DEPOSITIONAL ENVIRONMENTS AND STRATIGRAPHY OF THE POLLACK FARM SITE, DELAWARE[1]

Kelvin W. Ramsey[2]

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.

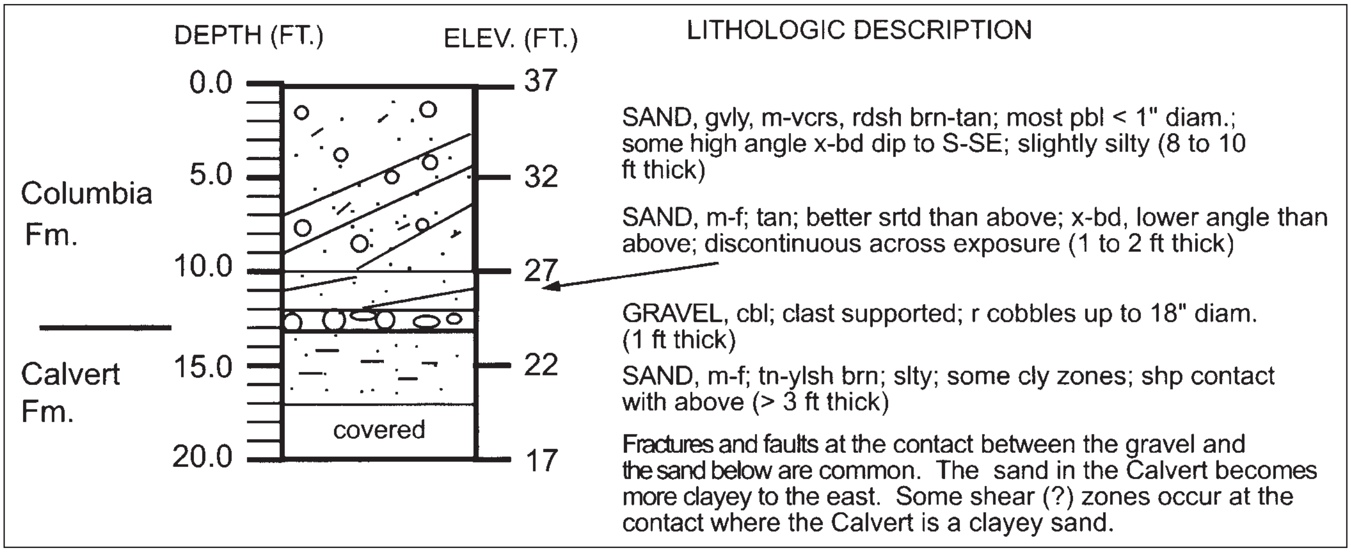

Figure 3. Measured section at the west wall (Fig. 1).

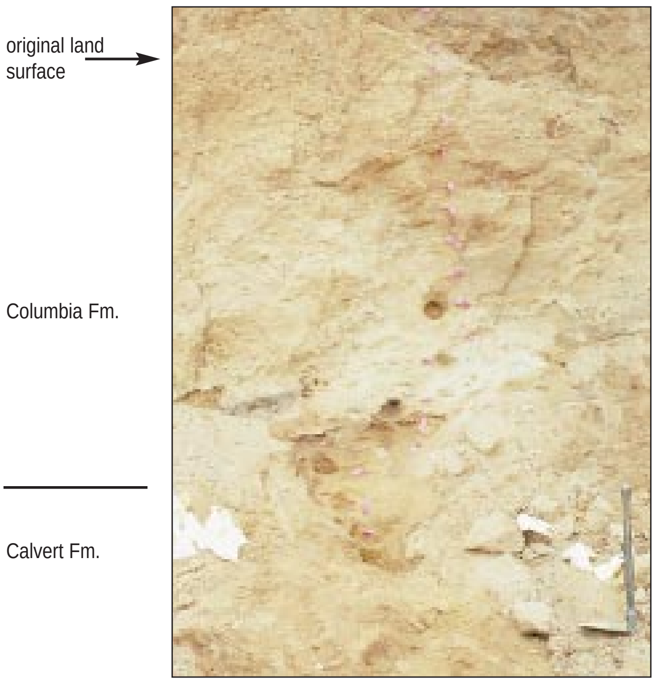

Figure 4. Photograph of a section of the west wall showing the Columbia Formation overlying the Calvert Formation. Length of shovel is 1.5 ft.

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 stratigraphic 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).

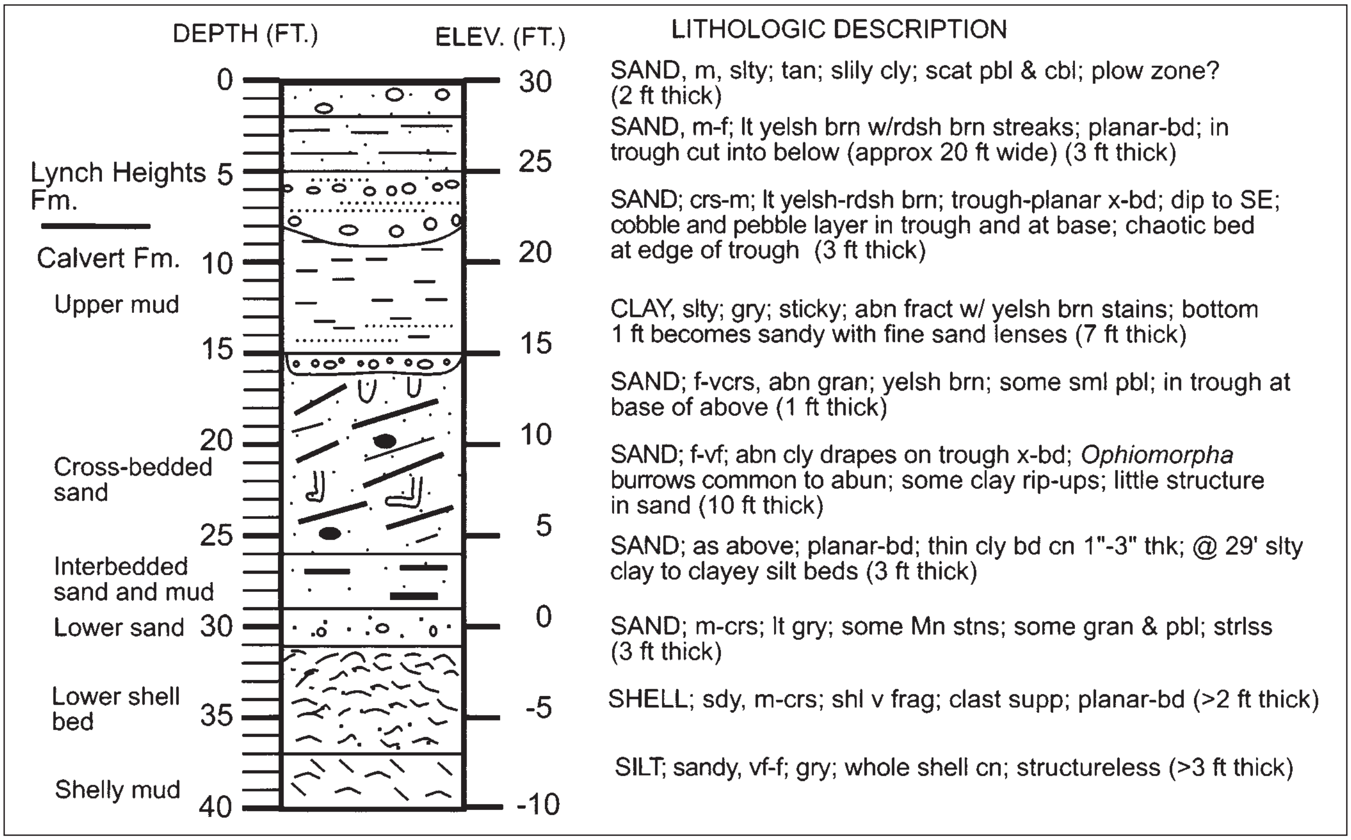

Figure 5. Measured section at the east wall (Fig. 1).

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.

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.

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).

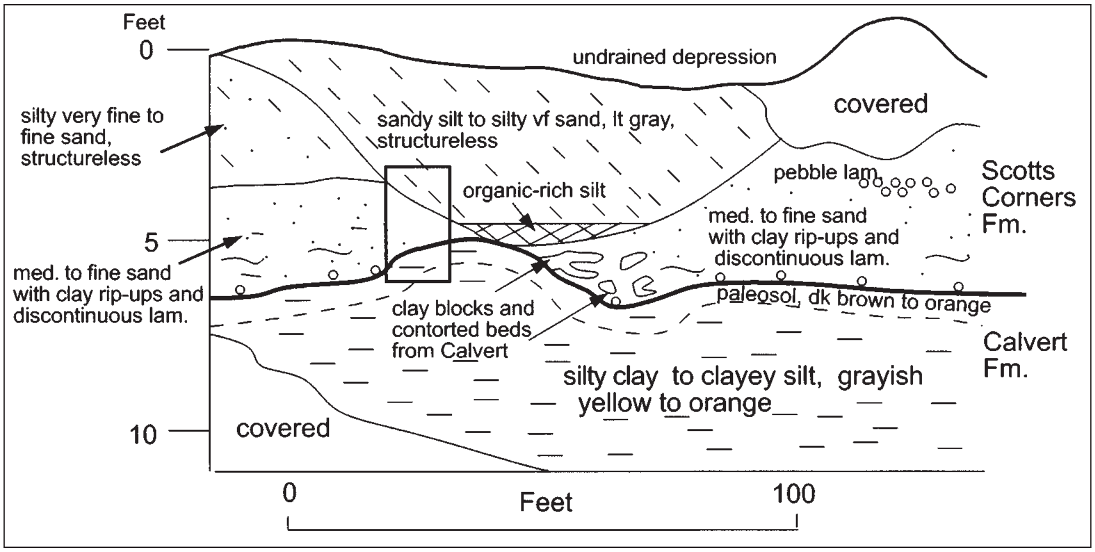

Figure 7. Sketch of site Id11-b (Fig. 1) showing the stratigraphic relationships of the undrained depression deposits and the Scotts Corners and Calvert formations The photograph shows a portion of the exposure outlined as a box on the sketch.

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,

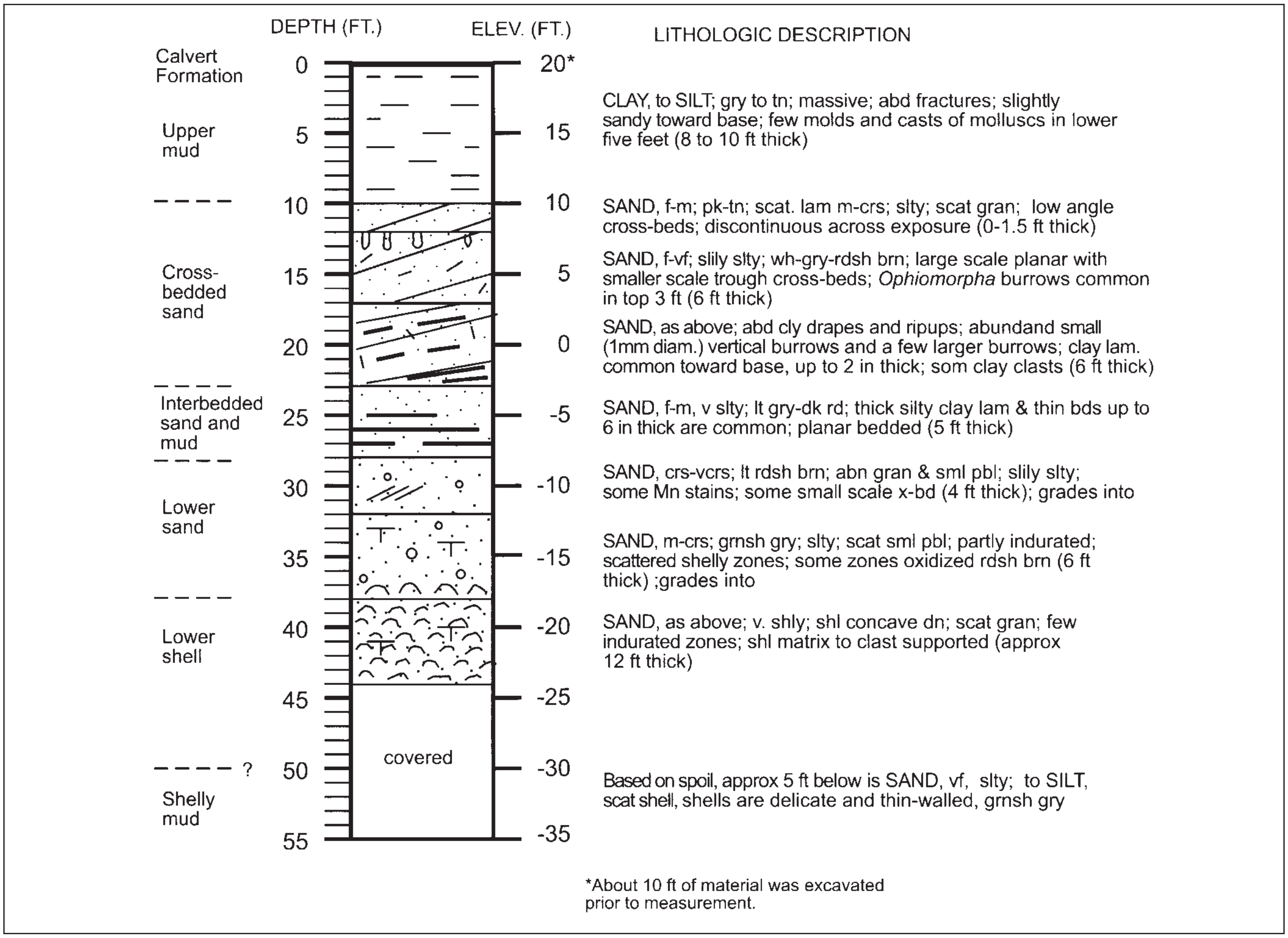

Figure 8. Measured section at the central wall (Fig. 1).

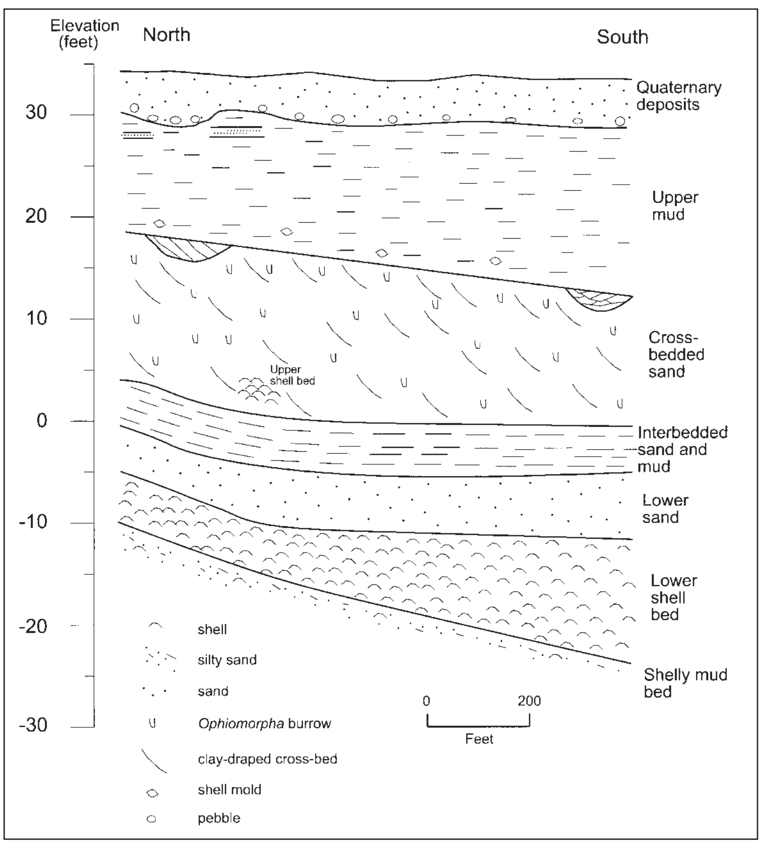

Figure 9. North (on left) to south schematic cross section showing the stratigraphic relationships of beds within the Calvert Formation at the Pollack Farm Site. Cross section is based on measured sections and other data along the east and central walls and along the deep trench excavation.

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 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. Glycimerid shells (maximum diameters approximately 3 in) form the large clasts and shell hash the smaller clasts that fine upward. Some of the glycimerid 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.

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.

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 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).

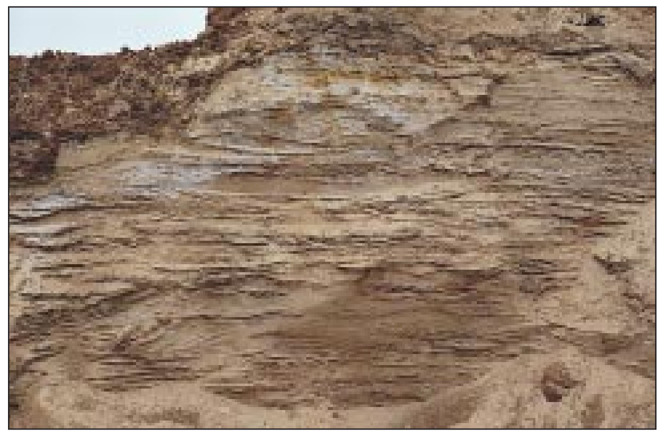

Figure 19. Photograph of the upper 10 ft of the cross-bedded sand. Clay laminae and drapes stand out in relief in the sand. Section located along the south end of the east wall near the north end of the deep trench excavation.

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 to 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).

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

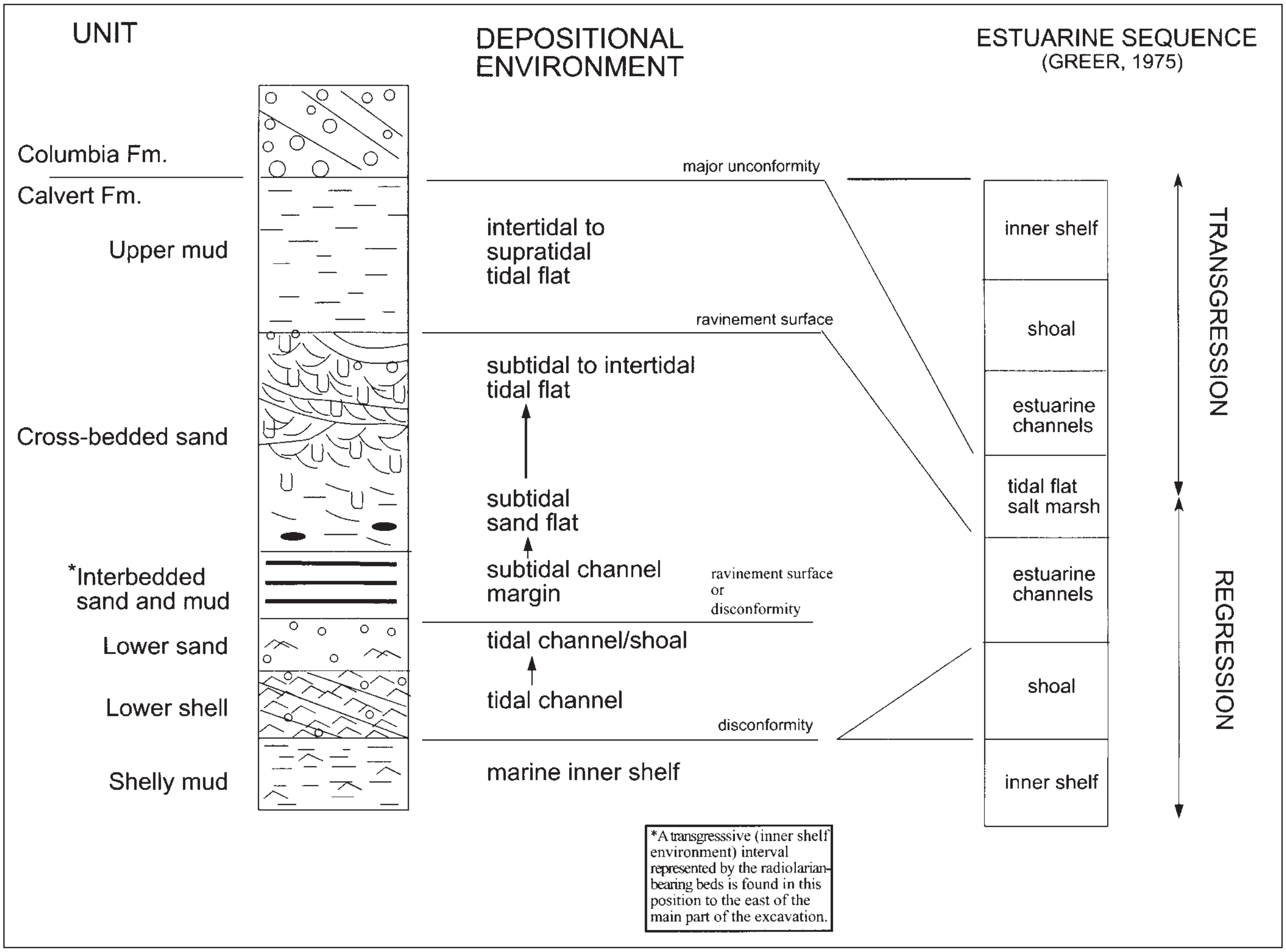

Figure 23. Comparison of the Calvert depositional environments at the Pollack Farm Site to those of a modern prograding tidal system (Greer, 1975).

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).

REFERENCES CITED

Andres, A.S., 1986, Stratigraphy and depositional history of the post-Choptank Chesapeake Group: Delaware Geological Survey Report of Investigations No. 42, 39 p.

Andres, A.S., and Howard, C.S., 1998, Analysis of deformation features at the Pollack Farm Site, Delaware, *in* Benson, R.N., ed., Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 47–53.

Benson, R.N., 1990, Geologic and hydrologic studies of the Oligocene-Pleistocene section near Lewes, Delaware: Delaware Geological Survey Report of Investigations No. 48, 34 p.

___1998, Radiolarians and diatoms from the Pollack Farm Site, Delaware: Marine–terrestrial correlation of Miocene vertebrate assemblages of the middle Atlantic Coastal Plain, *in* Benson, R.N., ed., Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 5–19.

Benson, R.N., Jordan, R.R., and Spoljaric, N., 1985, Geological studies of Cretaceous and Tertiary section, test well Je32-04, central Delaware: Delaware Geological Survey Bulletin No. 17, 69 p.

Cutler, A.H., 1998, A note on the taphonomy of lower Miocene fossil land mammals from the marine Calvert Formation at the Pollack Farm Site, Delaware, *in* Benson, R.N., ed., Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 175–178.

Dörjes, J., and Howard, J.D., 1975, Estuaries of the Georgia coast, U.S.A.: Sedimentology and biology. IV. Fluvial-marine transition indicators in an estuarine environment, Ogeechee River-Ossabaw Sound: Senckenbergiana Maritima, v. 7, p. 137–179.

Frey, R.W., Voorhies, M.R., and Howard, J.D., 1975, Estuaries of the Georgia Coast, U.S.A.: Sedimentology and Biology. VIII. Fossil and recent skeletal remains in Georgia estuaries: Senckenbergiana Maritima, v. 7, p. 257–295.

Gernant, R.E., 1970, Invertebrate biofacies and paleoenvironments, *in* Gernant, R.E., Gibson, T.G., and Whitmore, F.C., Jr., eds., Environmental history of Maryland Miocene: Maryland Geological Survey Guidebook 3, p. 19–30.

Greer, S., 1975, Estuaries of the Georgia Coast, U.S.A.: Sedimentology and Biology. III. Sandbody geometry and sedimentary facies at the estuary-marine transition zone, Ossabaw Sound, Georgia: Senckenbergiana Maritima, v. 7, p. 105–135.

Groot, J.J., 1992, Plant microfossils of the Calvert Formation of

Delaware: Delaware Geological Survey Report of Investigations No. 50, 13 p.

___1998, Palynomorphs from the lower Miocene Pollack Farm Site, Delaware, *in* Benson, R.N., ed., Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 55–57.

Groot, J.J., Benson, R.N., and Wehmiller, J.F., 1995, Palynological, foraminiferal, and aminostratigraphic studies of Quaternary sediments from the U.S. middle Atlantic upper continental slope, continental shelf, and Coastal Plain: Quaternary Science Reviews, v. 14, p. 17–49.

Isphording, W.C., 1970, Petrology, stratigraphy, and re-definition of the Kirkwood Formation (Miocene) of New Jersey: Journal of Sedimentary Petrology, v. 40, p. 986–997.

Jordan, R.R., 1962, Stratigraphy of the sedimentary rocks of Delaware: Delaware Geological Survey Bulletin No. 9, 51 p.

___1964, Columbia (Pleistocene) sediments of Delaware: Delaware Geological Survey Bulletin No. 12, 69 p.

___1974, Pleistocene deposits of Delaware, *in* Oaks, R.Q., and DuBar, J.R., eds., Post-Miocene stratigraphy central and southern Atlantic Coastal Plain: Logan, Utah, Utah State University Press, p. 30–52.

Kidwell, S.M., 1982, Stratigraphy, invertebrate taphonomy, and depositional history of the Miocene Calvert and Choptank formations, Atlantic Coastal Plain: New Haven, Conn., Yale University, Ph.D. dissertation, 514 p.

___1988, Taphonomic comparison of passive and active continental margins: Neogene shell beds of the Atlantic Coastal Plain and northern Gulf of California: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 63, p. 201–223.

Klein, G., deV., 1977, Clastic tidal facies: Champaign, Ill., Continuing Education Publishing Company, 149 p.

Miller, M.F., Curran, H.A., and Martino, R.L., 1998, *Ophiomorpha nodosa* in estuarine sands of the lower Miocene Calvert Formation at the Pollack Farm Site, Delaware, *in* Benson. R.N., ed., Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 41–46.

Pickett, T.E., and Benson, R.N., 1983, Geology of the Dover Area, Delaware: Delaware Geological Survey Geologic Map Series No. 6, scale 1:24,000.

Ramsey, K.W., 1993, Geologic Map of the Milford and Mispillion River quadrangles: Delaware Geological Survey Geologic Map Series No. 8, scale 1:24,000.

___1994, Geomorphology and stratigraphy of the Quaternary of Delaware: 1994 Southeastern Friends of the Pleistocene Field Trip Guidebook, 66 p.

___1997, Geology of the Milford and Mispillion River quadrangles: Delaware Geological Survey Report of Investigations No. 55, 40 p.

Reineck, H.-E., and Singh, I.B., 1980, Depositional sedimentary environments–with reference to terrigenous clastics; 2nd ed.: New York, Springer-Verlag, 549 p.

Richards, H.G., and Harbison, A., 1942, Miocene invertebrate fauna of New Jersey: Proceedings of the Academy of Natural Sciences of Philadelphia, v. 94, p. 167–266.

Shattuck, G.B., 1904, Geological and paleontological relations, with a review of earlier investigations: Maryland Geological Survey, Miocene volume, p. xxxiii–cxxxvii.

Ward, L.W., 1998, Mollusks from the lower Miocene Pollack Farm Site, Kent County, Delaware: A preliminary analysis, *in* Benson, R.N., ed., Geology and paleontology of the lower Miocene Pollack Farm Fossil Site, Delaware: Delaware Geological Survey Special Publication No. 21, p. 59–131.

Ward, L.W., and Blackwelder, B.W., 1980, Stratigraphic revision of upper Miocene and lower Pliocene beds of the Chesapeake Group, middle Atlantic Coastal Plain: U. S. Geological Survey Professional Paper 1482-D, 61 p.

Wiedemann, H.U., 1972, Shell deposits and shell preservation in Quaternary and Tertiary estuarine sediments in Georgia, U.S.A: Sedimentary Geology, v. 7, p. 103–125.