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Miocene stratigraphy and paleoenvironments of the Calvert Cliffs, Maryland

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ABSTRACT

Miocene strata exposed in the Calvert Cliffs, along the western shore of the Chesapeake Bay, Maryland, have a long history of study owing to their rich fossil record, including a series of spectacular shell and bone beds. Owing to increasingly refined biostratigraphic age control, these outcrops continue to serve as important references for geological and paleontological analyses. The canonical Calvert, Choptank, and St. Marys Formations, first described by Shattuck (1904), are generally interpreted as shallowing-up, from a fully marine open shelf to a variety of marginal marine, coastal environments. More detailed paleoenvironmental interpretation is challenging, however, owing to pervasive bioturbation, which largely obliterates diagnostic physical sedimentary structures and mixes grain populations; most lithologic contacts, including regional unconformities, are burrowed firmgrounds at the scale of a single outcrop. This field trip will visit a series of classic localities in the Calvert Cliffs to discuss the use of sedimentologic, ichnologic, taphonomic, and faunal evidence to infer environments under these challenging conditions, which are common to Cretaceous and Cenozoic strata throughout the U.S. Gulf and Atlantic Coastal Plains. We will examine all of Shattuck's (1904) original lithologic "zones" within the Plum Point Member of the Calvert Formation, the Choptank Formation, and the Little Cove Point Member of the St. Marys Formation, as well as view the channelized "upland gravels" that are probably the estuarine and fluvial equivalents of the marine upper Miocene Eastover Formation in Virginia. The physical stratigraphic discussion will focus on the most controversial intervals within the succession, namely the unconformities that define the bases of the Choptank and St. Marys Formations, where misunderstanding would mislead historical analysis.

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INTRODUCTION

The Calvert Cliffs are a relatively continuous series of natural, 25–35 m- (80–120 foot-) high outcrops along the western shore of the Chesapeake Bay in Calvert County, Maryland (Fig. 1). The Miocene strata exposed in these cliffs—the canonical Calvert, Choptank, and St. Marys Formations (Shattuck, 1902, 1904)—have been the focus of paleontologic and stratigraphic analysis since the late nineteenth century (Darton, 1891; Harris, 1893; Shattuck, 1904). This attention owes largely to their abundant and diverse shallow-marine faunas, especially mollusks and vertebrates, which are concentrated in a series of spectacular shell and bone beds within otherwise fine-grained and unlithified siliciclastic sediments (Fig. 2). These resources have made these formations targets for testing general evolutionary and paleoecological principles (e.g., Kelley, 1983, 1988; Dietl et

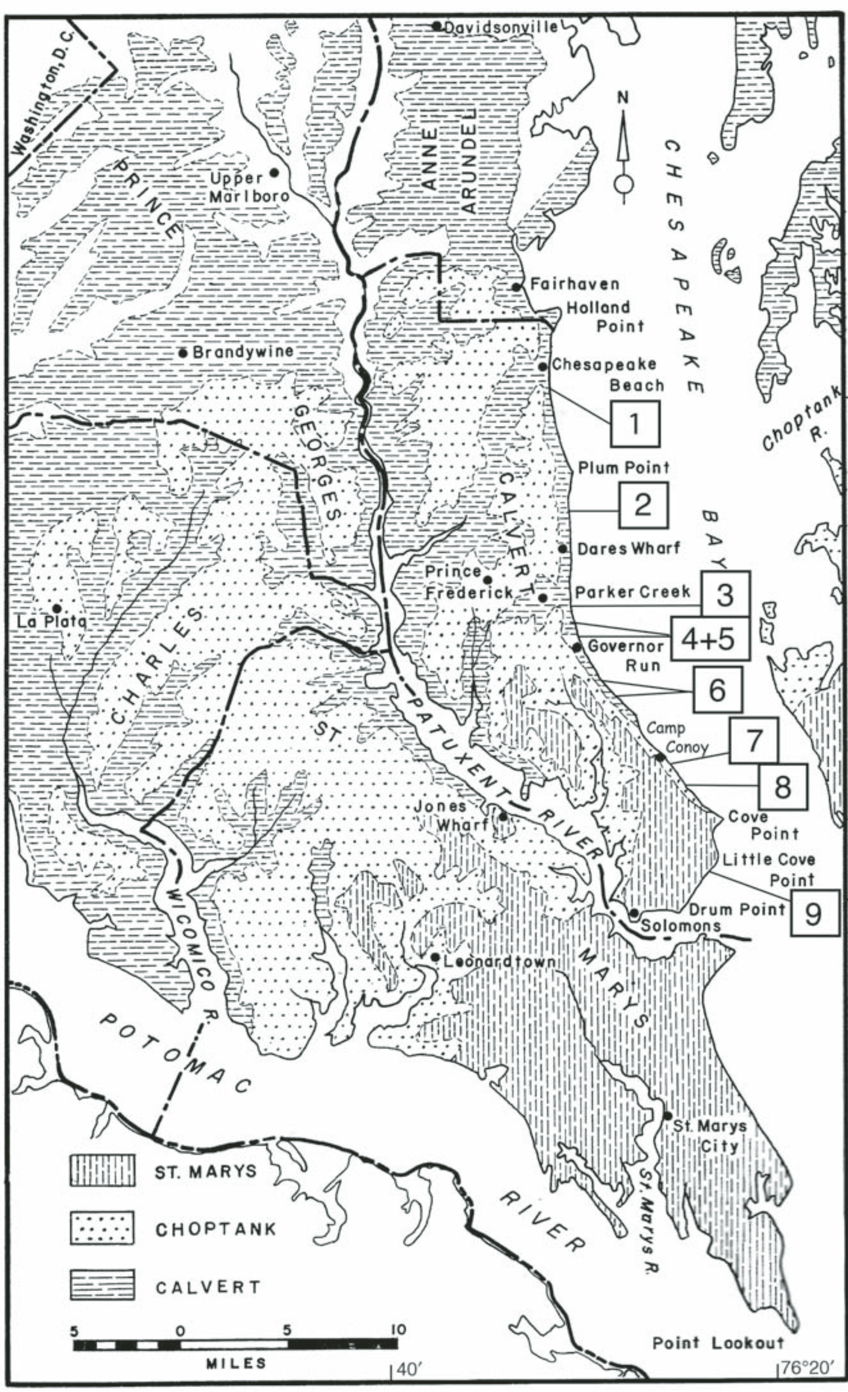


Figure 1. Location of field-trip stops in the Calvert Cliffs, along the Chesapeake Bay shoreline of Calvert County, Maryland. Map adapted from Vokes (1957 [1968]).

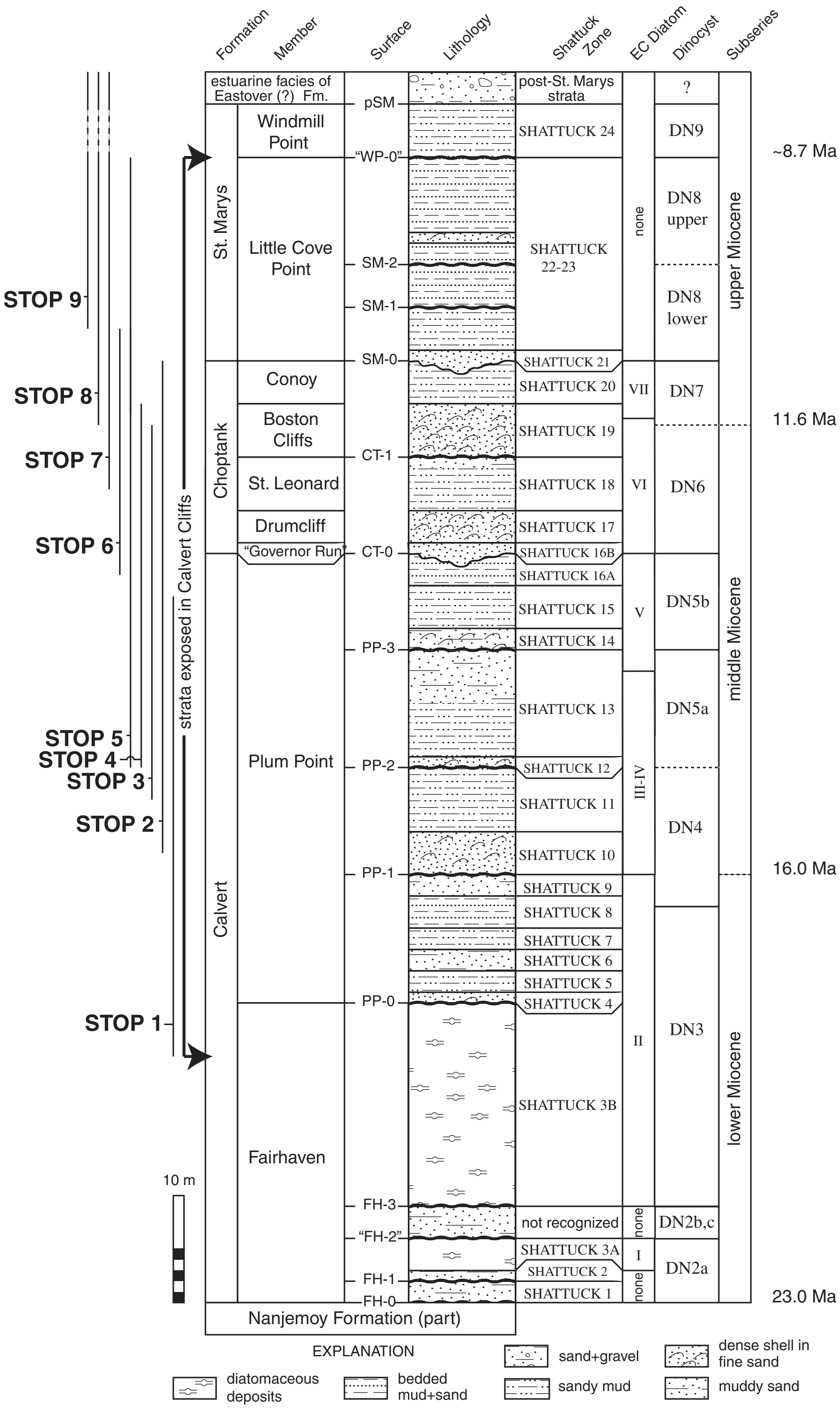


Figure 2. Generalized stratigraphic column for Miocene strata in Maryland, showing the increment exposed at each field stop in the Calvert Cliffs. Shattuck-Zones are informal lithologic units with distinct faunal content established by Shattuck (1904) and are still a practical basis for sampling. Current definitions of formations are very similar to those of Shattuck (1904), member names as explained in the text; the informal "Governor Run" sand is an incised valley fill comprising the yellow-weathering updip sand within Shattuck's original Zone 16 (herein, denoted as Shattuck-Zone 16B) but not the blue-gray interbedded silty sand and clay that he recognized downdip (herein, 16A), which Gernant (1970) erected as the Calvert Beach Member for outcrops there. Surfaces are regionally significant disconformities, numbered successively within host lithostratigraphic units, starting with 0 to denote the basal unconformity (FH—Fairhaven, Kidwell et al., 2015; PP—Plum Point, Kidwell, 1984; CT—Choptank, Kidwell, 1984; SM—St. Marys, Kidwell, 1997; pSM—post–St. Marys, Kidwell, 1997; "WP-0"—inferred for base of Windmill Point Member, Kidwell et al., 2012). East Coast (EC) Diatom Zones are those of Andrews (1978) and Abbott (1978). Dinocyst zones of de Verteuil and Norris (1996), refined by new samples and calibrated to the GTS-2012 (Gradstein and Ogg, 2012) by Kidwell et al. (2012). Chart adapted from Kidwell et al. (2012).

al., 2002; Buzas and Hayek, 2005; Grey et al., 2006), as well as for building systematic and phylogenetic understanding of major animal groups. Strata are also rich in biostratigraphically valuable microfossils, most particularly diatoms and dinoflagellates (Abbott, 1978; Andrews, 1978; de Verteuil and Norris, 1996). These refined zonations make the Calvert Cliffs critical reference material for both the Salisbury embayment and broader Baltimore Canyon trough, and also support analyses of general relationships between climate and sea-level change and the tectonic and geomorphic evolution of the Atlantic margin (e.g., Pazzaglia, 1993; Miller and Sugarman, 1995; Browning et al., 2006; Miller et al., 2013). The cliffs have consequently been a perennial destination for professional, student, and amateur field trips. The most widely available field guides, with measured sections for individual localities, include Glaser (1968), Gernant (1970), Gernant et al. (1971), Blackwelder and Ward (1976), Ward and Powars (1989, 2004), Ward (1992), and Ward and Andrews (2008).

The Miocene section in Maryland is widely accepted as a shallowing-upward succession, from fully marine, open shelf to freshwater-influenced tidal coastal settings, based largely on fossil content. It also includes signals of relatively high productivity, such as diatomaceous sediments (especially in the Calvert Formation) and relatively large-bodied mollusks and vertebrates, especially whales and sharks. However, two basic conditions challenge paleoenvironmental interpretation at the next level of detail.

(1) *Physical sedimentary structures are extremely rare*. Most beds are massive, either homogeneous or burrow-mottled. Primary laminations and cross-bedding are restricted almost exclusively to parts of the St. Marys Formation and to post-Miocene strata. As a result, bedding—more precisely, parting—is expressed largely by burrowed firmgrounds, which require good weathering or freshly scraped exposures to detect. Modern sheetwash and freeze-thaw effects, superimposed on original bioturbation, tend to make almost all transitions appear to be gradational. Like scour surfaces, hardgrounds, and other bedding planes and set boundaries, firmgrounds are important to recognize because they imply hiatuses in the record (see the still-valuable Rhoads, 1975, and the efficient chapter in Catuneanu, 2006). The sharp-edged burrows of firmgrounds indicate that (i) a sedimentary increment has persisted at the sediment-water interface sufficiently long without disturbance or additional sediment aggradation to have dewatered via auto-compaction, and/or (ii) a phase of erosion has removed watery surficial sediments, exhuming firmer layers, typically ≥10 cm below the sediment-water interface.

(2) *Most beds are composed of mixed siliciclastic grain populations*—e.g., sandy clay, clayey silt, silty sand—with various admixtures of gravel-sized (>2 mm) shell carbonate. Quantitative grain-size analysis of bulk sediment samples is possible via wet sieving and acid digestion, allowing a given bed to be described precisely. However, processes responsible for the delivery and deposition of the clay, silt, and sand components of the siliciclastic matrix need to be evaluated separately. The abundance and arrangement of the gravel-sized skeletal component will reflect many biological processes in addition to seabed dynamics. Only a fraction of the original skeletal input is likely to have survived, but taphonomic analysis indicates that most skeletal assemblages are time-averaged accumulations, reflecting the mixing of many successive generations in the seabed before permanent burial (for interpretation of shell and bone beds, see Kidwell, 1991; Brett, 1995; Rogers and Kidwell, 2007). Owing to bioturbation, the mixed-grain populations of the siliciclastic matrix must also be viewed as time-averaged records of grain supply and water energy.

These gross lithologic features—largely massive, burrow-mottled sediments, having mixed grain sizes and more or less abundantly preserved skeletal remains—imply that each bed is a historically complex entity, and place a premium on paleoecological inference from trace and body fossils, including taphonomic insights from modes of fossil preservation and concentration. These challenging conditions are common in Cretaceous to Cenozoic marine strata throughout the U.S. Atlantic and Gulf Coastal Plains.

Here, we focus on the present state of understanding of paleoenvironments in the Calvert Cliffs succession, reviewing the stratigraphy as a context for environmental history. We include sedimentologic, ichnologic, taphonomic, and molluscan paleoecological evidence. For consistency with previous stratigraphic publications, and because molluscan paleoecological inference relies on functional groups (life habits and feeding modes) that are generally conserved within families, we retain the classic taxonomy of Clark et al. (1904). For updated molluscan systematics, see Ward (1992).

As a stratigraphic framework, we stress, like most other researchers, the original informal lithologic zones of Shattuck (1904): each "Shattuck-Zone" denoted a more or less tabular, regionally extensive unit with a consistent lithology and distinct faunal content (Fig. 2). With remarkably few exceptions, which are highlighted here and in Powars et al. (this volume) and Kidwell et al. (2012), Shattuck-Zones are still a practical basis for identifying units in the field, i.e., to label samples, if precise geographic information is also supplied.

Practical Issues

Field stops are closely spaced by car (<30 min) and so most of our time will be spent examining outcrops, with opportunity for collecting fossils from beach drift and fallen blocks. Trip leaders will usually be able to identify the stratigraphic source of beach material. Most stops entail wading or walking along narrow beaches strewn with fallen logs, and some have stretches of bouldery riprap, so wear appropriate shoes (dive booties work well). Given high tides and limited daylight hours, we may not be able to visit all field stops.

This guidebook includes measured sections for two important localities that may, in the future, become more fully exposed: Western Shores (**stop 6B**; Matoaka Cottages and Western Shores), where formerly extensive exposures are now heavily vegetated, and Calvert Cliffs State Park (**stop 8**), which can only be examined from a distance. Detailed measured sections are already published for other historically important, now inaccessible localities, most particularly the cliffs to the immediate north and south of the BGE (Baltimore Gas and Electric, but now owned by Exelon) power plant (also known as Flag Ponds and Camp Conoy; Shattuck, 1904; Gernant, 1970; Blackwelder and Ward, 1976; Kidwell, 1984, 1997; Ward, 1992; Ward and Andrews, 2008).

STRATIGRAPHIC FRAMEWORK

The Miocene record exposed in the Calvert Cliffs is very thin: only ~75 m of section survives from an elapsed 9 m.y. (Fig. 2). The local rock accumulation rate of ~8 m/m.y. is an order of magnitude lower than in coeval records sampled in more seaward positions by cores and seismic reflection, for example, under the Eastern Shore of Maryland and in the offshore Baltimore Canyon shelf (e.g., Miller and Sugarman, 1995; see cross sections in Powars et al., this volume). The thinness of the outcropping record reflects the geographic position of the modern Calvert Cliffs well landward of the tectonic hingeline of the Atlantic passive margin. The Miocene record continues to thin toward the stable craton, where its edge is approximated by the modern-day Fall Line, separating the Coastal Plain and Piedmont geologic provinces.

In detail, the Miocene succession in the Calvert Cliffs is a series of unconformity-bounded transgressive-regressive cycles, each comprising ~1 m.y. ("third-order depositional sequences"; Kidwell, 1984, 1988, 1997) (Fig. 3). The sequence-bounding surfaces present as burrowed firmgrounds in individual measured sections, but, with one exception (the PP-2 surface), they demonstrably truncate underlying strata at a regional scale and mark maximum regression. Independent micropaleontological analysis reveals that every dinoflagellate biozone that can be recognized in thick records offshore is present in the cliffs succession (de Verteuil and Norris, 1996; and see in Kidwell, 1984, the diatom data of W.H. Abbott, using Abbott, 1978). The outcropping record is thus operationally complete at this scale of temporal resolution (e.g., sensu Sadler, 1981), despite its overall thinness, and is thus appropriate for many kinds of broad-scale historical and paleobiological analysis. The record is much less complete at finer scales of temporal resolution given the physical evidence, namely the gaps signified by the regionally extensive unconformities that bound the sequences; the firmgrounds that convey parting within sequences, already mentioned above; and taphonomic and microstratigraphic evidence for stratigraphic amalgamation and condensation within each of the major shell and bone beds (described below and by Kidwell, 1989).

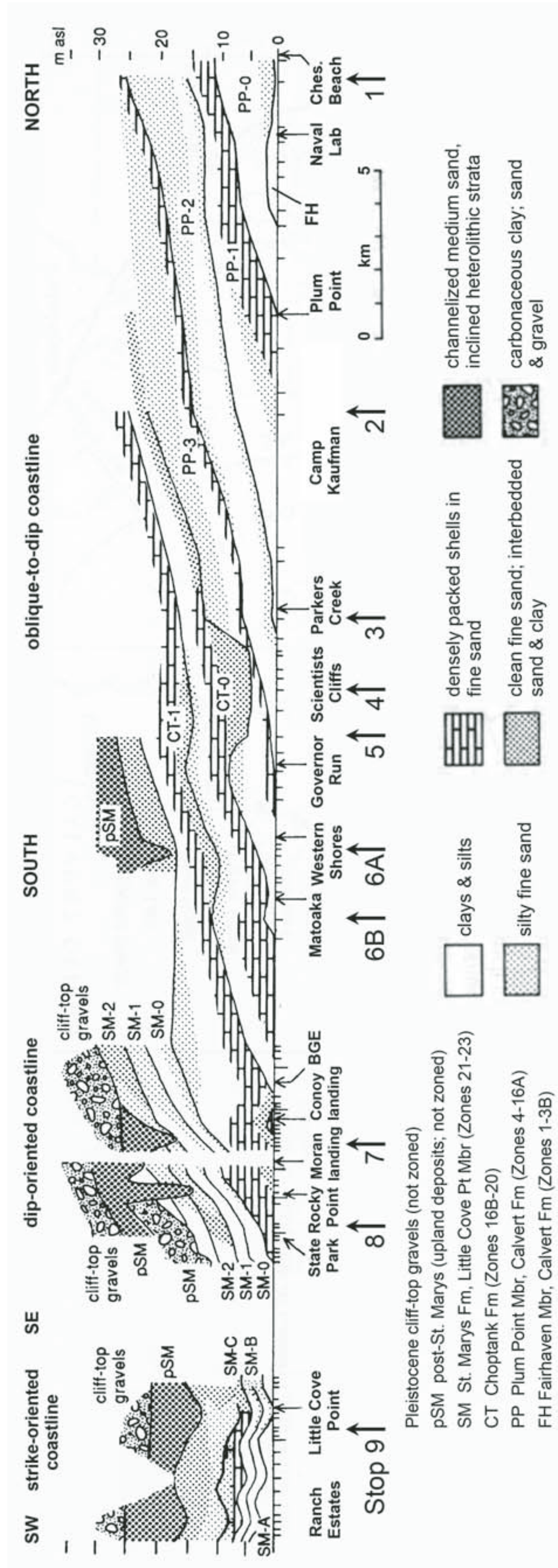


Figure 3. Cross section of the Calvert Cliffs, showing south-dipping Miocene strata as a series of disconformity-bounded depositional sequences. Sequences labeled for their basal surface, defined in Figure 2. Each tick mark along the datum is a measured section; small arrows point to key map names, large arrows to field stops. Zones are Shattuck-Zones. Adapted from Kidwell (1997).

This basic anatomy of ~million-year-scale unconformity-bounded sequences in the Calvert, Choptank, and St. Marys Formations (Figs. 2 and 3) is now widely accepted, with these surfaces traceable into the subsurface both within the local Salisbury embayment and elsewhere in the larger Baltimore Canyon trough (e.g., Greenlee and Moore, 1988; Ward, 1992; Poag and Ward, 1993; Gibson and Andrews, 1994; Miller and Sugarman, 1995; de Verteuil and Norris, 1996; Ward and Andrews, 2008; Metzger et al., 2000; Browning et al., 2006). We thus use Kidwell's (1984, 1997) labeling system to refer to these regionally valuable disconformities in the Calvert Cliffs succession. Surfaces are numbered successively within formal lithostratigraphic units: the PP-0 is the basal disconformity of the Plum Point Member (Calvert Formation), and CT-0 and SM-0 denote the basal unconformities of the Choptank and St. Marys Formations, respectively. Each depositional sequence is designated by its basal surface—e.g., the PP-0 sequence rests on the PP-0 surface and extends up to the PP-1 surface (Figs. 2 and 3; this system was extended to the Fairhaven Member of the Calvert Formation by Kidwell et al., 2012). New dinoflagellate data are refining our understanding of previously controversial intervals within the Calvert Cliffs, for example, along the Calvert/Choptank and Choptank/St. Marys formational contacts (Kidwell et al., 2012). New coring is revealing even more about changes in thickness and pinchouts of these bodies within the Salisbury embayment (Alemán González et al., 2012; Powars et al., 2015b).

Lithostratigraphic Revisions of Miocene Formations

Most reinterpretations of Shattuck's (1904) formal lithostratigraphy concern the Fairhaven Member of the Calvert Formation (largely unexposed in the Calvert Cliffs, and thus not covered by this field guide) and the Calvert-Choptank and Choptank-St. Marys formational boundaries. For recent reviews, see Ward (1992; Ward and Andrews, 2008), Kidwell (1997), the Miocene section in Powars et al. (this volume), and locality-specific notes in the road log here.

Following our re-analysis using ~40 new dinoflagellate samples (Kidwell et al., 2012), we can provide the following synopsis of recommended updates to formal lithostratigraphic units, which Figure 2 summarizes. The base of the Choptank Formation is a regional unconformity that cuts through the interval that Shattuck (1904) designated as "Zone 16" (Kidwell, 1984; interpretation now accepted by Ward and Andrews, 2008) (Fig. 3). Gernant's (1970) "Calvert Beach Member," erected to denote the entirety of Shattuck's original Zone 16, should be abandoned: Shattuck-Zone 16A strata below Kidwell's (1984) CT-0 unconformity should be assigned to the existing Plum Point Member of the Calvert Formation; and Shattuck-Zone 16B strata that lie above CT-0 surface, infilling an erosional paleovalley (incised valley) between Governor Run and Parkers Creek, should remain a part of the Choptank Formation (Kidwell's 1984 Governor Run sand, which will be formalized as a new member) (**stops 3–6B**).

The base of the St. Marys Formation is also a regional unconformity that bevels across Shattuck-Zones 19 and 20 of the Choptank Formation within the Calvert Cliffs (Kidwell, 1984), thus preserving Shattuck's original grouping of zones (contra Ward, 1992, and Ward and Andrews, 2008) (**stops 7–8**). Gernant's (1970) Conoy Member, formalizing Shattuck-Zone 20, thus remains in the Choptank Formation; it is confirmed as biostratigraphically related to the underlying Shattuck-Zone 19 (dinocyst zone DN7) and as distinct from overlying strata (DN8; de Verteuil and Norris, 1996; Kidwell, 1997; Kidwell et al., 2012). Shattuck-Zone 21, recognized by Gernant (1970) as a basal lenticular sand body of the St. Marys Formation that pinches out downdip within the Conoy Cliffs, is probably an incised channel fill associated with Kidwell's (1984) SM-0 unconformity (Kidwell, 1988; contra Kidwell, 1997, who thought it might be a remnant of the Choptank Formation that survived beveling by the SM-0 disconformity; Fig. 3). In most outcrops within the Calvert Cliffs, the St. Marys Formation is thus represented by strata that Shattuck would have assigned to his zones 22 and 23, which cannot be differentiated consistently. We apply "Little Cove Point Member" to the entire Shattuck-Zone 21–23 interval. This definition matches the informal use of this name by Ward (1992), but is narrower than the formal definition of the unit by Ward and Andrews (2008), who have it encompassing Shattuck-Zone 20 as well as Shattuck-Zones 21–23.

Strata above the Miocene St. Marys Formation

The lithology and physical anatomy of relatively coarse-grained and channelized strata present >~30 m elevation in the Calvert Cliffs—part of a thin veneer of "upland deposits" or "upland gravels" present throughout southern Maryland (Hack, 1955; Schlee, 1957)—are relatively well exposed in the southern half of Calvert County (our **stops 6B through 9**), but have still received little attention here (observations at Little Cove Point by Newell and Rader, 1982, and McCartan et al., 1985; cross-sectional panels in Kidwell, 1997). Regionally, Shattuck (1906) interpreted them as the product of repeated events of (post-Miocene) marine inundation and emergence, including estuarine deposits, resting unconformably on older strata; Hack (1955) and Schlee (1957), working largely with inland outcrops and corings, considered them to be exclusively fluvial (and see Glaser, 1968). Determining the age of these strata is still a work in progress, as with any complex of cross-cutting lenticular bodies, using a combination of pollen and, from intervening marine beds, dinoflagellates (e.g., McCartan et al., 1990; Pazzaglia et al., 1997), and is focused on basic and regional questions of geomorphic and tectonic evolution (Pazzaglia, 1993; Pazzaglia and Brandon, 1996).

Outcrops in the Calvert Cliffs have not yet yielded biostratigraphically useful dinoflagellates (de Verteuil and Norris, 1996; Kidwell et al., 2012) and their pollen has been largely unevaluated (but see report of a late Miocene/Eastover flora from these beds at Little Cove Point by Blandin, 1996, p. 84). Although abundantly burrowed, no macrobenthic or vertebrate skeletal remains have been found to our knowledge. Most workers postulate that the upland gravels exposed in the Calvert Cliffs (pSM—"post–St. Marys" unit in Figs. 2, 3, and 4) are updip, fluvial-estuarine facies of either the upper Miocene Eastover or Pliocene Yorktown Formations, which are best known from their shallow-marine facies in Virginia (Stephenson and MacNeil, 1954; Gernant et al., 1971; Ward, 1992; Ward and Powars, 1989; Kidwell, 1997; Ward and Andrews, 2008).

PALEOENVIRONMENTAL TRENDS IN THE CALVERT CLIFFS

Notwithstanding the persistent and repetitive transgressive-regressive alternations of a limited suite of mud-rich, fine-sand-rich, and shell-rich lithologies through the Shattuck-Zones 4–23 succession in the Calvert Cliffs, there is a long-standing consensus that the record reflects overall shallowing. Facies reflect settings between the end members of relatively deep subtidal shelf

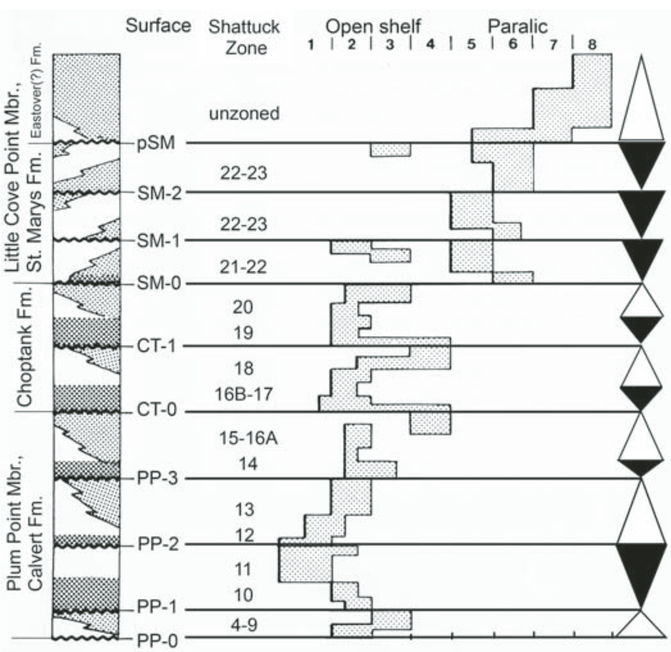


Figure 4. Paleoenvironmental trends through the Calvert (Plum Point Member), Choptank, and St. Marys (Little Cove Point Member) Formations, and post–St. Marys strata of likely late Miocene age ("upland gravels"; likely equivalents of shallow-marine facies of the Eastover Formation in Virginia), as exposed in the Calvert Cliffs. Lithologic column is schematic to underscore qualitative changes in sequence anatomy, from asymmetric regressive-dominated, open-shelf sequences in the Plum Point–Choptank interval, to "shaved" transgressive-dominated paralic sequences in the Little Cove Point interval. Open-shelf environments as defined in Figure 5: 1—outer shelf; 2—inner shelf; 3—shoreface; 4—intertidal and low-energy, very shallow subtidal, fully marine. Paralic environments from coastal embayments of limited fetch and/or reduced salinity: 5—below wavebase; 6—above wavebase; 7—intertidal flats and tidal inlets; 8—tide-influenced fluvial and fluvial. Adapted from Kidwell (1988).

to marginal-marine and even beach and intertidal environments, based on a combination of grain size, trace fossil, and body fossil evidence (e.g., Gernant, 1970; Gernant et al., 1971; Newell and Rader, 1982; Kidwell, 1984, 1988, 1997; McCartan et al., 1985; Ward and Strickland, 1985; Ward, 1992; Ward and Andrews, 2008) (Fig. 4). Most of these workers have incorporated ecological and taphonomic (preservational) insights from mollusks and subsidiary shelled macrobenthos such as ostracodes, barnacles, bryozoans, and corals. Most vertebrate paleontologic studies have focused on improving occurrence data and taxonomy, but important paleoecologic and taphonomic insights can be derived from that rich fauna, which includes abundant and diverse cetaceans, crocodiles, sea turtles, sharks, and other fish, as well as rare non-marine mammals, reptiles, and amphibians (Eastman, 1904; Whitmore *in* Gernant et al., 1971; Whitmore, 1994; Gottfried et al., 1994; Fuller and Godfrey, 2007; Eshelman et al., 2007; Visaggi and Godfrey, 2010; Weems and George, 2013). Plant material—carbonized wood, rare nuts and seeds—has been largely too scarce for study (but see Vogt and Parrish, 2012), and pollen has been little studied. Foraminifera and diatoms have been used almost exclusively for biostratigraphy (but see use of % planktonic metrics for water depth, e.g., by Gibson and Andrews, 1994; Culver and Buzas, 2000). Paleoenvironmental interpretations here mostly follow the facies analyses of Kidwell (1984, 1997).

Outer-Shelf Muds and Maximum Water Depth

Maximum water depth within the Calvert Cliffs succession was reached in Shattuck-Zone 12, which is encased between the two finest-grained facies in the succession (clays and sandy silts of Shattuck-Zones 11 and lower 13; **stops 2 and 3**). Those muds are homogeneous to thoroughly burrow-mottled, preserving no physical sedimentary structures or taphonomic evidence for storm reworking of the seabed (although storms likely delivered the fine sand and silt grains; Figs. 5, 6A, 7). They also contain the deepest water ostracode assemblage observed in the Maryland Miocene (Gernant *in* Gernant et al., 1971) and the deepest water foraminifera assemblage (highest diversity and planktonic abundance; Gibson *in* Gernant et al., 1971; comparably deep-water sediments also occur at the base of the Fairhaven Member, Gibson and Andrews, 1994).

Shattuck-Zone 12, bracketed by these two outer-shelf muds, is a famous bone bed—it is a thin, laterally extensive and fundamentally tabular, bone-rich, thoroughly bioturbated, silty fine sand with poorly preserved skeletal carbonate. Vertebrate fossils are dominated by articulated and disarticulated but well-preserved elements from sharks and marine mammals, reptiles (sea turtles), and amphibians, whose remains would have settled to the seafloor after death. Terrestrial species are also reported, but in much smaller numbers and mostly as isolated elements. The bone bed clearly had a complex origin (see further discussion at **stops 2 and 3**). Kidwell (1984, 1989) interpreted Shattuck-Zone 12 as a relatively deep-water, mid-cycle bone

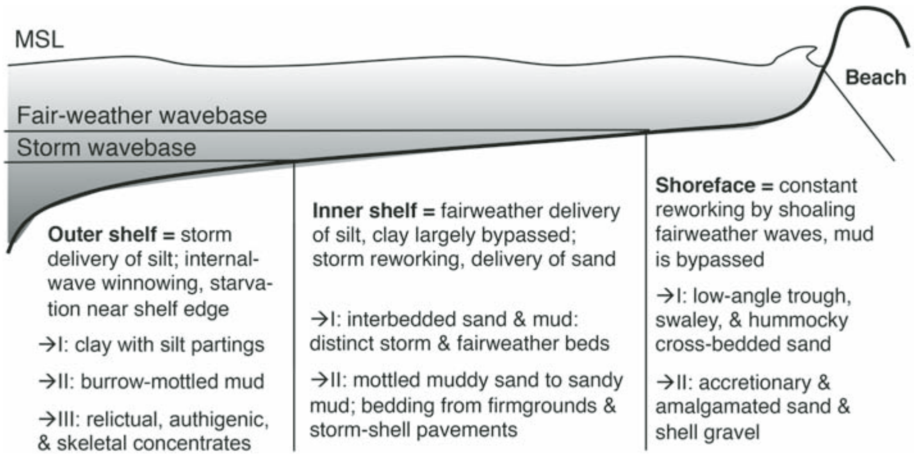


Figure 5. Definition of subtidal environments on the basis of fair-weather and storm wavebases, here for an open shelf, and resulting facies. MSL—mean sea level.

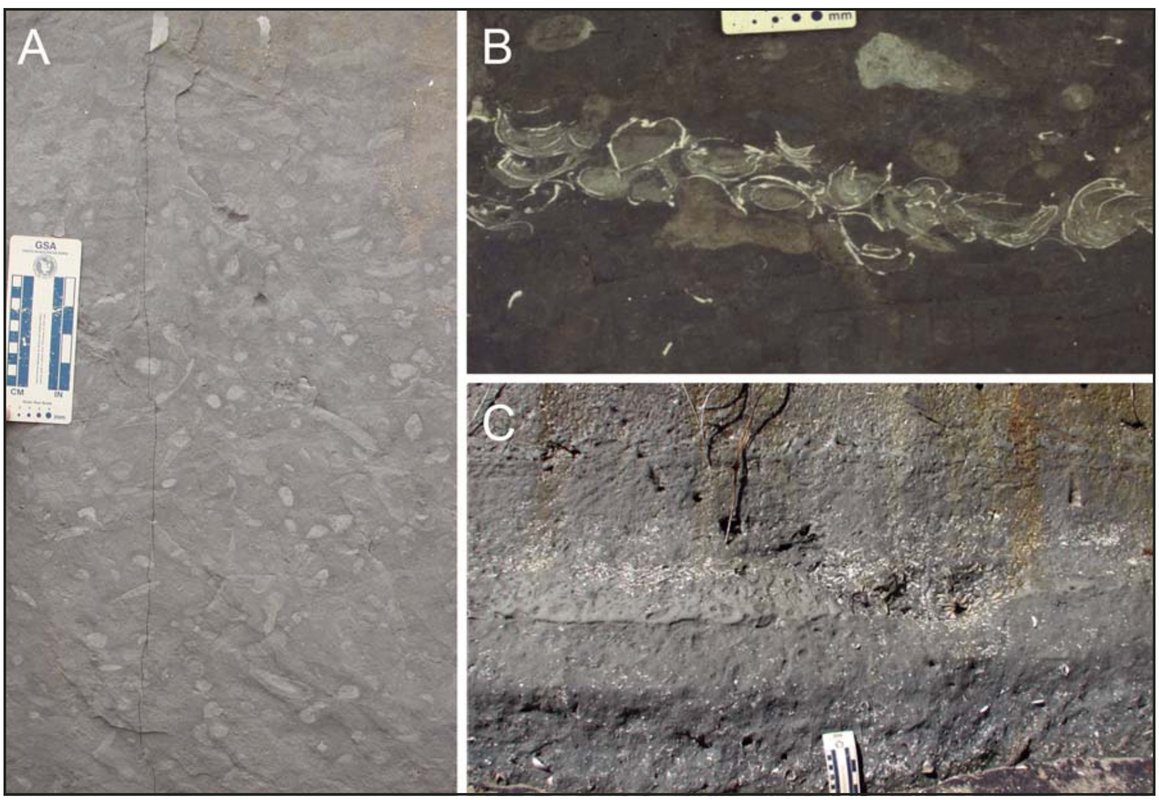


Figure 6. Field photographs of shelf facies. (A) Outer-shelf burrow-mottled silty clay, Shattuck-Zone 11 at Parkers Creek (**stop 3**). (B) Inner-shelf burrow-mottled sandy mud, with a thin bed of storm-exhumed, -reoriented, and -nested shells of the gregarious infaunal bivalve *Glossus*, infilled with primary, laminated light-colored silt. Such shell pavements provide taphonomic evidence that storms had sufficient energy to erode the seafloor locally and delivered silt and very fine sand during waning-flow conditions; Shattuck-Zone 13, Scientists Cliffs (**stop 4**; reprinted from Kidwell, 1991). (C) Inner-shelf deposits that preserve greater segregation of grain sizes: interbedded burrow-mottled muddy sand and homogeneous clay; Shattuck-Zone 16A at Calvert Beach (**stop 6A**).

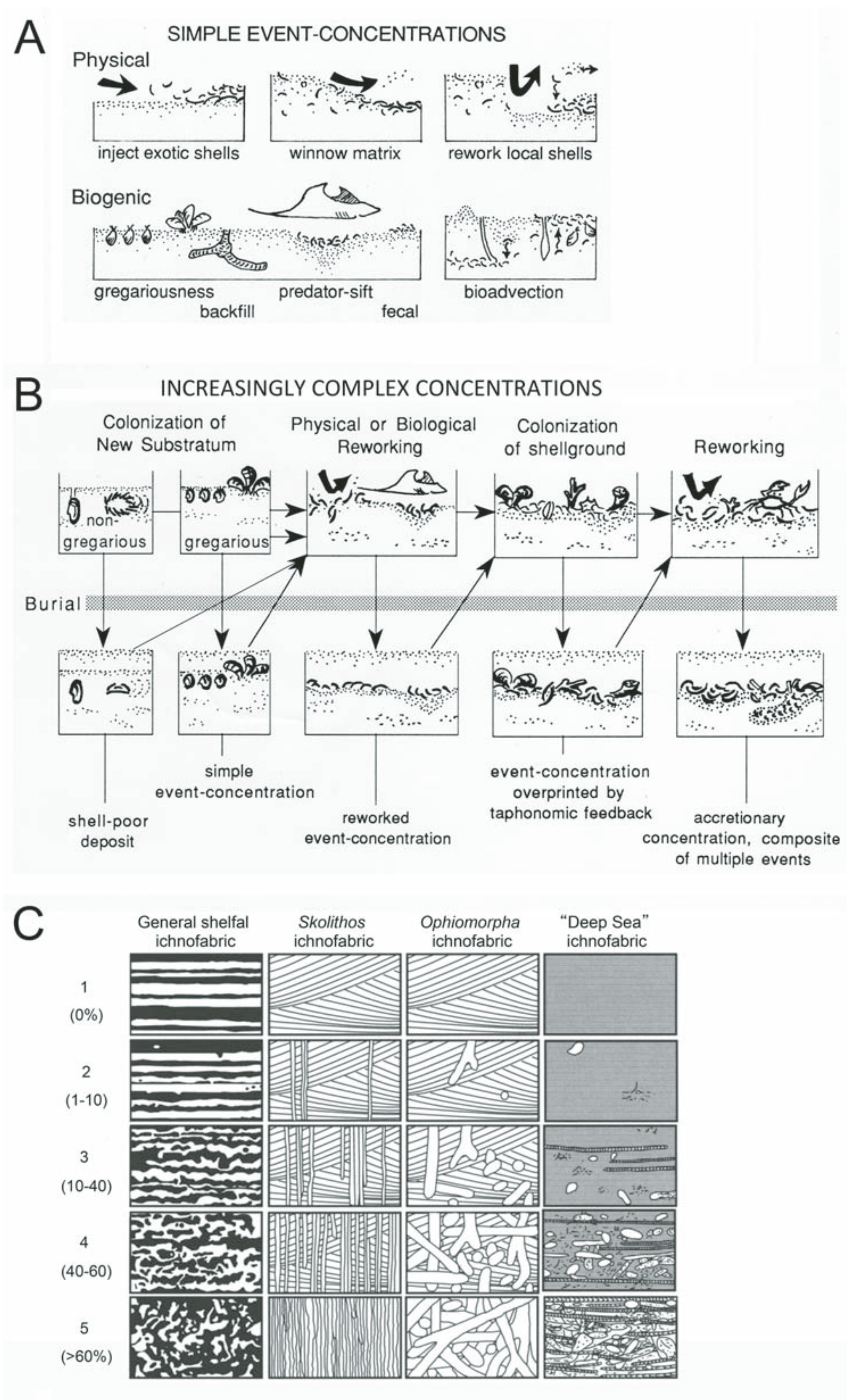


Figure 7. Taphonomic and ichnologic inference of seabed dynamics. Many biological and physical processes, acting alone or in sequence, can affect the postmortem preservation, arrangement, and burial of skeletal remains, producing a wide array of relatively simple, single-event concentrations (A) and more complex, multiple-event composite accumulations (B), which typically have a complex internal stratigraphy and/or skeletal remains in diverse states of preservation. The vast majority of shell and bone beds reflect multiple, short-term events of burial, recolonization, and reworking of the seafloor. Where skeletal input is persistent and/or siliciclastic dilution relatively low, relatively thick and laterally extensive shell beds can accumulate, such as Shattuck-Zones 10, 14, 17, and 19, and bone beds such as Shattuck-Zone 12. (C) Ichnofabric indices categorize the thoroughness of biogenic reworking of the seabed and depth of penetration below the sediment-water interface, which are complex functions of the oxygenation of overlying water (needed to support metazoan burrowers), physical energy (which can obliterate biogenic structures), and elapsed time (dewatering and other conditioning of sediment; extent of ecological succession). Bioturbators in shelf settings (first column on left) can ultimately produce a thoroughly "burrow-mottled" fabric, with small-scale pods and wisps of slightly coarser-grained sediment existing in a finer-grained matrix (or vice versa; mottling may be expressed in color in addition to or instead of grain size; ichnofabric 5). If the original sediment is composed of a single grain population, the result may be complete homogenization (ichnofabric 6, not illustrated), although structureless sediments can arise in other ways (e.g., dewatering). A and B are reprinted from Kidwell (1991); C is adapted from Droser and Bottjer (1989).

bed, with bones concentrated by siliciclastic sediment starvation and small-scale winnowing such as by internal waves, analogous to the glauconite- and commonly skeletal-rich sands that mark intervals of maximum transgression and distal starvation on other shelves. Unlike all other surfaces within the Calvert Cliffs succession, there is no evidence that the PP-2 surface along the base of this bone bed truncates underlying beds. It is possible that it subsumes a cryptic sequence boundary, which is a surface of offlap and shallowing, even subaerial exposure, that promoted sand delivery and even permitted terrestrial animals to live in this region. But its first-order significance is probably as a marker of maximum transgression and slow net sedimentation owing to low siliciclastic supply (Kidwell, 1984, 1989, 1997; and see Gernant *in* Gernant et al., 1971).

The combined evidence thus suggests outer shelf conditions for the entire Shattuck-Zones 11–lower 13 interval.

Inner-Shelf Mixed-Grain Facies

Inner-shelf facies are common throughout the Maryland Miocene (Figs. 4, 5, 6B, 6C). These deposits that accumulated above storm wavebase but below fair-weather wavebase constitute a broad transitional zone between the fair-weather–dominated shoreface and the consistently quiet-seafloor conditions on the outer shelf. During fair-weather intervals, the inner shelf is characterized by the accumulation of siliciclastic mud that has been transported in suspension across the shoreface. Where overlying waters are oxygenated, benthic organisms colonize and bioturbate the seabed, disrupting primary laminations and leaving multiple generations of dead remains, which may be more or less concentrated depending on the actions of the shell-producers and other organisms (Fig. 7; and see **stop 1**). During storms, the seabed can be physically stirred and even eroded, exposing dewatered (firm) sediments (typically ≥10 cm below the original sediment-water interface) and exhuming and reorienting skeletal remains buried within that mixed layer, redepositing them locally in distinctive bioclastic fabrics. Suspended mud is moved away, largely offshore ("local winnowing of fines"), and, as the storm wanes, sand eroded from the beach and shoreface is swept seaward, producing a distinct post-storm layer on the inner shelf (e.g., Aigner, 1985). A storm bed may be partly or completely reworked by subsequent storms, depending on the thickness and erodibility of intervening fair-weather deposits, producing a composite sand-rich bed that is typically thicker and laterally more persistent than a simple, single-event storm bed (individual storm beds are commonly patchy). In detail, composite storm beds commonly have a complex internal stratigraphy and/or ecologically and taphonomically mixed skeletal assemblage. These features reveal accretion or amalgamation via multiple phases of physical reworking, biological colonization, and time-averaging of skeletal remains (Fig. 7B).

Two end-member facies types can thus result on inner shelves: (1) interbedded sandy storm beds (tempestites) and intervening fair-weather muds, with sand beds becoming thinner, less amalgamated, and less frequent offshore; bioturbation during the fair-weather phase is insufficiently intense and/or deeply penetrating to erase the storm signal. And (2) burrow-mottled mixtures of grain populations, grading offshore from muddy sand to sandy mud; fair-weather bioturbation has obliterated sandy storm beds as distinct entities (Figs. 6B, 6C). All gradations are possible between these end-members, depending on the intensity and depth of penetration of the burrowers. Ichnofabric indices such as those of Droser and Bottjer (1989) can be used to score these variants (Fig. 7C).

Molluscan and other macrobenthic shells occur in virtually every Miocene facies that can be classed as inner shelf on the basis of grain size and bedding characteristics. Operationally, shells are defined as biogenic particles ≥2 mm, i.e., gravel. In some beds, shells are sparse and widely dispersed, that is spaced >>a body length apart from each other, and thus constituting only a few % shells by volume (see system of Kidwell and Holland, 1991). Such specimens can still be valuable sources of environmental insight, based on ecological inference from shell form (infaunal? long-lived?) and from living relatives (salinity, nutrient regimes).

Maryland Miocene inner-shelf facies are also characterized by a great diversity of relatively small-scale shell concentrations, which provide taphonomic as well as ecological insight into environmental conditions. Shells are either loosely packed (within a body length of each other, usually ~10–25% of the bulk sediment by volume) or densely packed (shell-supported bed; ≥30 or 40% volume). Some of these concentrations reflect the original gregarious behavior of the shell producer, for example, clumps of corbulid bivalves, which create byssal "nests" on soft seafloors (Shattuck-Zones 5–9, **stop 1**); whereas others reflect the action of other organisms on living or dead shells, for example, predatory middens and burrows that have been lined or packed with shells (**stop 1** again, and Shattuck-Zones 13 and 15, **stops 3 and 4**; Kidwell, 1991; Figs. 7A and 7B).

Of particular environmental value are thin pavements, small lenses, and thin, complexly shingled shell concentrations that signal storm or other physical reworking of the seabed. Pavements of disarticulated, concave-up shells of the infaunal bivalve *Glossus*, for example, indicate that the Shattuck-Zone 13 seafloor at **stop 4** was in fact above storm-wavebase, even though the matrix is completely burrow-mottled, otherwise suggesting outer-shelf conditions; silt and very fine sand laminae preserved in these shells demonstrate that the storms that exhumed and reoriented these shells also delivered coarse sediment (Fig. 6B). Bimodally oriented *Turritella* associated with bedding planes within Shattuck-Zones 22–23 at Little Cove Point (SM-A and -B sequences, **stop 9**) indicate both that those facies were subject to tidal oscillations and that the seabed itself must have been relatively firm, so that shells could roll freely rather than become mired in mud. Slightly thicker (~10 cm) shell beds, such as *Turritella* beds slightly higher in that same section at **stop 9**, reveal the effects of repeated storm events, accreting a laterally extensive bed via the arrangement of many fundamentally lenticular concentrations along a single (apparently hiatal) horizon (there, the SM-B′ surface).

Shoreface Sands

Relatively well-sorted, that is mud-poor, sands accumulate in the shallowest part of the subtidal realm known as the shoreface, which is above fair-weather wavebase but below the beach zone of wave swash. In terms of physical sedimentary structures, shoreface sands are typified by small-scale low-angle ripple cross-sets and, in the lower shoreface, by storm-generated swaley and hummocky cross-stratification, which may be more or less disturbed by a distinctive suite of burrowers (e.g., *Skolithos*). These distinctive structures can nonetheless be sparse or absent in resultant facies, which are commonly accretionary (~thin-bedded) or amalgamated (massive) sands. Repeated reworking of the same material by fair-weather and, especially, storm waves and currents permits only localized preservation of distinctive sedimentary structures.

The four major shell beds in the Calvert-Choptank interval—Shattuck-Zones 10, 14, 17, and 19—are best described as very shelly variants of shoreface sands (Kidwell, 1989) (Figs. 8–9; **stops 1, 2, 6, 7**). Each is a meter or more thick and has a complex internal stratigraphy, typically with (1) a basal hashy sand (shell fragments, typically <1 cm or <0.5 cm); (2) one or more scour- or firmground-bounded layers of densely packed and mostly disarticulated whole shells in well-sorted sand; and (3) typically transition both laterally and up-section to an (inner shelf) interval of interbedded densely and loosely packed shells in sand, sometimes with shell-poor silty sand lenses or interbeds, and with relatively high proportions of still-articulated although typically reoriented bivalves and less hash. Most then grade rapidly or are sharply overlain by relatively shell-poor mud (outer shelf or relatively deep inner-shelf deposits; Figs. 3, 4, 8). Molluscan diversity typically increases, shell hash decreases, and the effectiveness of siliciclastic grain sorting decreases, all suggesting overall deepening during the accretion of each internally complex shell bed, all within the realm of storm reworking and also, for the most part, with fair-weather effects (shoreface winnowing of fines).

This interpretation is congruent with the interpretation of these major shell beds by Gernant (1970), who recognized the role of repeated storm reworking of the seafloor to create bands of densely packed, reoriented shells produced by local populations of mostly infaunal mollusks (his "allochthonous-autochthonous shell beds"; Gernant et al., 1971). He did not place these accumulations in a larger context of transgressive-regressive cycles and changing sediment dynamics (see next section), but recognized the somewhat puzzling presence of shells from a range of shallow to deeper water species (e.g., in Shattuck-Zone 10). He described all four of the major shell beds as fundamentally shallow-marine accumulations (in the 30–50 m water depth for Shattuck-Zones 10 and 14; 8–15 m and <25–35 m for Shattuck-Zones 17 and 19), and recognized that each represented a deepening relative to underlying strata (Gernant et al., 1971).

Arrangement in Transgressive-Regressive Cycles

In general, depositional sequences from the Calvert (Plum Point Member) and Choptank Formations are dominated by open-shelf facies, which are arranged in symmetrical to regression-dominated transgressive-regressive cycles (Fig. 4). To a first approximation, each sequence rests on a *Thalassinoides*-burrowed disconformity, is truncated by another *Thalassinoides*-burrowed disconformity, and comprises facies that first fine and then coarsen upward. Each sequence typically has a basal, densely fossiliferous (20%–70% skeletal material by volume), well-sorted fine sand with a complex internal stratigraphy of skeletal assemblages (each of the four major shell beds fall in this category; Shattuck-Zones 10, 14, 17 and 19). This shell-rich transgressive phase is overlain by a sparsely fossiliferous, coarsening-upward series of clay, sandy silt, silty sand, and/or sand, arranged in a regressive/progradational series (i.e., updip shallow-water sands extend basinward over downdip deeper-water clays) (see geometry of "shazam" lines, symbolic of lateral interfingering or intergradation, within Figs. 3 and 4). The deepest water conditions within each sequence were attained during the final stage of accumulation of the basal shell and/or bone sand or during the clayey beds that abruptly cap these skeletal sands (commonly a distinct flooding surface; Fig. 8B). The regressive/progradational phase of each sequence is typically thicker than the basal transgressive skeletal sand, despite evidence of erosional beveling and/or incision by the next disconformity (all from Kidwell, 1984, 1988, 1989).

Swift et al. (1991) suggested that this same Plum Point/Choptank record was subdivided instead into a series of strictly shallowing-up parasequences. Parasequences were bounded by the flooding surfaces that *cap* each of the major shell beds (e.g., the Shattuck-Zone 17 shell bed culminates a coarsening and shallowing phase from Shattuck-Zones 15–16; Shattuck-Zones 18–19 constitute the next shallowing-up parasequence). This is a useful alternative model, and has considerable merit based on grain-size trends (e.g., see the repeated, coarsening-up trends evident in the profiles for **stops 1–6** covering the Plum Point/Choptank interval). However, we find the taphonomic, physical stratigraphic, and molluscan paleoecological evidence for deepening-up and transgressively/retrogradationally stacked facies *within* each major shell bed (Fig. 8A) to still be compelling. The presence of a substantive increment of deepening-up is contrary to the modern concept of a parasequence, which lacks any deposits capturing the deepening phase. The evidence for erosional beveling along the basal disconformities of each of these transgressive shell beds is also compelling, i.e., that these surfaces signal intervals of maximum regression, even if those phases did not attain subaerial exposure (see below).

We have thus retained the original sequences as defined by Kidwell (1984), both as best reflecting the underlying dynamics of sediment accumulation and because independent biostratigraphy corroborates their value as geohistorically useful subdivisions. The extreme thinness of the Miocene record at the

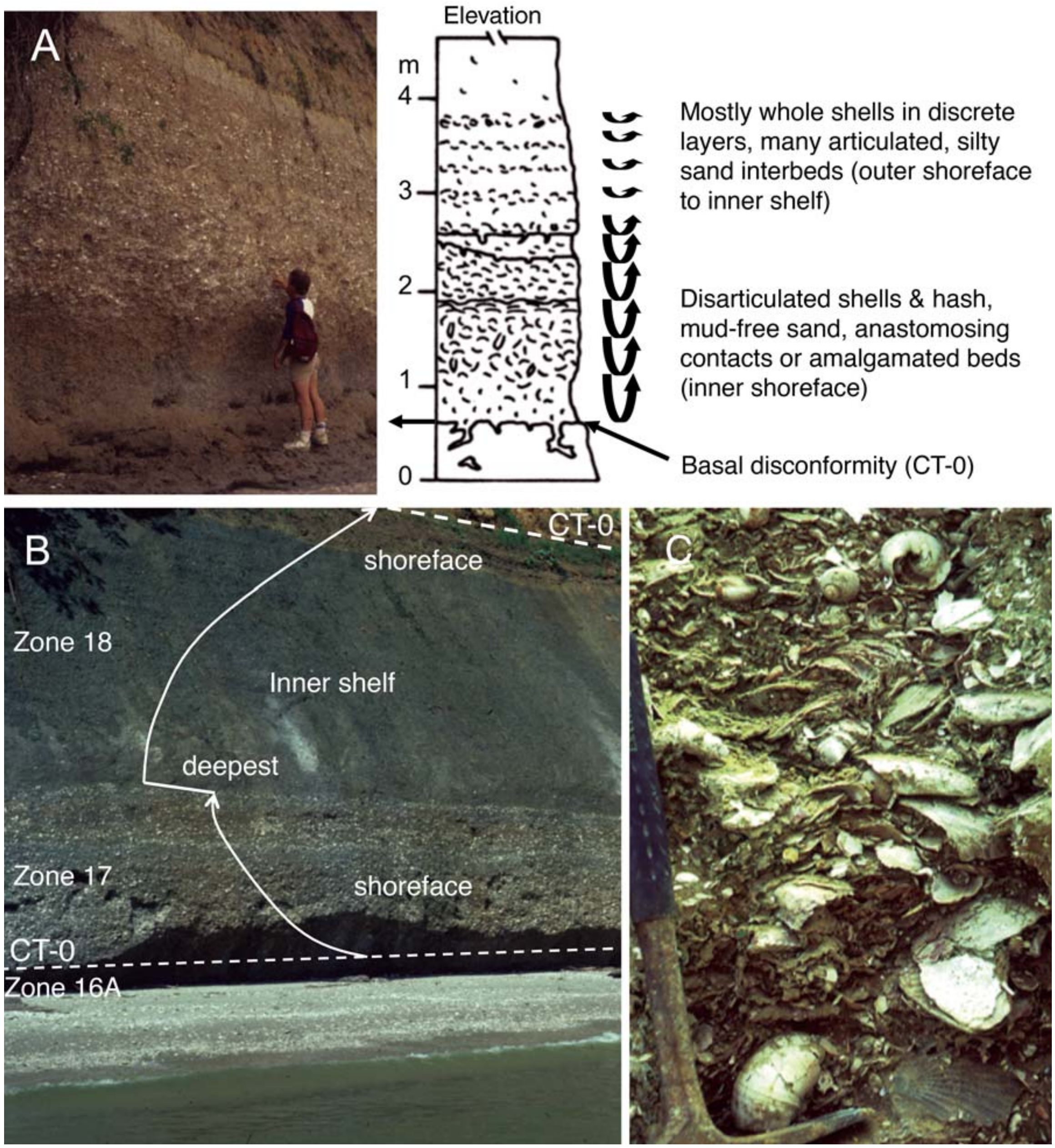


Figure 8. (A) Each of the major shell beds in the Plum Point–Choptank part of the Miocene succession (Shattuck-Zones 10, 14, 17, and 19) constitutes the majority or entirety of the transgressive phase of an ~1-m.y.-duration sequence and has a complex internal stratigraphy that reveals repeated episodes of sediment deposition, benthic colonization, and reworking, with alternating soft, firm, and shell-gravel seabeds, as illustrated here in Shattuck-Zone 17 (Drumcliff Member of Choptank Formation; all images for Matoaka, 78SK35; between **stops 6A and 6B**). (B) Sedimentologic and taphonomic evidence indicates decreasing water energy (deepening-up) in shoreface to inner-shelf depths. (C) Densely packed, mostly disarticulated shells of a mixture of epifaunal and infaunal species, probably reflecting an in situ ecological response to the increasing shelliness of the seafloor rather than postmortem transportation.

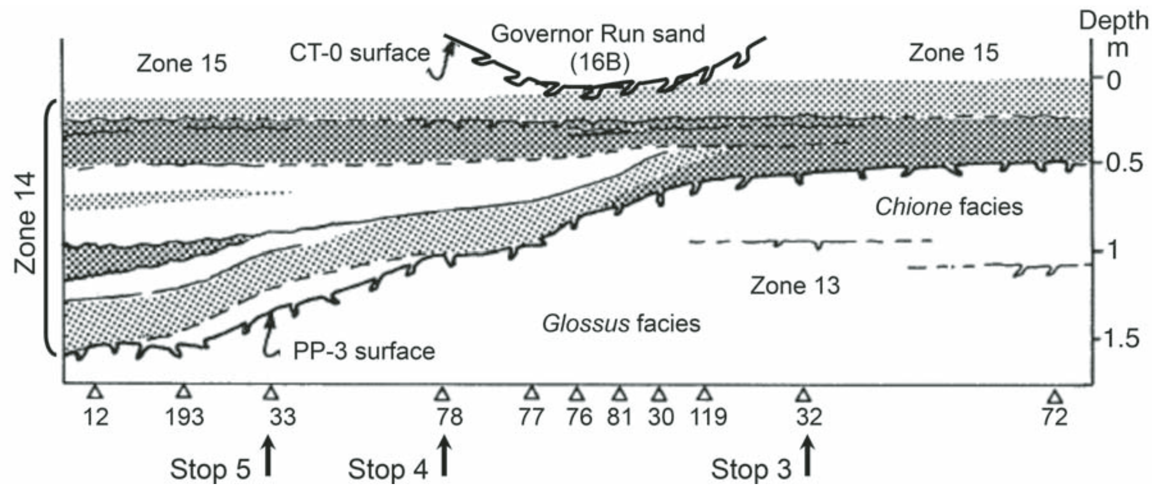


Figure 9. Cross section of the Shattuck-Zone 14 major shell bed, which thins updip as it onlaps against the basal PP-3 disconformity. Thinning is achieved by the pinchout of less shelly increments and the merging of bedding planes, which are a mix of scour and firmground surfaces. Within this major shell bed, shell abundance varies from <10% by volume (white; sparsely dispersed shell) to 10%–40% (light stipple; typically loosely packed) and >40% (dark stipple; densely packed). Shell abundance is low in the underlying Shattuck-Zone 13, whose regressively stacked facies are truncated by the PP-3 disconformity, and in the overlying Shattuck-Zone 15, which is locally incised here by the CT-0 disconformity (base of Choptank Formation). See road log for fuller treatment (**stop 3**, Parkers Creek; **stop 4**, Scientists Cliffs; and **stop 5**, Governor Run). Other numbered localities are measured sections of Kidwell (1982). Top of Shattuck-Zone 14 is used as datum for cross section. Adapted from Kidwell (1989).

million-year-scale seems to mitigate against the preservation of parasequences (i.e., fourth-order and finer shallowing-up cycles; Kidwell, 1997).

Coastal (Paralic) Facies

The St. Marys Formation (Little Cove Point Member) is quite different from Plum Point and Choptank strata. Surface-bounded increments are thinner (<5 m), cannot be traced outside the Calvert Cliffs with confidence, show more rapid lateral (and vertical) facies changes, and include facies from shallower-water, more tide-dominated environments (Kidwell, 1988, 1997; Figs. 3 and 4). In addition, within each sequence, facies are arranged in deepening-upward, transgressive series (downdip-facies step landward up over updip-facies, implying retrogradation); regressive series are missing, having either never accumulated (sediment bypass) or been "shaved" off, even though the overall succession is shallowing-upward (Fig. 4). This strong variability in lithology at the dm- to m-scale within the Little Cove Point Member produces a higher frequency of notches and ledges in outcrop profiles than observed lower in the Miocene succession, with more strongly alternating wet (or vegetated) and dry increments: the contrast is immediately evident, even without insights from sedimentary structures and fossil assemblages (see outcrop photos associated with **stops 7, 8, and 9**).

The lower part of the Little Cove Point Member includes facies that are readily classified as from near or below storm wavebase (burrow-mottled muds; e.g., as seen in Kidwell's SM-0 sequence at **stops 7 and 8**) and from the deeper part of the inner shelf (mottled sandy muds with shell pavements, e.g., as seen in the SM-A, -B, and -B′ sequences at **stop 9**; Fig. 10C). It also includes, however, cross-bedded coquinas with negligible burrow disruptions, suggesting mobile, tide-swept banks of shell gravel (Fig. 10A), and sands with parallel beach laminations and with abundant *Ophiomorpha* burrows (**stop 9**). The importance of tidal features, including bimodally oriented *Turritella* pavements (Fig. 10C), combined with the much more limited lateral extents of facies, suggest a small enclosing water body, hence the usefully vague "paralic" designation in Figure 4, especially when combined with paleoecological evidence for reduced salinity. Gernant et al. (1971), for example, reported distinctive brackish-water ostracode phenotypes, and many molluscan assemblages are strongly dominated by single species and generally contain a higher proportion of gastropods, suggesting more stressed, perhaps lagoonal or bay conditions (Gernant et al., 1971; Ward, 1992). Some descriptions of beach and littoral deposits at Little Cove Point (**stop 9**; Newell and Rader, 1982; McCartan et al., 1985) refer to strata within the overlying upland gravels rather than the St. Marys Formation as defined by us (see discussion **stop 9** below). However, similar facies are present in definite SM sequences further updip (**stops 7 and 8**; Kidwell, 1997), and so the environmental inferences are still very relevant.

The Little Cove Point Member of the St. Marys Formation and the upland gravels are both rich in discrete trace fossils that remain virtually unexamined. These strata deserve professional ichnological study (the entire Miocene succession would benefit from it). *Thalassinoides*, *Gyrolithes*, *Ophiomorpha*, and *Arenicolites* are all present, recognizable even by very early workers and

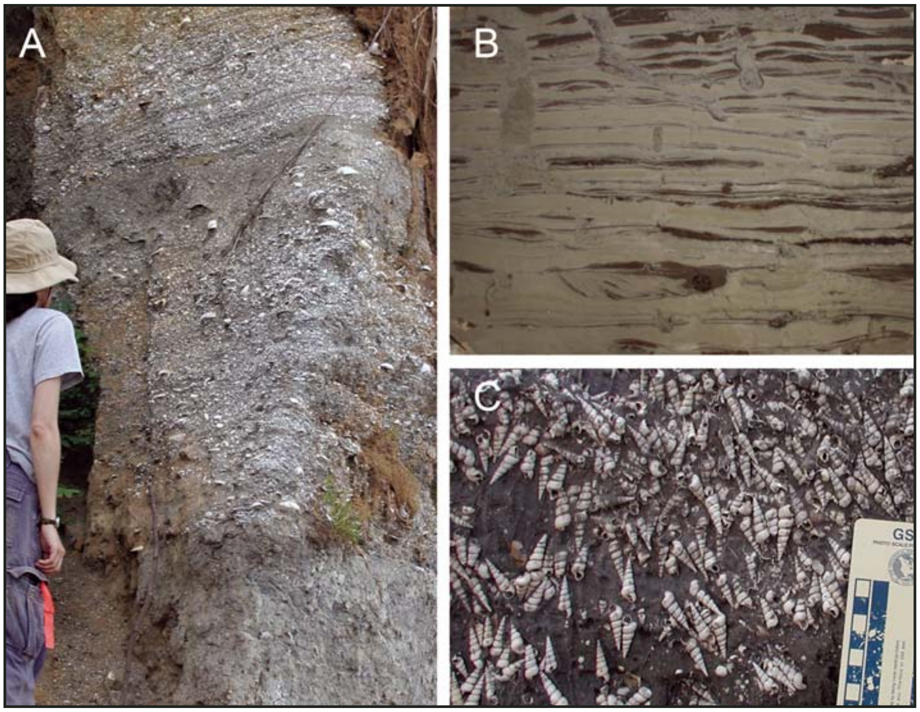


Figure 10. Tide-influenced features in the Little Cove Point Member, St. Marys Formation. (A) Cross-sets with densely packed, disarticulated shells, overwhelmingly dominated by the small bivalve *Spisula* (SM-C sequence, **stop 9**). (B) Acrylic peel of burrow-disrupted lenticular bedding (provisional SM-0 sequence, **stop 6B**). (C) Bimodally oriented *Turritella* gastropod shells, bedding-plane view of a local firmground in block on beach (SM-B′ sequence, **stop 9**).

by non-specialist geologists today, but this listing does not do credit to the true diversity and the environmental insights that could be gained.

Question of Subaerial Exposure

Subaerial exposure is axiomatic with "sequence boundaries," but requires case-by-case evaluation. All of the disconformities in the Calvert Cliffs succession—the PP-, the CT-, and a subset of the SM- surfaces in Figures 2 and 3—can be traced regionally and all demonstrably truncate underlying strata, with the exception of the PP-2 surface (a surface of maximum transgression, see discussion above). These features suggest formation during a relative lowstand, which permitted localized fluvial incision during fall and shoreface beveling (ravinement) during the next relative rise. However, none of these surfaces exhibit unambiguous evidence for subaerial exposure, such as paleosols, root casts, or fluvial (as opposed to tidal) channel fills. They are, instead, expressed simply as burrowed firmgrounds, usually with *Thalassinoides*, where the more or less hashy fine sand of the basal transgressive sand of the next sequence is piped down into the underlying unit (all from Kidwell, 1984).

Notwithstanding this lack of direct evidence for subaerial exposure, the Miocene surfaces clearly did form during "maximum regression," at the least, and most of them likely did become emergent surfaces (for full discussion, see Kidwell, 1984). For example, the incised valley associated with the basal-Choptank, CT-0 surface between Parkers Creek (**stop 3**) and Governor Run (**stop 5**) is both overlain by and cuts across intertidal to very shallow subtidal facies (mud and sand rich in mussels and sand dollars in Shattuck-Zone 16B/Governor Run sand; *Pandora* facies of Shattuck-Zone 13) (see discussion in the sections for those stops). The interfluves of the CT-0 surface were thus certainly subaerially exposed, along with updip regions, and the channel form implies fluvial incision even if none of the infilling facies were fluvial. The PP-1, PP-3, and CT-1 surfaces are similarly sandwiched by very shallow facies (**stops 1–6**).

The SM-0 surface at the base of the St. Marys Formation removes the greatest amount of stratigraphy, has the taphonomically most complicated mantling skeletal accumulation (with phosphatic steinkerns), and is associated with the most dramatic diagenetic modification in underlying strata (ferricrete precipitation and both aragonitic and locally calcite loss in the Boston Cliffs Member; **stop 7**; see fuller discussion in the road log). Stratigraphically higher surfaces within the St. Marys Formation mostly juxtapose subtidal facies upon subtidal facies, and appear to have formed via transgressive ravinement rather than lowstand incision (Kidwell, 1997) (**stops 8–9**). However, given the beach, intertidal, and tidal-inlet setting of so many facies within the Little Cove Point Member in the Calvert Cliffs (see above), at least brief subaerial exposure is very likely for each of these, too.

The environmental context of all of these surfaces deserves additional work, especially with new geochemical and paleontological methods. Interestingly, surfaces within the tidal to fluvial upland gravels, which truly must involve subaerial exposure, are very localized in extent. They also lack obvious paleosols or rooted horizons, even along the "master surface" that can be drawn onto cross sections based on the deepest reach of this set of shingled channels (the "SM-3" surface in Kidwell, 1988; see data on post–St. Marys interval in Kidwell, 1997). This unit reflects lateral shifting in the locus of channeling and rapid infilling (local aggradation), rather than widespread erosional beveling, lag formation, and/or paleosol development.

ROAD LOG

Safety and Permissions

We are guests of private landowners and parklands, which have strict rules against climbing or digging in the cliffs. Collecting from blocks on the beach is generally permitted. Please follow the instructions provided by leaders at each stop. ***(If you are taking this trip at a later date on your own, you must secure permission from the appropriate person to visit stops. Every stop except stops 1 and 6 requires permission.)***

DAY 1. PLUM POINT MEMBER OF THE CALVERT FORMATION AND LOWER PART OF THE CHOPTANK FORMATION: *Upper lower to middle Miocene open-shelf facies in unconformity-bounded transgressive-regressive sequences*

Directions to stop 1. From the Baltimore Hilton (39.2856° N, 76.6214° W), proceed along various interstates and State Route 2 south into Calvert County (~60 miles), where we will turn southeast on State Route 260 toward Chesapeake Beach. Along this route, we will be driving over gently rolling topography developed mostly upon the Choptank Formation and, locally, upper Tertiary and Pleistocene sands and gravels known as the "upland deposits." The area still has a rural character, despite serving as exurbs for commuters to Baltimore and Washington, D.C. Tobacco was a major crop in Calvert County into the 1980s. Many of the old drying barns, owned by individual small farmers, are still standing throughout the region, distinguished by their exterior walls of vertical boards. These boards were hinged under the eaves and propped open at the bottom to promote drying of the leaves, which were hung upside down on racks.

At Chesapeake Beach, where Route 260 terminates at a traffic light, turn right (south) onto State Route 261 (Bayside Road) and proceed 2 miles through town to the easy-to-miss entrance to Brownies Beach Road, which is on your left immediately after crossing a small bridge over Brownies Creek. The road terminates at the parking lot for Bay Front Park (38.68° N, 76.53° W), which is owned by the town of Chesapeake Beach.

Stop 1. Bay Front Park ("Chesapeake Beach"): Plum Point Member of the Calvert Formation (Access to Shattuck-Zones 3–10, Visual Examination of Shattuck-Zones 11–15)

Walk down the dirt road to the sandy beach, which is present even at high tide, and proceed south. We typically have to climb over several sets of fallen tree trucks to reach the base of the cliffs, and at that point will start wading: the beach is narrow even at low tide.

Context

This stretch of cliffs is referred to as Chesapeake Beach in Shattuck (1904) and many subsequent publications; other names are Brownie's Beach (Kidwell, 1982) and, for the southern end of the accessible shoreline here, North Randle Cliff (Kidwell, 1982, 1984; Ward, 1992; Ward and Andrews, 2008). These are the northernmost exposures of Miocene strata within the Calvert Cliffs.

The cliffs here are ~30 m high and nearly vertical, and the coastline is unaltered, although heavy armoring and jetties to protect private property to the north in Chesapeake Beach proper have interfered with southward longshore drift for many decades.

Points of Interest

A few tens of cm of Shattuck-Zone 3B sandy clay, which is the upper part of the Fairhaven Member of the Calvert Formation, are exposed at beach level (Fig. 11). These sediments are penetrated by *Thalassinoides* burrows associated with Kidwell's PP-0 disconformity, one of Shattuck's original unconformities marking the base of his Plum Point Member (see detailed description and discussion in Kidwell, 1984, and the photo in her figure 10; Fig. 12). Brownish, shark tooth–rich sand from Shattuck-Zone 4 is piped down into these burrows, and this infill is preferentially eroded by modern wave action, leaving a characteristically "pocked" exposure of blue-gray Fairhaven clay. We will walk directly on this PP-0 disconformity surface while wading along the base of the cliff; this stop is especially good for fossil shark-teeth–hunting in the modern beach (see discussion of that fauna in Visaggi and Godfrey, 2010). The PP-0 surface (Shattuck-Zone 4/3 contact) rises in elevation toward the south, reaching a maximum elevation of ~2 m a.m.s.l. (above mean sea level) ~3 km to the south (at Locust Grove Beach, 78SK13 in Kidwell, 1982, 1984), and from there dips southward, leaving a local "paleohigh" (see Fig. 3). Shattuck-Zone 4 rises in elevation along this stretch of cliffs, mantling the PP-0 surface, but pinches out southward against this local high. This pinchout and the thinning of other strata immediately above Shattuck-Zone 4 indicate that this feature existed as paleorelief on the PP-0 seafloor. The paleorelief possibly arose solely from irregular erosion of underlying Fairhaven Member, but small-scale warping of those strata is suggested from the bedding implicit in shell pavements.

Shattuck-Zone 4 mantles the PP-0 surface and is easily recognized by its brownish, thoroughly burrow-mottled silty sand, and by abundant, large, and commonly articulated specimens of the pycnodontid oyster "*Ostrea*" *percrassa*. Specimens are neither attached to nor resting on the PP-0 surface itself, but are instead concentrated ~10 cm above that surface; they occur as whole and broken individuals in diverse orientations within discrete lenses of shell-supported fabric. Pycnodontids are full-salinity oysters and these thick-shelled individuals would have been relatively long-lived (many decades). After an early adulthood attached to some small fragment of hard substratum, they would have lived unattached in these sands, suggesting relatively

Stop 1. Chesapeake Beach

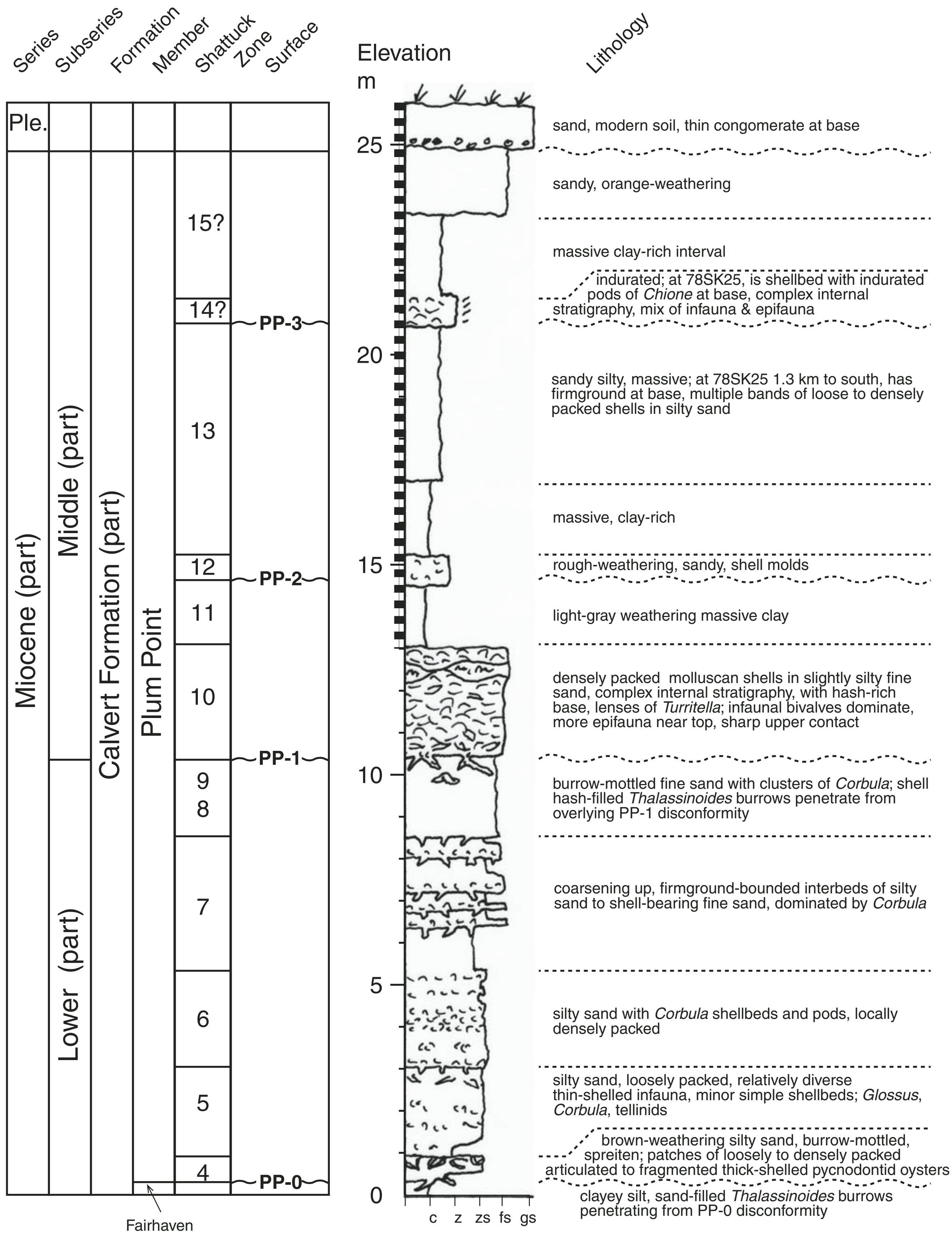


Figure 11. Lithologic profile of outcrop, scaled to grain size, between Chesapeake Beach and Randle Cliff, showing the entirety of the Plum Point Member of the Calvert Formation (**stop 1**). Dashed vertical line shows part of section that is estimated rather than measured and described directly. Grain size of siliciclastic component of sediment: c—clay or silty clay; z—silt, clayey silt, sandy silt; zs—silty sand (10%–49% mud by weight); fs—fine sand, <10% mud; gs—medium or coarse sand, lithic gravel (quartz or clay clasts). All lithologic profiles herein use the same conventions. Based on section 78SK24 in Kidwell (1982, 1984), whose interpretations of Shattuck-Zone equivalents are very similar to those of Shattuck's (1904) original section VII; Ward (1992) and Ward and Andrews (2008) interpret Shattuck-Zones 14–15 here as Shattuck-Zones 17–19.

low rates of sediment accumulation. Gernant (*in* Gernant et al., 1971) interpreted the bed as a relatively high-energy lag of shells ripped from their original attachment to the hard clay of the unconformity, in waters 25–35 m deep.

Shattuck-Zones 5 through 9 constitute the sheer cliff of subtly coarsening-upward clays, sandy silt, and silty sand that extends from Shattuck-Zone 4 up to the base of the dramatic, densely fossiliferous shell bed known as Shattuck-Zone 10, whose base lies ~10 m above beach level. Zones 5–9 comprise beautifully burrow-mottled dark-gray sandy silts to silty sands—the ichnofauna deserves more detailed analysis. Strata are dominated by thin-shelled aragonitic infaunal bivalves, which are sparsely distributed through the most mud-rich intervals, but also occur in a variety of small-scale skeletal concentrations that typically have a less muddy sand matrix. These small-scale ("minor simple") shell beds are mostly single-event concentrations. They include ~10-cm-diameter clusters of articulated *Corbula elevata* (modern corbulids mutually attach using byssal threads, thereby creating a stable "nest" on soft seafloors; reflects gregarious behavior), clumps of fragmental shells that might reflect debris from predators or scavengers, single-shell-thick pavements of disarticulated valves or articulated specimens that have been rotated out of life position ("storm beds"), and slightly thicker tabular bodies of loosely to densely packed, mostly disarticulated shells reflecting the amalgamation of multiple, short-term events of skeletal concentration. The overall trend through Shattuck-Zones 5–9 is coarsening up, achieved by increasingly close-spaced and discrete beds of fine, mud-poor sand, mostly resting on firmgrounds (sharp, burrowed contacts; Fig. 11). This trend indicates shallowing-up, or at least increasing water energy and frequency of physical reworking events within the inner shelf contra Gernant (*in* Gernant et al., 1971), who inferred deepening-upward from Shattuck-Zones 4–8, shallowing then into Shattuck-Zone 9, based on ostracode assemblages).

Shattuck-Zone 10, one of the four major shell beds within the Calvert and Choptank Formations, rests on the regional PP-1 disconformity of Kidwell (1984; see Kidwell, 1989, for

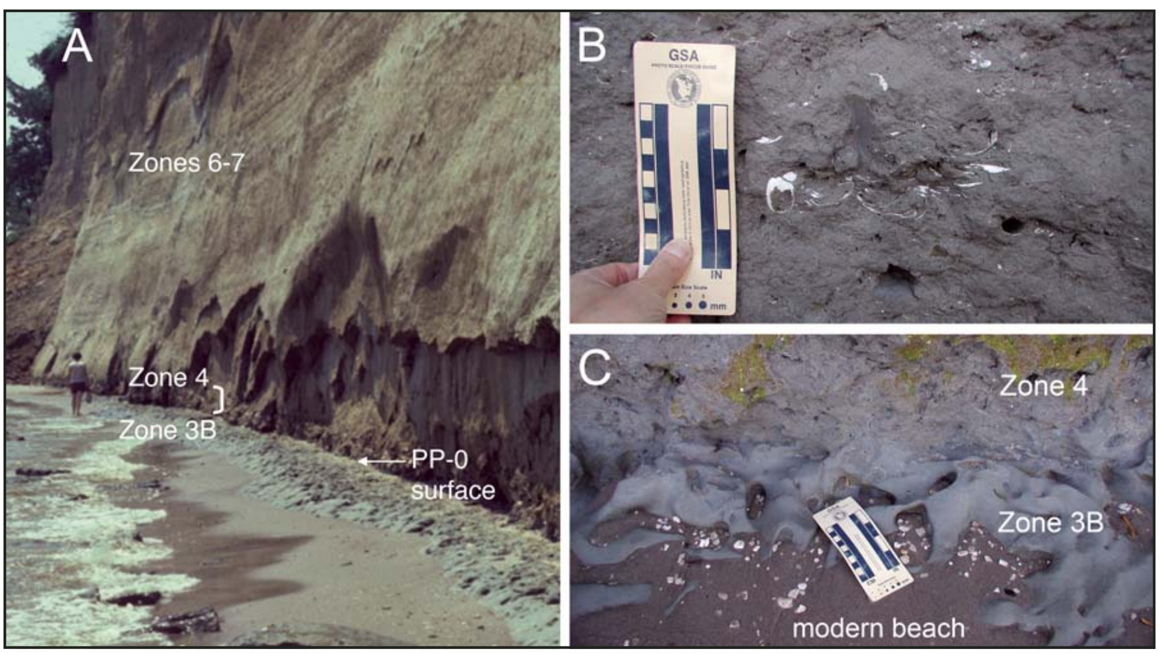


Figure 12. Outcrop images from **stop 1**, between Chesapeake Beach and Randle Cliff. (A) Cliff face, with PP-0 disconformity exposed at beach level. (B) Example of small-scale, probably biogenic shell concentration in typically rough-weathering, burrow-mottled silty sand; Shattuck-Zone 5. (C) *Thalassinoides* burrows in the PP-0 firmground. The firmground weathers as a pocked surface because the loosely consolidated sand of Shattuck-Zone 4 that infills the burrows has been preferentially removed by modern wave action from the tightly consolidated, more resistant, and smooth-weathering clay of Shattuck-Zone 3B.

discussion and comparison of major shell beds, including fauna, but for species-level lists, see Shattuck, 1904, and Ward and Andrews, 2008). The basal contact of the shell bed is subtle here and at several other exposures because the upper, sandiest part of the Shattuck-Zone 5–9 interval is preserved: the basal, shell-hash–rich fine sand of the Shattuck-Zone 10 shell bed thus rests directly on an only slightly siltier fine sand. Under favorable weathering conditions and good access, it is clear that the PP-1 surface is a *Thalassinoides*-burrowed firmground, and that the gradational appearance of the basal contact of Zone 10 owes to intense piping of shelly sand down into another sand, which is then more or less obscured by modern sheet wash. Shattuck-Zone 10 itself is ~2 m thick, dominated by aragonitic, mostly infaunal and semi-infaunal bivalves (of the latter, *Glycymeris*, *Anadara*, and *Atrina* are most notable), and comprises a complex internal stratigraphy, from a basal shell hash, to large disarticulated shells loosely packed in a shell hash, to lenses of densely packed high-spired *Turritella plebeia*, and densely packed shell gravel rich in scallops. It is overlain sharply by the sheer, blocky clay of Shattuck-Zone 11. Shattuck-Zone 10 can be examined closely at this locality via large blocks that may have fallen to beach level or by scaling especially large slumps, if available. We will see the upper part of Shattuck-Zone 10 at field-trip stop 2 (Camp Kaufman), where the transition to Shattuck-Zone 11 is quite different (interbedding of shelly sands and clay).

Shattuck-Zone 12 lies only 1–2 m above the top of the Zone 10 shell bed. However, based on measured sections just a few km south, at the Naval Research Laboratory facility military facility, several discrete bone-rich sands are actually present in this interval, which is dominated by quite shelly silty sand (see sand facies in Fig. 3): the fauna and taphonomic aspect of those silty sands looks like Shattuck-Zone 13 as observed even further downdip. It thus appears that the Shattuck-Zone 12–13 interval thickens *updip*, contrary to typical downdip-thickening observed in the major shell beds, and does so by the intercalation of less fossiliferous increments. This geometry would be consistent with, and strongly argue for, the bone bed being a distal, starved deposit (Kidwell, 1989).

Strata above Shattuck-Zone 12 are weathered, difficult to access, and thus ambiguous in identity: they almost certainly extend up to Shattuck-Zone 14 or 15 (Shattuck, 1904; Kidwell, 1984, 1997; Fig. 11) and possibly into the Choptank Formation (Ward and Andrews, 2008). One shell-rich layer within this upper part of the cliffs is partly indurated here and at the Naval Research Laboratory facility, and has been tentatively interpreted as Shattuck-Zone 14 by multiple workers, but without any micropaleontologic biostratigraphic verification. We will see Shattuck-Zone 14 again at **stops 2, 3, and 4**.

Directions to stop 2. Return to vehicles and proceed south on Route 261 (Bayside Road) to the intersection with Tobacco Road on your left; turn onto Tobacco Road and drive to its intersection with Route 263; turn left (east) toward the hamlet of Wilson and continue on Wilson Road for a total of ~7 miles. Park where directed by the owner of this private property.

Stop 2. Between Plum Point and Camp Kaufman:
Plum Point Member of the Calvert Formation (Access to Shattuck-Zones 10–15)

We will reach the cliffs by walking down a small wooded ravine to the beach, where a spring-fed creek reaches the bay. Cliffs are present to both the south (toward old Camp Kaufman, now Pine View Estates) and the north (toward Plum Point). We will walk north, giving us access to the upper part of the Shattuck-Zone 10 shell bed, as well as clear views of strata up through the Shattuck-Zone 14 shell bed and overlying weathered Miocene units.

Context

This field stop is located ~2.5 km south of the end of Plum Point Road, and ~2 km south of Shattuck's Plum Point outcrop, where he described several meters of his Zone 10 exposed at beach level (most comparable to Carpenter Beach section 78SK11 of Kidwell, 1982; and see "Plum Point" section in Ward and Powars, 2004). As a result, only a thin increment of Shattuck-Zone 10 will be exposed at our field stop. This locality is referred to as "south of Plum Point" in Ward and Andrews (2008), and as "North of Camp Kaufman" in Kidwell (1982, her 78SK6 and 79SK121).

The cliffs here are ~30 m high in natural, unaltered exposures with patches of beach present even at normal high tide.

Points of Interest

Walking north, an increasing thickness of loosely to densely packed 10-cm-scale shell beds and intervening less shelly beds are exposed at the base of the cliff face (Figs. 13 and 14). These are part of a transitional facies between the main body of Shattuck-Zone 10 (a densely packed, internally complex shell bed) and burrow-mottled clays of Shattuck-Zone 11 (Fig. 3, and more detailed figure 7 in Kidwell, 1984). We will walk north only far enough to see the top ~0.5 m of this facies. The densest shell layer exposed, usually at beach level, has a sharp, undulatory top and includes worn specimens of the sturdy venerid *Chione parkeria* as well as disarticulated scallops and ostreids. Such layers are interbedded with looser packed or even sparsely dispersed shells in siltier matrix, a signal of inner-shelf depositional conditions.

Shattuck-Zone 11 comprises ~6 m of gray sandy silt and (light-gray weathering) clay that form a nearly vertical but textured (not smooth) cliff face. This texture reflects intense burrow-mottling. Fresh surfaces—created by scraping the cm-thick rind of freeze-thaw waste or sheet wash from the cliff face,

→

Figure 13. Lithologic profile of outcrop between Plum Point and old Camp Kaufman (**stop 2**). Based on sections 78SK6 and 78SK121 in Kidwell (1982, 1984), whose interpretations of Shattuck-Zone equivalents are very similar to those of Shattuck's (1904) original section VIII and Ward and Andrews (2008). St. L.—St. Leonard; BC—Boston Cliffs; Con.—Conoy.

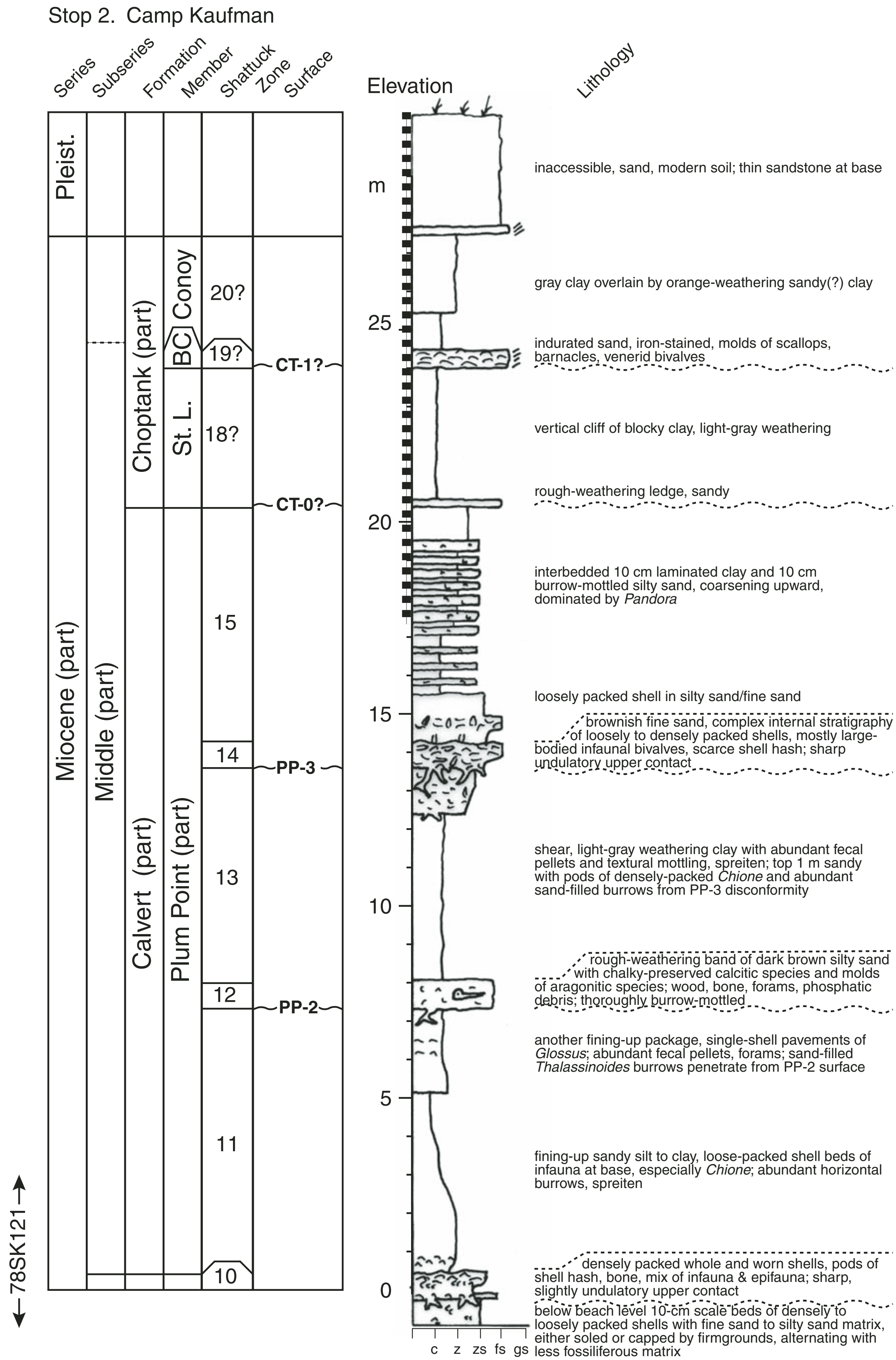

Stop 2. Camp Kaufman
Series
Subseries
Formation
Member
Shattuck Zone
Surface
Elevation
Lithology
Pleist.
Miocene (part)
Middle (part)
Choptank (part)
Calvert (part)
Conoy
BC
St. L.
Plum Point (part)
20?
19?
18?
15
14
13
12
11
10
CT-1?
CT-0?
PP-3
PP-2
m
25
20
15
10
5
0
c
z
zs
fs
gs
78SK121
inaccessible, sand, modern soil; thin sandstone at base
gray clay overlain by orange-weathering sandy(?) clay
indurated sand, iron-stained, molds of scallops, barnacles, venerid bivalves
vertical cliff of blocky clay, light-gray weathering
rough-weathering ledge, sandy
interbedded 10 cm laminated clay and 10 cm burrow-mottled silty sand, coarsening upward, dominated by Pandora
loosely packed shell in silty sand/fine sand
brownish fine sand, complex internal stratigraphy of loosely to densely packed shells, mostly large-bodied infaunal bivalves, scarce shell hash; sharp undulatory upper contact
shear, light-gray weathering clay with abundant fecal pellets and textural mottling, spreiten; top 1 m sandy with pods of densely-packed Chione and abundant sand-filled burrows from PP-3 disconformity
rough-weathering band of dark brown silty sand with chalky-preserved calcitic species and molds of aragonitic species; wood, bone, forams, phosphatic debris; thoroughly burrow-mottled
another fining-up package, single-shell pavements of Glossus; abundant fecal pellets, forams; sand-filled Thalassinoides burrows penetrate from PP-2 surface
fining-up sandy silt to clay, loose-packed shell beds of infauna at base, especially Chione; abundant horizontal burrows, spreiten
densely packed whole and worn shells, pods of shell hash, bone, mix of infauna & epifauna; sharp, slightly undulatory upper contact
below beach level 10-cm scale beds of densely to loosely packed shells with fine sand to silty sand matrix, either soled or capped by firmgrounds, alternating with less fossiliferous matrix

Figure 14. View from offshore of the cliff between Plum Point and old Camp Kaufman, a short distance south of **stop 2**. Photo by Dave Powars.

or examining wave-polished blocks along the beach—reveal diverse, mostly feeding traces, including 1-cm-diameter horizontal galleries with spreiten, fecal-pellet–packed sand blebs, and clay-filled burrows. Molluscan shells are sparse, mostly very thin-shelled infaunal bivalves, with rare single-shell pavements. The scarcity of evidence of physical reworking (e.g., of exhumed and reoriented bivalves), combined with the scarcity of grains coarser than silt, indicate a seafloor below storm wavebase; the great lateral extent of this massive clay facies within Shattuck-Zone 11 suggests an open-shelf setting. Shattuck-Zones 11 to lower 13 also yield the highest diversity of foraminifera and proportion of planktonic specimens (Gibson *in* Gernant et al., 1971).

Shattuck-Zone 12—the Parkers Creek bone bed of Kidwell (1984)—is a tabular, ~60-cm-thick bed of silty sand that rests on her PP-2 surface and weathers as a dark-brown, roughly textured ledge (commonly damp and so may be preferentially vegetated in many cliff faces). Fossil preservation in this exposure is typically poor: *Chione parkeria* are abundant but preserved only as molds with traces of chalky aragonite, and even barnacle and scallop debris is disintegrating. Black phosphatic debris (small pellets, disciniscid brachiopod fragments), bone, wood, and foraminifera are, however, abundant and well preserved. The matrix is thoroughly burrow-mottled, and the basal contact (PP-2 surface) is a firmground with 2-cm-diameter branching burrows extending several 10s of cm into underlying clay of Shattuck-Zone 11, creating a sharp albeit complexly invaginated contact. The bone bed has been interpreted as a stratigraphically condensed accumulation in relatively deep water, fostered by a combination of sediment-starvation and outer-shelf winnowing during maximum marine transgression (surface or interval of maximum transgression; for fuller treatment, see Kidwell, 1984, 1989). We will see this same interval at beach level at our next locality (**stop 3**, Parkers Creek). The bone bed maintains the same, thin, tabular nature across the entire outcrop belt, including downdip of this locality. As mentioned, it appears to divide into a series of distinct bone-rich layers further updip, where this interval thickens (Naval Research Laboratory facility, just south of **stop 1**; Kidwell, 1989). A second, light-brown, sandy interval located ~2 m below Shattuck-Zone 12 here, within Shattuck-Zone 11, may be a harbinger of this "opening up" of this condensed, maximum-transgressive interval.

Shattuck-Zone 13 here is a ~5-m-high cliff face of burrow-mottled clay (same trace-fossil suite as Shattuck-Zone 11), which rests rather sharply on the Shattuck-Zone 12 bone bed and grades up to burrow-mottled sandy silt and very silty sand with dispersed shells. This clayey Zone-13 interval immediately above the Zone 12 bone bed is, grossly, a mirror image of the clayey Zone 11 interval below the bone bed, and, among other evidence, supports the deep-water origin of this part of the Miocene record in the cliffs. See further discussion at **stop 3** (Parkers Creek), and a better view of storm-generated shell pavements in the upper part of Shattuck-Zone 13 at **stop 4** (Scientists Cliffs).

Shattuck-Zone 14 is the second of the four major-complex shell beds in the Miocene succession, and mantles the PP-3 disconformity. Viewed from beach level, it is a relatively obscure, rough-weathering, and frequently damp band approximately half-way up the cliff face. Shattuck-Zone 14 is quite thin (<1 m) at this relatively updip exposure (see Kidwell, 1989, for stratigraphic and taphonomic details, and Shattuck, 1904, and Ward, 1992, for species lists). However, when viewed closely, either in situ or in large fallen blocks, Shattuck-Zone 14 is impressively fossiliferous and has a complex internal microstratigraphy of

(1) loosely packed, disarticulated and articulated specimens of large venerid, glossid, and crassatellid bivalves in silty sand; (2) densely packed disarticulated bivalves, the muricid *Ecphora*, and shell hash in fine sand; and (3) a capping lag rich in pectinids, lucinids, and *Bicorbula*, including many articulated specimens rotated from life position. A 20-cm-thick band of loosely packed whole and articulated lucinid, small glossid, pectinid, and venerid bivalves lies ~30 cm above the top of this main shell bed and becomes amalgamated onto it when traced downdip (e.g., at **stop 3**, Parkers Creek; Kidwell, 1989). The basal PP-3 disconformity juxtaposes this complex shell bed against the relatively shelly, silty sand upper facies of Shattuck-Zone 13 here at Camp Kaufman, further contributing to the overall shelliness of this rough-weathering interval within the cliff face (in contrast, Ward and Andrews, 2008, describe Shattuck-Zone 14 as very thick here, clearly encompassing most of what we assign to this upper facies of Shattuck-Zone 13). The uppermost meter of that sandy silt to very silty sand facies of Shattuck-Zone 13 contains small clumps and (burrow-fill) pods of loosely packed small shells (corbulids, small *Glossus* and *Chione, Anomia*). This assemblage amalgamates onto the underside of Shattuck-Zone 14 further downdip. This entire Shattuck-Zone 10–14 interval deserves more detailed stratigraphic dissection!

Above Shattuck-Zone 14 is a final ~6 m of dark-gray, fine-grained strata attributed by Shattuck to his Zone 15, but most subsequent workers have postulated that higher Shattuck-Zones 17–20 are also present here. The upper part of this interval is distinctly banded when viewed from beach level, and float blocks (as well as in situ examination of its lower part) reveal it to be interbedded silty sand and shelly sand with abundant specimens of the fragile, extremely shallow subtidal bivalve *Pandora*, grading upward into interbedded *Pandora*-rich silty sand and thin bands of laminated clay. This facies is a slightly coarser-grained version of the *Pandora* facies observed in Shattuck-Zone 15 further downdip (e.g., **stop 3**, Parkers Creek; Kidwell, 1984). A hazy line in the cliff capping this interval may signify Kidwell's CT-0 disconformity. This unit boundary is overlain by ~2.5–3 m of light-gray to buff-weathering blocky clay (Shattuck-Zone 18?), an ~0.5-m-thick rough limonite-stained sandy shell bed (Shattuck-Zone 19?; pectinids, molds of aragonitic bivalves in float blocks), and 3–4 m of gray clay, whose upper part is deeply weathered (Shattuck-Zone 20?). We will have better access to these units at later stops.

Directions to stop 3. Return to vehicle, continue south on Wilson Road ~2 miles to its junction with Route 402 (Dares Beach Road). Turn right (west) to rejoin Route 2/4 at the small city of Prince Frederick, which has developed hugely in the last 20–30 years. At this junction, proceed south (left) on Route 2/4 for 5.4 miles to the exit for Port Republic, which is still simply a post office address (but the post office is no longer in the kitchen of a local farm house). Proceed eastward on this Parkers Creek Road for 300 m to Scientists Cliffs Road (first road leading off to the right), and then take Scientists Cliff Road to its termination at the locked entrance to the property of the American Chestnut Land Trust, a total distance from Route 2/4 of ~3 miles. Participants in the 2015 GSA Annual Meeting field trip will have permission to enter the property, which was formerly owned by Dr. Page Jett, a longtime general practitioner in Calvert County. Notice the spectacular tidal creek and marshland of Parkers Creek to your left (north) as we drive through the property to reach the beach. All of this land, along with the former "Goldstein Farm" on the far side of Parkers Creek, is now protected as a natural reserve (www.acltweb.org).

Stop 3. Parkers Creek: Plum Point Member of the Calvert Formation and Choptank Formation (Access to Shattuck-Zones 11–14, Visual Examination of Shattuck-Zones 15, 16B–17)

Once at the beach, turn right (south) to the base of the cliffs. We will walk south toward the northern edge of the private beach community of Scientists Cliffs, which is marked by a wooden staircase providing those homeowners with access to the bay. The beach is narrow even at low tide, and so we will mostly be wading at this stop.

Context

All workers consistently refer to these cliffs immediately south of the mouth of Parkers Creek as Parkers Creek, from Shattuck (1904) onward (his section X, 0.5 miles south of the Creek mouth; measured section 78SK32 of Kidwell, 1982; and see Ward, 1992; Ward and Powars, 2004; and Ward and Andrews, 2008). Cliffs to the north of the creek mouth are referred to as Dares Beach, which is the name of the community to their north, or Goldstein Farm for the former property owner, and have no published measured sections (see 78- and 79SK72 in Kidwell, 1982).

The cliffs here are ~20 m high in natural, unaltered exposures with very little or no beach, although the beach is quite wide at the mouth of Parkers Creek, with a well-developed spit built by longshore drift (mostly from the south). To the north (3–4 km), the Dares Beach community has, over the years, maintained a number of small jetties to capture longshore drift, but is now almost entirely armored with large riprap and seawalls. The Scientists Cliffs community to the south has also had a series of small rock or wood jetties, but mostly further south (**stops 4 and 5**).

Points of Interest

The base of the section is a smooth-weathering, thoroughly burrow-mottled gray silty clay from the upper part of Shattuck-Zone 11 (Figs. 15 and 16). Depending on how much beach sand has been banked up against the base of the cliff, ~1 m will be exposed. Although this clay can appear to be homogeneous, it contains hazy-edged, 2-cm-diameter, inclined tubes with silt halos and sharp-edged, 1-cm-diameter, clay-filled burrows, superimposed on a vaguely color-mottled matrix with abundant fecal pellets (Fig. 6A). This facies is fairly classic outer shelf—the inner part of the outer shelf—with silt-sized particles delivered during

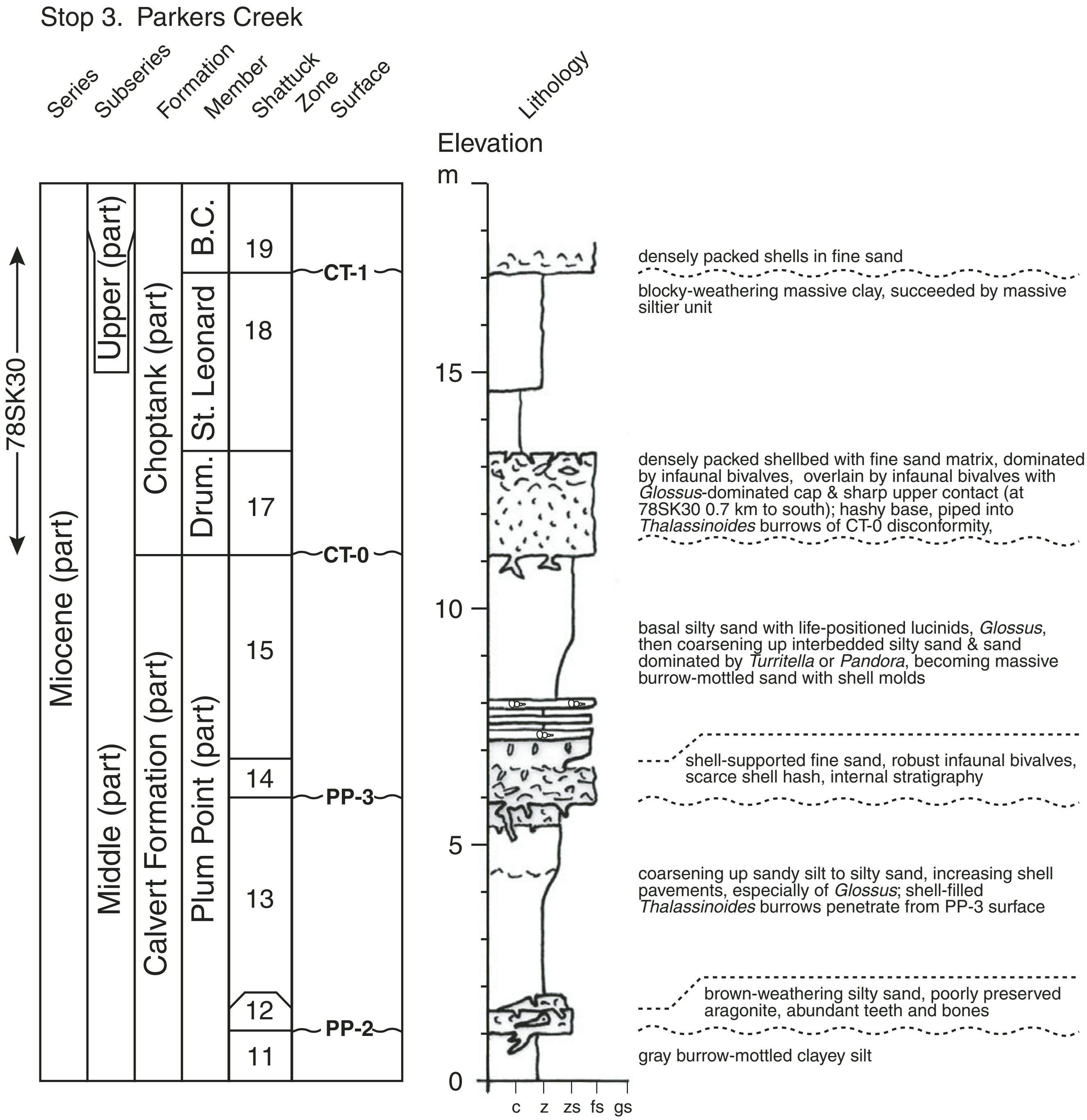


Figure 15. Lithologic profile of outcrop south of Parkers Creek (**stop 3**). Based on section 78SK32, with upper part from section 78SK30, of Kidwell (1982, 1984), whose interpretations of Shattuck-Zone equivalents are very similar to those of Shattuck's (1904) original section X and Ward and Andrews (2008). See Figure 6A for photograph of Shattuck-Zone 11 here, and Figure 9 for detailed cross section of the Shattuck-Zone 14 shell bed and position of CT-0 disconformity. Drum.—Drumcliff; B.C.—Boston Cliffs.

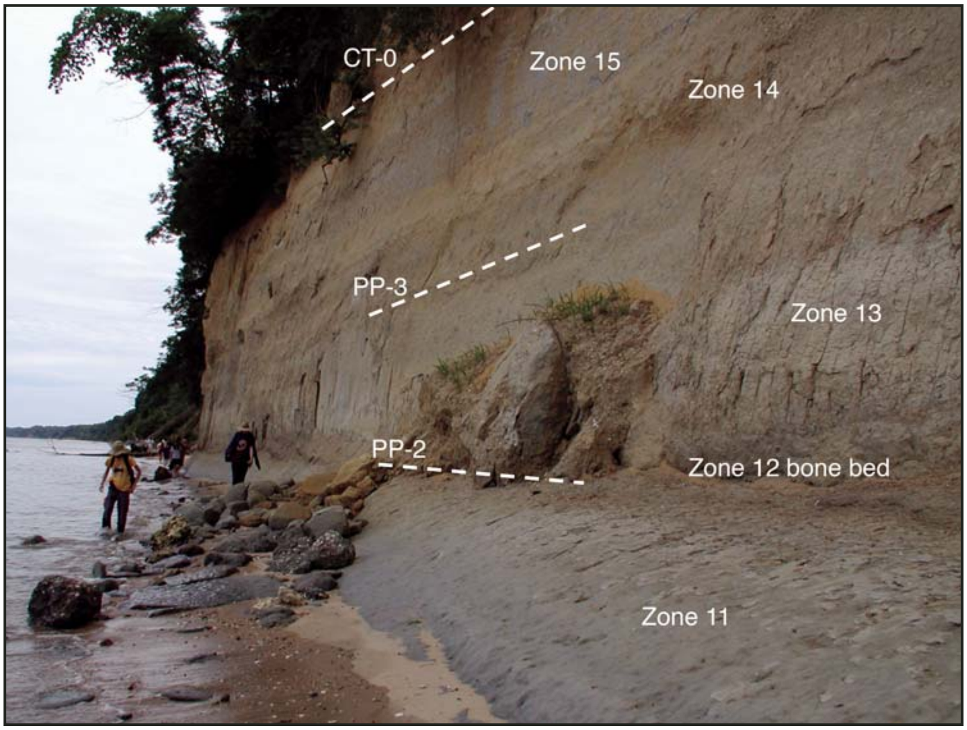


Figure 16. View looking south from Parkers Creek. Walking south from here toward the northern end of the Scientists Cliffs community, we will see the CT-0 disconformity bevel across Shattuck-Zone 15 to within a meter of the top of the Shattuck-Zone 14 shell bed. This stretch of cliffs is where Shattuck (1904) originally recognized his unconformity at the base of the Choptank Formation, with his Zone 16 (Shattuck-Zone 16B herein) resting erosionally on his Zone 15. Controversy over this unconformity is limited to areas further south (**stops 4, 5, 6**). The ledge low in the cliff is a bedding-plane exposure of the PP-2 disconformity, a regionally extensive burrowed firmground developed on the tightly consolidated clays of Shattuck-Zone 11 and mantled by the exceptionally bone-rich sand of Shattuck-Zone 12. This interval marks maximum water depth within the Calvert Cliffs succession.

storms but no evidence of actual storm-wave reworking of the seafloor (Fig. 5). The few shells present are sparsely dispersed and very small; if they were reworked by storms, bioturbators were able to re-disperse and randomize their positions.

Shattuck-Zone 11 culminates in a sharp burrowed firmground (the PP-2 surface of Kidwell, 1984). The upper part of Shattuck-Zone 11 thus includes 2–3-cm-diameter, sharp-edged burrows filled with brownish, relatively glauconite-rich, silty sand that has been piped down from Shattuck-Zone 12 (Parkers Creek bone bed), which is very thin here (20–25 cm). The entire bone bed is readily eroded by rain and waves, creating a notch or ledge in the cliff face, providing a bedding-plane view of the PP-2 firmground (Fig. 16). Sandy burrow fill has been preferentially eroded by modern waves, leaving a distinctively pocked ledge of Shattuck-Zone 11 clay much like the PP-0 disconformity surface exposed at beach level at **stop 1** (Fig. 12).

In the Shattuck-Zone 12 bone bed, vertebrate material is, in absolute terms, sparsely distributed and mostly dissociated teeth and rounded bone fragments, but well-preserved specimens have also been excavated (see exemplary material at the Calvert Marine Museum in Solomons, MD; www.calvertmarinemuseum.com). Aragonitic shell material—mostly specimens of *Chione parkeria* and articulated, life-positioned *Glossus fraterna*—is poorly preserved, but molds indicate that the bed originally included small patches of shell-supported structure, at least in the lower half. Where the bone bed is relatively thick, its upper contact is sharp and distinctly burrowed, with burrows filled with greenish-gray clay and/or silt from the overlying Shattuck-Zone 13. However, in many stretches along this outcrop, the entire unit is a complex of intersecting burrow fills, overlain gradationally by ~40 cm of transitional brown silty sand with clay-filled burrows. This is clearly an interval of many, closely spaced, mutually intersecting firmgrounds that have the net effect of generating a broadly tabular sand body. It is interpreted to have accumulated under prolonged conditions of ~zero net siliciclastic accumulation—sediment starvation—on the ~outer shelf, allowing marine vertebrate material to become relatively concentrated without high-energy reworking (Kidwell, 1984, 1989). Such conditions were attained during maximum transgression (see discussion of its origin in a regional perspective in the text for **stops 1 and 2** and in the main text). It is possible that this interval includes a "cryptic" sequence boundary, i.e., a surface of offlap and shallowing, perhaps even exposure, that allowed sand delivery and permitted terrestrial animals to live in this region. However, sand is commonly associated with mid-cycle starved intervals—these include "relictual" winnowed sands present at modern-day shelf-slope breaks (drowning surfaces and type III unconformities; e.g., Galloway, 1989).

Shattuck-Zone 13 is also directly accessible at beach level and closely resembles Shattuck-Zone 11 except that it is siltier and coarsens upward into very silty fine sand. Shell material is still sparse but is better preserved, and includes some single-shell pavements of disarticulated bivalves (mostly *Glossus*). Much of Shattuck-Zone 13 at **stop 2** consisted of this sandier, *Glossus*-dominated facies (Figs. 3 and 13; see facies in cross sections of Kidwell, 1984). The upper contact of Shattuck-Zone 13 is Kidwell's PP-3 disconformity, which is another *Thalassinoides*-burrowed firmground. Sharp-edged, 2–4-cm-diameter pods filled with shelly silty sand can be found several tens of cm below the surface of origin for these burrows. This shelly sand has been piped down from Shattuck-Zone 14, and should not be confused with shells occurring in the more tightly consolidated, silt-rich matrix of uppermost Shattuck-Zone 13.

Shattuck-Zone 14 is the second of the four major complex shell beds in the Maryland Miocene succession and mantles the PP-3 surface (for taphonomic and stratigraphic details, see Kidwell, 1989; for species lists, see Shattuck, 1904, and Ward, 1992). The outcrop here at Parkers Creek is near the right edge of the detailed cross section of this shell bed in Figure 9 (locality 78SK32). The shell bed can be observed in fallen blocks and sometimes accessed directly via small slumps here. Compared to the other major shell beds (Shattuck-Zones 10, 17, and 19), Zone 14 is visually dominated—here and elsewhere—by especially large and thick-shelled infaunal bivalves such as *Mercenaria* and *Clementia*, by a generally siltier sand matrix, and by poorer preservation (aragonitic shell is typically chalky and crumbly); it also contains far less intervening fine shell hash, and typically lacks a basal shell hash (which can be 0.5–1.5 m thick in the other major shell beds). Here at Parkers Creek, the densely packed facies within Shattuck-Zone 14 is only a few tens of cm thick, but still has a complex internal stratigraphy with,

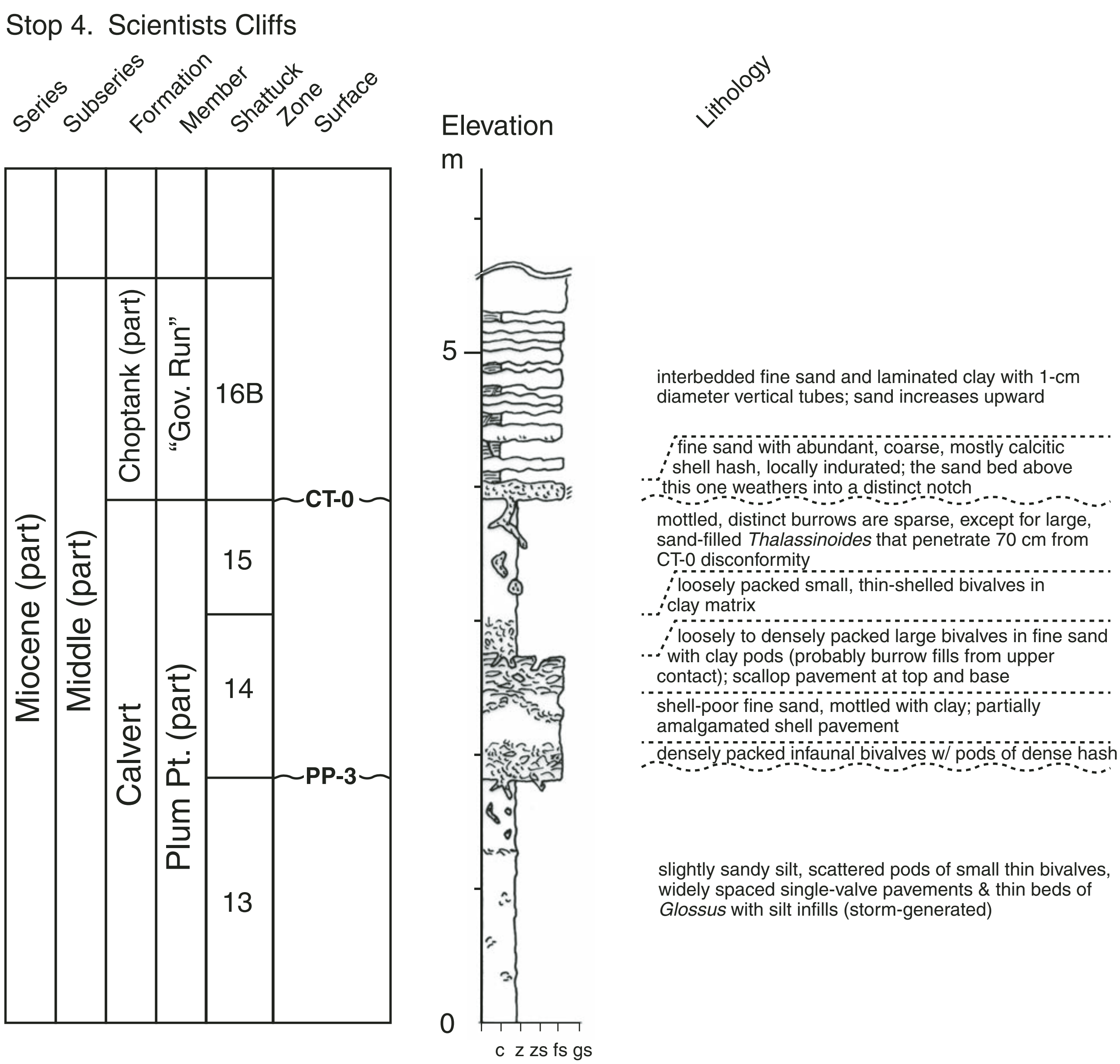


Figure 17. Lithologic profile of outcrop at Scientists Cliffs between jetties 19 and 20, Gate A (**stop 4**); note different thickness scale than other profiles. Based on section 79SK78 in Kidwell (1982, 1984). See Figure 6B for photograph of Shattuck-Zone 13 here, and Figure 9 for detailed cross section of the Shattuck-Zone 14 shell bed. "Gov. Run"—informal "Governor Run" sand of Kidwell (1984).

as seen elsewhere, a capping *Glossus*-dominated shell stringer and articulated, life-positioned lucinid bivalves *Lucinoma*. This aspect contrasts with the series of distinct sand-rich shell layers separated by intervening shell-poor mud that constitute this same shell bed further downdip/south (e.g., **stop 4**, Scientists Cliffs; Figures 9, 17, 18A).

The Shattuck-Zone 14 shell bed is overlain here by ~2 m of generally coarsening upward and banded sandy silt and shelly silty sand—this is Shattuck-Zone 15 according to Shattuck (1904) and accepted by all workers since. Fossil assemblages are dominated by the same assemblage of relatively thin-shelled bivalves that are present in the upper part of Shattuck-Zone 14, plus *Bicorbula*, *Turritella*, *Pandora*, and tellinids. This interval of rather sparsely shelly and distinctly thin-bedded sediments is overlain sharply by the densely and diversely fossiliferous Shattuck-Zone 17 shell bed, separated by the CT-0 unconformity of Kidwell (1984), which was first recognized here by Shattuck (1904). Zone 17 is rarely accessible here, because it is so high in the cliffs, and is quite thin, consisting of several bands of densely fossiliferous sand, each a few tens of cm thick, with intervening sand. A complete section of Shattuck-Zones 17 through 19 measured at the northern end of Scientists Cliffs (78SK30 of Kidwell, 1982) is attached to the profile in Figure 15 as a proxy.

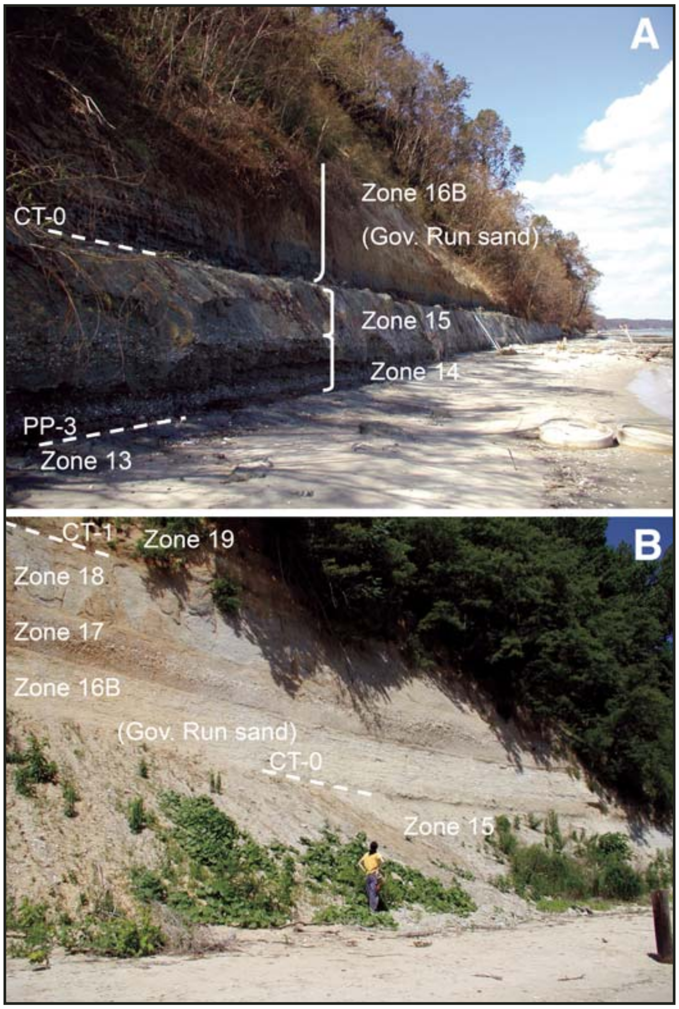


Figure 18. (A) Looking north at the well-exposed CT-0 unconformity in Gate A of Scientists Cliffs; photo taken in 2003 immediately after Hurricane Isabel. The interbedded clay and hashy sand facies at the base of the Governor Run sand (Shattuck-Zone 16B) is obvious right above the CT-0 unconformity: these beds are much more easily eroded than are the well-consolidated silty sand and sandy silt of Shattuck-Zone 15. Note strongly recessive slope created by the (largely vegetated) central sand facies of the Governor Run sand above this basal interval. (B) Cliff at southern end of Gate A of Scientists Cliffs (jetties 1 and 2), in the Governor Run cliff, on the southern flank of the incised paleovalley. Beds of clay and sand within Shattuck-Zone 16B here dip gently toward the north, toward the axis of the Governor Run paleovalley, contrary to the southerly regional dip.

Stops 3–5: The Calvert-Choptank Boundary and Origin of the CT-0 Unconformity

Stratigraphic relationships above Shattuck-Zone 15 in the Parkers Creek cliffs (**stop 3**) have been controversial ever since Shattuck (1904) recognized an unconformity between his Zones 15 and 16 here. This stratigraphic interval is also especially interesting paleoenvironmentally. The extremely shallow water, arguably intertidal facies that are present above the CT-0 surface constitute some of the clearest evidence that the CT-0 disconformity, and probably most of the others in the Calvert and Choptank Formations (excepting PP-2), became subaerially emergent, notwithstanding the lack of rooting and other unambiguous evidence. This interval is also important in sampling—and in disentangling confusion from past sampling—for paleontologic and historical geologic analysis.

These cliffs stretching between Parkers Creek and the northern end of the Scientists Cliffs community are famous for exposing a low-angle truncation of Calvert Formation strata by the Choptank Formation, first recognized by Shattuck (1904) and confirmed by Dryden (1930, 1936), Gernant (1970), and all subsequent workers. Weather conditions permitting, we will be able to walk out this transition, past section 79SK119–78SK30 at the northern end of Scientists Cliffs. Along this stretch, we will observe (1) the southward/downdip thinning of Shattuck-Zone 15 underneath the CT-0 surface (evident by truncation of bedding); and (2) the appearance above this CT-0 surface of a new unit, labeled "Zone 16" by Shattuck (1904), below the distinctive, densely shelly sand of Shattuck-Zone 17, which remains relatively high on the cliff face (Fig. 3). Shattuck (1904) used this erosion surface to define the base of his Choptank Formation, recognizing that his Zones 16 and 17 onlapped it northward (the updip limit of his Zone 16 is here in these cliffs; he suggested that his Zone 19 rested directly upon it further north in Calvert County, inland from the cliffs).

As we walk south toward the northernmost end of Scientists Cliffs (set of stairs coming down to beach level), we will also observe the first appearance of a distinct interbedded clay and silty sand interval between the CT-0 surface and the base of the Shattuck-Zone 17 shell bed. The sands interbedded with these clays are rich in calcitic sand-dollar and barnacle debris, and weather as a series of distinct notches in the cliff face. This "Zone 16" interval thickens to ~6 m at 78SK30, where the basal clay/sand interval includes both traces and body fossils of burrowing echinoids ("nests" of *Echinocardium* as well as sand dollars); loose, yellow-weathering fine sand with only thin, widely spaced laminated clays dominates the rest of the interval ("Governor Run sand" of Kidwell, 1984). These poorly consolidated sands, and the cliffs along the entire Scientists Cliffs shorefront, are now extremely overgrown and poorly exposed, and so observations of "Zone 16" at 78SK30 and further south largely depend on recent cliff falls or hurricanes (Fig. 18A). Good exposures of the underlying, more consolidated Shattuck-Zones 13 through 15 of the Calvert Formation are distributed along the modern shoreline in different positions than in the 1970s–1980s, but are still relatively abundant (see **stop 4**).

A series of detailed and closely spaced measured sections south of here on Scientists Cliffs property reveals that the CT-0 surface continues to cut into the Calvert Formation, eventually reaching the top of Shattuck-Zone 14 near **stop 4** (Figs. 3 and 9). The CT-0 disconformity then climbs back up-section, toward the base of Shattuck-Zone 17, describing a large incised paleovalley with ~7 m of paleorelief over ~4 km laterally (Kidwell, 1984; Fig. 18). The "Zone 16" sand and basal interbedded sand and clay observed here at 78SK30 are part of the infill of this paleovalley, and lap out both against this northern flank here and against the southern flank of the paleovalley at Governor Run (**stop 5**). We will see counterpart interbedded clays and sands there, with heavily encrusted clusters of mussels and other intertidal indicators. These stata are separated from the silty Shattuck-Zone 15 of the Calvert Formation by the CT-0 surface, which is mantled by a basal sand lag rich in sand dollar debris (**stop 5**, Governor Run).

This paleochannel-filling complex of intertidal to very shallow subtidal, sand-rich facies constitutes the Governor Run sand of Kidwell (1984; Shattuck-Zone 16B here). These beds contain diatoms and dinoflagellates that are biostratigraphically distinct from those of the upper Calvert Formation (Kidwell, 1984; de Verteuil and Norris, 1996). The Governor Run sand is currently very poorly exposed everywhere within the Scientists Cliffs, which are heavily overgrown. In addition, the cliffs at Governor Run can now only be examined from a distance. **Stops 4 and 5** are thus optional for this trip, but may become more practical in the future.

Directions to stops 4, 5, and 6. Return to vehicle, retrace route to exit American Chestnut Land Trust property and regain Parkers Creek Road. From there, proceed to hotel in Solomons by traveling south on Route 2/4. Otherwise proceed to optional **stops 4, 5, and/or 6**. Optional stops 4 and 5 are accessed via Parkers Creek Road. Optional **stop 6** requires taking Parkers Creek Road back to Route 2/4 and driving south to the town of St. Leonard.

Stops 4 and 5. The "Governor Run" Incised Valley Associated with the CT-0 Unconformity

The basal-Choptank, CT-0 erosion surface is clear in the stretch of cliffs between Parkers Creek and the northern end of Scientists Cliffs, where it was first recognized by Shattuck (1904) (**stop 3**). However, its presence further downdip within intervals of supposed Shattuck-Zones 15 and 16 (e.g., at Governor Run, **stop 5**, where many biostratigraphers have collected sample series) could not be resolved, leading to considerable confusion in attributing samples near this contact to one formation (Calvert) or the other (Choptank).

Based on many closely spaced measured sections between Parkers Creek and Governor Run, a distance of ~4 km, Kidwell (1984) recognized that the CT-0 surface locally removes Calvert strata to the top of Shattuck-Zone 14 (near **stop 4**) but then climbs back up-section to approach the base of Shattuck-Zone 17, describing a broad incised valley (Fig. 2). This interpretation was supported by diatom biostratigraphic analysis (and see dinoflagellate evidence of de Verteuil and Norris, 1996). The yellow-weathering sand of Shattuck-Zone 16 within this channel—Kidwell's (1984) Governor Run sand, which actually has multiple facies; entire channel fill now designated as Shattuck-Zone 16B—is thus both lithologically and chronologically distinct from underlying silty Shattuck-Zone 15. The Governor Run sand/Shattuck-Zone 16B is also distinct from the blue-gray, *Turritella*-rich interbedded clay and silty sand facies that Shattuck (1904) described as Zone 16 further downdip at Calvert Beach (**stop 6A**), ~5 km away (downdip) from the southern flank of the paleovalley in Scientists Cliffs. That *Turritella*-rich version of Shattuck's original Zone 16 at Calvert Beach is now referred to as Shattuck-Zone 16A, and it is assigned to the Plum Point Member of the Calvert Formation (Gernant's, 1970, "Calvert Beach Member" should be abandoned; Fig. 2; Kidwell et al., 2012). Additional but smaller incised valleys, similarly supported by micropaleontologic biostratigraphic evidence, exist along the CT-0 surface (e.g., see Patuxent River cross section in Kidwell, 1984; Ward and Andrews, 2008). Additional examples should be expected along this and other disconformities in the succession.

Dryden (1930) also recognized the paleochannel cut into Calvert strata between Parkers Creek to Governor Run, also on the basis of a cross section pinned by many closely spaced sections in Scientists Cliffs. He later rejected it as a post-depositional "downward sag" (Dryden, 1936), but apparently continued to work on the problem (see discussion in Ward and Andrews, 2008). Gernant (1970) believed that the distinctive yellow sand of Shattuck-Zone 16 found in this Parkers Creek/Scientists Cliffs region (Shattuck-Zone 16B here, Governor Run sand) was a diagenetic artifact, that is due to unusual weathering of the blue-gray clay facies that was present below Shattuck-Zone 17 at Calvert Beach (**stop 6A**). With the exception of Kidwell (1982, 1984, 1988, 1997), who has continued to accept the paleochannel, workers have not mentioned the feature or have rejected it implicitly. The existence of this incised paleovalley associated with the CT-0 surface now seems to be generally accepted (de Verteuil and Norris, 1996; Ward and Andrews, 2008; Powars et al., 2015b). Moreover, on the basis of dinoflagellate data from cores in the offshore Baltimore Canyon trough, de Verteuil (1997) suggested that the Governor Run sand may actually be the remnant of a distinct third-order sequence, wedged between Kidwell's PP-3 and CT-0 sequences, that is not otherwise preserved within the coastal plain outcrop belt. This finding underscores the importance to geohistorical analysis of having many closely spaced and closely described (and sampled) measured sections where the stratigraphic record is very thin, such as the Miocene succession exposed in the Calvert Cliffs.

Directions to stop 4. Return to vehicle, retrace route to exit land trust property and regain Parkers Creek Road. Once on Parkers Creek Road, watch for the entrance, on the left, to "Gate A" of the Scientists Cliffs community. It will be a small rustic sign. Park as directed by private landowners.

Stop 4. Scientists Cliffs (Northern Part of Gate A, between Jetties 19 and 20), Plum Point Member of the Calvert Formation and Choptank Formation (Access to Shattuck-Zones 13–15, CT-0 Surface, and Zone 16B; Visual Examination of Shattuck-Zones 17–19)

Once at the beach, small outcrops of Shattuck-Zones 13 (in part), 14, and 15 (in part) are usually exposed both to the immediate north and south, especially if cliff-covering vines have been trimmed. The beach is narrow here even at low tide.

Context

Scientists Cliffs is a 2.5-km-long stretch of privately owned property with few natural landmarks positioned between Parkers Creek to the north (**stop 3**) and Governor Run to the south (**stop 5**). Shattuck (1904) did not describe any sections from these exposures, but numerous ones are available in the unpublished dissertations of Dryden (1930) and Kidwell (1982). Locations are usually described relative to subdivisions within the Scientists Cliffs community (Gates A to E from south to north) and numbered jetties. Both authors produced detailed cross sections of the Shattuck-Zones 13–19 interval.

The cliffs have a maximum height of 30 m. However, with the exception of outcrops at the northern and southern edges of the property, the cliffs are relatively gently sloped and vegetated except after major storms or cliff falls, with fairly small exposures a few meters high at the shoreline.

Many small rock, concrete, and wooden jetties have been installed at regular, closely spaced intervals along the full length of Scientists Cliffs since the community was established in 1935. The foot of the cliff to the south of the beach-access stairs here within Gate A has recently been armored with m-scale gabions. Such wire-mesh cages of cobble-sized rocks are easier to install than boulder riprap and dissipate more wave energy, but the cages deteriorate rapidly in salt water.

Points of Interest

Hurricanes and major storms regularly expose Shattuck-Zones 13–15 at the base of these cliffs, creating a ledge ~2 m above tide level that approximates the CT-0 disconformity (Figs. 17 and 18A). The overlying Governor Run sand (Shattuck-Zone 16B) is generally recessive, owing to the well-sorted fine sand that dominates it, which is why the cliffs are more gently sloped and more fully vegetated here compared to cliffs closer to Parkers Creek (**stop 3**) and Governor Run (**stop 5**). We are likely to see the basal interbedded clay and hashy-sand facies of the Governor Run sand, which mantles the CT-0 surface. The major shell beds of Shattuck-Zones 17 and 19 are likely to be visible only through small windows in vegetation 10–20 m higher in the cliff.

Shattuck-Zone 13 is the relatively unfossiliferous and massive dark-gray clayey unit at beach level. Examined closely, it is beautifully burrow-mottled and contains small pods of thin-shelled bivalves and a few widely spaced pavements of the bivalve *Glossus* (Fig. 6B). Such pavements, especially when the shells are of infaunal species and/or have better-sorted or coarser-grained infills than surrounding matrix, as observed here, indicate physical reworking of the seabed, and thus a seafloor shallower than storm wavebase (Figs. 4, 5; see main text). This "*Glossus* facies" is also present low in Shattuck-Zone 13 at **stop 1** (Chesapeake Beach) and **stop 2** (Camp Kaufman). It is one of the deepest water facies in the Calvert Cliffs.

The Shattuck-Zone 14 major shell bed is a series of closely spaced, densely packed shell layers, much as we have already observed at **stops 2 and 3** today, and rests on the PP-3 unconformity, which presents here as a *Thalassinoides*-burrowed firmground (Figs. 8 and 17). More or less hashy fine sand from the Zone-14 shell bed is piped several tens of cm down into the underlying Shattuck-Zone 13. The complex shell bed is overlain by a massive, burrow-mottled silty/sandy clay, which is piped downward, leaving clay pods in the upper, densest part of the shell bed. The lowermost ~20 cm of this clay at the top of Shattuck-Zone 14 contains loosely packed small thin bivalves—in outcrops to the north, these shells become amalgamated down onto the major shell bed, producing a lucinid-*Glossus*–rich upper layer, as observed at **stop 2**. A shell pavement within the middle part of the shell bed captures the same process of amalgamation in progress: within a few meters laterally, you can see how it is "attached" to the underside of the top, densely packed part of the shell bed at some points, but is separated by shell-poor matrix at other points.

The details of the Shattuck-Zone 14 shell bed in the beach-level exposures here in Scientists Cliffs—shot through with multiple firmgrounds, shell pavements, and pods and layers of originally muddier matrix—attest to the highly dynamic and incremental formation of a complex internal stratigraphy via repeated episodes of benthic colonization, physical reworking that exhumes shells and winnows the originally muddy matrix, and superposition of new muddy increments (Figs. 8 and 9). Gernant (1970) recognized these complex dynamics within the two major complex shell beds of the Choptank

Formation—Shattuck-Zones 17 and 19—and they are equally evident within the two major shell beds of the Plum Point Member seen today (Shattuck-Zones 10 and 14).

This outcrop also presents ~1 m of Shattuck-Zone 15 below the CT-0 unconformity. Shattuck-Zone 15 is more easily identified by what it is not than by what it is: it is the dark-gray, burrow-mottled clay between the obvious Shattuck-Zone 14 shell bed below and the calcitic-hash–rich, locally indurated and well-sorted fine sand of the Governor Run sand above (Fig. 17). Shattuck-Zone 15 in outcrops further north (**stop 3,** Parkers Creek) and south (**stop 5,** Governor Run) is also quite shell-poor, especially in its lowermost meter or so. The CT-0 surface presents here as a *Thalassinoides*-burrowed firmground; burrows are filled with hashy sand and penetrate 75 cm into underlying, clayey Shattuck-Zone 15.

Only the lowermost few meters of the Governor Run sand (Shattuck-Zone 16B) are reliably exposed in these cliffs, largely because the basal facies of this body is interbedded sand and clay, with clay dominating, as also observed in the northern Scientists Cliffs (section 78SK30 of Kidwell, 1982, at the south end of **stop 3**, Parkers Creek). The lowermost sand layer here is relatively thick, locally consisting of several tens of cm of very hashy sand, with many generations of intersecting *Thalassinoides* burrows. This basal sand can be locally indurated—syntaxial cement focused on fragments of sand dollars seems to nucleate the process—and so it is usually the second, non-indurated sand layer within the Governor Run interval that is most easily eroded by modern weathering. That sand leaves a distinct notch that is more or less continuous laterally, depending on how individual sand beds anastomose laterally. The intervening clays are typically laminated, and commonly have ~1-cm-diameter vertical tubes, which appear to be related to infaunal echinoid traces within the sand layers (*Echinocardium* is preserved elsewhere along the base of the Governor Run sand; Kidwell, 1984).

A short distance north of **stop 4**, the CT-0 surface incises all the way down into the upper part of Shattuck-Zone 14 shell bed (at jetty 30, the boundary of Gates B and C; section 79SK76 of Kidwell, 1982), as also recognized by Dryden (1930; and see mention in Ward and Andrews, 2008). From that point northward to midway along the Parkers Creek Cliffs (section 79SK119 of Kidwell, 1982, 1984), Shattuck-Zone 15 has been removed entirely: the distinctive barnacle and/or echinoid basal hash of the Governor Run sand rests directly on the more diverse and aragonitic shell-rich fine sand of Shattuck-Zone 14. Along this stretch, where a calcitic-shell–rich sand is superimposed on a major shell bed, the basal hash is mostly likely to be indurated.

In the opposite direction, moving south (regionally downdip) of **stop 4**, the CT-0 surface continues to rise both stratigraphically and in elevation. About 1.7 m of Shattuck-Zone 15 survives at **stop 5** in the northern end of the Governor Run cliffs, and 5 m survives ~100 m further south at the southern end of the Governor Run cliffs (see discussion below). The CT-0 surface thus exhibits a valley-shaped topographic paleolow with 7 m stratigraphic relief over the 4-km distance from Parkers Creek to Governor Run, and individual outcrops in this stretch, although small, provide clear evidence that underlying beds have been erosionally truncated. The channel shape is thus not the result of post-depositional deformation, as suggested by Dryden (1936), nor an artifact of differential diagenesis, as suggested by Gernant (1970), but an incised paleovalley (as originally suggested by Dryden, 1930) that is filled by a distinctive suite of shallow-water to intertidal facies (Kidwell, 1984). This paleogeography and history is now generally accepted (Ward and Andrews, 2008, assign the entire lenticular sand body to Shattuck-Zone 17). Additional, albeit smaller sand-filled incised valleys exist elsewhere along the CT-0 surface, most notably at Drumcliff on the Patuxent River (Kidwell, 1984; Ward and Andrews, 2008), but have not been named.

Kidwell (1984) used "Governor Run" to denote this lenticular valley fill because that name has long-standing formal use in this region, even though the CT-0 disconformity cuts most deeply in the Gate B–E segment of Scientists Cliffs and the infilling sand (Shattuck-Zone 16B) has its maximal thickness there (see discussion **stop 5**). The generally poor quality of exposures of the Governor Run sand in Scientists Cliffs was an additional factor in proposing that the eventual type section for this member be positioned within flanking beds of the paleovalley in the Governor Run cliffs.

Directions to stop 5. From here, either (1) return to vehicle and drive to the parking lot at the south end of Scientists Cliffs property (Gate A), or (2) walk ~1 km south along the beach to that lot, with drivers moving the vehicles.

Stop 5. Governor Run: Plum Point Member of the Calvert Formation and Choptank Formation (Access to Shattuck-Zones 13–15, Visual Examination of Shattuck-Zones 16B–19)

The cliffs are ~100 m south of the parking lot for Gate A of Scientists Cliffs, and have a fairly wide beach even at high tide. The highest cliffs are 30 m. Jetty 1 marks the boundary of the Governor Run and Scientists Cliffs communities.

Context

Governor Run is a very old name for this area. It was the site of a colonial era loading dock for tobacco, and became one of many steamship ports along the Calvert County shoreline in the late 1800s; the hamlet remained a departure point for charter fishing into the 1940s. These cliffs have been a reference point since Shattuck (1904; his locality XII). Because these cliffs expose the critical but subtle Shattuck-Zones 15–16 transition, it has been a common section for biostratigraphic sampling and several measured sections are available (Gernant, 1969; Kidwell, 1982 [78SK33, 78SK34, 79SK193, 83SK246]; de Verteuil and Norris, 1996). Kidwell (1984) used "Governor Run" to denote the CT-0 paleovalley fill (Shattuck-Zone 16B) because it is such a long-standing formal geographic name and the critical southern flank is exposed here, even though the paleovalley incises most deeply and has the thickest fill further north within Scientists Cliffs (**stop 4**).

The cliffs at Governor Run are ~30 m high, but in the past several decades have had a thick crust of freeze-thaw debris or sheet wash that masks many stratigraphic details, in contrast with the quality of exposures available in the 1970s to 1990s. The oldest jetties along the shoreline of Scientists Cliffs, Governor Run, and Kenwood Beach to the immediate south (developed in the 1920s) were installed after the devastating storms of 1933 and 1936, which removed formerly broad sandy beaches. Although homes in these communities have been modernized and enlarged, many foundations date to the 1930s to 1960s and so are in peril from cliff retreat ("slope recession"), an increasingly important subject of research in Calvert County (for recent review, see Zwissler et al., 2014). The county recently purchased and demolished several cliff-top homes from the Scientists Cliffs and Kenwood Beach communities. Two large-riprap jetties at the southern edge of the Scientists Cliffs Gate A parking area have largely succeeded in maintaining a beach there by trapping south-directed longshore drift.

Points of Interest

This stretch of cliffs was critical to realizing that the CT-0 unconformity formed an erosional paleovalley between here (**stop 5**) and Parkers Creek (**stop 3**) to the north, with maximum incision down to the top of Shattuck-Zone 14 in the intervening Scientists Cliffs (**stop 4**) (Dryden, 1930; Kidwell, 1982, 1984). Here at Governor Run, the CT-0 surface climbs up-section toward the base of the Shattuck-Zone 17 major shell bed, demonstrating that the surface forms an erosional paleovalley rather than continuing downdip as in Shattuck's (1904) conception, along the base of his blue clay variant of "Zone 16." His full description of "Zone 16" here at Governor Run was 13 feet of "bluish sandy clay," as distinguished from "Zone 15," described as 4 feet of "bluish clay"; downdip at Calvert Beach (**stop 6A**), he described Zone 16 (now 16A) as 9 feet of "greenish sandy clay" with a fairly rich fauna and Zone 15 was not exposed. The ambiguity of his original descriptions at Governor Run launched decades of confusion about his basal Choptank unconformity, one of only two that he recognized in the Miocene succession.

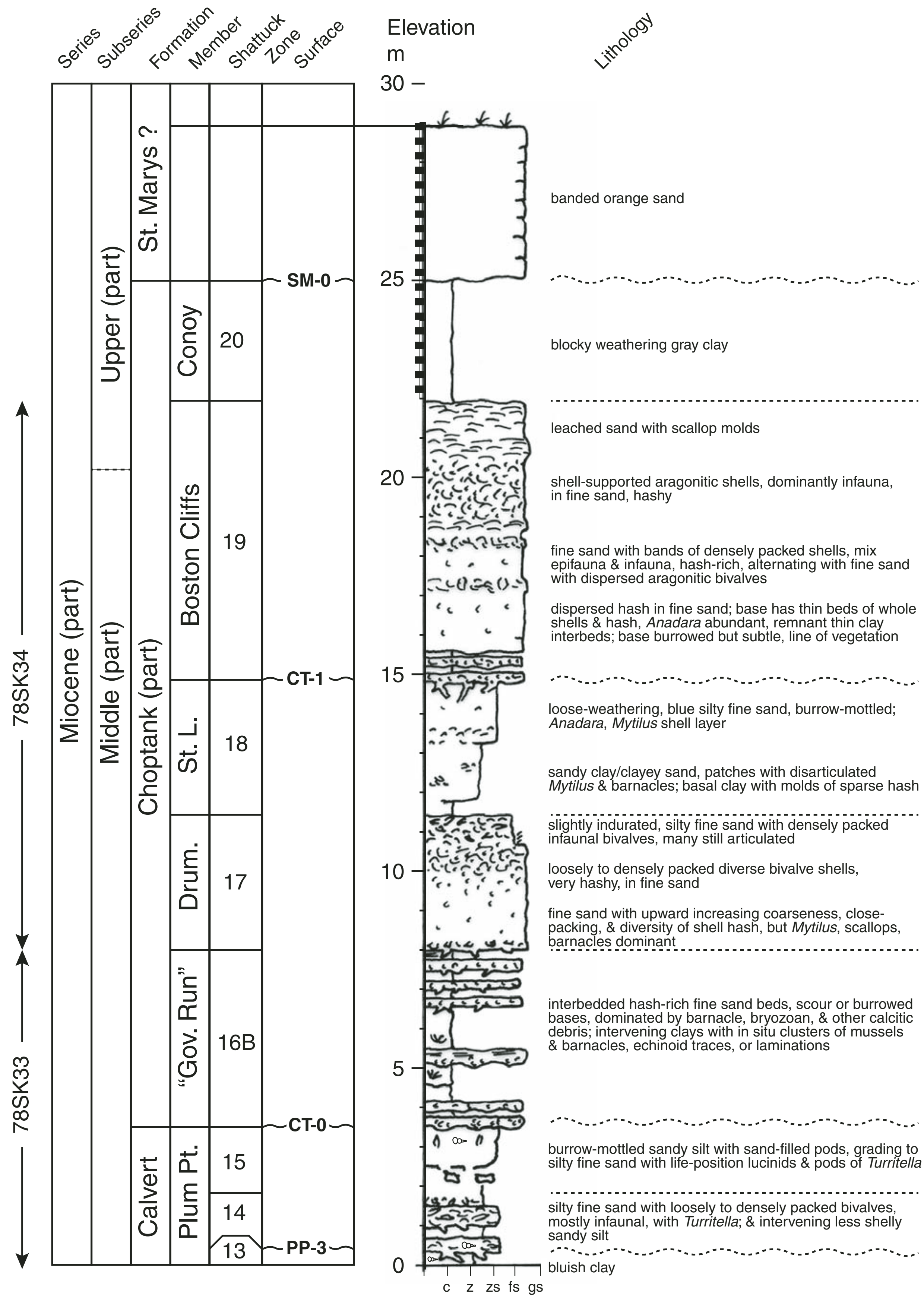
The observations here follow Kidwell (1982, 1984), using her sections 78SK33 and 78SK34 (corroborated by 83SK246), which are located at the highest point in the cliff between jetties 1 and 2 on the southern edge of Scientists Cliffs proper (Figs. 19 and 18B). Her Governor Run section 78SK193 is further south within this same cliff face, where the CT-0 unconformity has climbed higher toward the base of Shattuck-Zone 17.

The Shattuck-Zone 14 shell bed and the upper part of Shattuck-Zone 13 are present at beach level but are now rarely exposed (Fig. 19 is based on observations in 1978, 1979, and 1983; Ward and Andrews' [2008] figure 29 photograph was taken in 1985). The Zone-14 shell bed is a series of densely packed, shelly fine sands dominated by relatively large and robust infaunal bivalves with abundant wood; its uppermost 15–20 cm is silty fine sand (12% mud) with loosely packed *Glossus*, many articulated. This *Glossus* layer grades rapidly into 1.7-m interval of (1) burrow-mottled sandy silt with irregular, unlined, 6-cm-diameter burrow pods of fine sand and rare shell debris; and (2) burrow-mottled, sparsely shelly, silty sand with *Turritella* clustered in sandy pods and life-positioned lucinid bivalves. This interval is attributed to Shattuck-Zone 15, and, like Shattuck-Zone 14 beneath it at this and other outcrops, yielded diatoms diagnostic of ECDZ-V of Abbott (1978; Kidwell, 1984). The top of Shattuck-Zone 14 is a useful datum for evaluating paleotopography on the CT-0 surface, as already seen at **stops 3 and 4**.

Shattuck-Zone 15 at Governor Run is overlain by a thick and distinctive series of interbedded hash-rich fine sands and clays, designated informally as the Governor Run sand by Kidwell (1984; plan is to formalize as a basal member of the Choptank Formation). The basal contact of this body is sharp and undulatory (maximum of ~10 cm over m-lateral scale)—this is the CT-0 surface. It is mantled by a 12–15-cm-thick, hashy sand bed that is dominated by whole clusters and fragments of large balanid barnacles, sand-dollar fragments, and fragments of scallops encrusted by bryozoans. This bed is distinctly gritty and locally indurated; depending on weathering, it may be a slight notch, a ledge, or completely obscure, requiring cm-scale examination of the cliff face to detect. This largely calcitic fauna characterizes most of the hashy sand bodies between the CT-0 surface and the base of the Shattuck-Zone 17 major shell bed, which preserves a diverse, largely aragonitic infaunal bivalve fauna. Clay beds within the Governor Run sand constitute approximately half of its total thickness in this profile: they become fully dominant when traced southward in this cliff face, up against the south flank of the paleovalley, and are present both in the basal ~1 m of the Governor Run sand and as local thin beds even where the paleovalley cuts most deeply into underlying strata further north (e.g., **stop 4**, Scientists Cliffs). Most of the clay interbeds here are mottled, massive, and contain whole and in some instances life-positioned clusters of the mussel *Mytilus* and of barnacles. In contrast to the largely laminated clay beds present along the northern flank of the paleovalley (78SK30, **stop 3**), only few clays are laminated. Several of these have distinctive vertical tubes produced by the infaunal echinoid *Echinocardium*, as along the northern flank. These well-bedded lithologies and associated shelly macrobenthos are typical of intertidal flat to very shallow subtidal depositional environments. Present along the base and lapping the flanks of this paleovalley, they suggest that (1) incision occurred during a true lowstand, and (2) the interfluves of this valley—that is the broader geographic extent of the CT-0 disconformity—were subaerially exposed, despite the absence of rooting features (see discussion in main text).

The CT-0 surface thus juxtaposes the distinctly intertidal to extremely shallow subtidal shelly fauna of the Governor Run sand against the fully and relatively deeply subtidal Shattuck-Zone 15. Clay beds within the Governor Run sand, all the way down to its base, are also characterized by diatoms diagnostic of ECDZ-VI of Abbott (1978; Kidwell, 1984). The sands and clays of the Governor Run sand are thus quite distinct, both lithologically and

Stop 5. Governor Run



faunally, from the more massive clayey sediments of Shattuck-Zone 15.

The Governor Run sand is ~4 m thick in this profile. It is overlain by an additional meter of hashy fine sand with a similar balanid-mussel fauna that actually constitutes the basal part of Shattuck-Zone 17, the remainder of which is a densely shelly fine sand with diverse, dominantly infaunal bivalve fauna (Fig. 19). This increment of the cliff recognized as the Governor Run sand thus approximates the interval originally attributed by Shattuck to his Zone 16. The Governor Run sand is denoted as Shattuck-Zone 16B here (Figs. 2 and 3) to discriminate it from strata assigned by Shattuck (1904) to his Zone 16 downdip at Calvert Beach (**stop 6A**).

In the remainder of this section (Fig. 19), the Shattuck-Zone 17 major shell bed is overlain by the gray and distinctly siltier beds of Shattuck-Zone 18, succeeded by a very thickly developed Shattuck-Zone 19 interval of hash-rich fine sand and densely packed shells, and then by blocky weathering clay of Shattuck-Zone 20. Shattuck-Zones 17 and 19 are the two major complex shell beds of the Choptank Formation. We will see Shattuck-Zone 17 (Drumcliff Member of the Choptank Formation) at beach level at **stop 6A**, and Shattuck-Zones 19 and 20 (Boston Cliffs Member and Conoy Member of the Choptank Formation) at several stops on Day 2.

The cliff face that continues to the south of jetty 1 is also important. In addition to the features observed in the single profile at jetties 1 and 2 (Fig. 19), the channel-filling nature of the Governor Run sand is revealed within these cliffs by: (1) the way the entire body thins southward, against the rising CT-0 surface; (2) the southward thinning and pinchout of individual sand interbeds toward that paleovalley wall; and (3) the slight northward dip of these flanking beds toward the axis of the paleovalley, contrary to the otherwise southerly dip of Shattuck-Zone 17 above and Shattuck-Zones 14–15 below (Kidwell, 1984). (1) In a section measured a few tens of meters south of the section illustrated in Figure 19—Kidwell's (1982) section 78SK193, labeled "Governor Run"—the CT-0 unconformity climbs upsection toward the base of Shattuck-Zone 17. The CT-0 surface there is ~5 m above the top of Shattuck-Zone 14, thus preserving a much thicker increment of Shattuck-Zone 15. This thick section of Shattuck-Zone 15 has in its lowermost few meters the same silty sand/sand as seen in the 1.7 m preserved at jetties 1–2, overlain by coarsening upward silty clay, sandy silt, and silty sand with thin bands of laminated clay. *Pandora* dominates this "upper Zone 15" assemblage, closely resembling Shattuck-Zone 15 at Parkers Creek (**stop 3**). (2) The Governor Run sand itself is only 2.4 m thick, and includes small, 25-cm-scale "bioherms" of mussels and edgewise conglomerates of their shells, much as expected along the extreme margin of a tidal channel. (3) Northward from the main profile at jetties 1–2, toward the parking lot, the CT-0 surface erodes Shattuck-Zone 15 to a thickness less than 1 m. These beds at the base of the cliff are rarely exposed. However, standing close to the parking lot and looking south, with a raking, low-angle view across the cliff face, the interbedded sands and clays of the Governor Run sand above the CT-0 surface are commonly sufficiently weathered for one to see their slight, northward dip, with sand beds becoming thicker and clays thinner northward (axis-ward) off the flank of the paleovalley. This dip is contrary to the south-directed dip of Shattuck-Zone 14, at the base of the section.

Figure 19. Lithologic profile of outcrop in the Governor Run cliff, at southern end of Scientists Cliffs (between jetties 1 and 2; **stop 5**). Based on sections 78SK33 and 78SK34 in Kidwell (1982, 1984) and 83SK246 of Kidwell (1997); Shattuck's (1904) original section XII. See Figure 18B for photograph. The CT-0 surface, separating Shattuck-Zone 16B (Governor Run sand) from Shattuck-Zone 15, rises through the section here based on Kidwell (1982, 1984; and see Dryden 1930), toward her section 79SK193 located further south (left) in this same outcrop. Ward and Andrews (2008) accept an erosional paleovalley in this region, but extend Shattuck-Zone 15 all the way to the base of the Shattuck-Zone 17 shell bed here (their figure 29, same location as Fig. 18B herein). "Gov. Run"—"Governor Run"; Drum.—Drumcliff; St. L.—St. Leonard.

The existence of an erosional paleovalley along the CT-0 unconformity reconciles a great deal of biostratigraphic and other confusion about this interval (Kidwell, 1984, 1997). For example, the updip, yellow-weathering sand facies recognized by Shattuck (1904) and Gernant (1970) within Zone 16 in this region should remain in the Choptank Formation (Governor Run sand, Shattuck-Zone 16B), whether or not that sand is formalized to member status within the Choptank Formation (our intention). In contrast, the downdip, *Turritella*-rich blue clay and silty sand that Shattuck recognized as Zone 16 at Calvert Beach (Gernant's, 1970, Calvert Beach Member of the Choptank Formation; Shattuck-Zone 16A here; **stop 6**) should be excluded from the Choptank Formation and reassigned to the Calvert Formation, as also recommended formally by Ward and Andrews (2008).

The term "Calvert Beach Member" (**stop 6**) should be abandoned entirely, and not used to denote any part of Shattuck's original Zone 16. Those beds at Calvert Beach belong to the Calvert Formation, and should simply be subsumed as the uppermost part of the Plum Point Member of that formation. Another argument for abandoning "Calvert Beach Member" is the temporary expansion of that name to include Shattuck-Zones 14–16, inclusive of the Governor Run sand, by Ward (1992), an operational definition adopted by others (e.g., Gibson and Andrews, 1994, etc.). Ward and Andrews (2008) subsequently recognized a paleovalley in the Scientists Cliffs region and recommend abandoning "Calvert Beach" for any increment within the Miocene succession. They did not assign any increment to "Zone 16": they assigned the Governor Run sand (our Shattuck-Zone 16B) to the existing Drumcliff Member (Shattuck-Zone 17), and subsumed our Shattuck-Zone 16A into Shattuck-Zone 15, in that way making it part of the existing Plum Point Member of the Calvert Formation.

Directions to stop 6. Return to Parkers Creek Road, turn left (west), and proceed to junction with Route 765. Turn left onto Route 765 and proceed ~2.5 miles to the village of St. Leonard, which now has a traffic circle at the intersection with Calvert Beach Road. You will drive past the modern Port Republic post office and the entrance to the Western Shores community. (Alternatively, instead of Route 765, use the divided highway Route 2/4 and exit at St. Leonard.) At the traffic circle in St. Leonard, proceed east on Calvert Beach Road ~1 mile to a gravel road forking to the left labeled "Matoaka Lane" (sign for "Matoaka Cottages" or "Cottages for Rent"). Drive past several small homes to the end of gravel trail, which is along the wooded cliff top among a series of rustic cabins. Park where directed. This large property belongs to Larry and the late Connie Smith, who have welcomed visits by professional paleontologists and amateurs since the 1960s, when they converted this former youth camp. There is a modest day-use fee (www.matoakabeachcabins.com/).

Stop 6. Matoaka Beach

■ **Stop 6A. Calvert Beach:** Plum Point Member of Calvert Formation, Drumcliff Member of Choptank Formation (Access to Shattuck-Zones 16A and 17)

Walk down the trail to the beach, at the mouth of a small spring-fed stream. The Calvert Beach and Long Beach communities are to the right (south). For **stop 6A**, we will examine outcrops in the small bluffs between these two communities, a distance of ~1 km one way.

■ **Stop 6B.** View of Now-Vegetated Cliffs South of Western Shores, a Historic Reference Section for the Entire Choptank Formation (Shattuck-Zones 16A, 17–20)

To the north, the coast is a forest-topped highland with steep, densely vegetated slope down to the beach, stretching ~2 km from here to the main beach of the Western Shores community. If time and tide permit, we will walk along this stretch of shoreline, examining the stratigraphy through windows in the vegetation or in large blocks that may be on the beach (**stop 6B**).

Context

The small bluffs of **stop 6A** constitute the Calvert Beach locality of Gernant (1970; loc. 67-65), the type section of his "Calvert Beach Member," which most workers now recommend be abandoned as a formal name (see discussion above). This is also the site of Shattuck's (1904) measured section XIII ("2.75 miles south of Governor Run"). It is section 78SK36 of Kidwell (1982) (Fig. 20), located a few 100 m north of the exposures illustrated in Figure 8 (78SK35 of Kidwell, 1982, 1984, 1989).

The shoreline to the north, toward Western Shores (**stop 6B**) was characterized by nearly vertical, unvegetated cliff faces from at least the 1940s until the early 1990s, providing a superb, almost continuous cross-sectional view of Choptank and higher strata (see Fig. 8B here and other photographs from these periods in Gernant, 1970; Kidwell, 1984; Ward and Andrews, 2008). Gernant (1970) proposed that these cliffs constitute the key reference section for the Choptank Formation (his section 66-5), since the type section for the formation along the Choptank River on the eastern shore of Maryland exposes only Shattuck-Zone 19. It is odd that Shattuck (1904) chose to publish a measured section from the small bluff at Calvert Beach (**stop 6A**) rather than in these cliffs where Shattuck-Zones 16B–20 and higher strata are present (**stop 6B**); perhaps these cliffs were vegetated then as they are now. To supplement the Western Shores section published by Gernant (1970) and the interpreted photograph of Ward and Andrews (2008, their figure 50 taken in 1979), we provide a measured section from the southern end of Western Shores that has been the source of samples for biostratigraphic analysis, including the dinoflagellate zonation of de Verteuil and Norris (1996) (Fig. 21).

A series of small rock jetties have been progressively enlarged over the decades at Matoaka Cottages, trapping longshore drift of sand, primarily from the north, and the cliffs here are thickly overgrown by kudzu, a widespread invasive Asian vine in the southeastern United States. To the south **(stop 6A**), the Calvert and Long Beach communities also maintain jetties, most notably two very long ones that protect the opening of "Flag Harbor," which was excavated in the late 1940s, taking advantage of a relatively long and sinuous natural salt marsh. The shoreline immediately south of the heavily armored Long Beach shoreline is the Flag Ponds Nature Park, a natural spit and back-barrier wetland that is prograding southward. The shoreline extending northward of Matoaka Cottages toward Western Shores (**stop 6B**) also remains natural, although a small stretch of riprap has been emplaced at the main beach, at the terminus of Miles Road. Houses in that beach community date only to the 1960s and were built far back from the cliff face then.

Points of Interest

At the foot of low bluffs between the beach at Matoaka Cottages and the northern edge of Flag Harbor, Shattuck-Zone 16A constitutes ~2 m of interbedded dark-gray shell-bearing silty fine sand and subsidiary bluish clay (Fig. 20: note difference in scale from other profiles). Shells are mostly concentrated along the firmground-burrowed bases of the silty sand beds, and are dominated by whole *Turritella*. This facies is interpreted as the inner part of the open shelf, i.e., accumulating between fair-weather and storm wavebase, on the basis of the wide range of grain sizes present (Figs. 4, 5, 6C). The silty sand beds reflect intervals with consistent delivery of relatively coarse-grained sediment to the open shelf but (dynamic) bypassing of mud. The inclusion of 10-cm-scale colonies of bifoliate bryozoans suggests that the seabed was stable for sufficient periods to permit their growth, but the fauna is otherwise dominated by soft-bottom species, including ones that can tolerate or thrive under a steady supply of organic matter (lucinid bivalves, turritellid gastropods). The clay interbeds may signal deeper increments (flooding increments) or, alternatively, less stormy climate intervals, when more mud came to permanent rest here.

The upper part of Shattuck-Zone 16A has abundant large-diameter, *Thalassinoides* burrows extending down from the CT-0 unconformity. These burrows are filled with fine sand and abundant shell hash, derived from the overlying Shattuck-Zone 17 shell bed (Drumcliff Member of Gernant, 1970). This is the lower of two major shell beds in the Choptank Formation and has a complex internal stratigraphy, even though only the lowermost ~2 m are preserved here (upper section leached). The basal, CT-0 unconformity is placed at the highest stratigraphic level that still includes some well-preserved Shattuck-Zone 16A beds, at least as windows among the *Thalassinoides* burrows. The lowermost 1 m of the Drumcliff shell bed is intensely burrowed hashy silty fine sand to sandy silt, consisting of many intersecting generations of *Thalassinoides* and some small remnant pods of unreworked Shattuck-Zone 16A, the likely source of finer grains. Large, mostly disarticulated valves of aragonitic

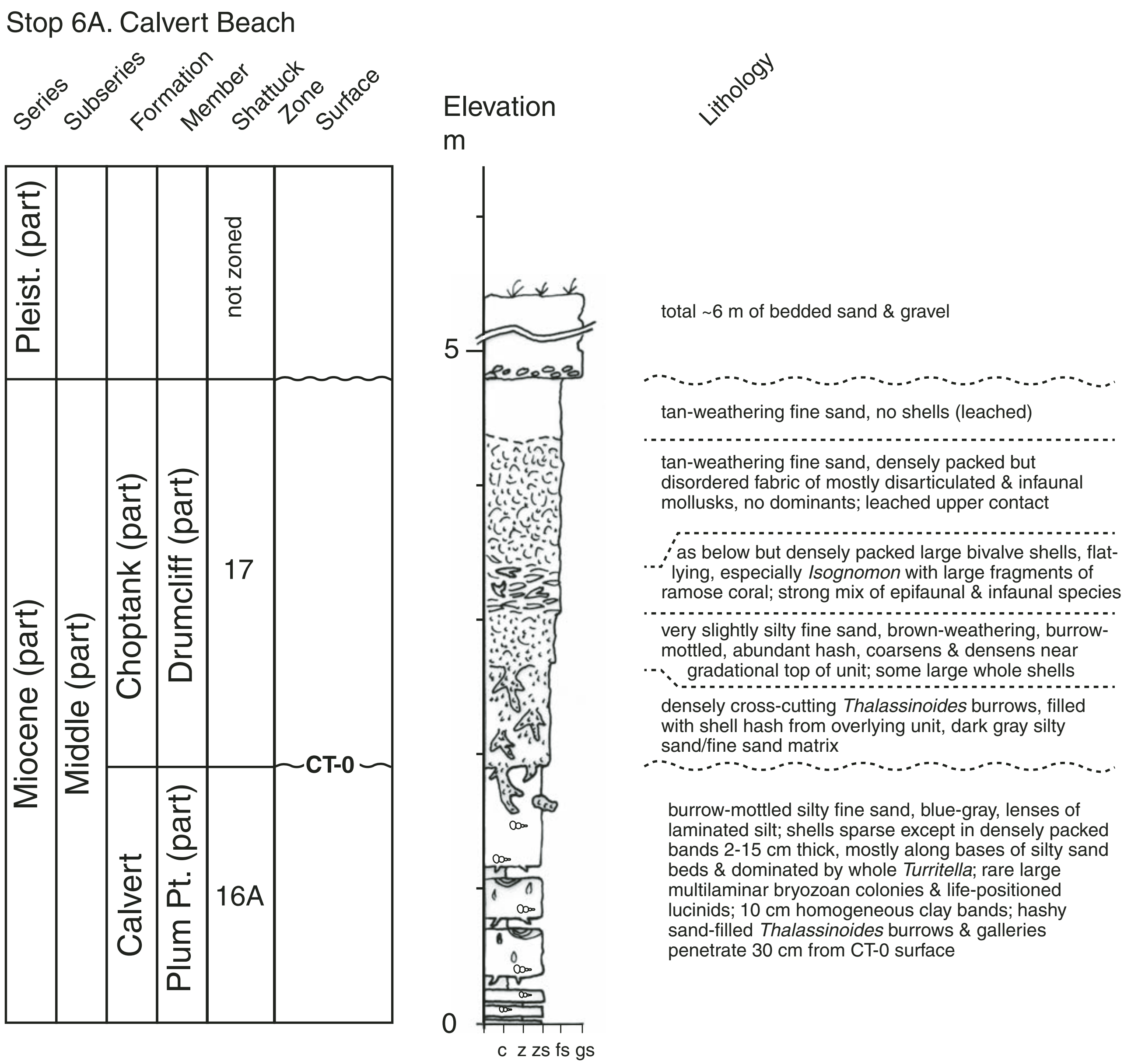
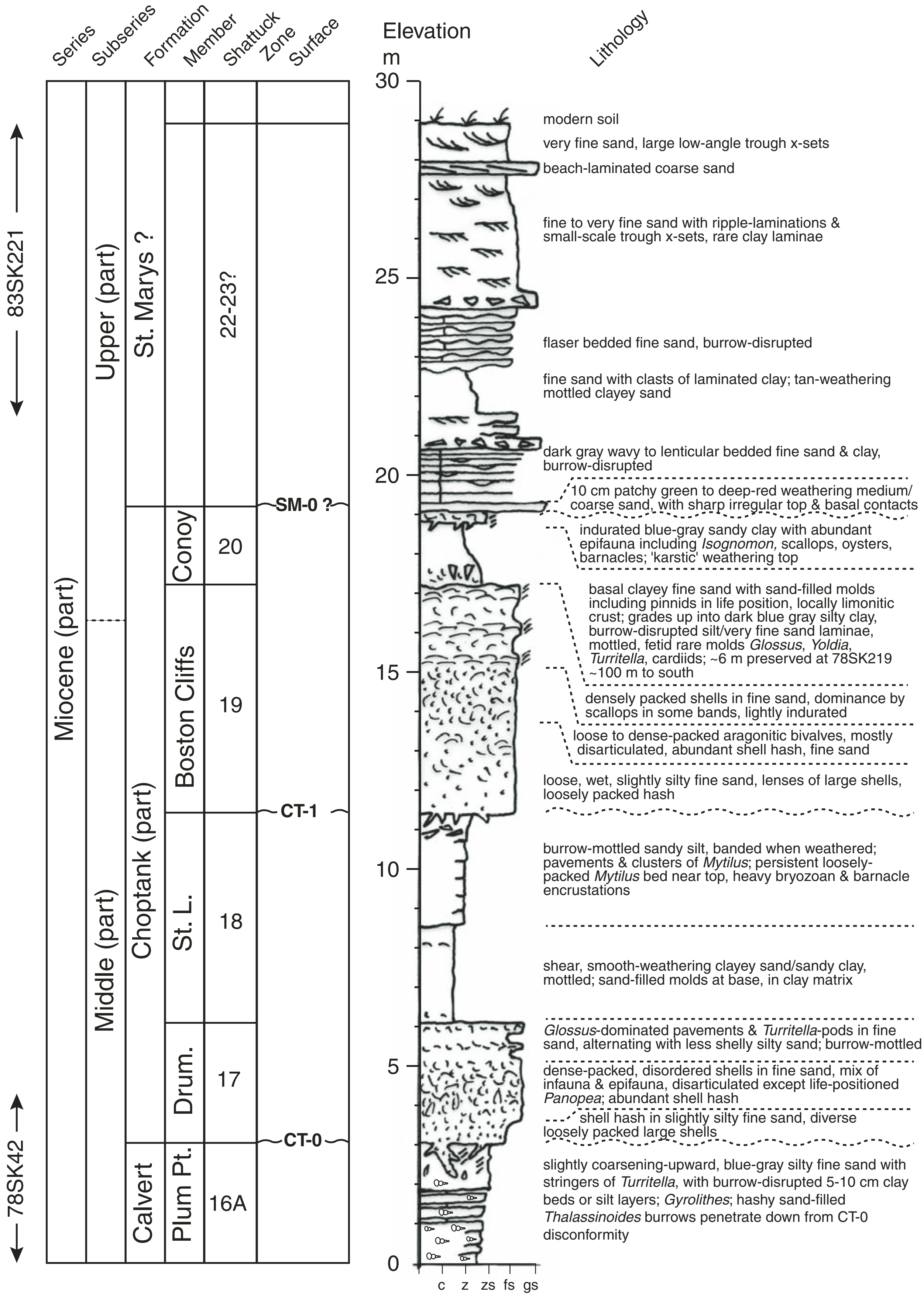


Figure 20. Lithologic profile of outcrop at Calvert Beach (**stop 6A**); note different thickness scale than other profiles. Based on section 78SK36 in Kidwell (1982, 1984). This outcrop is the type section of Gernant's (1970) Calvert Beach Member of the Choptank Formation, Shattuck-Zone 16A. These beds have been re-assigned to the Plum Point Member of the Calvert Formation, and Gernant's name abandoned, because they lie underneath the CT-0 disconformity and share diatoms and dinocysts with that unit (Fig. 2; Kidwell, 1984; de Verteuil and Norris, 1996; Ward and Andrews, 2008). See Figure 6C for photograph of Shattuck-Zone 16A here, and Figure 8 for photographs of Shattuck-Zone 17 (Drumcliff Member of Choptank Formation) in a nearby outcrop (78SK35).

Stop 6B. South of Western Shores



infaunal bivalves visually dominate the upper half of the shell bed. It includes an extremely unusual interval dominated by flat-lying articulated *Isognomon maxillata* (now *Hippochaeta maxillata*), a thick-shelled byssate bivalve that, although found with vertical commissures in some shell-poor facies (e.g., along the Patuxent River), probably lived epifaunally here, given the large clionid and lithophagid borings over most surfaces (e.g., Chinzei et al., 1982; Savazzi, 1995). Small (<10 cm) ramose colonies of the coral *Septastrea* co-occur, and can be found as worn specimens in modern beach float. The well-sorted fine-sand matrix and strongly amalgamated and environmentally condensed skeletal assemblages, composed of shallow but open (full salinity) waters, suggest lower shoreface to inner-shelf conditions (Fig. 8; Kidwell, 1989).

The long stretch of high, ~30-m terrain north of Matoaka Cottages, toward the Western Shores community, has in the past presented superb, almost continuous exposures of Shattuck-Zones 16A and 17 through 20, as well as higher strata of uncertain assignment (Fig. 21 profile at 83SK220; measured sections 78SK42 and 83SK221 used to supplement those notes; and see 78SK35, 79SK84, and 79SK192 in Kidwell, 1982; outcrop figures in Kidwell, 1984, 1989; and figure 50 in Ward and Andrews, 2008, taken in 1979). Depending on damage from storms and hurricanes within the past year, we may have some windows into this section.

The CT-0 unconformity is a burrowed firmground with beautiful *Thalassinoides* burrows that penetrate a meter or more into the underlying, *Turritella*-rich interbedded silty sand and clay of Shattuck-Zone 16A, as just seen at Calvert Beach (**stop 6A**) (see figure 11 in Kidwell, 1984). Resting on the CT-0 disconformity, Shattuck-Zones 17–18 comprise a relatively symmetrical transgressive-regressive cycle (CT-0 sequence of Kidwell, 1984, 1997) (Fig. 8B). Here, where the entirety of Shattuck-Zone 17 shell bed is preserved, we can see that the upper part has some silty sand interbeds, is less completely amalgamated, and less hashy, with a deeper-water *Glossus* and *Turritella*-dominated fauna than the main part of the shell bed, indicating that the major shell bed accumulated under deepening-up conditions, or at least decreasing water energy (for taphonomic and sedimentologic details, see Kidwell, 1989; for species lists, see Shattuck, 1904; Gernant, 1970; Kidwell, 1986; Ward, 1992). The complex shell bed is rather sharply overlain by the clayey, shell-poor Shattuck-Zone 18, which becomes less muddy and more distinctly bedded upward, with increasing abundance and dominance by very shallow subtidal fauna (including mussels and barnacles).

The overlying CT-1 sequence comprises another, very similar transgressive-regressive cycle, in this instance resting on the CT-1 disconformity, which is another *Thalassinoides* firmground. The Shattuck-Zone 19 shell bed is less obviously deepening upward, but is distinctly deeper than the underlying Shattuck-Zone 18 (thus is transgressive), and is sharply overlain by a clayey even deeper-water unit (Shattuck-Zone 20). Analysis of legacy samples from this measured section for dinoflagellates corroborates that the clay immediately above the Shattuck-Zone 19 shell bed, provisionally identified as Shattuck-Zone 20 (Conoy Member of Gernant, 1970), does yield DN7, as reported by de Verteuil and Norris (1996) for Shattuck-Zones 19 and 20 here and elsewhere (Kidwell et al., 2012).

The upper part of these cliffs are a series of relatively fine-grained sands and subsidiary clay that resemble the Little Cove Point Member of the St. Marys Formation further south in Calvert Cliffs, as opposed to medium to coarse sands present in post–St. Marys strata (pSM of Kidwell, 1997; "upland gravels"; and see Ward and Andrews, 2008). This set of strata rests erosionally on the Choptank Formation. The provisional SM-0 surface is even higher immediately south of 83SK220/221, preserving 4 m and perhaps 6.5 m of Shattuck-Zone 20 (83SK219), but 100 m further south toward Matoaka it cuts down through Shattuck-Zones 20 and 19 to the top of Shattuck-Zone 18. Clays above the provisional SM-0 surface here yield pollen rather than diagnostic dinoflagellates and are characterized by lenticular bedding and other tidal indicators (Fig. 10B). It is thus possible that these strata are post–St. Marys. The absence of useful dinoflagellates, however, may well simply reflect ecological exclusion: these outcrops are ~6 km updip of the nearest exposures of the Little Cove Point Member (in the Conoy Cliffs), where they consist of extremely shallow-water *Ophiomorpha* sands (**stop 7**, Day 2).

Return to vehicle and proceed to the Comfort Inn hotel (38.3336° N, 76.4625° W) at Solomons Island by traveling south on Route 2/4.

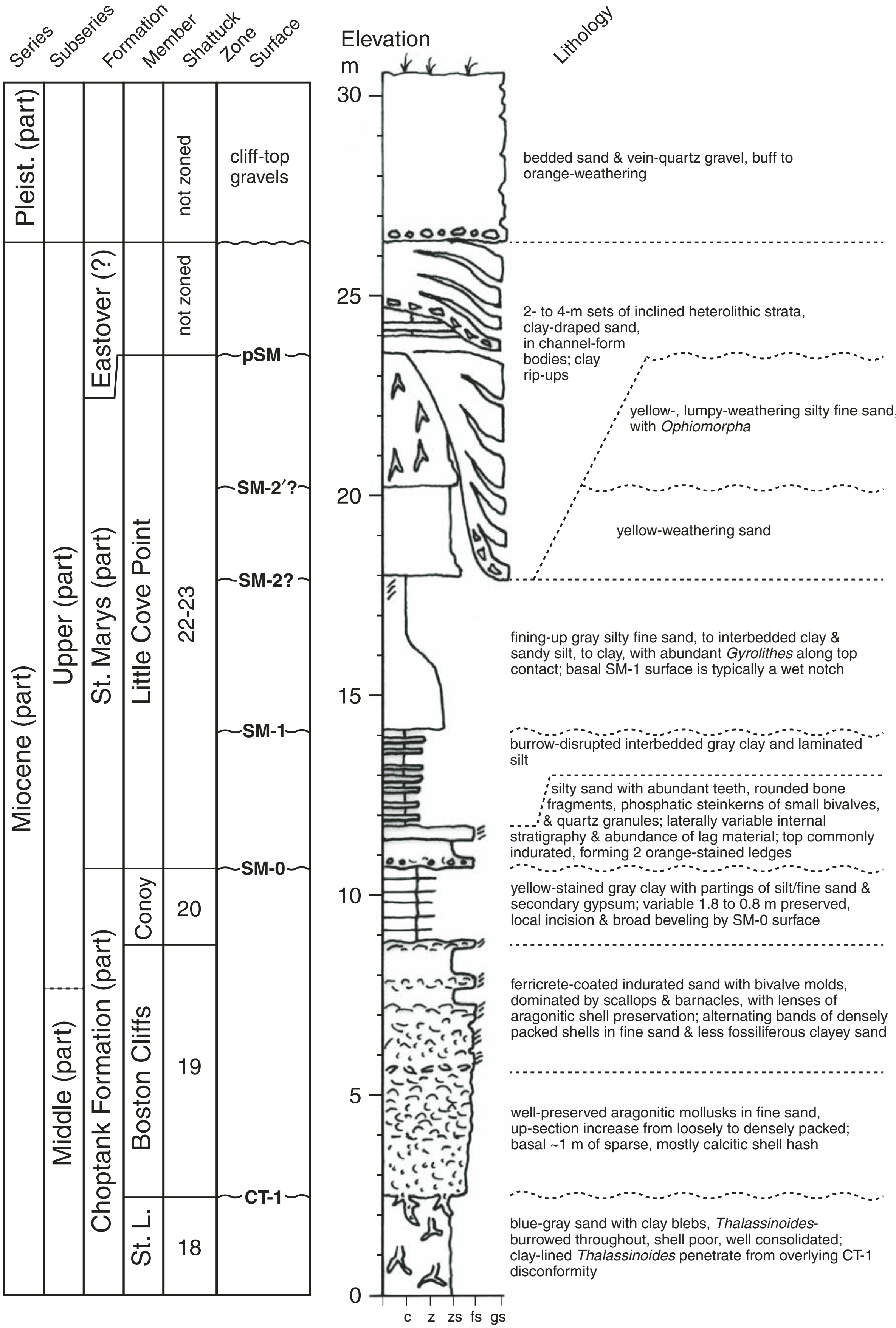
Figure 21. Lithologic profile of previously well-exposed outcrop in the cliffs south of the main beach at Western Shores (**stop 6B**), a key reference section for the entirety of the Choptank Formation historically (Gernant, 1970). Based on section 78SK42 in Kidwell (1982, 1984) and sections 83SK220 and -221 in Kidwell (1997), whose interpretation of Shattuck-Zones concurs with Gernant (1970; his loc. 66-5; concurrence also by Ward and Andrews, 2008). See Figure 8 for photographs of Drumcliff Member in a nearby outcrop (78SK35). Drum.—Drumcliff; St. L.—St. Leonard.

DAY 2. UPPER PART OF THE CHOPTANK FORMATION, THE ST. MARYS FORMATION, AND POST–ST. MARYS STRATA (UPLAND GRAVELS): *Upper middle to upper Miocene shelf, estuarine, and fluvial facies*

We will do a small amount of back-tracking by vehicle this morning, ~4 extra miles round trip, in order to visit the three key outcrops for Day 2 in correct stratigraphic order, from north to south (**stops 7–9**). Depending on time, tides, daylight, and energy, one or more vehicles from the 2015 GSA Annual Meeting trip can visit optional stops listed on Day 1 that could not be fit in then. We will otherwise travel back to the Baltimore Hilton (or, for some, BWI Airport).

Today's **stops 7–9** will address the much more heterolithic facies that are preserved in the youngest part of the Miocene

Stop 7. South Camp Conoy



succession in the Calvert Cliffs—the Little Cove Point Member of the St. Marys Formation—and in younger, probably Pliocene upland gravels. The change from the more subtle variability within the older Calvert and Choptank strata seen on Day 1 reflects the transition from laterally extensive open-shelf environments to a series of geomorphically more complex and temporally variable coastal (marginal marine and shoreline) paleoenvironments ("paralic" in Fig. 4). This greater variability is also an expression of the offlapping character of the Little Cove Point Member of the St. Marys Formation—it represents a seaward shingling of successively younger, very thin increments, suggesting decreasing accommodation (Kidwell, 1988, 1997). Stratigraphic complexity in this part of the record also arises from erosional beveling by the basal, SM-0 surface of the St. Marys Formation of the underlying Choptank Formation, which was subject to local warping and perhaps faulting, especially near **stop 7** (cliffs between Conoy and Moran landings; Gernant, 1970; Kidwell, 1997; Powars et al., this volume). New dinoflagellate biostratigraphic data are clarifying the complex relationships within this interval (de Verteuil and Norris, 1996; Kidwell et al., 2012).

Directions to stop 7. From the hotel in Solomons, proceed north on State Route 2/4 for 6 miles to the exit for the town of Lusby and the Calvert Cliffs State Park (or drive north on the more interesting "old Route 2/4," now renumbered as Route 765, to the same destination). Do not enter the main entrance to the park, which leads to a large parking lot and picnic facilities around a lake. Instead, continue north on "old Route 2/4" (Route 765) ~0.4 miles to a narrow paved road on the right labeled "Camp Conoy Road." You will pass the historic Middleham and St. Peter's church on your right; if you pass the Frying Pan restaurant on the left, you have gone too far. Drive ~1.5 miles to where county maintenance ends—several side roads will be gated—and proceed to parking area designated for us on private property **(stop 7).**

Figure 22. Lithologic profile of outcrop in cliffs between Camp Conoy and Moran landing (**stop 7**), showing Choptank/St. Marys transition and upland gravels. The basal unconformity of the St. Marys Formation (SM-0) erosionally thins Shattuck-Zone 20 (Conoy Member of the Choptank Formation; DN7) from the BGE power plant toward us here at Moran landing (Fig. 2), where Shattuck-Zone 20 has already been reduced to just a few meters' thickness. In the cliffs to our immediate south in Rocky Point, the SM-0 surface has completely removed Shattuck-Zone 20, superimposing DN8-bearing beds of the SM-0 sequence directly on top of the Shattuck-Zone 19 major shell bed (Fig. 2, and see other cross sections and profile 83SK213a in Kidwell, 1997). The profile here is based on sections 83SK227 and -228 in Kidwell (1997) and sections 79SK153 and -156 (Kidwell, 1982, 1984); no others have been published for these cliffs. At BGE to our north, Ward and Andrews (2008, their figure 52) assign Shattuck-Zone 20 the same interval as do Shattuck (1904), Gernant (1970), and Kidwell (1982, 1984, 1997), but at Rocky Point to our south, they interpret Shattuck-Zone 20 as still present (Ward and Andrews, 2008, their figure 53), equating it with Kidwell's SM-0 sequence there. St. L.—St. Leonard.

Stop 7. Moran Landing, Cliffs South of Old Camp Conoy: Choptank Formation, Little Cove Point Member of St. Marys Formation, and Post–St. Marys Strata (Access to Shattuck-Zones 18–20 and SM-0 Surface; Visual Examination of Shattuck-Zones 22–23)

From the parking spot, walk down to the beach. Looking north you have a superb, oblique view of a large cliffed promontory with excellent exposure of tabular units of the Choptank and St. Marys Formations, of channel-form "post–St. Marys" strata, and of thin tabular "cliff-top gravels" (Figs. 22 and 23). These cliffs are in fully natural form.

Context

Kidwell's sections 83SK229 and –228 were measured in this southern cliff face and her section 83SK227 was measured just around the corner on the northern side of this same promontory. Figures 23B–23C, reprinted from Kidwell (1997), provide a direct view of the entire promontory from offshore, with section locations marked. To reach the promontory, we will walk past section 79SK153 (Kidwell, 1982, and see 83SK251), which is a low bluff that usually provides a good, beach-level exposure of the densely fossiliferous Shattuck-Zone 19 shell bed. That unit is largely obscured by talus along the base of the promontory itself. It may not be possible to transit far along the shoreline of the promontory itself, even if tide is low—the tumbled, indurated blocks of the Shattuck-Zone 19 shell bed make for tedious walking, although climbing this talus can sometimes give in situ access to the Choptank–St. Marys formational contact in that cliff face.

The property providing us access was owned by the late Mrs. Margaret Moran, giving the name "Moran landing" to this beach at the mouth of a small, unnamed creek and (now former) salt marsh along the north edge of this property. "Moran" has been used to designate localities here since the 1960s (Gernant, 1970; Kidwell, 1982, 1984, 1997; no other measured sections are available). Moran landing is also now applied to a fault postulated to run down this modern valley toward the bay (see Powars et al., this volume). The next named cultural feature to the north is the former Boy Scout property, Camp Conoy, and thus these cliffs to the north of Moran landing, comprising several promontories, are also known as the "Conoy Cliffs" (or "South Conoy," because they are south of the beach-access point for that camp). A large segment of the Conoy Cliffs north of that camp landing were radically landscaped in the 1960s during installation of the "BGE" power plant, now owned by Exelon. The surviving northern segment of the Conoy Cliffs is the type section for Gernant's (1970) Conoy Member of the Choptank Formation (Shattuck-Zone 20).

To the south of Moran landing is a major cliffed shoreline known as Point of Rocks (presumably for the indurated Shattuck-Zone 19 that armors it) that consists of multiple promontories. The cliffed segment that fronts the former Moran property has been radically landscaped and rip-rapped but the rest of the point remains in natural state. Kidwell (1997, her figure 7) provides a

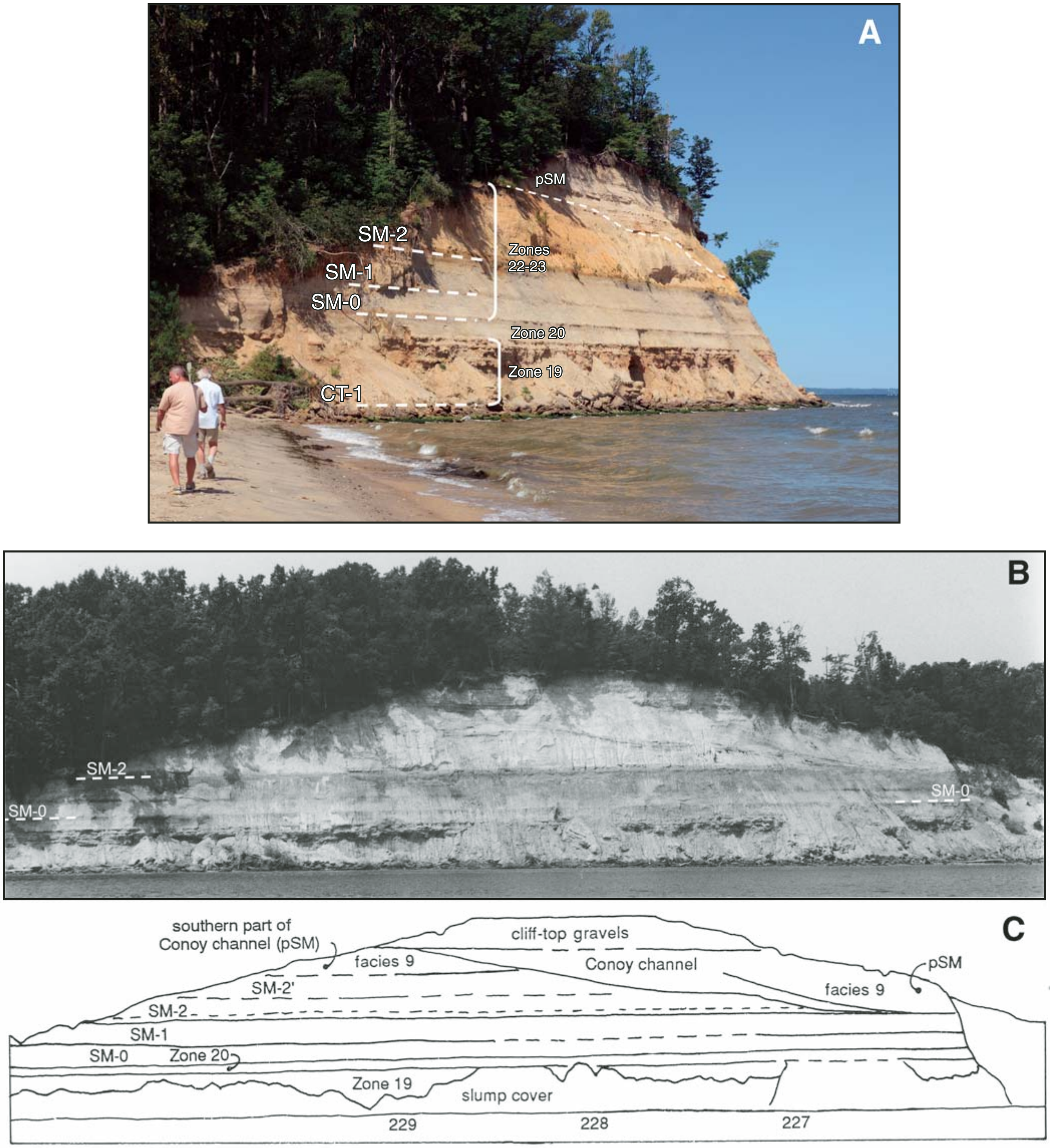


Figure 23. (A) Photograph of cliff face north of Moran landing (southern Conoy Cliffs); profile in Figure 22 is from this face. Lettering is interpretation of Kidwell (1997). The SM-0 surface is the unconformity along the base of the St. Marys Formation. It bevels southward (downdip, toward viewer) across Shattuck-Zone 20 (Conoy Member) of the Choptank Formation in these cliffs, and to our south in Rocky Point has cut all the way down to the top of Shattuck-Zone 19 (will be seen at **stop 8**). Post–St. Marys (pSM) strata infill a series of laterally shingled channels that incise to various depths into the St. Marys Formation, here down to the SM-2 surface. Ward and Andrews (2008) do not provide a measured section here, but in sections both at BGE to the north and Rocky Point to the south, they describe Shattuck-Zone 20 (Conoy Member) as a laterally persistent and much thicker unit (it encompasses Kidwell's [1997] SM-0 sequence even here in this cliff), and assign the entire interval to the St. Marys Formation. Photo by Dave Powars. (B–C) Photograph from offshore, with line drawing of major stratigraphic units, reprinted from Kidwell (1997).

view of the stratigraphy in the Point of Rocks cliffs from offshore and positions four of her six measured sections there, which appear to be the only sections measured from these outcrops (but see interpreted photograph in Ward and Andrews, 2008, their figure 53). **Stop 8** (Camp Bay Breeze, Calvert Cliffs State Park) is at the southern end of Point of Rocks.

Points of Interest

The Shattuck-Zone 19 shell bed—the Boston Cliffs Member of Gernant (1970)—rests on a *Thalassinoides*-burrowed firmground that is the CT-1 disconformity of Kidwell (1984) (Fig. 22). Approximately 1 m of very blue-gray clayey sand is exposed beneath the CT-1 surface here. It is labeled conservatively as "Shattuck-Zone 18" in Figure 22, but Kidwell (1984, 1997) assigned this distinctive sand to Shattuck-Zone 19. It may well infill a small paleovalley developed on Kidwell's CT-1 surface within the Conoy Cliffs (Fig. 3). In better exposures further north in the Conoy Cliffs, this blue clayey sand is clearly and very intensely burrowed by *Thalassinoides* and rests directly on brown-weathering, densely shelly sands of Shattuck-Zone 17 (Drumcliff Member of Choptank Formation; sections 83SK224, -225, -226). This blue sand contrasts with the silty sand of the coarsening-upward Shattuck-Zone 18 that is exposed above Shattuck-Zone 17 immediately north of the BGE plant (Flag Ponds locality XIV of Shattuck, 1904; 83SK222 and -223, and 79SK162, -163, -164, -165 of Kidwell, 1982) and further north in the Calvert Cliffs (e.g., **stop 6B**; Figs. 2 and 21). This blue sand may thus be a distinct, basal sand of the Shattuck-Zone 19 shell bed, somewhat analogous to the Governor Run sand that exists locally under the Shattuck-Zone 17 shell bed (**stops 3 and 4**). We can find no micropaleontological biostratigraphic evidence to support its assignment one way or the other (Kidwell et al., 2012).

Shattuck-Zone 19 (Boston Cliffs Member) is several meters thick and has a complex internal stratigraphy (for taphonomic and stratigraphic details, see Kidwell, 1989; for species lists, see Shattuck, 1904, and Ward and Andrews, 2008). Very roughly, its lower ~half is dominated by aragonitic infaunal bivalves, and its upper half is very rich in scallops. This upper half is more or less indurated (silty sand interbeds are not indurated, and preserve aragonitic fauna), and its upper contact is ferricrete-cemented, leaving even calcitic scallops preserved only as molds. Such heavy crusting and corrosion is present in the Boston Cliffs Member only in this area and to the south. It is correlated with proximity to the SM-0 unconformity, which cuts progressively down-section through Shattuck-Zone 20 (Conoy Member) within the Conoy Cliffs and lies within ~1 meter of the top of the Boston Cliffs shell bed in the profile here (Figs. 3 and 22; detailed cross section of figure 4 in Kidwell, 1997). In Rocky Point cliffs and southward (**stop 8**), the SM-0 lies along the top of Shattuck-Zone 19 shell bed, juxtaposing St. Marys strata directly upon the Boston Cliffs Member (Kidwell, 1984, 1988, 1997; Fig. 3). This interpretation is contrary to that of Ward (1992; Ward and Andrews, 2008, figure 53), who interprets Shattuck-Zone 20 as a continuous tabular body from the BGE/Conoy area to Little Cove Point (**stop 9**).

This progressive, downdip erosional beveling of Shattuck-Zone 20 (Conoy Member) by the SM-0 disconformity between the BGE plant and Point of Rocks exemplifies the subtlety of stratigraphic relations in these (and other very thin) rock successions. In the promontory immediately north of Moran landing, Shattuck-Zone 20 (Conoy Member) has been thinned to <2 m of clayey strata. This remnant preserved above the Boston Cliffs shell bed yields distinctive, DN7 dinoflagellates like the type Conoy Member to the north (and the upper Boston Cliffs Member both here and elsewhere; de Verteuil and Norris, 1996, Kidwell et al., 2012). This remnant Conoy Member is green-gray with yellow-weathering lenses and veins of gypsum (oxidative weathering product of authigenic pyrite; the member is fetid in many outcrops). This weathered version of Conoy Member clay and the ferricreted upper part of the Boston Cliffs shell bed are found only here and further south where the SM-0 surface is stratigraphically very close, and probably reflect Miocene-age meteoric weathering of these Choptank strata. This interval would make a fascinating topic for isotopic analysis, focusing on localities here and to the south with macroscopic evidence of subaerial exposure, as contrasted with localities further north in the Calvert Cliffs.

Missing from this cliffed promontory north of Moran landing is Shattuck-Zone 21, a brownish silty sand that Shattuck (1904) recognized at BGE (his Flag Ponds locality) and assigned to the St. Marys Formation. This body pinches out immediately south of BGE within the northern Conoy Cliffs, as recognized by Gernant (1970; and see confirmation by Kidwell, 1997, her figure 4; contra Ward, 1992, and Ward and Andrews, 2008, who map it as part of an undifferentiated Shattuck-Zone 21–23 interval that persists as a tabular body south to the Little Cove Point area). This downdip disappearance of Shattuck-Zone 21 owes either to lap out against the flank of a paleovalley cut locally into Shattuck-Zone 20 (Gernant, 1970; Kidwell et al., 2012) or is simply part of the low-angle truncation of originally tabular strata by the SM-0 disconformity (Kidwell, 1997). In either case, the set of Shattuck-Zones 17–20 strata underneath this lenticular body shows a local reversal in dip within the Conoy Cliffs (Gernant, 1970, photographic figure 4; Kidwell, 1997, cross-sectional figure 4) that signals mild tectonic warping. The disappearance of Shattuck-Zone 21 in this stretch of the cliffs may well be a syndepositional response to that warping (Gernant, 1970), and is associated with the fault inferred at Moran landing (Kidwell, 1997; Powars et al., this volume).

The SM-0 surface itself is mantled by a very thin (~10 cm) and laterally patchy lag of quartz pebbles, shark teeth, fish debris, and phosphatic steinkerns of small bivalves (Kidwell, 1984, 1989, 1997). This thin lag is capped by ≤1 m of beige-weathering silty sand and a limonite-cemented sandstone: this "orange nose" is more immediately recognizable in outcrop and from offshore than the thin, patchy, and typically unlithified phosphatic lag. In some measured sections of this Conoy/St. Marys transition in this area, several quartz-pebble lags occur in close succession.

This "SM-0 mantling sand" is overlain by ~12 m of strata attributable to Shattuck-Zones 22–23, based on Shattuck's description of that interval at BGE in the northern Conoy Cliffs (his Flag Ponds). These strata comprise the remainder of the gray part of the exposure in the cliff north of Moran landing (Fig. 22), above the thin remnant of the Conoy Member, and continue a few meters up into the lower part of the yellow-weathering slope in the left part of that promontory, where channel-form upland gravels have not removed them (Fig. 23). These Shattuck-Zones 22–23 strata rest directly upon the Boston Cliffs Member in Rocky Point, immediately south of Moran landing, and can be traced confidently to the southern end of the Calvert Cliffs State Park property (Fig. 3). Kidwell (1988, 1997) recognized three fundamentally tabular sequences within the Shattuck-Zone 22–23 interval in this area (SM-0, SM-1, SM-2, and provisionally SM-2′; Figs. 2, 22, 23). Each sequence is a few meters thick and characterized by a basal firmground, a thin (~10 cm) mantling shell-rich silty sand, and then fining- and deepening-up facies sequence to the next sequence boundary. Cross sections also reveal that, within each of these tabular units, facies are arranged retrogradationally: downdip facies climb stratigraphically up over updip facies (Fig. 3, and more detailed examples in Kidwell, 1997). Shallowing-up, regressively arranged stacks of facies are absent, hence the label "shaved sequences" (see change in facies stacking patterns in schematic Fig. 4).

Although each SM sequence is composed only of deepening-upward, transgressively arranged facies, the overall succession of sequences is shallowing-upward, with regressive (progradational) stacking: each successive sequence is dominated by more-landward facies. In the profile visible here (Fig. 22), the first ~6 m coarsens up from gray interbedded clay and sandy silt (SM-0 sequence) to silty fine sand with mollusks (SM-1), and the upper ~6 m (SM-2 and 2′ sequences) are yellow-weathering silty fine sand with *Ophiomorpha*. We will see downdip variants of these strata at **stops 8 and 9.** In the promontory north of Moran landing, the full section of SM sequences is only preserved in the southern (left) side of the cliff face (section 83SK228). Large channels of upland gravels (post–St. Marys interval of Kidwell, 1997) otherwise cut down to the SM-2 disconformity (Figs. 23B–23C).

Thus, between BGE/Flag Ponds and Moran landing, both Shattuck-Zones 20 and 21 progressively "disappear" under the SM-0 disconformity recognized by Kidwell (1984, 1988, 1997). Immediately south of Moran landing, in the Rocky Point cliffs, the SM-0 surface juxtaposes strata of Shattuck-Zones 22–23 directly upon the Shattuck-Zone 19 shell bed (Boston Cliffs Member): induration of that shell bed during "lowstand" might have made it somewhat erosion-proof, checking further loss of Choptank strata. These clayey strata resting on the Boston Cliffs Member in Rocky Point and outcrops further south within the Calvert Cliffs have been interpreted by others to include Shattuck-Zones 20 and 21, such as rest on the Boston Cliffs Member in the northern Conoy Cliffs (BGE, Flag Ponds) and further north (Ward, 1992; Ward and Andrews, 2008, their figure 53; and see earlier reports). That correlation is contradicted by detailed physical stratigraphic and micropaleontological biostratigraphic analysis (de Verteuil and Norris, 1996; Kidwell, 1997), corroborated by new dinocyst analyses (Kidwell et al., 2012). All of Kidwell's SM sequences, here at Moran landing and at both more northern and southern outcrops in the Calvert Cliffs, yield dinoflagellates diagnostic of biozone DN8, and thus are distinctly younger than the erosionally truncated, underlying strata she identified as belonging to the Choptank Formation inclusive of the Conoy Member (Fig. 2). We will see this juxtaposition of Shattuck-Zones 22–23 on Shattuck-Zone 19 again at **stop 8** (Calvert Cliffs State Park).

Post–St. Marys strata—the "SM-3 sequence" of Kidwell (1988), pSM sequence of Kidwell (1997)—are channelized bodies of interbedded medium sand, well-rounded quartz gravel (granule to small pebbles), and clay, and are capped by fundamentally tabular ("cliff-top gravels" in Fig. 3). These are grouped as upland gravels in many reports (see Powars et al., this volume). These yellow-weathering strata constitute the upper ~half of the promontory north of Moran landing (Figs. 22 and 23). These distinctly non-tabular, channel-form sands are quite obvious once pointed out, but, probably owing to the difficulty of direct access so high on the cliffs, have remained largely undescribed. The poorly to non-fossiliferous sands they encompass have nonetheless long been proposed as possible estuarine to fluvial facies of late Miocene or Pliocene age strata in Virginia (Eastover and Yorktown Formations; Stephenson and MacNeil, 1954; Ward, 1992; Kidwell, 1997; Ward and Andrews, 2008). They typically cross-cut an array of older strata and are thus of increasing interest for insights into the evolution of modern geomorphology and as evidence of tectonic dynamism, notwithstanding the challenges of geochronology (e.g., Pazzaglia, 1993). The channels high in the promontory north of Moran landing have not been sampled directly. However, directly sampled counterpart channels in Rocky Point include large-scale inclined heterolithic strata diagnostic of tide-influenced rivers, large-scale trough sets signaling fluvial conditions, and wedge-shaped cross-sets most typical of tidal inlets (see figure 5 in Kidwell, 1997). We will see more pSM channel bodies at **stops 8 and 9** (State Park and Little Cove Point).

Directions to stop 8. Return to vehicle and backtrack along Camp Conoy Road to the gated gravel road on the left that leads to Camp Bay Breeze. Proceed past picnic facilities and some camp buildings, and park at the end of the road, closest to the bay, or where directed by park personnel. This property is a former campground for the Girl Scouts of America that is now operated by Calvert County for youth groups. We have permission for a short visit.

Stop 8. Camp Bay Breeze, Calvert Cliffs State Park: Choptank Formation (Shattuck-Zone 19), Little Cove Point Member of St. Marys Formation (Shattuck-Zones 22–23), and Post–St. Marys Strata

From the parking spot, walk down the trail in the ravine to the beach—it will stop first at a low bluff, providing a reasonably good view of the main cliffs of the state park to our south. The state now forbids even walking along the beach or wading offshore of these cliffs owing to their instability. This stop is thus limited to viewing the stratigraphy from a distance and sampling beach float and large fallen blocks at this northern edge. Ordinarily, visitors would view these cliffs from the beach at their south end, reachable by the "Red" nature trail from the parking lot at the main entrance to the park (Route 765).

Context

The only sections ever measured in the park appear to be those of Kidwell (1982, 1997). The small bluff at Camp Bay Breeze is the location of her sections 79SK151 and 83SK214. Section 83SK240, adapted here (Fig. 24), is from the northern half of the main cliffs to the south of us (Fig. 25), where a series of additional sections was measured. Good cliff outcrops are also available at the southern part of the park.

The shoreline along this entire stretch has been left to natural processes of erosion and deposition for the entire, multicentennial duration of European and post-colonial agriculture and forestry. These cliffs are usually viewed from the south, where a large beach and tidal marsh can be reached via a 1.8-mile-long trail that starts at the main parking area.

Points of Interest

The base of the cliff is Shattuck-Zone 19/Boston Cliffs Member of the Choptank Formation, which is dominated here (and in the southern end of the cliffs of Rocky Point, immediately to our north) by aragonitic infaunal bivalves, which are loosely packed in a hash-poor fine sand. Large scallops are scarce relative to other outcrops, forming just a few thin pavements. The upper 30 cm of the Boston Cliffs Member is largely indurated, with only poorly preserved molds, even of calcitic scallops and barnacles, and is capped by an ~10-cm-thick ferricrete with a relatively smooth upper surface, which is Kidwell's (1997) SM-0 surface (Fig. 25).

Grains of medium quartz sand occur in the ferricrete cap of the Boston Cliffs shell bed and in the ~30 cm of gray silty sand present immediately above it, a much subtler signal of the SM-0 disconformity than the basal lag just seen at **stop 7**, although even there the lag is patchy. The rest of the SM-0 sequence here is ~3 m of overall fining-up, dark-gray, laminated silty clay with burrow-disrupted silt laminations that impart a distinct, thick-bedded appearance. Its uppermost ~1 meter is a smooth-weathering, usually dry, slightly silty clay with molds of the small bivalves *Nuculana* and *Corbula*, fine shell hash in pods of laminated silty, *Gyrolithes*, and sand-filled burrows that extend down from the capping SM-1 firmground. This lowermost dark-gray clayey unit (SM-0 sequence) as well as the overlying SM-1 and SM-2 sequences yield dinoflagellates from DN8 of de Verteuil and Norris (1996; new data in Kidwell et al., 2012), clearly differentiating it from the DN7-yielding gray clays of the Conoy Member (Shattuck-Zone 20) that rest on the Boston Cliffs Member at **stop 7** (Moran landing) and further north within the cliffs. Treating these stratigraphically low clays at State Park (the SM-0 sequence) as equivalent to the Conoy Member (Shattuck-Zone 20) and other stratigraphically low bodies (e.g., Shattuck-Zone 21) encountered further north in the cliffs would analytically coarsen paleobiologic and paleoenvironmental inferences significantly.

The SM-1 sequence is another 2–3-m-thick, fundamentally tabular and fining-up body, dominated by smooth-weathering silty clay. It is characterized by a change in slope of the cliff face, and set off by a thin, shelly silty fine sand marking its base and a wet notch coinciding with the basal shelly silty fine sand on the overlying SM-2 surface. The shells of both of those surface-mantling silty sands are preserved mostly as molds.

The SM-2 and provisional SM-2′ sequences, constituting the remainder of the Little Cove Point Member, are lithologically more heterogeneous, as is typical for this interval everywhere and for the succeeding pSM interval, as discussed in the main text and in the text for **stop 7**. This first-order lithologic heterogeneity is consistent with overall shallowing into geomorphically complex marginal marine and shoreline environments ("coastal" as opposed to open shelf). Here, the SM-2 sequence includes a lenticular body of horizontally to gently (south-)dipping laminated very fine sand (foreshore remnant?) and interbedded fine sand and sticky clay ("lagoonal"? bay margin?). The SM-2′ sequence contains the same lithologies but with clay dominant, and its top is typically weathered to a light tan (modern? ancient?). The SM-2 and -2′ interval is largely excised by pSM channels in the Rocky Point cliffs immediately north of our stop here, but at **stop 7** (Moran landing) this upper part of the Little Cove Point Member was mostly yellow-weathering sand, locally with *Ophiomorpha* burrows, signaling a very shallow subtidal seabed.

The pSM (post–St. Marys) interval—upland gravels in Powars et al. (this volume)—comprises two physically distinct, broadly lenticular bodies, each including multiple layers and/or channel-form bodies (Figs. 22 and 23). The "lower channel" at State Park is very organic rich, including abundant leaf and seed fossils in interbedded sand/clay intervals, coaly interbeds, and abundant root traces, suggestive of an abandoned low-gradient fluvial channel or coastal swamp. It is unique within the Calvert Cliffs in our experience. The "upper channel" consists almost exclusively of medium, coarse, and pebbly sands in small (10 cm) to large trough and wedge cross-sets, some with evidence of bidirectional paleocurrents, indicating higher-flow tidal inlets and coastal streams. Macroinvertebrate and vertebrate fossils are still unknown from anywhere within the pSM interval, and samples have not yet yielded dinoflagellates of biostratigraphic value (but have yielded pollen).

Directions to stop 9. Return to vehicle and retrace route back to the paved Camp Conoy Road; turn left and return to the junction with Route 765 (old Route 2/4). Turn left (south) and proceed ~3 miles along either Route 765 or the divided Route 2/4 to the Southern Connector Blvd. (Route 760). Turn east (left) onto that boulevard and follow it to the traffic circle, where we turn left on Rousby Hall Road and proceed to the main entrance of

Stop 8. State Park

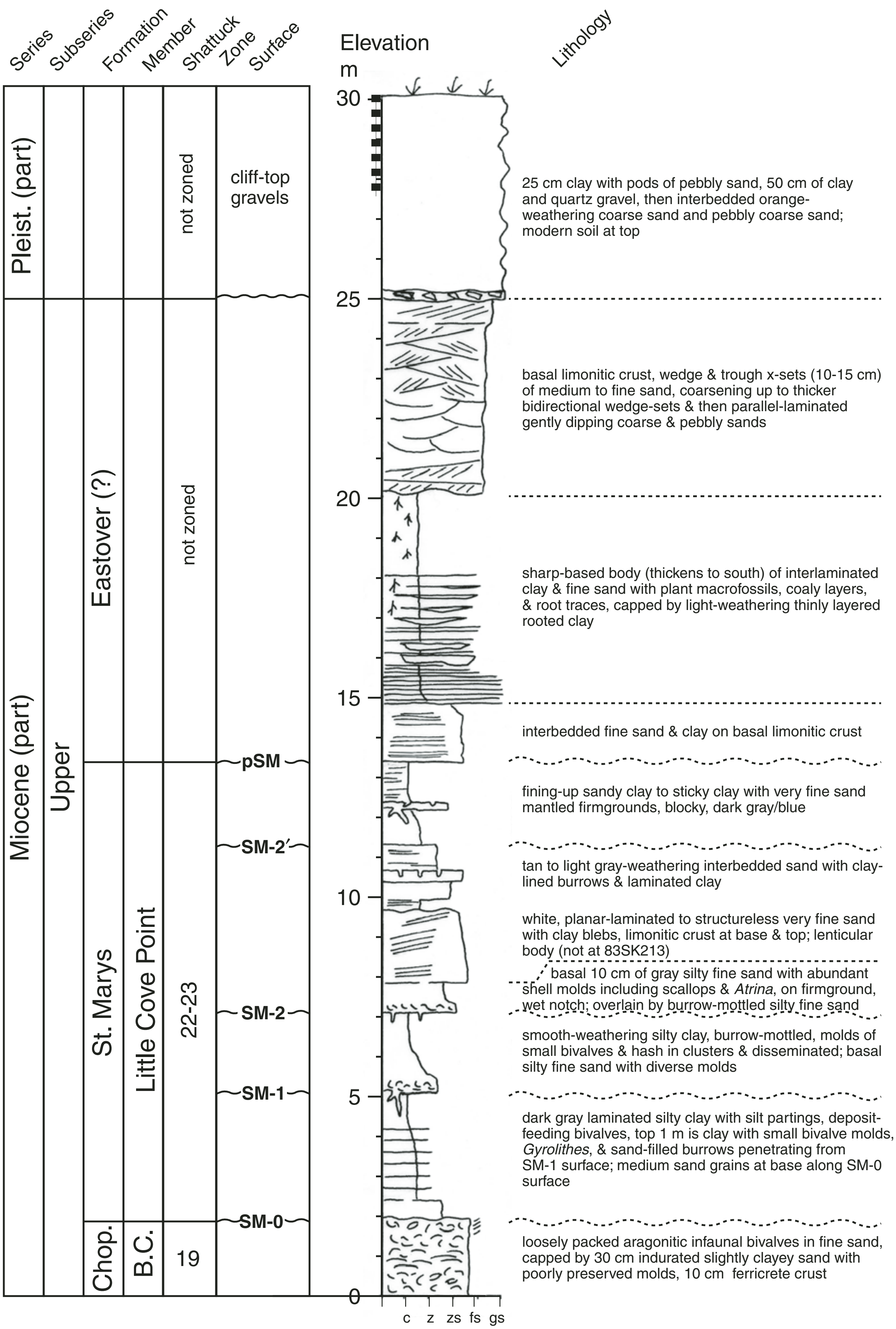


Figure 24. Lithologic profile of outcrop at Calvert Cliffs State Park, in cliffs immediately south of Camp Bay Breeze (**stop 8**), displaying the entirety of Shattuck-Zones 22–23 (large part of Little Cove Point Member of St. Marys Formation). Based on section 83SK240 in Kidwell (1997), among eight measured; no others have been published from the park. Chop.—Choptank; B.C.—Boston Cliffs.

the Chesapeake Ranch Estates community (on our left) where we will be guests of the landowner association. We will follow Catalina Road to Driftwood Beach.

Stop 9. Little Cove Point, Chesapeake Ranch Estates: Little Cove Point Member of St. Marys Formation and Post–St. Marys Strata (pSM; Likely Eastover Equivalent) (Access to Shattuck-Zones 22–23)

Walk north along the beach from the Driftwood Beach parking lot: we will examine strata at beach level between here and Little Cove Point, but likely will not reach the point itself (a distance of ~1.5 km). The beach at the foot of the cliffs here is fairly narrow at high tide and usually interrupted by one or more large landslides, which range in mass properties from thixotrophic to solid depending on time since collapse and the source unit in the cliffs. Fossils can be collected from the beach and from fallen blocks.

Context

This stretch of cliffs has been referred to as Little Cove Point by every worker going back to Shattuck (1904) and is a regular stop on professional and student field trips. There are thus many versions of sections measured here and considerable variation among workers in how to subdivide the record and re-identify Shattuck's original Zones 22 and 23 that he recognized here (e.g., Gernant et al., 1971; Blackwelder and Ward, 1976; Newell and Rader, 1982; McCartan et al., 1985; Ward, 1992; Kidwell, 1997; Ward and Andrews, 2008).

Almost every published section has been measured in the cliffs to the north of the Driftwood Beach parking lot, going back to Shattuck (1904). The stratigraphy in the lower ~quarter (dark-gray part) of these cliffs is quite consistent along this stretch, although the quality of preservation of shells varies greatly. However, the next, lighter-gray interval of the cliff face, categorized here as the upper part of the Little Cove Point Member, and the overlying buff- to gold-weathering pSM interval, is laterally quite variable, including multiple channels (see detailed cross-section figure 6 in Kidwell, 1997). Additional high cliffs immediately south of Driftwood Beach, and another set adjacent to Seahorse Beach at the southern end of the Ranch Estates property, also provide beautiful exposures of the Little Cove Point Member and pSM interval. The only published measured sections from these other cliffs are in Kidwell (1997).

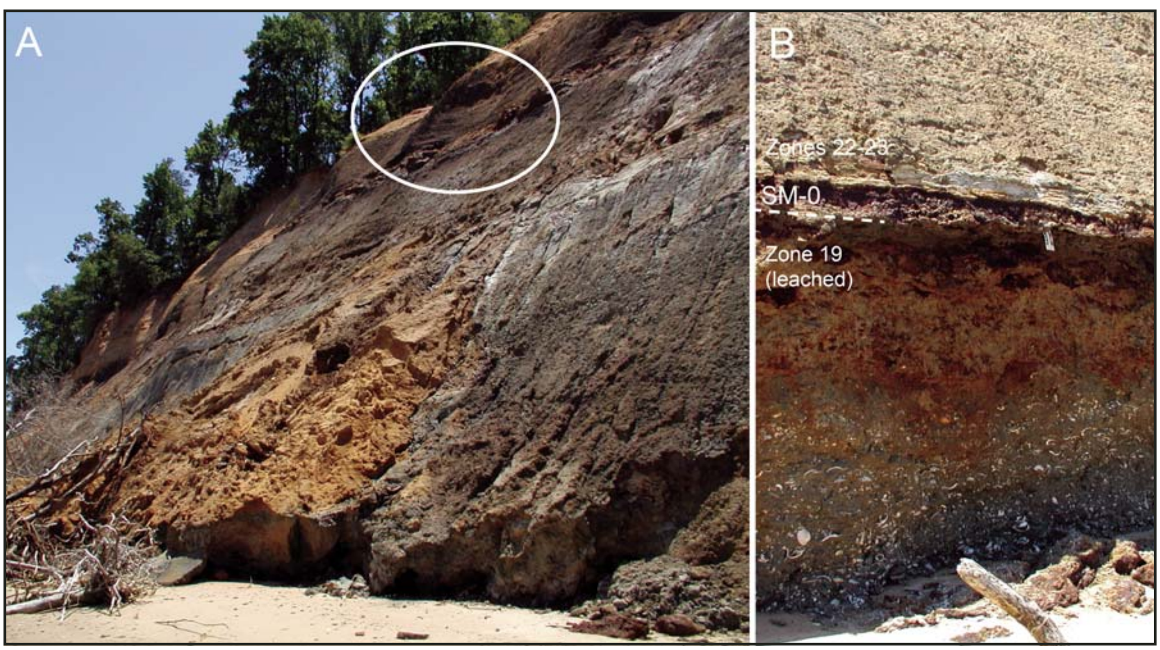
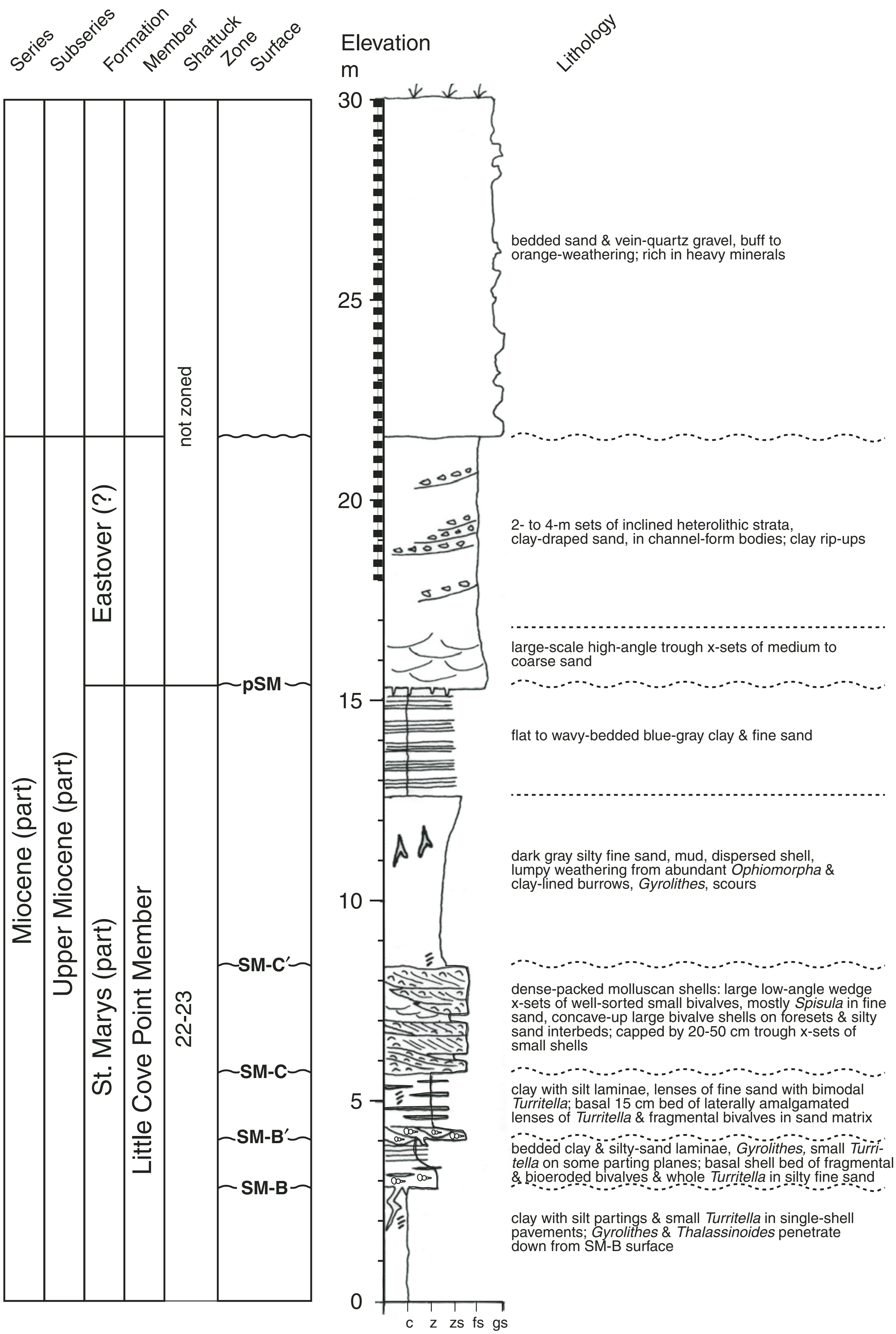


Figure 25. (A) Outcrop photograph of cliff profiled in Figure 24, showing the relatively closely parted and lithologically variable facies present in the Little Cove Point Member at this relatively updip outcrop. The carbonaceous "lower channel" of the pSM interval is circled. (B) The SM-0 unconformity forms the upper contact of the Shattuck-Zone 19 major shell bed (Boston Cliffs Member of Choptank Formation), which presents as limonite-encrusted sandstone within 2 m of beach level. The upper part of the shell bed is leached of aragonitic shells and usually covered by slumped material, as in photo A.

Stop 9. Little Cove Point



Until the past decade or so, the cliffs along the extensive Ranch Estates property had been left largely wild, with only a few stone jetties emplaced at Driftwood Beach itself. The upland gravels that constitute the yellow-weathering, upper third to half of these tall cliffs are very permeable, and commonly fail as catastrophic, thixotrophic flows that detach along the contact with the more tightly consolidated and less permeable silty sands and clayey silts in the lower part of the cliff. In recent years, several cliff-edge homes have been demolished under a federal-state buyout program. Significant riprap now armors several short lengths of cliffs south of Driftwood Beach and along a stretch immediately north of Driftwood Beach, and the ghost of an offshore breakwater is evident in air photos, such as the terrain view of Google Map, a short distance further up bay.

Points of Interest

The cliff face at Little Cove Point is divisible into two, roughly equal parts: (1) a lower, gray interval of tightly consolidated muddy strata with mollusks and well-consolidated, burrowed silty sand that presents a nearly vertical cliff (comprising the Little Cove Point Member of the St. Marys Formation; designated by Shattuck, 1904, as outcrops of his Zones 22 and 23); and (2) an upper, yellow-weathering, more gently sloping to concave interval dominated by loosely consolidated and coarser sands (upland deposits lacking in benthic macrofossils; not zoned by Shattuck, 1904, his Pleistocene "loam, sand and gravel"; Eastover(?) Formation of Ward, 1992, and Ward and Andrews, 2008; pSM and cliff-top gravels of Kidwell, 1997, which are Eastover(?) Formation and Pleistocene, respectively) (Figs. 26 and 27).

The overall succession in this outcrop is distinctly coarsening-upward, as accentuated in Figure 26 (section 83SK255 of Kidwell, 1997). All workers have stressed this obvious grain-size trend, and some have interpreted the succession as a single conformable series of Miocene facies, subsuming more or less of Shattuck's "Pleistocene sands" (Newell and Rader, 1982; McCartan et al., 1985). In contrast, Kidwell (1988, 1997; and see Blandin, 1996) identified a series of disconformity-bounded units that were roughly comparable to those recognized in outcrops further north within the Calvert Cliffs—that is, as a series of thin SM sequences within the Little Cove Point Member (undifferentiated Shattuck-Zones 22–23, Miocene), truncated by a complex of "post–St. Marys" channels (denoted pSM; probably upper Miocene equivalent of Eastover Formation in Virginia), which are cut in turn by cliff-top gravels (Pleistocene; Fig. 3). Owing to an absence of outcrops at Cove Point, it was unclear precisely how sequences within the Little Cove Point Member here at the southernmost extent of the Calvert Cliffs (Kidwell's provisional SM-A thru SM-C′ sequences; **stop 9**, Fig. 26) correlated with the SM-0 through SM-2′ sequences recognized in cliffs to the north (**stops 7 and 8**; Figs. 3, 22, and 24).

New analyses of samples (Kidwell et al., 2012) confirm that dinocyst assemblages support physical subdivision and correlation of at least two sequences within the Little Cove Point Member between these southern and northern parts of the Calvert Cliffs (de Verteuil and Norris, 1996)—namely, the SM-0 and SM-1 sequences as one entity (yield DN8 lower; the SE9 allo-unit of de Verteuil and Norris, 1996; subsumes the SM-A sequence at the base of the section at **stop 9**, and the SM-2 and SM-2′ sequences as the second entity (yield DN8 upper; the SE10 allo-unit of de Verteuil and Norris, 1996; subsumes the SM-B, -B′, -C, and -C′ sequences at **stop 9**). These dinocyst-supported subdivisions do not correspond to Shattuck's (1904) original zone 22 and 23 subdivisions, and thus we continue to recommend that workers not apply either of those zone numbers anywhere in the cliffs, but rather simply refer to an interval as undifferentiated "Shattuck-Zones 22–23." Assignment of the lowermost few meters of section at **stop 9** to Shattuck-Zone 20 (Conoy Member; as proposed by Ward, 1992, and figure 59 in Ward and Andrews, 2008) is contradicted by dinocyst evidence: Shattuck-Zone 20/Conoy Member at its type section in the Conoy Cliffs, where it rests directly on Shattuck-Zone 19/Boston Cliffs Member, yields species diagnostic of DN7 (de Verteuil and Norris, 1996; Kidwell et al., 2012).

Paleoenvironmentally, the burrow-mottled clay at the base of the section at **stop 9** (SM-A; Fig. 27B) is the deepest water unit in the section. The preservation of a few silt partings, usually strewn with small (≤1 cm), flat-lying *Turritella* shells, suggests that the seafloor was probably positioned slightly above storm wavebase.

Sequences SM-B and -B′ are distinctly shallower, from depths above storm wavebase but still well below fair-weather wavebase. Their basic lithology is burrow-mottled silty clay to clayey silt, and partings are more closely spaced and mantled by thicker (to 5 mm), coarser (silt to silty very fine sand), and more shelly sediment (larger *Turritella* specimens, more closely spaced laterally). The fauna in sequences SM-B and -B′ is, like that of the SM-A sequence, still distinctly marine. However, (carbonized) wood is increasingly abundant and many shells are black-stained (probably iron mono-sulfides; signaling more organic-rich substrata than in the Calvert and Choptank units?). Both the SM-B and SM-B′ surfaces are burrowed firmgrounds, with *Thalassinoides* especially well-developed along the SM-B surface, and both are mantled by silty fine sand with loosely to densely packed whole and broken shells, mostly (but not exclusively) of *Turritella* and including badly bored and encrusted scallops. Both of these surface-mantling shell beds (locally

Figure 26. Lithologic profile of outcrop south of Little Cove Point on Chesapeake Ranch Estates (**stop 9**). Based on section 83SK255 in Kidwell (1997). General agreement exists among the many sections published here that, paleoenvironmentally, strata are shallowing-up from open-shelf into coastal, probably brackish ("bay," paralic) subtidal, intertidal, and channelized facies (see discussion in main text and road log and Fig. 10). Workers differ substantively on assigning beds to Shattuck-Zones: Ward (1992; Ward and Andrews, 2008, their figure 59) assigns the SM-A clay at the base of this profile to Shattuck-Zone 20/Conoy Member.

Figure 27. (A) Cliff face south of Little Cove Point (**stop 9**), showing the relatively closely parted and lithologically variable facies present in the Little Cove Point Member (St. Marys Formation) at this relatively downdip outcrop (comparable to this member at **stop 7**—South Conoy and **stop 8**—State Park, Figs. 23A and 25; contrast with more massive Plum Point and Choptank strata exposed at **stop 1**—Chesapeake Beach, **stop 2**—Camp Kaufman, **stop 3**—Parker Creek, and **stop 6**—Matoaka, Figs. 7B, 12, 14, 16). The lower, gray half of the cliff is the Miocene Little Cove Point Member; the uppermost dark layer immediately below the pSM disconformity, visible at the far end of the outcrop, is an interval of flat to wavy-bedded sand and clay (intertidal flat deposits; upper few m of the SM-C′ sequence). The upper half of the cliff face here, which is a more recessive and gold-weathering slope that is mostly obscured in this view, constitutes medium sands and gravels of the pSM (post–St. Marys) interval or "upland deposits," which accumulated as tidal inlet, tidal-influenced river, and fluvial facies in large channel-form bodies. (B) *Thalassinoides*-burrowed firmground marking the SM-B disconformity: silty sand (yields upper DN8 dinocysts, same as occur in the SM-2 and -2′ sequences in updip outcrops) is piped down into the shell-poor, tightly consolidated clay of the SM-A sequence (yields lower DN8 dinocysts, same as occur in the SM-0 and -1 sequences in updip outcrops; de Verteuil and Norris, 1996; Kidwell et al., 2012). This disconformity is only locally exposed in this stretch of cliffs, owing to variability in its elevation above modern sea level (post-depositional warping; see Fig. 3) and cover by slumps and modern beach deposits.

moldic) persist laterally for the ~4 km of cliffs that extend from Little Cove Point itself south to Drum Point: although quite thin (5–30 cm thick), each shell bed is fundamentally a hiatal skeletal concentration associated with a stratigraphically significant surface (for fuller treatment, see Kidwell, 1997). The SM-B′ sequence appears to be shallower water than the SM-B sequence. The basal SM-B′ shell bed is a laterally shingled, pinch-and-swell series of sharp-based, lenticular shelly fine sands; has a locally erosional and storm-guttered rather than burrowed contact with underlying beds; and the sequence itself includes many lenses of sand with flat-lying *Turritella* exhibiting bimodal current orientations (Fig. 10C), indicating currents that were sufficient to deliver sand and to reorient (and possibly exhume) *Turritella* postmortem.

Sequence SM-C is an ~2-m-thick increment of cross-bedded, densely shelly sand (Figs. 10A, 26, and 27) and is unique within the entire Calvert Cliffs succession. Like the four major shell beds of the Plum Point/Choptank interval, it has a sharp basal contact, mud-poor fine sand matrix, and a complex internal stratigraphy. However, (1) its internal anatomy is overwhelmingly dominated by physical sedimentary structures (large cross-sets of various geometries, including wedge sets typical of tidal inlets); (2) with the exception of a basal layer of *Turritella* that were perhaps reworked from underlying strata, the bed is dominated by a groundmass of small (<1 cm), whole bivalve shells that are remarkably well size sorted (mostly *Spisula*), with sparsely dispersed large shells (a distinctly bimodal size distribution; figure 2B in Kidwell and Holland, 1991); and (3) the shell concentration is laterally discontinuous within the available cliffs, constituting a local facies that happens to rest directly on the SM-C surface. Some of this lateral discontinuity is apparent rather than real—this shell bed seems to be especially prone to loss of original shell material, perhaps because major seepage occurs along the SM-C surface. However, the shell bed clearly interfingers laterally into swaley bedded fine sand (northward) and *Ophiomorpha*-burrowed silty sand (southward and up-section); in those areas, the SM-C surface is a locally scoured, *Thalassinoides*-burrowed firmground unadorned by mantling shells. Gernant (*in* Gernant et al., 1971) also recognized this lateral, northward transition to sandier and shallower facies, but lateral variability within the Little Cove Point Member here and elsewhere within the cliffs has otherwise been unappreciated.

Shallowing continues through the remaining increment of Little Cove Point Member in this section. The SM-C′ surface is marked by a relative concentration of bone debris, wood (carbonized), and shells, especially where it scours the top of the SM-C shell bed (Gernant *in* Gernant et al., 1971, also recognized this feature). However, it becomes difficult to trace >1 km north of Driftwood Beach, where *Ophiomorpha*-burrowed sands and clay-blebbed sands of the SM-C′ sequence rest on sandy facies of the SM-C sequence. These facies grade up-section into flat to wavy-bedded intertidal strata (as illustrated from a different locality in Fig. 10B; dark band immediately under the pSM disconformity in Fig. 27A), with abundant vertical and branching feeding traces. This intertidal-flat facies is commonly stained a dark-rust color and is partly indurated at **stop 9**; large blocks fall intact to the beach, providing an excellent opportunity for close examination. Dark-red–stained casts of ophiuroids (brittle stars) collected as pebbles along the modern shoreline here probably come from this interval.

Sequences within the Little Cove Point Member (all bearing the prefix SM-), both here at **stop 9** and further north in the cliffs (e.g., **stops 7 and 8**), are fundamentally tabular bodies. When traced laterally over a km or more within the Ranch Estates property, bed elevations above mean sea level can clearly vary by a few meters (Fig. 3, and figure 6 in Kidwell, 1997)—we will see this just in the short distance examined at **stop 9**. This variability appears to owe to postdepositional warping (differential compaction, perhaps small growth faulting) rather than primary, e.g., erosional relief.

True erosional channels, with incision of underlying beds and lenticular infills, are limited to the overlying interval, which is referred to as the post–St. Marys (pSM) interval by Kidwell (1997; SM-3 sequence of Kidwell, 1988) and as part of the upland gravels by many others, including Powars et al. (this volume). One quite large, low-relief channel dominated by inclined heterolithic strata (tidal-influenced river) is evident within the cliffs north of Driftwood Beach (our **stop 9**), and several channels dominated by more gravel-rich, tidal-inlet facies and diverse trace assemblages are present in cliffs to the south.

Previous workers have described similar features at **stop 9**, with more or less similar environmental interpretations. Gernant (*in* Gernant et al., 1971) described the lower part of the cliff (Kidwell's SM-B, -B′, and -C sequences; Fig. 27) as densely shelly sands, with cross-sets and sharp erosional bases, alternating with sparsely fossiliferous clays. He reported a molluscan fauna that was ecologically very similar to that of the major shell beds of the Calvert (Plum Point Member) and Choptank Formations except for the greater abundance of the gastropods *Nassarius* [carrion- and other detritus-feeding] and *Mangelia* [predator], which he interpreted as shallower-water indicators, and a brackish-water phenotype of the ostracode *Cyprideis*. He interpreted these beds, along with the remainder of the St. Marys Formation here (Kidwell's SM-C′ sequence) as extremely shallow marine or marginal marine environment, and that the sandy, "*Callianassa*"-rich sands found in the SM-C and -C′ interval to the north were even more definitely marginal marine. McCartan et al. (1985) attributed the entire lower part of the section (Kidwell's SM-A, -B, -B′, and -C sequences, plus the lower half of her SM-C′ sequence) to subtidal open-shelf conditions, without further specification; three meters of "alternating sand and clayey silt beds without shells" (the upper ~3 m of the SM-C′ sequence in Figs. 26 and 27) were interpreted as an "open bay facies," reflecting both the migration of a wave-dominated delta and tidal alternations (contra intertidal here); and the remaining 12 m of measured section comprised "medium-to-coarse sand and fine gravel" with *Ophiomorpha* burrows and cross beds that were interpreted as a "beach facies" ("shoreface" mentioned later in that paper; interval interpreted as "littoral" by Newell and Rader, 1982; subsumes all of Shattuck's Pleistocene strata, and Kidwell's, 1997, pSM and cliff-top gravel units).

The Little Cove Point Member (SM-prefixed sequences in Figs. 26 and 27) deserves closer evaluation throughout its outcrop area to reach more refined paleoenvironmental interpretations; the **stop 9** area provides especially favorable, beach-level outcrops to start such an analysis, but should not be the limit of it. At this point in our understanding, the fundamentally tabular geometry of the SM sequences, combined with relatively rapid facies changes from clays to cross-bedded shelly sands affected by an array of storm, wave, and tidal forces, suggests that the Little Cove Point Member accumulated in a smaller water body (or bodies) than did the older, fully open-shelf Miocene succession (for more in-depth discussion, see Kidwell, 1997). It was still a fundamentally level-bottom soft-sedimentary seabed (e.g., in contrast to the pSM interval), but both fair-weather and storm wavebases were at shallower depths than on the open shelf, the system was richer in organic matter (coastal detritus, perhaps subaquatic vegetation; faunas should be evaluated for epiphytes and other seagrass dwellers), and brackish-water indicators are increasingly present both up-section and updip. The progradationally shingled but transgression-dominated, shaved sequences (Fig. 4) argue for strong offlap. These features imply a low-gradient, fundamentally regressive strandplain that could capture a depositional record of small-scale, relative rises in sea level but would be subject to sediment bypass and stranding (non-deposition, some erosional beveling possible) during relative drops. It would be a regressive analog of the fundamentally transgressive estuaries existing today along the Atlantic Coastal Plain (all from Kidwell, 1988, 1997).

Directions back to Baltimore. Return to vehicle, retrace route to Route 2/4, and head north to Baltimore. Depending on time, tides, daylight, and energy, one or more vehicles can visit any of the optional **stops 4–6** listed on Day 1 that could not be fit in then.

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Notes