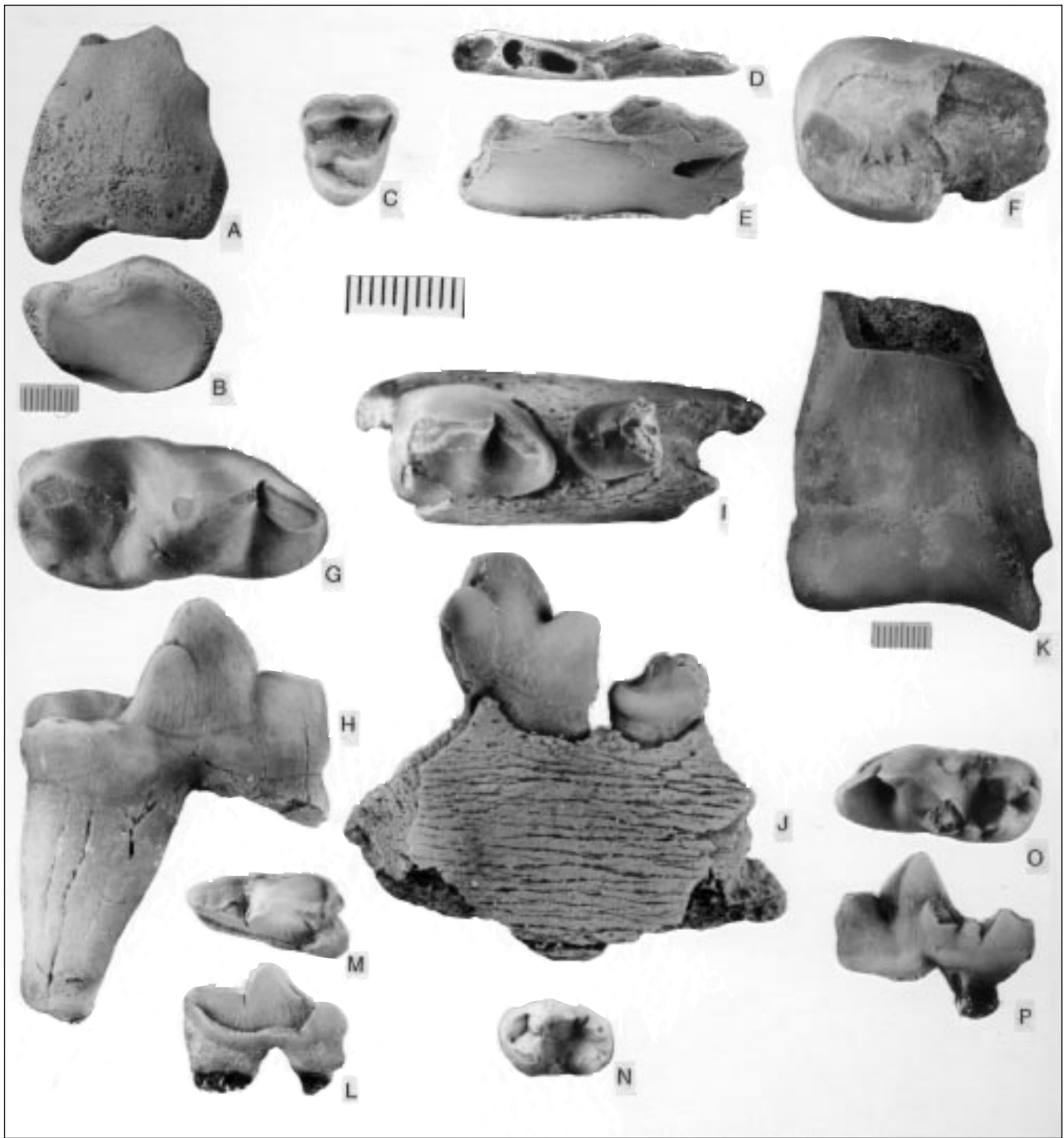


Figure 2. Carnivores of Pollack Farm Local Fauna. A–B, Ursidae, *?Hemicyon* sp., USNM 475830, distal end of radius in A, anterior, and B, distal views. C–E, Procyonidae; C, USNM 475815, right M1 of procyonine, ?genus. D–E, USNM 475814, part of right mandible of bassariscine, ?genus, in D, alveolar, and E, lingual views. F–K, Amphicyonidae; F, USNM 475916, *Amphicyon intermedius* incomplete right m2; G–H, USNM 475816, *Amphicyon intermedius* left m1 in G, occlusal, and H, lingual views; I–J, USNM 475811, *Cynelos* sp., mandibular fragment with parts of p4 and m1, in I, occlusal, and J, lingual views; K, USNM 475918, *?Cynelos* sp., distal end of right humerus. L–P, Canidae; L, USNM 475812, *Tomarctus* cf. *T. thomsoni*, right P4 in L, lingual, and M, occlusal views; N–P, *Tomarctus* cf. *T. canavus*; N, USNM 475930, left m2; O–P, USNM 475817, right m1 in O, occlusal, and P, lingual views. All approximately X2, except K, which is approximately X1. Scales in millimeters.

imen, enough remains to demonstrate that an entepicondylar foramen was present. A humerus of *Amphicyon* from Thomas Farm, Florida (UF/FSG 6334) is morphologically identical to the Delaware humerus, except that it is nearly twice the size. The Delaware specimen is therefore assigned to *Cynelos*, which is substantially smaller than *Amphicyon* and the only other amphicyonid presently known in the assemblage.

Family CANIDAE Fischer de Waldheim, 1817

***Tomarctus* Cope, 1873**

***Tomarctus* cf. *T. thomsoni* (Matthew, 1907)**

Material.—USNM 475812, right P4.

Discussion.—A small species of Caninae is represented by an upper carnassial (Fig 2L–M) that is virtually identical to P4 in the type of *Tomarctus thomsoni* (originally *Cynodesmus thomsoni* Matthew, 1907) (compare Fig. 2L–M with Matthew 1907, fig. 5). USNM 475812 is 13 mm from the most anterior part of its paracone to the most posterior part of the metacone, the same size as that given by Matthew (1907, p. 188) for P4 of *T. thomsoni*.

***Tomarctus* cf. *T. canavus* (Simpson), 1932**

Material.—USNM 475817, right m1; USNM 475930, cast of left m2 in private collection; USNM 475832, right c1.

Discussion.—The lower molars, m1 and m2 (Fig. 2N–P) are at least 20 percent larger than the same teeth of *T. thomsoni* (m1 is 17.5 mm anteroposteriorly, and m2 is 10.5 mm anteroposteriorly, versus 14.5 mm and 7.5 mm, respectively, in *T. thomsoni*). These teeth are most similar to Thomas Farm *Tomarctus canavus* specimens such as UF 94868, 19952, and especially to the unworn right m1 of UF 5658. This m1 and m2 are both slightly larger than the same teeth of the type of *T. canavus*; measurements given by Simpson (1932:20) are 16 mm AP and 7 mm TR for m1, and 9 mm AP by 6 mm TR for m2; The Delaware m1 is 17.5 mm AP by 7.6 mm TR, and the m2 is 10.5 mm AP by 6.3 mm TR. The morphology is very close, however (compare Fig. 2O–P with Simpson, 1932, fig. 4). In the Delaware specimen, the talonid basin forms a distinct cross or plus sign, as it does also in the Thomas farm specimens of *T. canavus*. These Pollack Farm teeth are also closely comparable to specimens identified as *Tomarctus* sp. in the AMNH collections from the Runningwater Formation of western Nebraska.

Order PERISSODACTYLA Owen, 1848

Family EQUIDAE Gray, 1821

***Archaeohippus* Gidley, 1906**

***Archaeohippus* cf. *A. blackbergi* (Hay, 1924)**

Material.—USNM 475782, left M1 or M2; 475783 left M1 or M2; 475777, left M1 or M2; 475776, left ?P4, missing most of ectoloph; USNM 475911, cast of right ?P4 in private collection; USNM 475910, cast of right P2 in private collection; 475792, ectoloph of right upper cheek tooth; USNM 475781, left m1 or m2; USNM 475915, cast of left p3 or p4 in private collection; USNM 475913, cast of right m1 or m2 in private collection; USNM 475914, cast of anterior half of left lower cheek tooth from private collection; 475796, distal end of left humerus; 475797, proximal end of right radius; 475806, proximal half right ulna; 475795, distal

Table 1

Measurements in millimeters of teeth of *Archaeohippus* cf. *A. blackbergi* from Pollack Farm Local Fauna. AP = anteroposterior, TR = transverse, CR = crown height at unworn paracone.

SPECIMEN	AP	TR	CR
USNM 475782, M1 or M2	11.1	13.0	—
USNM 475783, M1 or M2	10.7	12.9	—
USNM 475777, M1 or M2	0.5	12.1	—
USNM 475911, ?P4	11.0	12.9	8.1
USNM 475910, P2	11.5	10.1	—
USNM 475915, p3 or p4	11.1	9.2	—
USNM 475781, m1 or m2	9.9	6.6	—
USNM 475913, m1 or m2	10.2	6.5	—

end right radius; 475799, right astragalus; 475810, right partial astragalus; 475794, distal end of metapodial; 475804, distal end of metapodial.

Discussion.—The small species of *Archaeohippus* represented by these teeth and parts of postcranial elements was one of the more common elements of the fauna. These teeth are slightly smaller than those referred to *A. blackbergi* from Thomas Farm of Florida, although the upper end of the size range of the Pollack Farm teeth overlaps the lower end of the size range of the Florida sample (see Table 1 for measurements; compare with White, 1942, fig. 2). Morphologically they are very similar to some of the Florida specimens (UF 43620 for example), but also differ in some characters, or at least in the consistency of characters, from many of the Florida specimens.

In the six well-preserved upper teeth from the Pollack Farm Site (Fig 3A–F), the metaloph connects to the ectoloph in all but the P2; this seems also to be the condition in *A. blackbergi*. No crochet is present in any of the six Pollack Farm teeth that permit this determination; White (1942, fig. 2) indicates a crochet in more than half the molars and premolars of Thomas Farm *A. blackbergi*. None of the Pollack Farm teeth has any plications on the metaloph; plications are present on about one third of the Florida teeth of *A. blackbergi*. In the six well preserved upper teeth from Pollack Farm, the protocones are distinct from the protoconule (especially evident on the unworn tooth, USNM 475776, Fig. 3E), and distinct constrictions separate the hypocones from metaconules; in most Thomas Farm *A. blackbergi* the protocones are somewhat less distinct and the hypocones are not at all distinct within the metaloph. The Pollack Farm teeth all have a narrow crest extending from the posterior cingulum near the metastyle, diagonally toward the metaloph, closing off the postfossette; White (1942:19) termed this structure the hypoloph, and noted its presence in many teeth of Thomas Farm *A. blackbergi*, particularly in the premolars. In the Pollack Farm teeth this hypoloph usually joins the metaloph near or at the junction of metaconule and hypocone.

White (1942) demonstrated that the sample referred to *A. blackbergi* (White considered it *Parahippus blackbergi*) from Thomas Farm of Florida has a 16 percent variation in size, that all of the tooth characters were also extremely variable, but that the different character states were not associated in any consistent way that would permit separation into more than one species. Bader (1956) conducted a quantitative study of the Thomas Farm equidae and found that while tooth characters are variable, those of *A. blackbergi* were

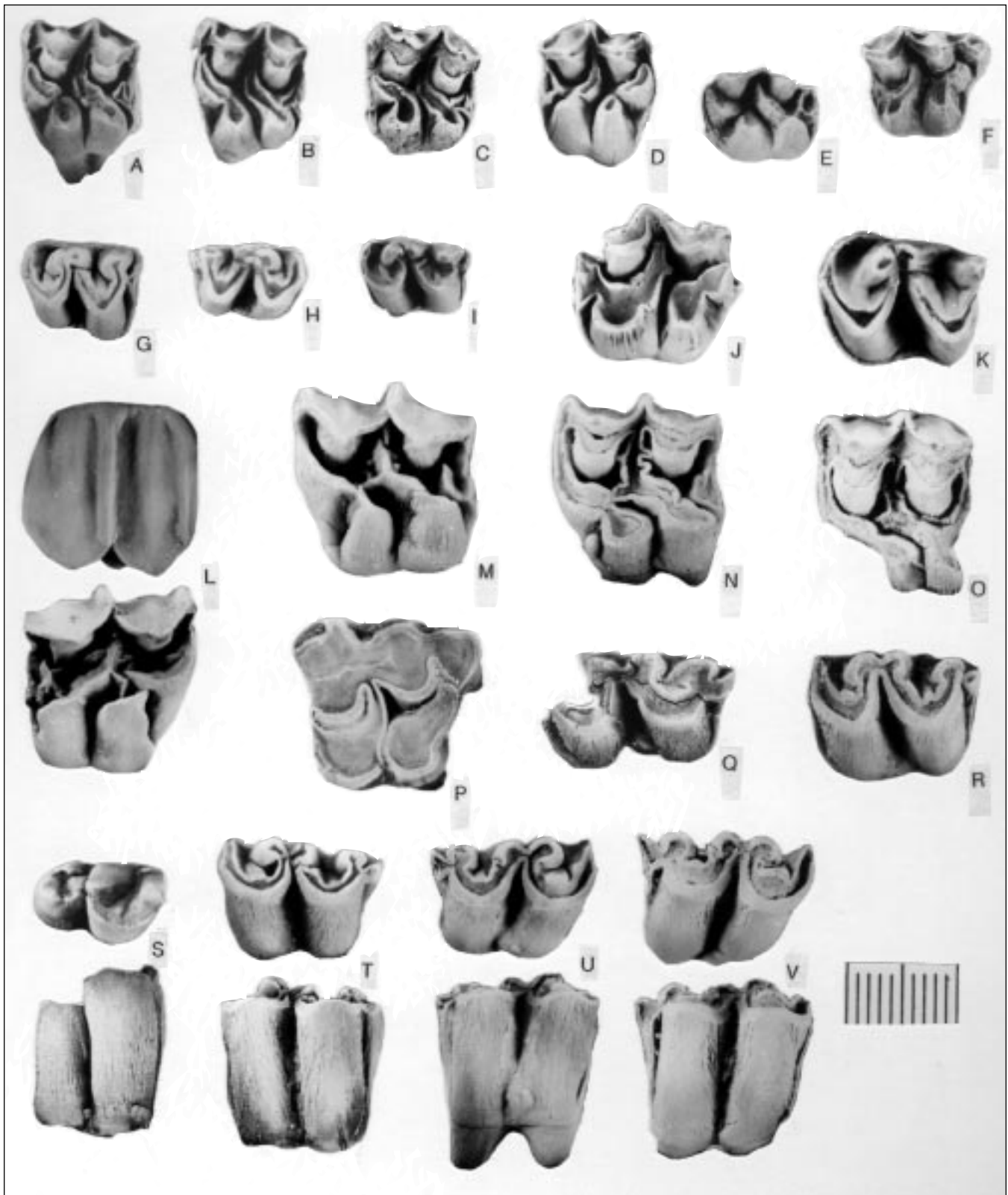


Figure 3. Equidae of Pollack Farm Local Fauna. A–I, *Archaeohippus* sp.; A, USNM 475782, left M1 or M2; B, USNM 475783, left M1 or M2; C, USNM 475777, left M1 or M2; D, USNM 475911, right ?P4 ; E, USNM 475776, part of left ?P4; F, USNM 475910, right dP2; G, USNM 475915, left p3 or p4; H, USNM 475913, right m1 or m2; I, USNM 475781, left m1 or m2. J–K, *Anchitherium* sp.; J, USNM 475775, right P2 missing ectoloph and parastyle; K, USNM 475780, left m1 or m2. L–V, *Parahippus leonensis*; L, USNM 475784, right M2 in buccal (above) and occlusal (below) views; M, USNM 475908, left ?M2; N, USNM 475906, left M1; O, USNM 475788, incomplete left dP3 or dP4; P, USNM 475907, right P2; Q, USNM 475778, left dp3; R, USNM 475903, left p4; S, USNM 475905, incomplete right m3, in occlusal (above) and buccal (below) views; T, USNM 475904, left m1 or m2, in occlusal (above) and buccal (below) views; U, USNM 475902, right m1 or m2, in occlusal (above) and buccal (below) views; V, USNM 475785, right m2. All approximately X2. Scale in millimeters.

comparable to other species of the genus.

We assign the Pollack Farm *Archaeohippus* tentatively to *A. blackbergi*, but emphasize that this species as presently constituted may include more than one species.

***Anchitherium* von Meyer, 1844**

***Anchitherium* sp.**

Material.—USNM 475775, right P2 missing ectoloph and parastyle; USNM 475780, left lower molar with posterior end missing.

Discussion.—These teeth (Fig. 3J-K) are of the same general size as, or perhaps slightly larger than, the *Parahippus* teeth discussed below, but clearly belong to a more primitive horse with lower crowned teeth. The P2 (Fig. 3J) is missing so much of the buccal portion that no standard measurements can be recorded; it is 14 mm from the posterior edge of the hypostyle to the anterior edge of the protoconule. The metaloph is connected to the ectoloph. Along the lingual margin, especially at the base of protocone and hypocone, is a heavy basal shelf; this shelf does not have a well defined edge as would be expected with an internal cingulum, but the present appearance may be due to post mortem abrasion.

USNM 475780 (Fig. 3K) is identified as a lower molar, rather than premolar, because the anterior part of the tooth is broader than the posterior part. The metaconid-metastylid column is connate in lingual view; the metaconid is distinct and slightly separated from the metastylid. No parastylid is developed; the paralophid simply descends lingually and turns backward toward the base of the metaconid. In size and morphology this lower molar is comparable to m1 or m2 of larger species of *Miohippus*, such as *M. validus*, but also resembles smaller species of *Anchitherium* such as *A. agatensis* and *A. clarencei*. The maximum width of the tooth, 12.7 mm, is from the lingual margin to the buccal base of the protoconid. If this tooth is m1 or m2, it is slightly smaller, and if m3 somewhat larger, than those teeth in the mandible (FSGS V-5423) from Thomas Farm of Florida referred by Simpson (1932) to *Anchitherium clarencei*, which have widths of 14.5 mm and 13.5 mm, and 11.5 mm, respectively. As in *A. clarencei*, this tooth has a distinct external cingulum and no internal cingulum.

These two teeth, neither of which is complete, are probably not sufficient basis for confident specific identification, but they surely represent an anchitherine horse, which we tentatively consider a small species of *Anchitherium*.

***Parahippus* Leidy, 1858**

***Parahippus leonensis* Sellards, 1916**

Material.—USNM 475784, unworn right M2; USNM 475908, cast of left unworn ?M1 in private collection; USNM 475906, cast of slightly worn left M1 in private collection; USNM 475907, cast of worn right P2 in private collection; USNM 475788, left DP3 or DP4, worn; USNM 475909, cast of P3 or P4, lacking ectoloph, in private collection; 475786, tooth fragment consisting of paracone and mesostyle; USNM 475902, cast of right m1 or m2 in private collection, slightly worn; USNM 475904, cast of left m1 or m2 in private collection, slightly worn; USNM 475903, cast of left p4 in private collection, moderate wear; USNM 475785, right m2, slight wear; USNM 475788, left dp3,

deciduous premolar, moderate wear; USNM 475905, cast of right m3, missing trigonid, from private collection; USNM 475787, trigonid of right lower cheek tooth, slight wear; USNM 475808, right astragalus; USNM 475790, left astragalus; USNM 475789, right calcaneum; USNM 475793, partial right calcaneum; USNM 475809, distal part of metapodial; USNM 475802, left navicular; USNM 475791, distal end left femur.

Discussion.—This material (Fig. 3L-V) represents a small species of *Parahippus* that has, compared to other *Parahippus*, a combination of primitive and advanced characters. For dental terminology used here, see MacFadden (1984:17, fig. 4). In one of the two unworn teeth, USNM 475784, the protocone is separated by a notch from the protoconule, whereas a sharp crest is continuous from protoconule to protocone in the other; with slight wear the protoconule and protocone are invariably linked. In these unworn teeth, shallow notches separate the crochet from the protoloph and the hypostyle from the hypocone, but with slight wear the prefossette and the postfossette become completely isolated. In the two unworn teeth, the protoconule-protocone connection appears to be higher than the crochet-protoloph connection, and the hypostyle-metaloph connection is even more imperfectly formed. The hypocone is strongly united to the metaconule in all specimens. At least two pli prefossettes and two pli postfossettes are developed on the metaloph on the few specimens where this can be determined. The pli caballin is absent on USNM 475906, barely indicated on USNM 475908, and prominent on USNM 475784. No cement is seen on any of the teeth, with the possible exception of USNM 475909, which might have a very thin coat of cement in the fossettes and on the anterior surface of the protoloph. The hypostyle is quite complicated, with at least one plication extending into the postfossette, and in the unworn tooth, USNM 475784, it is star-shaped. The metaconid and metastylid are distinctly separated in the lower teeth.

Table 2

Measurements in millimeters of elements of *Parahippus leonensis* from Pollack Farm Local Fauna. AP = anteroposterior, TR = transverse, CR = crown height of unworn teeth at mesostyle.

SPECIMEN	AP	TR	CR
USNM 475784, right M2	15.9	17.4	14.1
USNM 475906, left M1	15.0	17.1	—
USNM 475908 left ?M1	16.6	18.8	13.5
USNM 475907 right P2	16.5	15.9	—
USNM 475902 right m1 or m2	15.0	9.8	—
USNM 475903 left p4	16.0	11.6	—
USNM 475904 left m1 or m2	14.9	10.4	—
USNM 475785 right m2	16.2	10.1	—
USNM 475789 Right calcaneum maximum length,	58.4 mm		
USNM 475809 Distal metapodial, max width across trochlea,	18.5 mm		

Measurements are given in Table 2.

Morphologically, these teeth closely resemble the type of *Parahippus leonensis* Sellards, and in measurements and crown height, the holotype falls within the range of the present sample. Teeth in the sample referred to *Parahippus leonensis* from the Thomas Farm of Florida (Simpson, 1930, 1932) are also morphologically similar to the Pollack Farm

specimens in most respects, but differ in minor ways. Compared with Thomas Farm *P. leonensis*, the Pollack Farm teeth have less cement, but slightly greater expansion and separation of the metaconid-metastylid, and are perhaps slightly more advanced in the degree of connection between crochet and protoloph.

These Pollack Farm teeth are very similar to teeth from the Runningwater Formation of Nebraska in the American Museum of Natural History collections referred to *Parahippus leonensis*. Close comparisons are also seen with specimens of *Parahippus* from the Flint Hill fauna of South Dakota. The left M1, USNM 475908, appears to be morphologically identical to, though slightly larger than, the M1 of UCMP 32352 (comparison with cast in AMNH), from the Flint Hill Fauna of South Dakota, while other teeth from Flint Hill (UCMP 32353 for example) are slightly larger than the teeth from Delaware. A minor difference between the Delaware and Flint Hill specimens is that in the former the crochet-protoloph connection is more nearly complete.

This Pollack Farm *Parahippus*, like some specimens of *P. leonensis* from Thomas Farm, Florida, approaches *Merychippus* in some aspects of its morphology (near isolation of pre- and postfossettes, for example). In other features, such as virtual lack of cement, it is closely comparable to *Parahippus* known from other localities dated as early Hemingfordian. Referral to *Parahippus leonensis* seems most reasonable because of close similarity to the type.

Superfamily CHALICOTHERIOIDEA Gill, 1872

Family CHALICOTHERIIDAE Gill, 1872

cf. *Tylocephalonyx* Coombs, 1979

Material.—USNM 475848, an incomplete left upper molar; USNM 475843, left P3 or P4, lacking anterior cingulum; USNM 475838, cast of left metatarsal III, in private collection; USNM 475850, a left phalangeal duplex (the coossified proximal and medial phalanges of digit II of the manus); USNM 475849, distal phalanx; USNM 475935, incomplete distal phalanx.

Discussion.—These elements are so characteristic that familial allocation, to Chalicotheriidae, is without question; closer determination is less certain. The left upper molar (USNM 475848, Fig. 4A), missing part of the lingual margin and much of the ectoloph, is either M1 or M2. The anteroposterior length of the part preserved is 37.9 mm. If this tooth is M1, it would appear to be within the size range either of *Moropus elatus* (see measurements given by Coombs, 1978:15, table 1) or of *Tylocephalonyx skinneri* (see Coombs, 1979:16, table 2); if it is M2, it is somewhat smaller than *M. elatus* and *M. hollandi*, and approximately the size of *M. oregonensis*. Coombs (1979:20, table 4) compared dental characters of several species of chalicotheres. The Pollack Farm tooth has several of these characters, suggesting that it represents *Tylocephalonyx* rather than *Moropus*: the height of the posterior cingulum at the postfossette is strong (Coombs character 2), the height of the lingual cingulum just posterior to the protocone is strong (Coombs character 3), and the unworn protocone is blunt (Coombs character 6) and crescentic (Coombs character 11). The lingual cingulum posterior to the protocone, in addition to being prominent, is directed toward the anterior face of the hypocone, whereas in *Moropus* this cingulum appears to curve lingually to merge with the lingual base of the

hypocone. The result of this difference is that in *Tylocephalonyx* the hypocone extends linguad beyond this cingulum, and in *Moropus* the cingulum is the most lingual part of the tooth.

The premolar (USNM 475843, Fig. 4B) is unworn (was perhaps unerupted) and well preserved, except that the anterior cingulum has been broken away. Nevertheless, it is probably not possible to determine whether it is P3 or P4. Coombs (1979) remarked that in both *Moropus* and *Tylocephalonyx*, P3 and P4 are very similar to each other morphologically and differ but slightly in size. In this premolar (Fig. 4B), the paracone is the largest cusp, and with the metacone forms a weakly W-shaped ectoloph. Protoloph and metaloph are complete; near its junction with the paracone, the protoloph is raised into a small cusp, which is at least topographically a protoconule. The protoloph merges with the anterior surface of the protocone; the apex of the protocone is posterior to this junction. The metaloph is nearly parallel to the protoloph, and at its lingual end it turns anteriorly to merge with the posterior surface of the protocone. The anterior cingulum is broken from the tooth. The lingual cingulum is strong and continuous, and merges with the posterior cingulum at the point where the posterior cingulum is raised into what could be termed a hypostyle, which connects with the crest of the metaloph. In general, this tooth seems to be more similar to P3 and P4 of *T. skinneri*, which Coombs (1979:16) describes as “much closer to square-shaped than corresponding teeth of *Moropus elatus*.” Also, in these premolars of *Moropus*, the protoloph and metaloph tend to converge toward the protocone, whereas in *Tylocephalonyx* the lophes are more nearly parallel. USNM 475843 measures 21 mm anteroposteriorly and 23.6 mm transversely; these are within the ranges of measurements given by Coombs (1979, table 2) for P3 of *T. skinneri*; the transverse dimension is smaller than any recorded by Coombs for P4 of *T. skinneri*.

The left third metatarsal (USNM 475838, Fig. 4E) is from a fully adult animal and is well preserved. It is morphologically very similar to AMNH (FAM) 54915, the corresponding element of *T. skinneri* (see Coombs, 1979, fig. 24C–D), except that it is substantially shorter, and appears to be relatively more robust. Its greatest length is 92.7 mm, greatest distal width 37.4 mm, and minimum shaft width is 26.8 mm. The range of lengths cited by Coombs (1979, table 8) for *T. skinneri* is 104.7 mm to 131.7 mm; the shortest of these is about 13 percent larger than the Pollack Farm metatarsal. In the Pollack Farm specimen the quotient of length divided by distal width is 2.48 and of length divided by minimum shaft width is 3.45. Comparing these numbers to those in Coombs’s Table 8 (1979), shows that the Pollack Farm metatarsal is slightly more robust than the most robust *T. skinneri*, and much more robust than any comparable *Moropus elatus*. Coombs (1979) noted that a third metatarsal from the middle Hemingfordian Split Rock Fauna of central Wyoming differs from other (latest Hemingfordian) specimens of *T. skinneri* in two important ways: it has, between the proximal (ectocuneiform) facet and the facet for metatarsal IV, a narrow strip of articular surface, apparently for the cuboid (this facet is not present in other specimens), and the dorsal and volar parts of its metatarsal IV facet are confluent (separated by a trough in other specimens). Both these conditions are seen in the Pollack Farm metatarsal, which we consider to be early Hemingfordian on other fau-



Figure 4. Chalicothere (A–G) and rhinoceros (H–O) of the Pollack Farm Local Fauna. A–G, cf. *Tylocephalonyx* sp.; A, USNM 475848, incomplete left M1 or M2; B, USNM 475843, left P3 or P4; C–D, USNM 475849, ungual phalanx in C, lateral, and D, dorsal views; E, USNM 475838, left third metatarsal; F–G, USNM 475850, left phalangeal duplex of digit II of manus, in F, anterior, and G, radial views. H–O, Rhinocerotidae; H, USNM 475923, right M3; I, USNM 475842, right P2; J, USNM 475837, left M1 or M2; K, USNM 475841, left P1; L, USNM 475839, right dp3; M, USNM 475840, right i2; N–O, USNM 475931, part of right mandible with dp2–3, in N, occlusal, and O, lateral views. All approximately X1. Scale in millimeters.

nal grounds.

The phalangeal duplex (USNM 475850, Fig. 4F–G) is much abraded but does retain some characters that suggest generic allocation. Its overall length is 80.6 mm. Its metacarpal facet is asymmetrical, with a small “ulnar tongue” (see Coombs, 1979:47, fig. 25A), it has some degree of what Coombs (1979) termed “crooked fusion” between proximal and medial phalanges, and its distal facet appears to be quite deeply grooved. These details are all characteristic of *Tylocephalonyx*, but in this specimen they all seem to be developed to a lesser degree than in the duplex of *T. skinneri* illustrated by Coombs (1979:47, fig. 25).

The ungual phalanges (USNM 475849, USNM 475935) are also highly abraded. USNM 475849 (Fig. 4C–D) shows the deep fissure so characteristic of chalicotheres; it is small, with no enlarged dorsal process, perhaps belonging to one of the pedal digits. USNM 475935 consists essentially of the proximal, articular end, but the strongly keeled articulation that continues into a long dorsal process almost certainly identifies it as from digit II of the manus. Neither of these phalanges has generically diagnostic characters.

The elements that do have generically useful characters, i.e., the upper molar, upper premolar, and the third metatarsal, are more consistent with *Tylocephalonyx* than with *Moropus*. There is some indication, especially from the metatarsal, that this Pollack Farm chalicothere is smaller than *T. skinneri*, or at least that it has shorter but more robust feet. Its early Hemingfordian age would make it older than any material previously referred to *Tylocephalonyx*, and it seems worth reiterating that the Pollack Farm metatarsal has characters otherwise present only in the oldest material previously identified as *Tylocephalonyx*, from the late Hemingfordian Split Rock fauna of Wyoming. We also note that Frailey (1979) reported a chalicothere, which he regarded as a small indeterminate species of *Moropus*, from the Arikareean of Florida (Buda Local Fauna); however, Frailey (1979:148) pointed out characters of the metatarsals in which “the Buda chalicothere is similar to an unnamed new genus of North American Schizotheriinae in which the metapodials are much more shortened and stocky.” The unnamed genus became *Tylocephalonyx* Coombs, 1979. Albright (1991) recently described a fauna (the Toledo Bend Local Fauna) from extreme eastern Texas that he considered Arikareean, and which includes a chalicothere. Albright (1991:127) assigned his chalicothere to *Moropus* “based on the morphology and physical dimensions of the Mt IV..., and on its similarity to *Moropus* sp. described by Frailey (1979)” from the Buda Local Fauna; Albright also noted that metatarsal characters considered by Coombs (1978) to be diagnostic of *Moropus* (the occurrence of an ectocuneiform facet on Mt IV) appear to be absent on both the Buda and Toledo Bend material. The weight of evidence, though not conclusive, seems strongly to suggest that the chalicothere *Tylocephalonyx* might have had a long history in the eastern and gulf coast regions of North America before it first appears in the classical late Hemingfordian of the Great Plains.

Family RHINOCEROTIDAE Gray, 1825
Unidentified Genera (Figure 4H–O)

Material.—USNM 475837, right M1 or M2; USNM 475923, right M3; USNM 475842, right P2; USNM 475841,

left P1; USNM 475840, right tusk (lower second incisor); USNM 475931, cast of right dentary fragment with dp2 and dp3, and alveolus for dp1, in Virginia Museum of Natural History; USNM 475839, cast of right dp3 in private collection; USNM 475847, partial left astragalus.

Discussion.—It seems unlikely that this material can be confidently identified to genus, and perhaps equally unlikely that it all represents one taxon. Resemblances are seen to the smaller forms of both *Diceratherium* and *Menoceras*. Specimens representing young individuals of both genera were found in the collections of AMNH, and if these specimens are correctly referred, then the deciduous dentition in the Delaware material (USNM 475839 and 475931) seems to have closer resemblance to that of *Diceratherium* in some characteristics: dp2 is larger relative to dp3, and the alveolus for dp1 seen in USNM 475931 (Fig. 4N) indicates a relatively stouter dp1 than is present in material referred to *Menoceras*. This evidence is suggestive rather than indicative, however, and the Delaware material otherwise has characters that seem to indicate a rhino more progressive than *Diceratherium*. The P2 (USNM 475842, Fig. 4I) and the M3 (USNM 475923, Fig. 4H), for example, have distinct crochets. USNM 475837 (Fig. 4J), M1 or M2, is well worn, but shows the metaloph bulging anteriorly near the ectoloph, suggesting the base of a crochet, and the protoloph bulging posteriorly buccal to the protocone, suggesting an antecrochet. Also in this tooth, the protocone is well defined by posterior and anterior constrictions of the protoloph. H. E. Wood (1964) described *Menoceras barbouri* from the Thomas Farm of Florida as having the protocones only slightly pinched off in this way. In USNM 475837, the protocone is as distinct as it is in teleoceratine rhinoceroses, suggesting that this tooth might represent *Brachypotherium*. The Pollack Farm teeth are larger than those of *Menoceras barbouri*, and are just slightly smaller than those of the large aceratherine rhino *Floridaceras whitei* Wood, 1964, also from Thomas Farm.

Dimensions of the Pollack Farm rhino teeth are given

Table 3

Measurements in millimeters of teeth of Rhinocerotidae of the Pollack Farm Local Fauna. AP = anteroposterior, TR = transverse.

SPECIMEN	AP	TR
USNM 475841, dP1	24.3	22.6
USNM 475842, P2	30.5	34.7
USNM 475837, M1 or M2	46.0	51.6
USNM 475921, M3	37.1	42.6
USNM 475931, dp2	24.8	13.9
USNM 475931, dp3	30.2	16.3
USNM 475839, dp3	31.8	17.8
USNM 475840, I2	—	19.3

in Table 3.

Order ARTIODACTYLA Owen, 1848
Suborder SUIFORMS Jaekel, 1911
Family TAYASSUIDAE Palmer, 1897
Cynorca Cope, 1867
Cynorca sociale (Marsh, 1875)

Material.—USNM 475835, LC1, missing most of crown; USNM 475820, LP2; USNM 475821, LP3 in maxil-

lary fragment; USNM 475901, RP3; USNM 475893, RP4; USNM 475920, cast of LM1 in fragment of maxilla, from private collection; USNM 475892, part of RM1 with metacone, protocone, and metaconule; USNM 475932, cast of Lc1, missing much of crown, from private collection; anterior half of Rp2 in private collection; USNM 475823, Lm1; USNM 475922, cast of anterior half Rm1 in private collection; USNM 475822, Lm2; USNM 475921, cast of Lm3 in private collection; USNM 475919, cast of part of left mandibular ramus, edentulous, with alveoli for c1, p2, p3, p4, and part of m1; USNM 475878, fragment of right mandibular ramus, edentulous, with alveoli for p2, p3, and part of p4; USNM 475882, distal end right humerus; USNM 475806, proximal half right ulna; USNM 475827, right metacarpal III; USNM 475791, distal end left femur; USNM 475888, distal end right tibia; USNM 475871, right calcaneum, missing tuber calcis; USNM 475868, left astragalus; USNM 475875, right astragalus; USNM 475879, left astragalus; USNM 475890, left astragalus; USNM 475869, left navicular; USNM 475826, right metatarsal II; USNM 475800, proximal half left metatarsal II; USNM 475877, distal end metapodial; USNM 475885, medial phalanx; USNM 475874, medial phalanx.

Discussion.—This small peccary is among the most common of the land mammals comprising the Pollack Farm Local Fauna, suggesting that it was also among the more common of the land mammals in Delaware during Hemingfordian time. It is represented by teeth and miscellaneous postcranial elements (Fig. 5A–J). Most dental positions are represented, even though no single specimen has more than one tooth, and there is no association to suggest that any two teeth might have been derived from one individual. All of the teeth clearly represent a small species of *Cynorca*, and there is no evidence to suggest that more than one species of *Cynorca* is represented. The appropriate species name to be applied is less clear.

The upper canine is represented by only one specimen, which lacks most of the crown. The size of canines in peccaries is so variable (Wright and Eshelman, 1987:609), and primitively sexually dimorphic (Wright, 1993), that they are not diagnostic in any case.

The P2 and P3 differ in size, but are similar in that each consists predominantly of a large paracone buttressed posteriorly and posterobuccally by a broad posterior cingular shelf and anteriorly by a small but distinct anterior cingulum. The posterior cingulum has a very rugose occlusal surface on the unworn P3 (USNM 475901, Fig. 5C). Morphologically these teeth are closely comparable to those of *Cynorca proterva* (Wright and Eshelman, 1987: fig. 3), to those of “tayassuid species A” of Wright and Eshelman (1987: fig. 3), and also to those of specimens referred to *C. sociale* by Woodburne (1969: pl. 41, fig. 7). They are slightly larger than comparable teeth of *C. sociale* and “tayassuid species A,” and slightly smaller than those of *C. proterva*.

The Delaware P4 (USNM 475893, Fig. 5D) is like that of other *Cynorca* species in being more nearly molariform than the more anterior premolars. In most respects it is similar to the P4 of *C. proterva*, “tayassuid species A,” and *C. sociale*. It differs in having more definite separation of the paracone and metacone, and in this respect appears to be more nearly comparable to the P4 of *C. occidentale* (see Woodburne, 1969, pl. 43, fig. 3). In size, it is like P2 and P3

in being larger than that of *C. sociale* and “tayassuid species A,” and smaller than that of *C. proterva*.

The M1 (USNM 475920, Fig. 5E) does not differ from that of the other small species of *Cynorca*, except for its intermediate size, larger than that of *C. sociale* and “tayassuid species A,” and smaller than that of *C. proterva*. M2 and M3 are not represented in the Delaware sample; M2 alveoli preserved in USNM 475920 indicate that, as in other *Cynorca*, M2 is substantially larger than M1.

The lower canine is represented by USNM 475932, which lacks much of the crown and affords no useful information. Lower premolars are represented in the Pollack Farm sample only by the anterior half of p2 (specimen in private collection). Little can be said beyond noting that the main cusp, the protoconid, is very tall and is buttressed anteriorly by a low accessory cusp (paraconid?). Wright and Eshelman (1987:607) mention that in “tayassuid species A” and in *C. proterva* the protoconid is tall and steep-sided, more so in the former than in the latter. Wright and Eshelman (1987:606) also note that their “tayassuid species A” compares most favorably with specimens of *C. sociale*, especially in having steep-sided protoconids on p2 and p3. In the Delaware p2, the protoconid appears to have been even taller and more nearly cylindrical than in the other species mentioned. Each of the lower molars is represented in the Delaware sample. Morphologically, nothing distinguishes them from the corresponding teeth of other small *Cynorca*.

Measurements suggest that the lower molars were not only larger than those of “tayassuid species A” and *C. sociale*, but perhaps also larger than those of *C. proterva*, although the small sample size ($N = 1$ for each tooth) renders the comparison virtually meaningless. It does seem worth noting that the m3 is relatively larger even than in the other species. Woodburne (1969) pointed out that M3/m3 are reduced in size in later species of *Cynorca*, especially in the Barstovian species *C. occidentale*. Using measurements in the tables provided by Woodburne (1969) and Wright and Eshelman (1987), the ratio of m2 length/m3 length is 0.71 in “tayassuid species A,” 0.83–0.86 in *C. sociale*, 0.82–0.84 in *C. proterva*, and 0.82–0.94 in *C. occidentale*. This ratio in the Delaware sample is 0.75 (calculated from measurements of two teeth probably not of the same individual), a value intermediate between “tayassuid species A” one hand and *C. sociale* and *C. proterva* on the other.

Wright and Eshelman (1987) noted the similarities between their “tayassuid species A” from bed 2 of the Calvert Formation at Popes Creek, Maryland, and specimens that Woodburne (1969) had referred to *C. sociale* from the early Miocene John Day Formation of Oregon, but they did not refer the Maryland material to *C. sociale*. The Delaware material also seems to share the greatest similarity with *C. sociale* and “tayassuid species A.” The differences in size (if real—the sample sizes are so small that the differences may not be significant) seem sufficiently slight to be explained as individual variation or as differences in geographically distant populations. And there seems to be no other justification for not assigning the Delaware material to *Cynorca sociale*. “Tayassuid species A” of Wright and Eshelman (1987) could probably be assigned to the species with the same justification.

***Hesperhys* Douglass, 1903 or *Desmathyus* Matthew, 1907**

Material.—USNM 475819; right p4; USNM 475813, right i3.

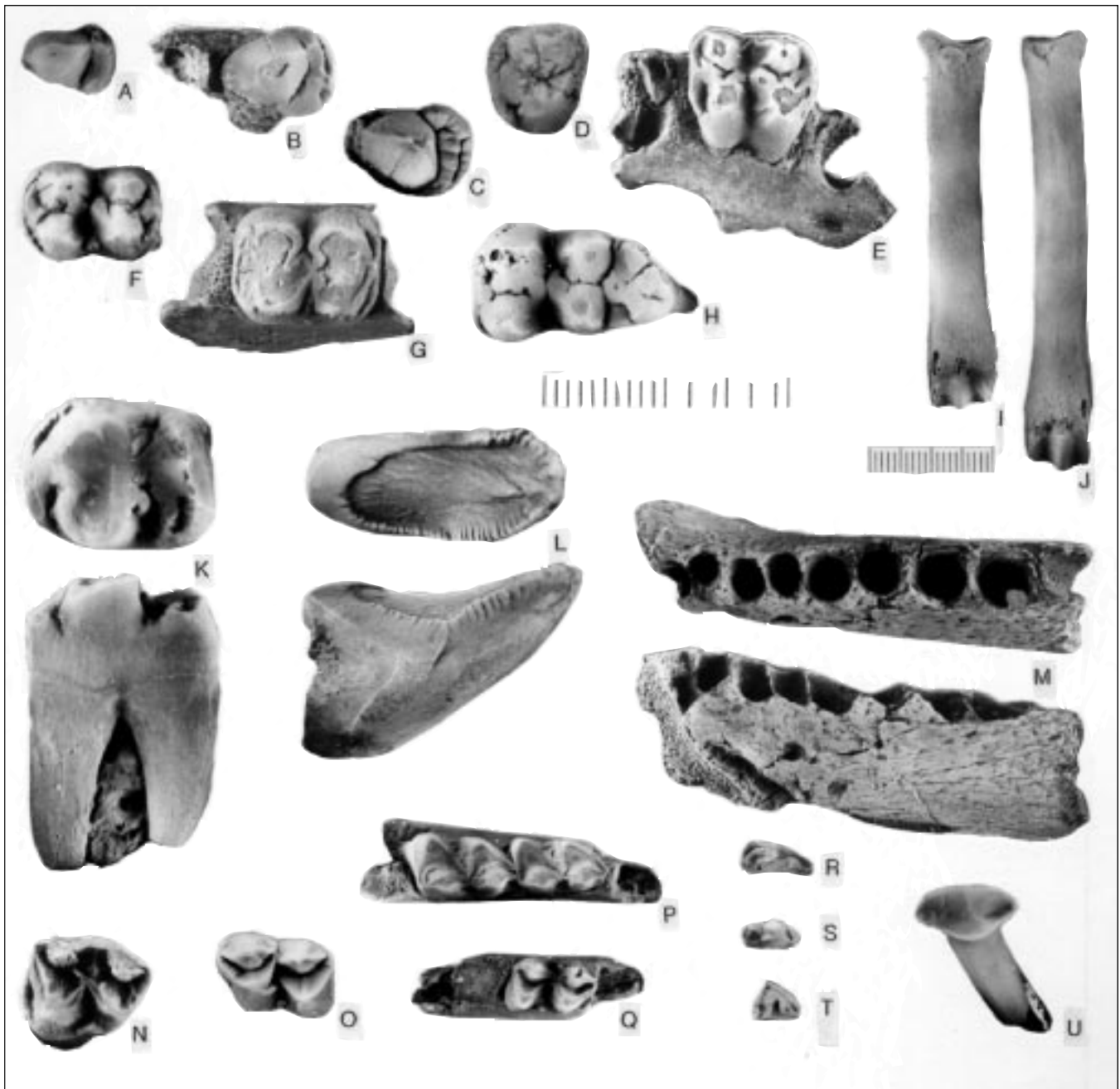


Figure 5. Artiodactyls of Pollack Farm Local Fauna. A–J, *Cynorca sociale*; A, USNM 475820, left P2; B, USNM 475821, left P3; C, USNM 475901, right P3; D, USNM 475893, right P4; E, USNM 475920, maxilla fragment with left M1; F, USNM 475823, left m1; G, USNM 475822, mandibular fragment with left m2; H, USNM 475921, left m3; I, USNM 475827, right third metacarpal; J, USNM 475826, right second metatarsal. K–L, *Desmathyus* or *Hesperhys*; K, USNM 475819, right p4 in occlusal (above) and lingual (below) view; L, USNM 475813, right i3, in occlusal (above) and lateral (below) view. M, USNM 475825, leptachenine oreodont, edentulous fragment of left dentary, in occlusal (above) and lateral (below) view. N–O, *Blastomeryx galushai*; N, USNM 475912, part of left M3; O, USNM 475873, left m1 or m2. P–T, Ruminantia, genus uncertain; P, USNM 475824, fragment of left dentary with m1–m2; Q, USNM 475828, fragment of right dentary with m1 or m2; R, USNM 475865, left p3 or p4; S, USNM 475866, right p2 or p3; T, USNM 475864, part of left premolar, probably p4. U, ?Anthracotheriidae, USNM 475803, ?right i1. All approximately X2 except I, J, which are approximately X1. Scale bars in millimeters.

Discussion.—This material (Fig. 5K–L) represents a much larger peccary than that discussed above. The p4 talonid is broad, but has a single central anteroposteriorly directed crest that forms the highest part of the talonid, as is seen in *Desmathyus* and *Hesperhys*; the talonid of p4 in *Cynorca*, by contrast, has both entoconid and hypoconid. Close general resemblance was found with several specimens in the Frick Collection (AMNH) identified as *Desmathyus* and *Hesperhys*; the closest match was with the right p4 in a very large peccary, labeled *Hesperhys*, in the Frick Collection (AMNH) from Humbug Quarry in the Sheep Creek Formation of western Nebraska (the specimen is uncataloged but has “Sioux County” field number 259-16237).

?Family ANTHRACOTHERIIDAE Leidy, 1869

Material.—USNM 475803, incisor, possibly right i1.

Discussion.—This incisor (Fig. 5U) has a long root and a broadly expanded crown that is blunt rather than spatulate. Although definitive identification is probably not possible, it is certainly not an incisor of any taxon that is otherwise represented by teeth in this assemblage. It could conceivably represent Tylopoda, perhaps a protoceratid or camelid, but its closest morphological comparisons seem to be with anthracotheres. In the absence of any other anthracothere material in the Pollack Farm assemblage, this identification must be considered provisional. The tooth is of appropriate size to be the lower first incisor; where known, i1 of anthracotheres is substantially smaller than i2 and i3 (for example, in *Elomeryx*, see Macdonald, 1956, fig. 5). The latest occurrence of anthracotheres in North America is the early Hemingfordian *Arretotherium fricki* (Macdonald and Schultz, 1965; Macdonald and Martin, 1987), from the Runningwater Formation of northwestern Nebraska, and from the Flint Hill fauna of South Dakota. Lower incisors of *A. fricki* are not known. Albright (1991) referred some teeth, including incisors, from the late Arikareean of eastern Texas to *A. acridens*, a species also known from classical late Arikareean localities of Nebraska, South Dakota and Montana.

Family OREODONTIDAE Leidy, 1869

?Subfamily

Material.—USNM 475825 (Fig. 5M), an edentulous fragment of left dentary with alveoli from posterior edge of the caniniform p1 to anterior edge of m2.

Discussion.—A small oreodont is represented by this single specimen. Enough of the jaw is preserved to show the large symphysis, deep alveolus for a large, caniniform p1, and absence of premolar diastemata, characters common to all oreodonts. In its small size and apparent crowding of premolars indicated by alveoli, the specimen is comparable to leptaucheniines such as *Cyclopidius*; its size, for example is close to that of *C. simus*. However, leptaucheniines are not otherwise known later than the end of the Arikareean, suggesting that this specimen instead might represent a small merychyine such as *Merychys minimus* or *M. crabilli*. Based on alveoli, we estimate the length of p1–p4 of the Delaware specimen at about 25 mm, which is smaller than any comparable measurement given for species of *Merychys* by Schultz and Falkenbach (1947, table 1). In the

absence of teeth, confident identification to genus is out of the question.

Suborder RUMINANTIA Scopoli, 1777

Family MOSCHIDAE Gray, 1821

Blastomeryx Cope, 1877

Blastomeryx (*Parablastomeryx*) *galushai* Frick, 1937

Material.—USNM 475912, cast of part of left M3 in private collection; USNM 475873, left m1 or m2.

Discussion.—The relatively small size of the metaconule of the upper molar (Fig. 5N) identifies it as an M3. So far as comparisons can be made it is identical to M3 of the holotype of *Blastomeryx* (*P.*) *galushai* (F:AM 33775), from the Runningwater Formation in Dawes County of Western Nebraska (Frick, 1937, fig. 22A). The similarity extends even to the presence of small bifurcations at the posterobuccal end of the protocone and the anterobuccal end of the metaconule. The maximum anteroposterior measurement of USNM 475912 is 10.2 mm; the comparable measurement of the type (F:AM 33775) is 9.9 mm. The lower molar (USNM 475873, Fig. 5O) has a distinct *Paleomeryx* fold, one of the characteristics of *Blastomeryx*, and is of appropriate size to be assigned to the same species; it measures 9.1 mm AP and 6.2 mm TR. These measurements indicate a substantially smaller animal than *Blastomeryx* (*Parablastomeryx*) *floridanus* (White, 1940; Maglio, 1966) of the Thomas Farm Local Fauna of Florida.

Families Uncertain

Genera and Species Unidentified

Material.—USNM 475824, left dentary fragment with m1–m2; USNM 475828, right dentary fragment with m1 or m2; USNM 475894, incomplete right P3; USNM 475865, left p3 or p4; USNM 475866, right p2; USNM 475864, incomplete left premolar, probably p4.

Discussion.—This material is all of approximately the right size to represent one species of small ruminant, but differences in premolars suggest that more than one species is represented. Unfortunately, important characters such as the length of the diastema and spacing of premolars are not preserved. The molar in USNM 475828 clearly lacks a *Paleomeryx* fold, has a small accessory cuspid between the bases of protoconid and hypoconid, and the anterior arm of its hypoconid fuses with the posterior arm of the protoconid and with the entoloph. In USNM 475824, which is similar in size and seems superficially similar, each of the molars, though badly worn, clearly had a *Paleomeryx* fold, each had accessory cuspids between bases of hypoconid and protoconid, and in each the anterior arm of the hypoconid is free. These differences suggest that the two specimens represent different taxa. The one molar in USNM 475828, possibly m1 though most likely m2, measures 7.3 mm AP and 4.7 mm TR. In USNM 475824, the m1 is 7.4 mm AP, 4.6 mm TR, and m2 is 8.3 mm AP, 5.9 mm TR.

Being preserved as isolated teeth, the premolars offer little aid to identification. The upper premolar, probably P3, USNM 475894, is incomplete posteriorly and well worn, but clearly had a distinct cusplike parastyle ahead of the large paracone, and a distinct protocone directly lingual to the paracone. USNM 475865, possibly p3 but most likely p4 (Fig. 5R), is sufficiently worn that the distinct paraconid has

a triangular outline, suggesting that it may have been bifurcate when unworn; a prominent metaconid wing extends posterolingually from the protocone, and the posterior hypoconid crest turns lingually to end at the posterolingual corner of the tooth in a slightly expanded entoconid; it is 5.6 mm AP and 2.6 mm TR. USNM 475866 is a simpler tooth, most likely p3 but possibly p2 (Fig. 5S); its bladelike paraconid is set obliquely to the anterior protoconid crest, the metaconid crest is but a rib at the posterolingual corner of the protoconid, and the hypoconid crest has a posterolingually directed spur midway between protoconid and the heel of the tooth. USNM 475864 is the anterior half of a tooth (Fig. 5T), almost certainly p4. It is somewhat worn, but clearly had a prominent paraconid that was bifurcate, and a distinct, cusp-like expansion of the metaconid.

The premolars with bifurcate paraconids, in some instances combined with a prominent metaconid, and the molars with *Paleomeryx* folds and free anterior wings of hypoconid, are more likely referable to a small species of blastomerycine moschid. They are too large to represent *Machaeromeryx gilchristensis* (White, 1941; Maglio 1966), the smaller blastomerycine from the Thomas Farm Local Fauna of Florida. The simpler premolar (USNM 475866) and the molar (USNM 475828) that lacks the *Paleomeryx* fold and has the anterior arm of the hypoconid fused to the posterior arm of the protoconid are more reminiscent of Leptomerycidae.

The nature of this material probably renders impossible its reference to genera, though the weight of evidence does suggest that two species of small ruminant are present, and that each may represent a different family.

AGE OF THE POLLACK FARM LOCAL FAUNA

Certain taxa within the Pollack Farm Local Fauna serve to constrain the age rather precisely within the North American Land Mammal Age system. *Amphicyon* and *Plesiosorex*, for example, are immigrant taxa whose first appearances in North America, about 20 million years ago, define the beginning of Hemingfordian time (Tedford et al., 1987). The fauna also includes the amphicyonid carnivore *Cynelos* which is among the taxa whose latest occurrence is in the early Hemingfordian (Tedford et al., 1987). The co-occurrence of these taxa restricts the age to early Hemingfordian, and other elements of the fauna are consistent with this date. The closest comparisons for some of the teeth from the Pollack Farm Site are with specimens from the Runningwater Formation of western Nebraska, its correlative in South Dakota (Flint Hill Local Fauna), with Quarry A Local Fauna of northeastern Colorado, and with the Thomas Farm Local Fauna of Florida. These are the well known, diverse faunas that typify the early Hemingfordian (Tedford et al., 1987).

Strontium-isotope age estimates on mollusk shells from the Pollack Farm Site range from 17.8 ma to 18.2 Ma with a mean of 17.9 ± 0.5 Ma (Jones et al., 1998). These dates are in very close agreement with radiometric dates established for late early Hemingfordian faunas of the western states (Tedford et al., 1987, fig. 6.2).

MARINE TO NONMARINE CORRELATIONS

The land mammals that constitute the Pollack Farm Local Fauna occur in coarse shelly intervals within the

Cheswold sands of the Miocene Calvert Formation (Benson, 1993, 1998). This shelly sand is dominated by disarticulated shells of bivalves, but also has abundant gastropods, together amounting to more than 100 species of mollusks (Ramsey, et al., 1992; Ward, 1998). Crustaceans and other invertebrates are also represented, but are much less common. Ward (1998, fig. 3) assigns the Pollack Farm mollusks to the lower part of his M13 Interval Zone, which he designates M13-A, of Burdigalian age, consistent with the Hemingfordian age determined by the land mammal assemblage. In addition to the terrestrial mammals discussed above, the associated vertebrates include numerous kinds of sharks and bony fish, amphibians (salamander), reptiles (crocodilians, turtles, lizards), and marine mammals (cetaceans, sirenian, and a pinniped); these are discussed in other chapters of the present volume.

Benson (1993, 1998) assigns radiolarians from sandy silts between the lower and upper shelly sands at the Pollack Farm Site to the *Stichocorys wolffii* Zone, a global marine, early Miocene biozone as defined regionally in the middle Atlantic Coastal Plain by Palmer (1986). Benson (1998) estimates its age as between 17.3 and 19.2 Ma and postulates, on the basis of information from boreholes and other stratigraphic data, that the Pollack Farm Site is in the upper part of the *S. wolffii* Zone, and, therefore, closer to 17.3 than to 19.2 Ma. Benson (1993, 1998) also identified the diatom *Actinoptychus heliopelta* from the radiolarian-bearing silts; the total range of this species (most of the early Miocene) defines East Coast Diatom Zone (ECDZ) 1 of Andrews (1988).

Radiolarian and diatom biostratigraphy and stratigraphic correlation of outcrops and borehole geophysical logs led Benson (1993, 1998) to conclude that the Shiloh marl of nearby New Jersey, the source of the Shiloh Local Fauna which consists of the single land vertebrate *Tapirus validus* described by Marsh (1871), is older than the fossiliferous beds exposed at the Pollack Farm Site. Benson (1998, fig. 5) shows that sands stratigraphically equivalent to the Shiloh marl underlie the lowermost beds excavated at the Pollack Farm Site and that the entire section exposed at the latter site is missing updip in Delaware and at the Shiloh, New Jersey, site by having been eroded. Sugarman et al. (1993) gave strontium-isotope age estimates of 20.0 to 20.3 Ma for the Shiloh marl, which Benson (1977) suggests is evidence for an unconformity between the Shiloh-equivalent beds and the ~18-Ma fossil-bearing beds at the Pollack Farm Site.

Farther to the northeast in coastal New Jersey, a small assemblage of land mammals, the Farmingdale Local Fauna (Tedford and Hunter, 1984), occurs in the basal Kirkwood Formation. Benson (1993, 1998) concluded on the basis of its stratigraphic position that the Farmingdale Local Fauna is older than the Shiloh Local Fauna. These correlations are consistent with the terrestrial mammal data; the single specimen of *Tapirus validus* that constitutes the Shiloh Local Fauna is not age-diagnostic, but better information is afforded by the assemblage called Farmingdale Fauna, which includes (Tedford and Hunter, 1984) a horse, *Anchitherium* sp., the rhinos *Diceratherium matutinum* and *Menoceras* cf. *M. cooki*, the entelodont *Daedon (Ammodon) leidyannum*, the peccary *Hesperhys antiquus*, and the protoceratid *Prosynthetoceras* sp. Tedford and Hunter (1984) considered

the Farmingdale Fauna early Hemingfordian, noting that its constituent genera are known to coexist in early Hemingfordian time at other sites in the western United States. However, these genera also coexist in Arikareean time, and some taxa, the large entelodont for example, are more characteristic of late Arikareean time. We note also that Tedford et al. (1987:185) list *Diceratherium* among the taxa whose latest occurrences are in the late Arikareean. A late Arikareean, rather than Hemingfordian, assignment for the Farmingdale fauna is also in better agreement with the strontium-isotope age estimates of 19.2 to 22.6 Ma \pm 0.5 m.y. for the lower Kirkwood Formation (Sugarman et al., 1993). Benson's (1998, fig. 6) summary of the age estimates derived from analysis of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios published by Sugarman et al. (1993) for the basal Kirkwood in the Berkeley and Lacey wells, those closest to the Farmingdale Site, shows a late Arikareean age for the Farmingdale Fauna.

From the Calvert Cliffs, along the western side of Chesapeake Bay in Maryland, a terrestrial mammalian assemblage occurs in the upper part ("Zones" 13–15) of the Calvert Formation and the basal part of the overlying Choptank Formation (Gazin and Collins, 1950; Tedford and Hunter, 1984). This fauna is substantially younger than the Pollack Farm assemblage. Tedford and Hunter (1984) concluded that the one land mammal that occurs slightly lower ("Zone" 10) in this sequence, "*Tomarctus*" *marylandica*, is consistent with an early Barstovian age assignment. The other land mammals, however, seem to be an essentially coeval assemblage representing later Barstovian time; presence of the proboscidean *Gomphotherium* is critical to this correlation, as the first appearance of proboscideans in North America is used to define the later part of the Barstovian Land Mammal Age (Tedford et al., 1987). Principally on the basis of the peccaries present, Wright and Eshelman (1987) considered bed 10 to be late Hemingfordian or early Barstovian, bed 14 to be early late Barstovian, and bed 17 to be late Barstovian. Correlations to microfossil biozones indicate bed 10 is of early Barstovian age (Benson, 1998, fig. 6).

To the west of Chesapeake Bay, the basal Calvert Formation crops out along the lower Potomac River. The peccary fossils discovered there, at the locality termed Popes Creek, were those called "tayassuid sp. A" by Wright and Eshelman (1987) and considered to be latest Arikareean or early Hemingfordian. These peccaries compare closely with the smaller peccary from the Pollack Farm Site that is referred herein to *Cynorca sociale*. This suggests a close temporal correlation between the lower Calvert Formation at the Pollack Farm Site in Delaware and the basal Calvert along the lower Potomac River. Benson (1998, fig.6) shows two different interpretations for correlation of the Popes Creek beds—early Hemingfordian on the basis of dinoflagellates or late Hemingfordian on the basis of radiolarians.

The Pollack Farm Local Fauna shares its greatest homotaxial similarity with the Thomas Farm Fauna of northern Florida. The Thomas Farm assemblage occurs in a sinkhole filling, isolated from a stratigraphic sequence that would link it directly to other chronologies; however, the land mammals of the Seaboard Local Fauna (Olsen, 1964) from the lower Torreya Formation, also in northern Florida, seem to be virtually identical to those from Thomas Farm (Tedford and Hunter, 1984), and do occur in a stratigraphic context that affords dating and correlation. According to Banks and Hunter

(1973), the invertebrate fauna from the Seaboard locality correlates with planktonic foraminiferal zones upper N5 and N6 of Blow (1969). Bryant et al. (1992) provided a strontium-isotope age estimate of 18.4 ± 1.0 Ma on a mollusk sample from the Seaboard locality; this age is consistent with the invertebrate and vertebrate biochronologies.

To summarize, the Pollack Farm Local Fauna is approximately 18 million years old, and referable to the early Hemingfordian; its stratigraphic context and direct faunal associations indicate correlation with the *Stichocorys wolffii* Radiolarian Zone, as defined by Palmer (1986) for the Miocene of the middle Atlantic coastal Plain, and with East Coast Diatom Zone 1 (Andrews, 1988). The abundant associated molluscan fauna (Ward, 1998) is of Burdigalian age, consistent with the early Hemingfordian age of the land mammals. Less direct but nevertheless confident correlations are with Planktonic Foraminiferal Zone upper N5 or N6, and with the later Burdigalian and late early Miocene of Europe.

PALEOENVIRONMENTAL SETTING

The deposits from which the terrestrial mammalian fossils were recovered are shallow marine sediments. The land mammal assemblage suggests a nearby forested habitat, probably with some open grassy areas, and fresh water. A possible Holocene analog might be one of the larger Virginia coastal barrier islands such as Cedar or Parramore Islands, which have forests, freshwater ponds, and some open park-like grasslands. Beaver, peccaries, and browsing and grazing horses could all find suitable habitat there. In fact, horses have been successfully introduced to barrier islands such as Assateague, in Virginia and Maryland, and Bogue Banks in North Carolina.

The chalicotheres and rhinos could also find suitable habitat on such islands, but these remains could also be transported as carcasses washed to sea by flooded rivers; however, Cutler (1998) concludes from his taphonomic studies that carcass rafting of the Pollack Farm vertebrate remains is unlikely. Gibson (1971, 1983) postulates that the northern part of Delaware during early to middle Miocene time was predominantly deltaic. This would help explain the diversity of habitats suggested by the terrestrial mammals as well as by the other vertebrates reported in this volume. Plant microfossils and dinocysts suggested to Groot (1992), and radiolarians and foraminifers suggested to Benson et al. (1985), that during the early Miocene this part of Delaware was covered by a relatively shallow marginal marine to inner neritic sea with broad coastal wetlands.

Thus a second and possibly more compelling modern analog would be a delta with flowing fresh-water rivers and streams, oxbow lakes and ponds, with marshes and swamps developed in the lowlands and forest and open park-like grasslands on the higher elevations.

The abundance of terrestrial mammal remains at the Pollack Farm Site is remarkable in comparison to other Atlantic Coastal Plain deposits such as the Lee Creek Mine, North Carolina, and the Calvert Cliffs of Maryland's Chesapeake Bay western shore, where terrestrial mammalian fossils are also found. The Pollack Farm Site was a temporary borrow pit of less than one-half square mile, available for collecting for about one year, and produced a minimum of 204 identifiable specimens of land mammals, representing a minimum of 26 species. In contrast, the Lee Creek Mine

began operation in 1964 and mined an average of 75 acres per year (McLellan, 1983); in more recent years the rate of mining has increased and the mined area is now several miles square. Collecting at Lee Creek began at least by 1967 (Ray, 1983) and continues to the present. The terrestrial mammal assemblage consists of approximately 143 identifiable bones and teeth, representing about 20 species.

Calvert Cliffs are a series of wave-cut bluffs up to 130 feet high that extend about 25 miles along the western shore of Chesapeake Bay (Vogt and Eshelman, 1987). Terrestrial mammalian fossils from the Chesapeake Group, including the Calvert Formation, of the Calvert Cliffs, consist of about 17 taxa represented by approximately 167 identifiable bones and teeth. Fossil vertebrates have been collected from these cliffs since at least 1818 and have been studied by scientists since at least 1842. The Smithsonian Institution has maintained a program of collecting at Calvert Cliffs since at least 1907, and amateurs have scoured the cliffs since the 1960s.

It is clear that the lower shell bed at the Pollack Farm Site represents an environment that was much more favorable for preservation of land mammal remains than were the other sites known in the middle Atlantic Coastal Plain.

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A NOTE ON THE TAPHONOMY OF LOWER MIOCENE FOSSIL LAND MAMMALS FROM THE MARINE CALVERT FORMATION AT THE POLLACK FARM SITE, DELAWARE¹

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ABSTRACT

The lower shell bed (marine) of the portion of the Cheswold sands of the lower Calvert Formation exposed at the Pollack Farm Site (now covered) near Cheswold, Delaware, is unusually rich in the remains of land mammals. Two models could possibly explain the occurrence of terrestrial fossils within marine sediments: (1) post-mortem rafting of animal carcasses during floods, and (2) reworking of terrigenous bones following a marine transgression. Observations of the surface features of the mammalian bones suggest that the bones were exposed subaerially for a period of time before burial and that they were buried and permineralized prior to transport and abrasion. Carcass rafting is therefore unlikely, and reworking is the favored model of assemblage formation. Concentrations of fossil and subfossil land mammal bones in Georgia estuaries and on the Atlantic continental shelf provide possible analogs.

INTRODUCTION

Terrestrial mammals occur sporadically in Tertiary marine sediments of the Atlantic Coastal Plain in the eastern United States. Such occurrences are important from a biostratigraphic standpoint in that they form a link between terrestrial and marine biochronologies (Tedford and Hunter, 1984; Wright and Eshelman, 1987). They may also provide the only glimpses of land faunas in areas where terrestrial sediments are absent or unfossiliferous.

The exposures of the Miocene Chesapeake Group in Maryland have yielded 167 identifiable terrestrial mammal bones and teeth representing about 17 taxa in the more than 150 years that the area has been actively studied by paleontologists (Emry and Eshelman, 1998). The Pollack Farm borrow pit (now covered) near Cheswold, Delaware, was excavated in 1991–1992 and is particularly significant for the richness of the terrestrial component of its fauna. In the single year that the pit was open for collecting, it yielded over 200 identifiable specimens representing at least 26 species, making it the most diverse Tertiary land mammal assemblage in eastern North America north of Florida (Emry and Eshelman, 1998). The terrestrial mammal-bearing shelly sand at the Pollack Farm Site is interpreted on the basis of stratigraphic position and radiolarian and diatom biostratigraphy to be within the Cheswold sands (Delaware Geological Survey informal designation) of the lower Miocene Calvert Formation (Ramsey et al. 1992; Benson, 1993, 1998; Ramsey, 1998). The land mammal age assigned to the terrestrial fauna by Emry and Eshelman (1998), early Hemingfordian, is consistent with this interpretation.

Fossils come from the lower shell bed exposed at the site (see Benson, 1998, fig. 2). This unit is a medium- to coarse-grained shelly sand with densely-packed bivalve shells, interpreted to be a channel-fill deposit within an estuarine environment (Ramsey et al. 1992; Ramsey, 1998). Cross-bedding within the beds indicates a dominance of ebb-tidal currents (Ramsey, 1998). Ward (1998) interprets the molluscan assemblage as reflecting deposition in a deltaic environment where brackish-water and marine mollusks are mixed. Emry and Eshelman (1998) estimate the density of

terrigeneous material within the lower shell bed to be 50–60 mammal teeth per 1000 kg of matrix.

The unusual richness of the land mammal assemblage at the Pollack Farm Site inevitably raises the question of its formation. What accounts for the presence of the land mammals in marine sediments? Mixed terrestrial/marine assemblages are generally explained in one of two ways: (1) seaward transport of land animal remains (usually by rafting of carcasses during floods), and (2) reworking following a marine transgression. Horner (1979), for example, interpreted the occurrence of dinosaurs in marine sediments of the Upper Cretaceous of Montana and the Atlantic Coastal Plain to be the result of carcass rafting. Gallagher et al. (1989), on the other hand, interpreted the occurrence of fossil and subfossil land mammals on the Atlantic continental shelf to be the result of sea-level rise and reworking. Similarly, Frey et al. (1975) described mixed marine and terrestrial assemblages owing to reworking in Georgia estuaries. In a nearshore estuarine setting such as where the sediments of the Pollack Farm Site were deposited, either the carcass-rafting or reworking model is plausible.

This study is a preliminary analysis of the taphonomy of the land mammal remains at the Pollack Farm Site, with a special emphasis on resolving the question of whether the terrestrial remains were derived through carcass rafting or reworking. The two models have different implications for the relative ages of the marine and terrestrial fossils. If the terrestrial mammals were introduced into the marine environment by flotation as fresh carcasses, then they would be precisely the same age as the marine fossils. On the other hand, if they were mixed with the marine fossils by erosion and reworking of terrestrial sediments during a transgressive episode, then they would be somewhat older.

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¹ In Benson, R.N., ed., 1998, *Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware*: Delaware Geological Survey Special Publication No. 21, p. 175–178.

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MATERIALS AND METHODS

The fossil material from the Pollack Farm Site was collected over a period of approximately one year after the initial excavation of the pit for construction in 1991. The pit was subsequently filled and flooded, and the fossil-bearing units are no longer accessible for study. Most of the material was not collected *in situ*, but instead from spoil piles. See Emry and Eshelman (1998) for details of collection methods and personnel. The specimens available for this study consisted of approximately 50 bones and 70 teeth housed in the USNM collections. Most attention was paid to the bones, as opposed to the teeth, because they tend to show more features that were unambiguously post-mortem. The surfaces of all bones were examined under the binocular microscope (up to 50X).

RESULTS

With the exception of teeth preserved within jaw fragments, the terrigenous bone material from the Pollack Farm Site is entirely disarticulated and disassociated. The bones are primarily small, robust elements, such as metatarsals. Mandibles and long bones occur as fragments. Most bones and teeth are black, although several (e.g., USNM 475850) are brown. Black color is usually attributed to phosphatization, but the taphonomic significance of the color differences among the specimens is not known.

Nearly all bones show some evidence of abrasion. Projections and prominences on bones are rounded or chipped. Fracture surfaces and the edges of cracks on bones may also be rounded, indicating that abrasion took place after the breakage or cracking. Many abraded surfaces show a high, glossy polish.

Bone surfaces typically show fine patterns of cracks along the length of the bones, resembling Stage 1 of the bone weathering stages devised by Behrensmeyer (1978). These cracks are produced during exposure of the bones on the land surface after the removal of skin and soft tissues by scavengers and/or decay. Some bone surfaces show evidence of relatively advanced weathering. The surface of one carnivore jaw fragment (USNM 475811) is intermediate between Stages 3 and 4 (Figure 1); this represents several years of exposure on the land surface. One specimen, a scapholunar bone (USNM 475829), shows an unusual "mosaic" pattern of cracking in which fractures intersect to create an array of irregular polygons on the bone surface; it is not known what conditions lead to this pattern (Behrensmeyer, 1978).

Several bones show scratches and gouges that are interpreted here to be tooth marks (Figure 2). Most show the rounded cross section typical of mammalian carnivore tooth marks (Shipman, 1981) and may have corresponding marks on the opposite surfaces of the bone, as would be produced by occluding teeth. One bone shows sets of parallel striations that resemble gnaw marks made by rodents (Lyman, 1994).



Figure 1. Weathered surface of carnivore jaw fragment (USNM 475811). Surface is intermediate between Weathering Stages 3 and 4 of Behrensmeyer (1978). Scale in mm.



Figure 2. Tooth marks on surface of a peccary calcaneum (USNM 494359). Scale in mm.

Other surface features common on the bones include patches of extremely fine dendritic etch marks visible only under the binocular microscope. The etchings were most likely produced by algal or fungal filaments that colonized exposed bone surfaces prior to burial. The etchings are primarily a surface feature, but where they are very dense they produce a pockmarked surface separated by plateaus of unetched surface. Etchings are most evident on concave surfaces and least evident on prominences. This pattern of distribution is at least partly due to removal of the etchings by abrasion. In some cases, however, etching occurs on top of abraded surfaces, so etching clearly postdates abrasion. The variable age relationships between etched and abraded surfaces suggests that episodes of etching and abrasion alternated with one another. This is reasonable given the shallow, subtidal environment of deposition: during periods of quiet water algae could grow freely on exposed surfaces, but during periods of agitation or transport algal growth would be inhibited and abrasion would predominate.

DISCUSSION

Although this analysis of the taphonomy of the Pollack Farm Site mammals is preliminary, the features observed here shed some light on the origin of the terrestrial mammal assemblage. One difference between the Pollack Farm assemblage and others interpreted to have been derived by

carcass rafting (e.g., Horner, 1979) is that the remains here occur as entirely disassociated elements (with the exception of several teeth found within mandibles). Articulated or closely associated remains would argue strongly for carcass rafting, because reworked bones would lack the connective tissues necessary to hold them together. However, lack of articulation is not evidence against rafting, because rafted carcasses often shed body parts during transport (Shäfer, 1972). Also, given the high energy of the depositional environment (implied by the coarse grain size, cross-bedding, and disarticulated bivalve shells) articulation of the bones is unlikely in any case.

More informative are the surface features of the bones. The weathered and cracked surfaces and the carnivore and rodent tooth marks all imply that the bones lay exposed in a subaerial environment prior to being introduced into their final burial environment. This argues against rafting because these "naked" bones would lack the soft tissues necessary for flotation. Such a period of exposure, followed by burial, is, however, compatible with the reworking model. Evidence for a period of burial prior to abrasion is provided by the glossy polish seen on many of the abrasion surfaces. Abraded bone generally does not take on a particularly high polish unless it has been permineralized (A.K. Behrensmeyer, pers. comm., 1997). The Pollack Farm Site bones were therefore probably buried and permineralized before they were transported and abraded.

Considering all of the evidence from the bone surfaces, the following sequence of post-mortem events is implied: (1) scavenging of carcasses (indicated by tooth marks), (2) exposure of bones on land surface for up to several years (indicated by bone weathering), (3) burial and permineralization of bones (implied by gloss on abrasion surfaces), and (4) exhumation of bones followed by alternation between abrasion and algal(?) etching in an estuarine environment.

This sequence of events, involving a period of burial followed by reworking, implies that the terrigenous fossils are somewhat older than the marine fossils with which they occur. It is not possible to tell how much older they are, nor is it possible to infer at this point the geologic circumstances that led to the reworking of the bones and their admixture with the marine fossils. A geologically ephemeral coastal environment such as a barrier island may have supported a terrestrial fauna (Emry and Eshelman, 1998) but later was destroyed by erosion, leaving behind the terrigenous bones as a lag deposit. Frey et al. (1975) describe the occurrence of Pleistocene and older terrestrial bones within Holocene estuarine sediments in Georgia. They interpret these mixed deposits to be the result of erosion and reworking by estuarine channels. On the other hand, the reworking may have been caused by a sea-level rise and regional transgression. Gallagher et al. (1989) attribute the occurrence of Quaternary land mammals on the Atlantic continental shelf to coastal reworking during the post-Pleistocene sea-level rise. They recorded both glacial and interglacial terrestrial taxa from the shelf deposits off New Jersey. They also note that the bones (both terrigenous and marine) on the continental shelf tend to be spatially concentrated and mixed with estuarine to open marine invertebrates, an observation that suggests these reworked deposits may be good analogs for the rich bone-bearing beds at the Pollack Farm Site.

Gallagher et al. (1996) have also discussed the possibility that the terrestrial elements in Miocene mixed faunas of the Atlantic are reworked. They suggest that the preponderance of resistant elements suggests that the terrestrial remains were derived from upstream habitats and had experienced prolonged transport. An alternate explanation is that the abrasion occurred during marine reworking of the terrestrial deposits, and therefore did not necessarily involve significant transport. Further study of the dendritic etchings that appear to be penecontemporaneous with abrasion could shed some light on this question. If they can be attributed to marine algae that would imply that at least some of the abrasion occurred in a marine environment. This would not exclude the possibility of earlier freshwater abrasion, of course, but it would make it unnecessary to explain the condition of the bones.

The comparative condition of the marine mammal bones in the deposit are also relevant to this question because they obviously would not require transport to be incorporated in a marine deposit. Though the taphonomy of these bones has not yet been studied in detail, their abraded condition resembles that of the terrestrial mammals (D.J. Bohaska, pers. comm., 1997), suggesting that the abrasion of both assemblages was *in situ*.

CONCLUSIONS

The surface features of the terrigenous bones from the Pollack Farm Site indicate that the bones were not rafted to the estuarine environment of deposition as fresh carcasses, but rather were introduced into the estuarine deposits by reworking. Weathered bone surfaces and mammalian tooth marks on the bones both indicate that the bones were exposed for a period of time on the land surface before burial, and the high polish of some of the bone surfaces imply that they were buried and permineralized before they were abraded. The Pollack Farm bone assemblage may be analogous to the concentrations of Quaternary mammalian bones interpreted by Gallagher et al. (1989) to have been reworked by the post-Pleistocene sea level rise.

A great deal more remains to be done on the taphonomy of this rich deposit. Comparison of the taphonomy of the terrigenous mammals with that of the marine mammals, for example, should prove particularly enlightening.

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FOSSIL MARINE MAMMALS OF THE LOWER MIOCENE POLLACK FARM SITE, DELAWARE¹

David J. Bohaska²

ABSTRACT

The Pollack Farm Site, a borrow pit (now covered) near Cheswold, Delaware, in the Cheswold sands of the lower Miocene Calvert Formation, produced a fragmentary marine mammal fauna. At least six cetaceans are present: five porpoises comprising a squalodont, *Squalodon calvertensis*, the squalodelphid *Phocageneus venustus*, the long-beaked platanistid *Zarhachis flagellator*, a rhabdosteid *Rhabdosteus* sp., and a small kentriodontid; and a sperm whale. Also present is a dugong, and one of the earliest records of a true seal, *Leptophoca lenis*. Although less diverse than the Calvert fauna as known from Maryland and Virginia, this is most likely a product of sampling. The absence of the common Calvert porpoise *Eurhinodelphis* from the Pollack Farm Site may be significant; the absence of mysticetes (whalebone or baleen whales) matches their unexplained absence from beds of similar age in the lower Calvert of Maryland and Virginia.

INTRODUCTION

The Pollack Farm Site (Delaware Geological Survey locality Id11-a), a borrow pit excavated near Cheswold, Delaware, for road bed material, exposed the Cheswold sands of the lower Miocene Calvert Formation (Ramsey et al., 1992). The site was the subject of intensive field study and fossil collecting from November 1991 through May 1992 by field crews from the Delaware Geological Survey, Virginia Museum of Natural History, and Smithsonian Institution, and members of the construction crews and amateur fossil collectors.

The beds at the site are equivalent in age to Bed 3A of the Fairhaven Member (diatomaceous earth) of the Calvert Formation in Maryland (Ward, 1993; Jones et al., 1995) and are discussed in more detail in other papers in this volume (Benson, 1998; Ramsey, 1998, Jones et al., 1998). On the basis of stratigraphic position, they are possibly the same age as the Popes Creek Sand Member (Gibson, 1983) of the Calvert Formation (Wetmore and Andrews, 1990; Gibson and Andrews, 1994), which does contain a diverse vertebrate fauna (largely unpublished). Specimens from the Popes Creek Sand are cited within this paper as the earliest occurrences of the represented taxa within the Calvert Formation in Maryland and Virginia and the nearest in age to those from the Pollack Farm Site. Unlike Bed 3A and the Popes Creek Sand, the Pollack Farm Site includes beds with a well preserved, abundant, and diverse molluscan fauna (Ward, 1998). The site also produced a diverse vertebrate fauna, distinguished from the other Chesapeake Group outcrops of Maryland and Virginia in containing a more diverse terrestrial mammal, terrestrial reptile, and amphibian assemblage, adding many new elements to the Calvert fauna. By contrast, the marine mammal collection, the subject of this paper, is more fragmentary and less diverse than the marine mammal fauna from the Calvert Formation of Maryland and Virginia, lacking the more nearly complete skulls and skeletons found there.

Acknowledgments

Field work at the Pollack Farm Site was a pleasant experience owing to the cooperation of the crews from the Delaware Department of Transportation, Pierson Engineering, and Century Engineering. Particular thanks go to Gordon

Simonson not only for providing many of the specimens used in this and other papers but for his logistical support.

Specimens cited in this paper were donated by David Duke, Gordon Simonson and Lauck W. Ward, and loaned by John Clark, Thomas R. O'Hagen and John Ricard. Additional cetacean specimens were donated by the above and Kenneth Webb, and loaned by David L. Anker, Michael Miskofsky, Mark L. Richerson, and Greg Turner.

Lauck W. Ward introduced me to the site, and Ralph E. Eshelman and Robert W. Purdy collected for the Smithsonian. Frederick Von Hofe Grady's skill in processing and picking the bags of concentrated matrix added several marine mammal specimens to the collection. Use of the Calvert Marine Museum collection was courtesy of curator Michael D. Gottfried. Norman L. Riker permitted examination of his Popes Creek Sand Member collection, and he donated *Phocageneus* specimens to extend the known range of that genus. William "Pat" Gotsis found the first known physterid in the Popes Creek Sand while this paper was in preparation.

Mario A. Cozzuol first recognized the complete periotic described as physeterid, and Clayton E. Ray the single seal bone. I discussed squalodonts with Alton Dooley, sirenians with Daryl Domning and sperm whales with James G. Mead.

Photography was by Peter Kroehler, Laurie Minor-Penland, and Victor Krantz.

Clayton E. Ray and Frank C. Whitmore, Jr., reviewed the manuscript and provided many useful comments.

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COLLECTING METHODS AND METHODS OF INVESTIGATION

Identifications of the scrappy material in this report are based primarily on comparisons with the Miocene Calvert fauna of Maryland and Virginia in the collections of the Department of Paleobiology, National Museum of Natural History, Smithsonian Institution (USNM) and of the Calvert Marine Museum (CMM-V). Since sampling techniques undoubtedly affect conclusions regarding relative abundances, a description follows.

¹ In Benson, R.N., ed., 1998, Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 179–191.

Collecting was done by careful inspection of spoil piles, particularly those rich in material derived from the shell beds. Spoil pile and *in situ* shell bed matrix was screen washed and inspected in the field; all fine concentrate and most of the coarse concentrate was fully picked in the laboratory. Picking of some of the fine concentrate (particularly that collected late in the field work) was facilitated by dissolving most of the carbonate shell fragments with acetic acid following a first picking to remove most of the identifiable mollusks and otoliths. All vertebrate material collected by the three institutions was retained.

Although most material described in this report was found loose in spoil piles, or received with no specific data, most was probably derived from the lower shell bed (see Benson, 1998, fig. 2), since spoil of this material was most intensively inspected. All terrestrial mammals found are consistent with one age, early Hemingfordian (Emry and Eshelman, 1998), confirmed by the early Miocene age based on radiolarians from a sandy silt between the lower and upper shell bed (Benson, 1998) and the strontium-isotope age estimate of 17.9 Ma on mollusks from the lower shell bed (Jones et al., 1998).

Almost all of the vertebrate fossils found by amateurs were inspected by Smithsonian staff. Because cetacean bones and teeth tend to be simpler, they are inherently less identifiable from teeth, postcranial, and scrap material than terrestrial mammals. More nearly complete cetacean material (skulls, jaws, and skeletons) has been and is found regularly in Maryland and Virginia. For these reasons, cetacean scrap was not solicited for donation or loan as rigorously as terrestrial mammals, which are more poorly known from Maryland and Virginia. As a result, the cetaceans represented in the institutional Pollack Farm Site collections are lower in number of specimens than would be preserved relative to land mammals in a marine deposit. No actual counts were made, but cetacean scrap was observed more often in the field and in amateur collections than land mammals. Potentially identifiable cetacean specimens (teeth, and jaw, skull, and limb fragments) were solicited on par with terrestrial mammal specimens, but vertebrae and ribs generally were not. (Although again not quantified, the majority of marine mammal remains found in Maryland and Virginia Calvert outcrops are also isolated vertebrae and other scrap; however, good collections of skulls and skeletons have been accumulated over the years).

SYSTEMATIC PALEONTOLOGY
Order CETACEA
Suborder ODONTOCETI
SQUALODONTIDAE

***Squalodon calvertensis* Kellogg, 1923**

Specimens (8).—USNM 488600, crown of anterior incisor, collected by L.W. Ward; USNM 487253, partial crown and partial root of anterior incisor, collected by G. Simonson; USNM 487254, partial crown and root of anterior incisor, collected by G. Simonson; USNM 488601, cast of anterior incisor, original found by and in the collection of J. Clark; USNM 487255, partial crown of incisor, collected by G. Simonson; USNM 487256, partial crown and roots of molariform tooth, collected by G. Simonson; USNM 487257, fragment of crown of molariform tooth, collected by R.E. Eshelman; USNM 488602, cast of partial crown and

roots of molariform tooth, original found by and in collection of J. Ricard.

Description.—The presence of at least one of the heterodont squalodonts or shark-toothed porpoises is most evident in the several molariform teeth in the collection (Fordyce [1982] argued that premolars and molars cannot be differentiated in squalodonts, so the term “molariform” is used here). USNM 487256 (Plate 1A) and USNM 488602 (Plate 1B) preserve the double roots, and the triangular, laterally compressed, wrinkled enamel crowns of the molariform teeth. The characteristic cusps along the cutting edges can be seen as one cusp on the posterior edge of USNM 487256, parts of two and possibly three cusps on USNM 487257, and hints of cusps on the broken edges of USNM 488602. In both USNM 487256 and USNM 488602, the two roots are joined for a distance below the crown, more so in USNM 487256 (22 mm vs. 19 mm measured on the lingual side). USNM 488602 has swollen-appearing roots, owing to a thickened layer of cementum.

The conical anterior incisors (USNM 488600, Plate 1C,D; USNM 487253) are large (compared with typical porpoise teeth), have prominent anterior and posterior cutting edges (particularly visible on USNM 488600, Plate 1D), and wrinkled enamel. The enamel-root boundary is sigmoid (most visible on USNM 487253) typical of, but not restricted to, squalodonts. All are interpreted as anterior incisors because they are relatively straight; reconstructions of *Squalodon* show these teeth extending directly anteriorly from the end of the rostrum and mandibles.

USNM 487254 also appears to be a squalodont anterior incisor. The enamel-root boundary appears to be sigmoid (wear prevents this from being certain). The wrinkled nature of the enamel is only debatably visible; the little enamel preserved is almost entirely worn smooth. Like the molar USNM 488602, the root (single in this case) has a thick layer of cementum.

Part of the crown is missing on USNM 488601, revealing a 20-mm-deep conical cavity diminishing to a point toward the root. Were it not for a 4 mm x 4 mm patch of probable enamel preserved on the crown, the cavity could be interpreted as the pulp cavity in the root, and the tooth identified as physeterid. A similar cavity is visible in USNM 487254, where a larger, undebatable patch of enamel is present.

USNM 487255 is more curved than the other incisors and is interpreted as a more posterior incisor (or canine; homologies are uncertain except possibly in an intact jaw). The cutting edges are preserved. The enamel is more striated than wrinkled.

Kellogg (1923) described two squalodonts from the Calvert Formation, the smaller *Squalodon calvertensis* (estimated body length 10 ft or 3 m, Kellogg, 1957) and a larger unnamed species (more complete remains from Maryland and Virginia are currently under study by Alton Dooley). Both species are present in the Popes Creek Sand in Maryland (*S. calvertensis*: CMM-V-206, CMM-V-207; *Squalodon* species: CMM-V-182). The Pollack Farm Site specimens are tentatively referred to *S. calvertensis* based on size.

Squalodonts are generally considered more primitive because of the retention of a prominent heterodont dentition. In the Maryland and Virginia Miocene they are reliably present as high as Bed 12 of the Calvert Formation (CMM-V-930).

SQUALODELPHIDAE

Phocageneus venustus Leidy, 1869

Specimens (3).— USNM 487258, tooth, collected by G. Simonson; USNM 488603, USNM 488604, casts of teeth, originals found by and in the collection of J. Ricard.

Description.—The best evidence of the presence of this species at the Pollack Farm Site is a single tooth, USNM 487258 (Plate 1E,F), with highly wrinkled enamel. A number of Calvert Formation odontocetes show limited heterodonty (as opposed to the obviously heterodont *Squalodon*), with all the teeth single rooted, variably more or less wrinkled enameled teeth more posterior in the tooth row, and smoother more peg-like teeth anteriorly (with few exceptions, modern porpoises have a homodont dentition of smooth enameled, peg-like teeth throughout their jaws). USNM 487258 matches *Phocageneus* in size and high degree of enamel wrinkling, and in the characters noted by Kellogg (1957, p. 286–287):

base of enameled crown becomes narrower as it approaches the root, and complication of the wrinkled enamel surface by both vertical and oblique striae, posterior teeth more rugose on the basal portion of the lingual side of the tooth than the labial side, and anterior and posterior cutting edges present.

A second tooth (USNM 488603, Plate 1H) may be a more anterior tooth of this species; it is less rugose and somewhat larger than similar teeth in Kellogg's referred specimen (1957). It resembles phocid canines, but the cutting edges are less prominent and the rugosity more so. A third rugose tooth (USNM 488604 Plate 1G) is smaller and tentatively referred to *Phocageneus*.

Phocageneus venustus is a poorly known species originally described from a single tooth, which for at least the time being must be considered to be from an unknown horizon. The specimen referred to the species by Kellogg (1957) came from what is now known as Bed 3B of the Fairhaven Member, Calvert Formation. Two teeth (USNM 488609, USNM 488610) probably from the Popes Creek Sand closely resemble some of the posterior teeth of *Phocageneus* (USNM 21039, Kellogg, 1957) although they are somewhat smaller. The skull is as yet undescribed and the species is only tentatively referred to the Squalodelphidae (Kellogg, 1957).

PLATANISTIDAE

Zarhachis flagellator Cope, 1868

Specimens (4).—USNM 487259, mandibular symphysis fragment, approaching distal end, collected by G. Simonson; USNM 487260, section of symphyseal portion and ascending ramus of right mandible, collected by G. Simonson; USNM 487262, anterior process of right periotic, collected by G. Simonson; USNM 487263, anterior process of right periotic, collected by D.J. Bohaska.

Description.—A 252-mm section of mandibular symphysis (USNM 487259, Plate 2A,C) clearly came from one of the extremely long-beaked porpoises. The two longitudinal grooves on the ventral side (Plate 2C) are characteristic of *Zarhachis*, *Pomatodelphis* and several other modern and fossil genera, and the mandible is dorsoventrally flattened as in *Zarhachis* and *Pomatodelphis*. Another mandibular frag-

ment (USNM 487260, Plate 2E) has the ventral groove and shows the U-shaped, instead of V-shaped juncture of the free ends of the mandible characteristic of these two genera.

Two anterior processes of the periotic (USNM 487262, 487263) are massive, as in *Zarhachis* and *Pomatodelphis*, have a longitudinal groove on the bullar facet (also seen on rhabdosteids) and a U-shaped anteroexternal sulcus (also in rhabdosteids).

The only periotic associated with a lower Calvert *Zarhachis* skull is USNM 10485, a partial right periotic lacking the posterior process. A complete right periotic (USNM 187414) associated with a skull shows no significant differences from this fragment; this skull is from the Choptank Formation and has been referred to *Pomatodelphis* (Muizon, 1987). Although being at least a different species (see below), this specimen and others of the same species were the most appropriate available for comparison.

The closely related and possibly congeneric *Zarhachis* and *Pomatodelphis* cannot be distinguished from one another from fragments of these kinds, and the specimens from the Pollack Farm Site are referred to *Z. flagellator* on the basis of stratigraphic position. The concept of *Z. flagellator* used here is based on the two specimens described by Kellogg (1924, 1926), derived from the lower Calvert Formation (Bed 5, and Bed 6,7 or 8). Two periotics (USNM 299950, 299951) are known from the Popes Creek Sand Member at Popes Creek, Maryland. A second species of *Zarhachis* or *Pomatodelphis* occurs higher in the Calvert (Bed 10 or 11, and Bed 12) and Choptank (Bed 17) (Gottfried et al., 1994) and possibly a third in the St. Marys (Gottfried et al. 1994). Complicating identification is the poor quality of the type specimen of *Z. flagellator* (a worn caudal vertebra) from an unknown horizon. Resolution of the taxonomy of *Zarhachis* and its relatives is not appropriate here.

Zarhachis is an extremely long-beaked porpoise, in which both upper and lower jaws are the same lengths (their anterior tips meet), estimated at 5 m (16 feet) total body length (Kellogg, 1957). The supraorbital process of the frontal is greatly thickened dorsally. It has been referred to the river porpoises (Platanistidae) and generally regarded as closest to *Platanista* (Kellogg, 1924; Muizon, 1987), although interpreting the habitat and lifestyle by analogy with modern river porpoises is questionable; *Zarhachis* is clearly different from modern members of the family. Modern platanistoids (often grouped together in the single family Platanistidae) live in both fresh and, if *Pontoporia* is included, nearshore marine environments.

RHABDOSTEIDAE (=EURHINODELPHIDAE)

Rhabdosteus sp.

Specimen.— USNM 487264, mandibular symphysis fragment, approaching distal end, collected by G. Simonson.

Description.—Another species of long-beaked porpoise is represented by a 174-mm section of mandible (USNM 487264, Plate 2B,D). Like *Zarhachis*, there are two longitudinal grooves ventrally. Unlike *Zarhachis*, but like *Rhabdosteus* and *Eurhinodelphis*, the mandible is narrower (*Zarhachis* and the present specimen are illustrated at the same scale in Plate 2), and relatively deeper dorso-ventrally. At least some specimens of both *Rhabdosteus* (for example, USNM 206006 and 20668) and *Eurhinodelphis* (for exam-

ple, USNM 187623, CMM-V-14) have grooves on the ventral surface of the mandible. *Rhabdosteus* has larger, fewer tooth sockets, with the sockets well defined by well developed septa between sockets, as in USNM 487264 from the Pollack Farm Site. *Eurhinodelphis* has more tooth sockets more closely spaced, with less well developed septa between sockets (Myrick 1979).

Rhabdosteus latiradix Cope 1868 is the genotypic species. Myrick (1979) in manuscript described several new species in the genus. Muizon (1988) considered *Rhabdosteus* a *nomen dubium* and referred specimens referred to the genus (in manuscript and in collections) to *Schizodelphis*, unfortunately using one of Myrick's unpublished names. Tentatively, the name *Rhabdosteus* is retained here. According to Kellogg (1957), *Rhabdosteus* is the most numerous odontocete in the Calvert fauna, whereas Myrick (1979) shows *Rhabdosteus* and *Eurhinodelphis*, at the generic level, about equal in number of identified specimens. In any case, each of the two genera is more numerous than any other odontocete genus in the Calvert. The low numbers of *Rhabdosteus* and absence of *Eurhinodelphis* at the Pollack Farm Site are surprising, although the low sample size may be a factor. Additional specimens may be unidentified among the fragmentary remains in the collections, although one would have expected to find the easily recognized anterior caudal vertebrae of *Eurhinodelphis* in the collections. *Eurhinodelphis* is present in the Popes Creek Sand Member at Popes Creek, Maryland (CMM-V-347).

Rhabdosteus was estimated at just under 3.7 m (12 feet) in total body length (Kellogg 1957); the rostrum extends well beyond the distal end of the mandible, and the distal one-third of the rostrum is seemingly edentulous in old individuals (Kellogg 1957). In Maryland and Virginia, *Rhabdosteus* is restricted to the Calvert Formation and has been found in the Popes Creek Sand Member (USNM 206006). Myrick (1979) inferred pelagic habits based on the wide distribution of some species; at least one member of the family (but probably not the same genus) occurred in fresh water (Fordyce, 1983).

KENTRIODONTIDAE

Specimens (2).—USNM 487265, tooth, collected by D.J. Bohaska (found *in situ* in cross-bedded sandy shell bed); USNM 488605, tooth, collected by Smithsonian field party.

Description.—A tooth (USNM 487265, Plate 1I) most closely resembles that of *Kentriodon pernix* Kellogg (1927) among the published Calvert odontocetes in its small size and simple architecture: smooth crown, lacking any rugosity, and conical shape. Faint carinae are present on the anterior and posterior sides of the tooth; Kellogg (1927) mentions a lack of carinae in *K. pernix*, although faint carinae appear present in his plate 8, figure 2, and are present, although faint, on some of the actual teeth illustrated in that figure. The base of the crown and top of the root are the same diameter in the individual teeth of the holotype of *K. pernix* (USNM 8060) and the Pollack Farm Site USNM 487265, resulting in a smooth transition from enamel to root.

The second Pollack Farm Site tooth (USNM 488605, Plate 1J) is more worn than the first, but is roughly equal in size and simple shape. USNM 488605 is broader at the base of the crown, the crown is more tightly curved, and the root

is broader than the crown in some areas, owing to the presence of cementum. Cementum is deposited on the root continuously during the life of a porpoise, and can result in thicker, swollen roots in older individuals. The cementum can break off, as can be seen in one area on USNM 488605; in this area the enamel crown and the dentine of the root have a smooth transition as in the holotype of *K. pernix*.

USNM 487265 and USNM 488605 also resemble teeth in another undescribed species in the Calvert. This second species (USNM 25005, USNM 457211, USNM 171077) resembles *K. pernix* in its small size and general skull outline, but its skull roof is laterally constricted and resembles the larger *Liolithax pappus* (Kellogg) 1955, which would place it in another subfamily. Two teeth associated with USNM 457211, and three in USNM 171077, are also small, simple and have faint carinae. The roots are expanded on USNM 457211 owing to a heavier layer of cementum, resembling the second tooth from the Pollack Farm Site (USNM 488605) more closely. In the other skull (USNM 171077) of this possible new species the one tooth (of three present) on which some of the root is exposed, shows no cementum.

Identification of a porpoise solely on teeth, particularly such simple ones, must be considered tentative. Given the small sample of teeth associated with identifiable skulls of these two species, the variability of teeth within the jaws of one individual (Kellogg, 1927, plate 8) and between individuals of one species, and the similarity of the teeth in the two species, it appears that these two species cannot be distinguished on the basis of teeth alone. For that reason the two Pollack Farm Site teeth are identified to family only, and assignment even at that level is tentative.

Several skulls are known from the Popes Creek Sand Member near Popes Creek, Maryland, which is thought to be similar in age to the Pollack Farm Site. CMM-V-247 and CMM-V-886 have the *K. pernix* skull roof; no specimens displaying the second skull roof type were recognized in the USNM or CMM collections from this level.

K. pernix was a small (1.6 m or 5.5 feet long) short-beaked porpoise reconstructed as resembling modern porpoises (Kellogg, 1927). The Kentriodontidae are generally considered to contain the ancestors of the modern delphinids, although no ancestor-descendant relationships at the generic or specific levels have been hypothesized (Ichishima et al., 1995).

PHYSETERIDAE

Specimens (3).—USNM 487266, distal portion of tooth, collected by G. Simonson; USNM 488606, cast of tooth, original found by and in the collection of T.R. O'Hagan; USNM 488607, cast of right periotic, original found by and in the collection of J. Ricard.

Description.—The distal end of a tooth 6.5 cm in length (USNM 487266, Plate 1K) is recognizable as a tooth by its cross section; dentine and cementum layers are visible. Its large diameter (2.4 cm maximum), lack of enamel (present in some fossil sperm whales, particularly *Scaldicetus*), and longitudinal grooving show it to be a sperm whale. An approximately 2-cm dished-out area represents wear created during life, and is similar to wear often seen on odontocete teeth, but particularly sperm whales. Other wear less certainly originated in life. No pulp cavity is present, presumably due to the distal location of this fragment.

USNM 488606 (Plate 1L,M), although nearly complete, is more questionable. It is large (9.4 cm long, 2.3 cm maximum diameter), lacks enamel, and has a well developed pulp cavity. It does not show the longitudinal grooves seen in USNM 487266 and is in the size range of a large *Squalodon* incisor or canine. A dark line partially circles the crown approximately 2 cm below its tip. This is interpreted here as a stain above the gum line; similar stains are seen in some modern *Physeter* teeth and many fossil teeth.

Transverse bands in the dentine usually seen on *Orycterocetus* and used in its diagnosis are not visible on either of the Pollack Farm Site teeth, either through absence or a covering of cementum.

The periotic (USNM 488607, Plate 1N–Q), is the only complete periotic found at the site. The accessory ossicle, well developed in sperm whales and some other odontocete families, is missing in this specimen, not an unusual occurrence. There is a depression on the ventral surface of the anterior process (Plate 1O), anterior to the fossa for the head of the malleus, where the accessory ossicle was attached. The anterior end of the anterior process is squared off and has a groove (Plate 1O); as a result the process has two heads, resembling the handle of a crutch in Kellogg's terminology (1931). As in *Physeter* (Kasuya, 1973), the *aqueductus fallopii*, *foramen singulare*, *ductus endolymphaticus*, and *tractus spiralis foraminosus* all open into the one opening of the fundus of the internal auditory meatus (Plate 1N).

Orycterocetus crocodilinus Cope (1868), see Kellogg (1965), is the only sperm whale as yet reliably ascribed to the Calvert Formation, and is the largest odontocete in the fauna (Kellogg, 1957; Gottfried et al., 1994). Among the suite of teeth in a sperm whale from the Calvert Formation in Maryland, USNM 336585, are teeth resembling *O. crocodilinus*; others resemble the genotypic *O. quadratidens* "from the miocene formation of Virginia" (Leidy, 1853b). Questions of synonymy should be held until the stratigraphic origin of *O. quadratidens* is determined, if possible, and better specimens are obtained in that formation. Although most cetaceans from the type locality (Charles County, Maryland) of *O. crocodilinus* have been ascribed to the Calvert Formation, this must also be considered questionable (see Gottfried et al., 1994). Published records have *O. crocodilinus* as low as Bed 9 of the Calvert Formation in Maryland (Kellogg, 1965); a physeterid with enamel-crowned teeth was recently found in the Popes Creek Sand (USNM 489195). With the lack of definitive characters to assign the fragmentary specimens from Delaware to *Orycterocetus*, they are referred to family only.

Order CARNIVORA PHOCIDAE

Leptophoca lenis True, 1906

Specimen.— USNM 475898, partial left calcaneum, collected by G. Simonson.

Description.—A worn partial distal half of a left calcaneum (USNM 475898, Plate 2F) preserves the posterior articular surface and the anterior half of the anteromedial articular surface. The "prominent longitudinal ridge . . . on the dorsal table, between the trochlear process and the anteromedial articular surface, . . . [extending from] the posterior articular surface to the cuboid articular surface" char-

acteristic of the Phocidae (Robinette and Stains, 1970, p. 530) is present, although because the trochlear process is missing, only a shelf remains where the groove lateral to this ridge should be.

The oldest currently described phocid is a phocine, *Leptophoca lenis* True (1906), from the Calvert Formation (Repenning et al., 1979). Although the monochine *Monotherium? wymani* (Leidy, 1853a), see Ray (1976), was reported from the Calvert Formation of Richmond, Virginia, later work near the type locality shows that the holotype probably came from higher in the Chesapeake Group (Andrews, 1986), and all of the stratigraphically controlled phocid remains from the Calvert in Maryland and Virginia are phocine and are tentatively referred to *Leptophoca lenis* (Clayton E. Ray, pers. comm.), as is the specimen from Delaware. (The holotype of *L. lenis* is an isolated humerus. As yet, no *Leptophoca* humerus has been found associated with any other element, and there are no well preserved Calvert phocid calcanea available in collections to refer even tentatively to *Leptophoca* for comparison with the Pollack Farm Site specimen.) The lowest Calvert phocid is an upper premolar (USNM 412122) reportedly from Bed 5 of the Calvert Formation at Chesapeake Beach, Maryland. (The locality data and stratigraphic level, "base of cliff," leave the possibility that this specimen came from a level equivalent to uppermost Bed 3B, Bed 4, or lower Bed 5, since Bed 4 cannot be easily distinguished at this locality. In any case, the difference in time represented is negligible.)

This leaves the Calvert *Leptophoca lenis* as the oldest known member of the Phocidae, and the Pollack Farm Site specimens the oldest in the Calvert. Although intensive collecting in Maryland and Virginia has resulted in a fair number of *Leptophoca* specimens, they are rare, and it is not surprising that only one was found at the Pollack Farm Site. Other early records of the family include an undescribed new species from the middle Miocene of Argentina (Cozzuol, 1992), and two specimens from the late Oligocene of South Carolina (Koretsky and Sanders, 1997).

Order SIRENIA Family DUGONGIDAE

Specimens (2).—USNM 487268, fragment of rib, collected by G. Simonson; USNM 488608, fragment of rib, collected by L.W. Ward.

Description.—Both ribs are solid or nearly so in cross section (some spongy bone is present in USNM 488608). This condition, termed osteosclerosis (Domning and Buffrénil 1991), is characteristic of the Sirenia. The condition also occurs in archaeocetes, a Paratheyean cetothere, and some seals.

Only one sirenian is described from the Calvert Formation, *Metaxytherium crataegense* (Kellogg, 1966; Aranda-Manteca et al., 1994), although there is the possibility of one or more additional species. Eastern North American sirenians were all members of the family Dugongidae until the arrival of manatees (family Trichechidae) in the Pleistocene.

Only one other sirenian rib fragment from the Pollack Farm Site was seen in an amateur collection; sirenians are rare in the Maryland and Virginia Calvert, and this appears to be the case at the Pollack Farm Site also. They have been found in the Popes Creek Sand Member (USNM 241562, CMM-V-244). Sirenians tend to occur in fresh and near-

shore marine waters; with the exception of the recently extinct *Hydrodamalis*, they are more abundant in warm water. This pattern is seen in the Eocene through modern record of the North American east coast; sirenians are most abundant in Florida and rarer to the north.

CONCLUSIONS

The Pollack Farm Site provided a more diverse molluscan assemblage than seen at the presumed same stratigraphic level in Maryland (Popes Creek Sand Member), and a greater terrestrial mammal, terrestrial reptile and amphibian assemblage than seen in the entire Chesapeake Group (Old Church through Chowan River formations; Maryland, Virginia, and North Carolina). In contrast, the marine mammal collections are more fragmentary and less diverse. The site does extend the record into Delaware, confirms several patterns seen elsewhere, and extends the record of the Calvert Formation.

Although Gottfried et al. (1994) list 21 cetacean species for the total Calvert Formation, versus six species identified at the Pollack Farm Site, the difference is not as lopsided as it would first appear. Of the 21 species, five are mysticetes, absent in the Maryland lower Calvert, as they are in Delaware. Of the cetaceans present in Maryland but absent in Delaware, an additional four are rare, poorly known (at least regionally) genera (*Araeodelphis*, *Pelodelphis*, *Tretosphys*, *Notocetus*) and one (*Zarhachis* or *Pomatodelphis inaequalis*) occurs higher in the Calvert. "*Delphinodon*" *dividum*, *Liolithax*, and *Hadrodelphis* are known by more adequate specimens but are not common. None of these last eight has been found in the Popes Creek Sand. One rare Calvert genus, *Phocageneus*, has been found at the Pollack Farm Site.

Of the Pollack Farm Site marine mammals, *Squalodon calvertensis*, *Phocageneus venustus*, *Zarhachis flagellator*, *Rhabdosteus*, a small kentriodontid, a physeterid, and a dugong have been found in the Popes Creek Sand. The Pollack Farm Site provides a lower occurrence of *Leptophoca*. Only *Eurhinodelphis* and a larger *Squalodon* species are known at Popes Creek and not at the Pollack Farm Site. When the Calvert fauna is subdivided by its occurrences in the members and beds of the formation, sample sizes become much smaller. Much is yet to be learned about the Calvert fauna, so the ranges and especially negative evidence of these rare species within the formation should not be taken as significant at this time.

Despite the precaution noted above, several patterns do emerge, particularly when dealing with the more common elements of the faunas. As in the lower Calvert, long-beaked porpoises are dominant, although (questionably, given the small sample) *Zarhachis* is more common than the Rhabdosteidae (=Eurhinodelphidae). Surprisingly, no specimens of *Eurhinodelphis* were recognized, despite its abundance in the Calvert and its easily recognizable caudal vertebrae. (In all these estimates, abundance is an impression based on relative numbers of specimens. A more rigorous estimate of minimum numbers of individuals would result in counts of one individual per species, except two for *Zarhachis*). In the Choptank and St. Marys formations of Maryland, the Rhabdosteidae are absent and *Zarhachis* or a related genus (*Pomatodelphis*) becomes the most common odontocete. *Squalodon* is present (more common in the lower Calvert but seen as high as Bed

12), again arguably more common at the Pollack Farm Site, and there are hints of the remaining cetacean fauna (short-beaked kentriodontids, sperm whales, and one of the rarer porpoises, *Phocageneus*).

It should be noted that *Squalodon* teeth and *Zarhachis* mandible fragments are easily recognized, whereas other porpoise teeth, rostral fragments, and other elements found at the Pollack Farm Site have not been identified to genus. This provides an alternate explanation for the seemingly greater relative abundance of these two genera in Delaware than in Maryland and Virginia.

Also as in the lower Maryland sequence, mysticetes are not present. As noted in Gottfried et al. (1994), this is particularly surprising given their widespread occurrences in earlier and later strata on the East Coast, including the higher Calvert and the rest of the Chesapeake Group. Wetmore and Andrews (1990) show a more restricted extent of deposits and therefore a possibly more restricted Salisbury Embayment at this time; perhaps a lack of prey kept them out of this area. The restricted basin might make the stranding of floating carcasses unlikely. Against the explanation of a more restricted basin during Bed 3A time is the absence of mysticetes in the more open and widespread Beds 3B through Bed 8 (Gottfried et al., 1994; Wetmore and Andrews, 1990; Ward and Powars, 1989). The Pollack Farm Site presumably was closer to the open ocean than the Maryland portion, and presumably would be more likely to receive the remains of a stranded animal.

The presence of a true, or earless, seal, *Leptophoca*, is not only the lowest record regionally but among the oldest in the world.

Interpretation of environmental conditions based on fossil marine mammals is questionable, owing to lack of knowledge of their habits and to their potential to strand, or their carcasses to be washed up, far from where they normally lived (Kellogg and Whitmore, 1957). *Zarhachis* has been consistently placed in the Platanistidae, or river porpoises, whether in the restricted (modern *Platanista*) or more general sense (modern *Platanista*, *Lipotes*, *Inia*, *Pontoporia*). Under either interpretation, *Zarhachis* is clearly very different from other members of the family and, this alone would suggest using analogues cautiously. One modern platanistid or platanistoid (*Pontoporia*) occurs in both fresh river and coastal marine/estuarine environments. *Zarhachis* and the closely related *Pomatodelphis* (except the fragmentary and held questionable here *P. stenorhynchus* of Europe, Kellogg, 1959) occur from Delaware to Alabama (Kellogg, 1959; Morgan, 1994; Hulbert and Whitmore, 1997) in nearshore deposits. Most Neogene marine mammal localities are of nearshore origin, however. The limited range of *Zarhachis* and *Pomatodelphis* and the lack of clear records from elsewhere would suggest non-open ocean habits. *Zarhachis* and *Pomatodelphis* have a body plan resembling modern river porpoises: long snout and relatively long flexible neck, unlike the typical form of open ocean pelagic odontocetes. A dead river-dwelling porpoise could easily float downstream into the marine environment and be preserved, a not unexpected process at the Pollack Farm Site where terrestrial vertebrates were found.

A member of the Rhabdosteidae has been found in fresh water deposits, although probably a different genus than *Rhabdosteus* (Fordyce, 1983).

An alternate hypothesis interprets the distribution of modern river porpoises as a relict distribution of a previously widespread marine family.

Sirenians (with the exception of Steller's sea cow *Hydrodamalis*) are generally tropical to subtropical in distribution, although manatee remains are known as far north as the Pleistocene of New Jersey (Gallagher et al., 1989) and individuals have strayed north as far as Massachusetts and England. The Pollack Farm Site sirenian specimens are unidentifiable, but the Maryland Calvert Formation *Metaxytherium crataegense* is widely distributed, as far as Florida (Simpson, 1932) and the southeastern Pacific Ocean in Peru (Muizon and Domning, 1985).

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PLATES

PLATE 1

All scale bars 1 cm

A–M. Teeth of cetaceans:

A. *Squalodon calvertensis*, molariform tooth, USNM 48756.

B. *Squalodon calvertensis*, molariform tooth, J. Ricard collection (cast, USNM 488602).

C, D. *Squalodon calvertensis*, anterior incisor, USNM 488600, C: lateral or medial view, D: anterior or posterior view.

E, F. *Phocageneus venustus*, posterior tooth, USNM 487258, E: medial view, F: lateral view.

G. ?*Phocageneus venustus*, tooth, J. Ricard collection; (cast, USNM 488604).

H. ?*Phocageneus venustus*, anterior tooth, J. Ricard collection (cast, USNM 488603).

I. Kentriodontidae, USNM 487265.

J. Kentriodontidae, USNM 488605.

K. Physeteridae, tooth, USNM 487266.

L, M. Physeteridae, tooth, T. O'Hagan collection (cast, USNM 488606); L: medial view, M: lateral view.

N–Q. Physeteridae, right periotic, J. Ricard collection (cast, USNM 488607); N: dorsal view, O: ventral view, P: lateral view, Q: medial view; ap=anterior process, ao=attachment area of accessory ossicle, fiam=fundus of the internal auditory meatus, pp=posterior process.

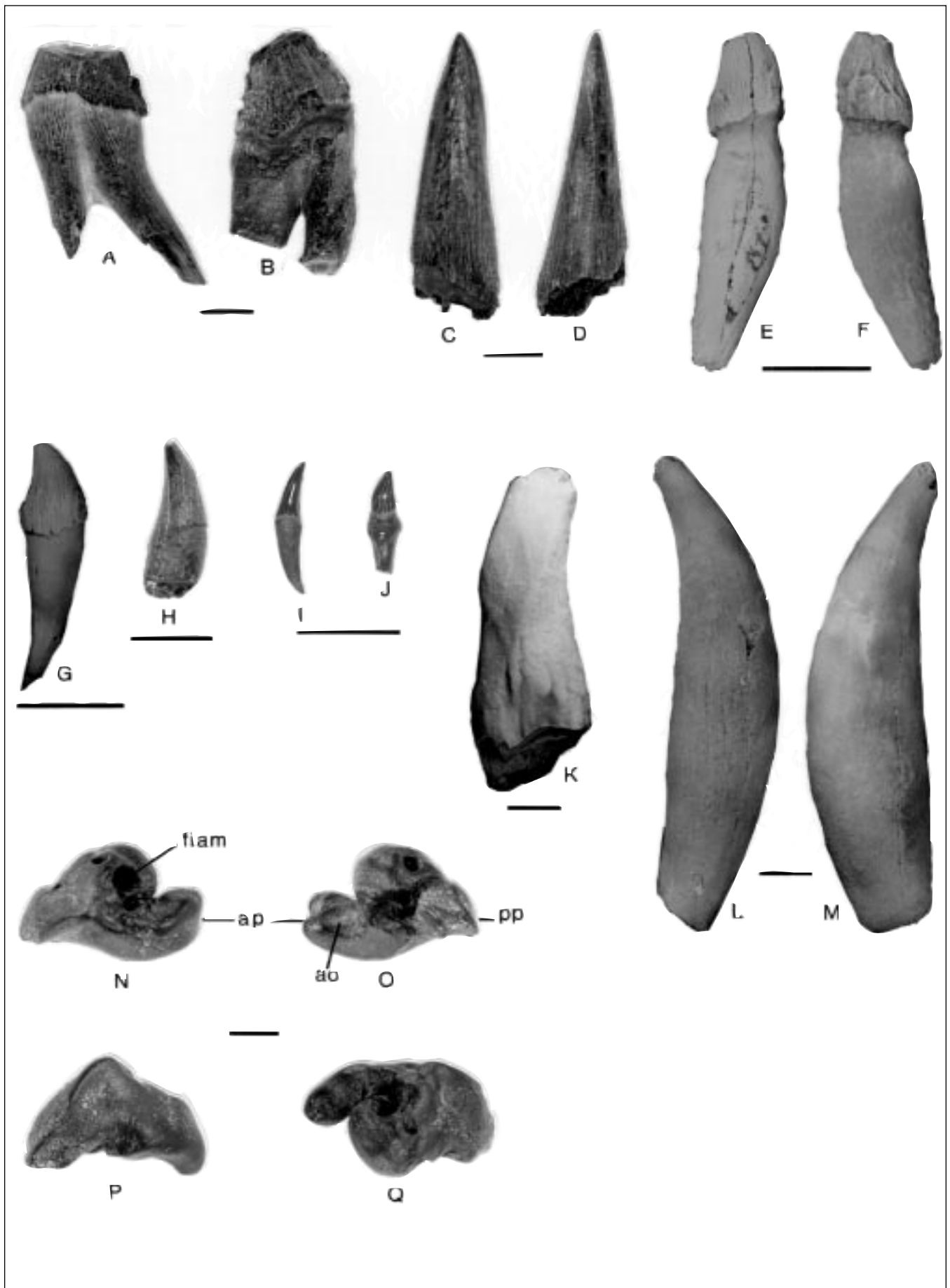


PLATE 2

All scale bars 1 cm

A–E. Odontocetes:

A, C. *Zarhachis flagellator*, symphyseal portion of mandible, USNM 487259; A: dorsal view, C: ventral view.

B, D. *Rhabdosteus* sp., symphyseal portion of mandible, USNM 487264; B: dorsal view, D: ventral view.

E. *Zarhachis flagellator*, mandible, USNM 487260, ventral view.

F–G. Phocids:

F. *Leptophoca lenis*, partial left calcaneum, USNM 475898, dorsal view.

G. *Callophoca obscura*, Pliocene, North Carolina; left calcaneum, USNM 373541, dorsal view (for orientation);
ams=anteromedial articular surface, dt=dorsal table (ridge), g=groove between ridge on dorsal table and trochlear
process, pas=posterior articular surface, t=trochlear process.

