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Diatom biostratigraphy and paleoecology of vertebrate-bearing Miocene localities in Virginia

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ABSTRACT

Siliceous microfossil samples were obtained from sediment collected with cetacean remains from three localities in eastern Virginia: the Carmel Church Quarry in Caroline County (CCQ), Westmoreland State Park in Westmoreland County (WSP), and the Rappahannock River in Richmond County (RMC). While the WSP and RMC deposits have been correlated with the upper part of the middle Miocene Calvert Formation based on past studies of diatoms and macroinvertebrates, the assignment of CCQ to the upper Calvert has been based primarily on lithostratigraphy and land mammal biostratigraphy.

Among these samples, CCQ exhibited the greatest diatom diversity with 28 species from 19 genera. At RMC 15 species from 12 genera were identified, while 19 species from 11 genera were found at WSP, which had the greatest abundance of diatoms. In addition, a single silicoflagellate taxon, *Dictyocha crux*, was identified at each site.

At CCQ, the co-occurrence of *Stephanopyxis grunowii* and *Delphineis biseriata* indicates a correlation with Bed 15 of the Calvert Formation. At RMC, the co-occurrence of *D. biseriata* and *D. penelliptica* also indicates a correlation with Bed 15. Useful marker diatoms were rare at WSP. Even so, the co-occurrence of *D. penelliptica* and *D. novaecaesaraea* combined with the absence of *D. biseriata* suggests a correlation with Beds 12-15 of the Calvert. Published reports based on mollusks from WSP indicate that this unit correlates with Beds 14-15.

All three sites contained abundant specimens associated with or tolerant of brackish water, including *Coscinodiscus rothii* at CCQ and WSP, *Hyalodiscus laevis* at CCQ and RMC, and *Paralia sulcata* at all three sites. There was a mix of both warm- and cool-water taxa (*Actinopterychus senarius*, *P. sulcata*) at all three sites. All three sites also included benthic taxa, suggesting that water depths throughout the area were no greater than 20 meters.

INTRODUCTION

Diatoms are important biostratigraphic markers due to their great morphological diversity, broad distribution, restricted stratigraphic ranges, and abundance (Andrews 1988). Additionally, the sensitivity of diatoms to environmental variables such as salinity, temperature, and depth of water makes them potentially useful bioindicators, within the limitations of time averaging in fossil deposits (see, for example, Bennington and Bambach, 1996).

Various exposures of Calvert Formation of the Middle Atlantic Coastal Plain have been used by Andrews (1976, 1978, 1980, 1988), Abbott (1980), and Abbott and Andrews (1979) to develop a biostratigraphic zonation based on marker diatoms for the western Atlantic Ocean. If the published correlation of the Carmel Church bonebed

within Bed 14 is correct, then this diatom assemblage should fall into East Coast Diatom Zone (ECDZ) 5 of Andrews (1988) and Andrews (1976). This study tests and attempts to validate these correlations in order to provide a guide for determining the geological range and environmental conditions of the locations within the vicinity of these three sites.

The Martin Marietta Carmel Church Quarry (CCQ) in Caroline County, Virginia; the Rappahannock River (RMC) in Richmond County, Virginia; and Westmoreland State Park (WSP) in Westmoreland County, Virginia (Fig. 1) have all produced numerous macrofossils, including vertebrates (Dooley et al., 2004; Dooley 2005, 2007). Previous work (Dooley et al. 2004; Dooley 2007) indicates that the

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main fossil-bearing unit at Carmel Church correlates with Bed 14 of the middle Miocene Calvert Formation based on terrestrial mammals and regional lithostratigraphy. The

deposits from Westmoreland and Richmond County are also believed to be from Bed 14 of the Calvert Formation (Ward and Andrews 2008).

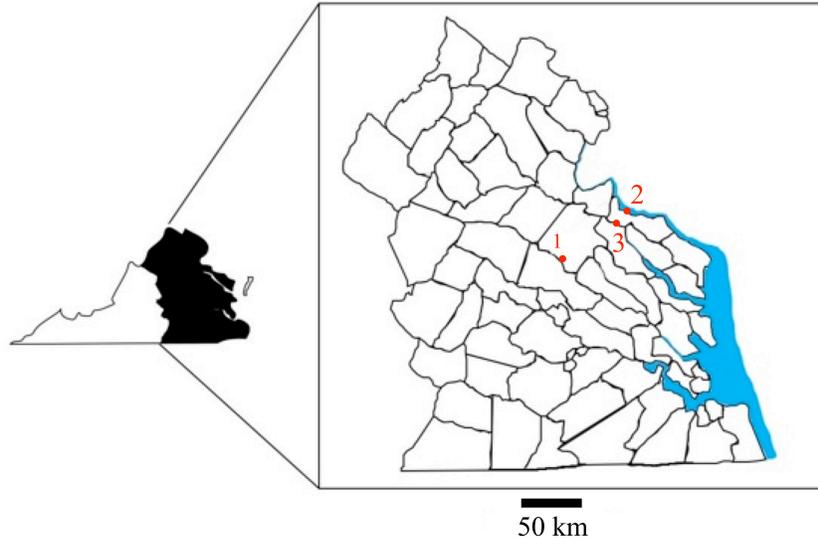


Fig. 1. Map of Virginia showing locations for samples used in this study. 1, Carmel Church Quarry (CCQ). 2, Westmoreland State Park (WSP). 3, Richmond County (RMC).

MATERIALS AND METHODS

Collection and Location of Samples

Samples of diatomaceous sediment were gathered from jacketed vertebrate fossils excavated from Carmel Church Quarry (37.907735°N, 77.481595°W, USGS Ruther Glen Quadrangle, 7.5' series), the Rappahannock River (38.058669°N, 76.917223°W, USGS Champlain Quadrangle, 7.5' series), and Westmoreland State Park (38.167868°N, 76.855972°W, USGS Stratford Hall Quadrangle, 7.5' series) (Fig. 1). The sediment collected from each sample is believed to be from the Calvert Formation, a silty, fine-grained sand with an olive-brown coloration when fresh (Ward and Andrews, 2008). The protocols by Hinchey and Green (1994) and

Lohman (1933) were used as guidelines for the following procedure.

Pre-treatment—Samples were placed in test tubes and soaked overnight in distilled water to break up large particles of sediment.

Removal of Carbonates—15mL of 10% hydrochloric acid (HCl) was added to each sample and heated to between 50-100°C. After two hours, distilled water was added and the samples were allowed to settle. After approximately two hours, the water was decanted and this step was repeated three times in order to dilute the samples.

Removal of Organics—Three different methods were applied in order to find an effective method of organic removal

which is more cost-efficient than using 30% hydrogen peroxide. Both 3% hydrogen peroxide (H_2O_2) and 5% sodium hypochlorite (Clorox® bleach) were used as potential alternatives; however, they were not as effective for these samples as the 30% H_2O_2 treatment.

The first set of samples was treated with 3% hydrogen peroxide. Due to its low concentration, this process was repeated three times. 15mL of 3% H_2O_2 was added to each sample and heated to between 50-100°C or until a reaction occurred. To avoid damage to diatom frustules, boiling the solution was avoided. The reaction took place in approximately two hours. The samples were then allowed to settle from four to eight hours. When the visible reaction ceased the remaining H_2O_2 was decanted off and distilled water was added to each of the samples to dilute them.

The next set of samples was treated with bleach; however, these samples only went through the cleaning process once. The bleach appeared to be slightly more effective than the 3% H_2O_2 and yielded lighter-colored sediment with slightly less organic material, making it easier to view the diatoms under the compound microscope. The same method was used for the samples treated with 30% H_2O_2 . This method appeared to be considerably more effective than the bleach treatment and drastically more effective than the 3% H_2O_2 treatment.

Removal of Clay – 15mL of 5% household ammonia (NH_3) was added to each test tube as a dispersant and then allowed to sit for four hours, after which it was decanted. This process was repeated six times. After the sixth treatment, the

NH_3 was decanted and distilled water was added to the samples until they were completely diluted

Preparation of Wet Mounts and Determination of Relative Abundance

Once the diatoms were isolated from the unwanted materials within the samples, portions of each sample were used to prepare temporary wet mounts, permanent resin mounts, and scanning electron microscope mounts. For wet mounts, samples were shaken slightly in order to suspend the sediment and then a few drops were collected in an eyedropper and placed onto a clean slide. Before placing on the cover slip, the sediment was spread into a thin, evenly distributed layer, which covered the entire surface of the slide. A drop of 90% isopropyl alcohol was added to minimize water bubbles and to increase surface area.

Each of the nine samples was partitioned into multiple slides. Photographs of the diatoms were taken using a Sanyo VPC-E870 digital camera. The relative abundance of each diatom species was determined by how many were found among the ten slides made for each sample. If less than two of a particular species was found, then it was considered rare. If there were three to five specimens were present, it was common; six to nine, abundant; and ten or more, dominant.

Identification of taxa was based on comparisons to published images and descriptions from Andrews (1976, 1978, 1980, 1988), Abbott and Andrews (1979), Abbott (1980), Schrader (1973), McCartney and Wise (1987), and Tynan (1957).

RESULTS

Although all three sites are within a 70 km radius, each contains its own unique and distinguishable characteristics based on the varying assemblages of microfossil taxa. As expected, all species found at each site have previously been reported from middle Miocene sediments.

The Carmel Church sample yielded 28 species and varieties of diatoms distributed among 19 genera. Thirteen of these species were found only at CCQ, including two taxa that were abundant at CCQ.

Westmoreland produced 19 taxa from 11 genera. Five species were found only in the WSP sample, including one taxon that was dominant at the site.

Richmond County produced 15 taxa from 12 genera. Two taxa were unique to RMC, but both were rare in this assemblage.

Each site also included a single silicoflagellate taxon, *Dictyocha crux*.

Taxa identified in this study are listed below, with reference images indicated:

Actinocyclus ellipticus var. *javanicus*. CCQ, common, Plate 1A. Abbott and Andrews, 1979 (Plate 1, Fig. 1).

Actinocyclus ingens. WSP, rare, Plate 4A. Andrews, 1976 (Plate 3, Fig. 10).

Actinocyclus octonarius. CCQ, common, Plate 1B. WSP, common, Plate 4B. Andrews 1976, (Plate 3, Fig. 7).

Actinocyclus robustus. CCQ, common, Plate 1C. WSP, common, Plate 4C. Abbott and Andrews, 1979 (Plate 1, Fig. 8).

Actinocyclus tenellus. WSP, rare, Plate 4D. Andrews, 1976 (Plate 3, Figs. 8,9).

Actinoptychus marylandicus. CCQ, rare, Plate 1E. Andrews, 1976 (Plate 4, Figs. 3-6).

Actinoptychus senarius. CCQ, common, Plate 1F. WSP, abundant, Plate 4E. RMC, abundant, Plate 6A. Andrews, 1976 (Plate 4, Figs. 7,8).

Actinoptychus virginicus. CCQ, rare, Plate 1D. Andrews, 1976 (Plate 4, Figs. 9-12).

Aulacodiscus crux. CCQ, rare, Plate 1G. Andrews, 1980 (Plate 1, Fig. 5).

Biddulphia tuomeyi. CCQ, common, Plate 1H. Abbott and Andrews, 1979 (Plate 2, Fig. 4; Plate 6, Fig. 8).

Chaetoceros lorenzianum. RMC, rare, Plate 6B. Andrews, 1980 (Plate. 1, Fig. 13).

Coscinodiscus marginatus. CCQ, abundant, Plate 2A. WSP, common, Plate 4F. Andrews, 1976 (Plate 2, Fig. 7).

Coscinodiscus perforatus. CCQ, dominant, Plate 2C. RMC, common, Plate 6C. Andrews, 1976 (Plate 2, Fig. 9).

Coscinodiscus perforatus var. *cellulosa*. CCQ, rare, Plate 2B. Andrews, 1976 (Plate 2, Fig. 10).

Coscinodiscus praeyabei. WSP, rare, Plate 4G. Abbott, 1980 (Plate 1, Fig. 3).

Coscinodiscus radiatus. WSP, dominant, Plate 4H. Abbott and Andrews (Plate 3, Fig. 8).

Coscinodiscus rothii. CCQ, dominant, Plate 2D. WSP, common, Plate 4I. Andrews, 1976 (Plate 2, Figs. 1,2).

Craspedodiscus coscinodiscus. CCQ, abundant, Plate 1I. WSP, rare, Plate 5A. RMC, rare, Plate 6D. Abbott and Andrews 1979 (Plate 3, Fig. 13).

- Delphineis biseriata*. CCQ, rare, Plate 2E. RMC, dominant, Plate 6E. Abbott and Andrews, 1979 (Plate 4, Fig. 2).
- Delphineis novaecaesaraea*. WSP, abundant, Plate 5B. RMC, common, Plate 6F. Andrews 1988 (Plate 2, Figs. 9-11).
- Delphineis penelliptica*. WSP, dominant, Plate 5C. RMC, dominant, Plate 6G. Andrews, 1988 (Plate 2, Figs. 17-20).
- Diploneis crabro*. CCQ, common, Plate 2F. Abbott and Andrews, 1979 (Plate 4, Fig. 7).
- Goniothecium rogersii*. CCQ, common, Plate 2G. Abbott and Andrews, 1979 (Plate 4, Fig. 13).
- Grammatophora marina*. CCQ, dominant, Plate 2H. Andrews, 1976 (Plate 7, Figs. 14,15); Andrews, 1980 (Plate. 2, Fig. 14).
- Hyalodiscus laevis*. CCQ, abundant, Plate 2I. RMC, abundant, Plate 6H. Andrews, 1976 (Plate 4, Fig. 2).
- Melosira westii*. CCQ, dominant, Plate 3A. WSP, dominant, Plate 5D. RMC, dominant, Plate 6I. Andrews, 1976 (Plate 1, Figs. 1,2).
- Navicula pennata*. WSP, common, Plate 5E. RMC, abundant, Plate 6J. Abbott and Andrews, 1979 (Plate 4, Fig. 25).
- Paralia sulcata*. CCQ, dominant, Plate 3B. WSP, dominant, Plate 5F. RMC, dominant, Plate 7A. Abbott and Andrews, 1979 (Plate 4, Fig. 29).
- Paralia sulcata* var. *coronata*. CCQ, abundant, Plate 3C. WSP, common, Plate 5G. RMC, common, Plate 7B. Abbott and Andrews, 1979 (Plate 4, Fig. 29).
- Rhaphoneis gemmifera*. CCQ, rare, Plate 3D. RMC, abundant, Plate 7C. Andrews, 1978 (Plate 3, Fig. 17), Abbott and Andrews, 1979 (Plate 5, Fig. 14).
- Rhizosolenia miocenica*. WSP, rare, Plate 5H. Abbott and Andrews, 1979 (Plate 5, Fig. 25).
- Rhizosolenia styliformis*. RMC, rare, Plate 7D. See Abbott and Andrews, 1979 (Plate 5 Fig. 25).
- Stephanopyxis grunowii*. CCQ, rare, Plate 3E. Abbott and Andrews, 1979 (Plate 5, Fig. 29).
- Stephanopyxis turris*. CCQ, rare, Plate 3F. Abbott and Andrews, 1979 (Plate 6, Figs 1,2 and Plate 8, Fig. 6).
- Terpsinöe americana*. CCQ, abundant, Plate 3G. Andrews, 1976 (Plate 5, Figs. 16,17).
- Thalassionema obtusa*. CCQ, common, Plate 3H. WSP, common, Plate 5I. Andrews, 1976 (Plate 6, Fig. 11).
- Thalassiothrix longissima*. CCQ, abundant, Plate 3I. Abbott and Andrews, 1979 (Plate 6, Fig. 13).
- Triceratium condecorum*. CCQ, common, Plate 3J. WSP, abundant, Plate 5J. RMC, rare, Plate 7E. Abbott and Andrews, 1979 (Plate 6, Figs. 14-16).
- Dictyochoa crux*. CCQ, abundant, Plate 3K. WSP, dominant, Plate 5K. RMC, rare, Plate 7F. Tynan, 1957 (Plate 1, Figs. 3-8).

BIOSTRATIGRAPHIC CORRELATION

Carmel Church—The presence of *Craspedodiscus coscinodiscus* (Plate 1I) and *Paralia sulcata* var. *coronata* (Plate 3C) indicate that the CCQ assemblage is restricted to the upper Calvert or lower Choptank Formations (Andrews 1976; Abbott and Andrews 1979). Species such as *Rhaphoneis gemmifera* (Plate 3D),

Actinoptychus virginicus (Plate 1D), *A. marylandicus* (Plate 1E), and *Delphineis biseriata* (Plate 2E) range from Bed 12 of the Calvert to Bed 19 of the Choptank (Andrews 1976; Andrews 1978; Abbott and Andrews 1979). Andrews (1988) placed *D. biseriata* in the upper part of Bed 15 of the Calvert to Bed 19 of the Choptank (ECDZ 6-7). *Stephanopyxis grunowii* (Plate 3E) has been reported only from the Calvert Formation (Abbott and Andrews, 1979). The co-occurrence of *D. biseriata* and *S. grunowii* restricts CCQ to Bed 15 of the Calvert (ECDZ 6 of Andrews, 1988) (Fig. 2).

While the sandy clay found at CCQ is lithically more consistent with Bed 14 of the Calvert Formation (Ward and Andrews, 2008) the diatom assemblage indicates that correlation of this unit with the finer-grained Bed 15 (as represented by the RMC sample) is more likely. It is likely that the observed grain-size variation between CCQ and RMC is due to a facies-change within Bed 15, given the extreme western (and likely near-shore) location of CCQ.

Westmoreland—Although not as diverse as Carmel Church, the Westmoreland assemblage is the most diatom-rich. Like Carmel Church, it too contains many long-ranging species with few short-ranging markers. *Delphineis penelliptica* (Plate 5C), a dominant, marker species from Westmoreland, restricts the range of this assemblage to between Beds 9-15 of the Calvert Formation (ECDZ 2-6) (Andrews, 1988) (Fig. 2). *Delphineis novaecaesaraea* (Plate 5B), another dominant marker species from WSP, ranges from Bed 12 of the Calvert to Bed 19 of the Choptank (ECDZ 4-7) (Andrews 1988). These

observations further indicate that the Westmoreland assemblage is exclusive to the Calvert and Choptank formations (ECDZ 2-7). The co-occurrence of *D. penelliptica* and *D. novaecaesaraea* indicates that the sample from WSP is restricted to Beds 12-15 of the Calvert Formation (Figure 2), which is consistent with published correlations based on molluscan biostratigraphy and lithostratigraphy (Ward 1992, 2005; Ward and Andrews 2008). On the contrary, species such as *Actinocyclus ingens* (Plate 4A) and *Thalassionema obtusa* (Plate 5I) suggests a range restricted to the Choptank Formation alone (Andrews, 1976). However, it is more likely that this represents a range extension for these taxa into the upper Calvert Formation. Both taxa are rare even in the Choptank Formation, and absent at most localities, so the time of first appearance may be poorly constrained.

Correlation of these deposits with Beds 12-15 of the Calvert Formation is consistent with the assignment of these deposits to Beds 14-15 based on mollusks and regional lithostratigraphy (Ward, 1992, 2005; Ward and Andrews, 2008).

Richmond County—Like the Carmel Church assemblage, Richmond County contains *Rhaphoneis gemmifera* (Plate 7C), a short-ranging marker species ranging from the upper Calvert and lower Choptank Formation (Andrews 1978; Abbott and Andrews 1979) and *Delphineis biseriata* (Plate 6E), which confines the geological range to Bed 15 of the Calvert to Bed 19 of the Choptank. Like Westmoreland, it also contains *D. novaecaesaraea* (Plate 6F) and *D. penelliptica* (Plate 6G). The co-occurrence of *D. biseriata* and *D. penelliptica* indicates that, like Carmel

Church, the sample at RMC is restricted to Bed 15 of the Calvert Formation (Figure 2). This is consistent with the assignment

of these beds to Beds 14-15 based on mollusks and lithostratigraphy (Ward 1992; Ward and Andrews 2008).

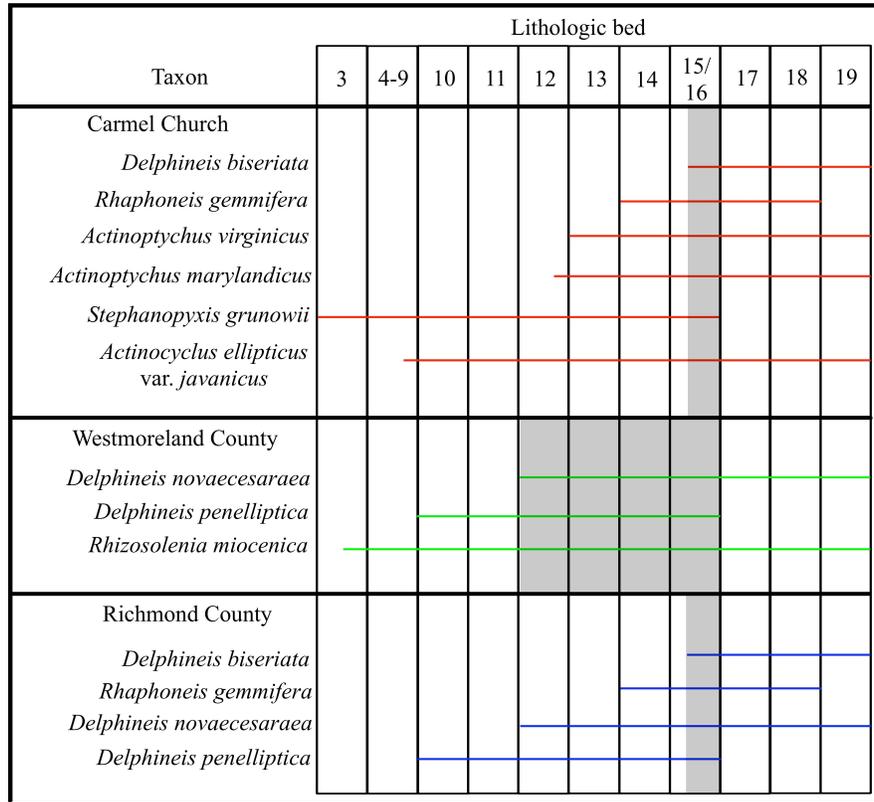


Fig. 2. Chart showing published lithostratigraphic ranges of marker diatoms from Carmel Church, Westmoreland State Park, and Richmond County.

ENVIRONMENTAL INTERPRETATIONS

Salinity—All three sites include taxa that prefer, or are tolerant of, brackish conditions. According to Abbott and Andrews (1979), *Coscinodiscus rothii*, which is found at CCQ, and WSP, prefers coastal brackish to freshwater environments. Modern species of *Hyalodiscus laevis* (found at CCQ and RMC), *Terpsinoë americana* (CCQ), and *Thalassiothrix longissima* (CCQ) also prefer brackish coastal waters (Andrews 1976; Abbott and Andrews 1979), *Paralia sulcata*, which is dominant at all three sites, can withstand saline concentrations ranging from 5-35 ‰. (Zong 1997). *Actinocyclus ingens*

(WSP) also tolerates a salinity range of 5-35 ‰ (Martinez-Macchiavello et al. 1996).

A notable exception to this pattern is the presence of *Diploneis crabro*, which is common at CCQ and favors hypersaline waters (Abbott and Andrews 1979). Given the location of CCQ on the western edge of the Salisbury Embayment, this suggests the possibility of an environment with more highly variable salinity, perhaps due to episodic freshwater input, tidal influences, or other factors.

Water depth—Benthic diatom taxa were recovered at all three localities. Like

other marine photosynthetic algae, benthic diatoms also require an adequate source of sunlight to survive. Wulff et al. (2005) found that marine benthic diatoms were able to photosynthesize in water depths up to 20 m. Eddsbagge (1968) suggests that *Grammatophora marina* (CCQ) resides in depths greater than 15 m; however, Andrews (1980) suggests that *G. marina* is found in shallow waters with depths from .61-1.52 m.

Temperature—*Paralia sulcata*, which is a dominant taxon at all three sites, prefer warm, coastal waters (Andrews 1979; Zong

1997). This is also true of *Biddulphia tuomeyi* (CCQ) (Andrews, 1979). However, *Actinopterychus senarius* (present at all three sites, and abundant at WSP and RMC) and *Thalassiothrix longissima* (abundant at CCQ) suggests a cool, coastal water environment (Andrews 1976; Andrews 1979). This mixed signal could indicate seasonal temperature fluctuations, or could be a result of cool water incursions into the Salisbury Embayment at the end of the Miocene Climatic Optimum (Böhme 2003; Wolfe 1994).

DISCUSSION

An interesting aspect to the samples from these three sites is the variation seen in the diatom floras, in spite of the physical proximity of the localities within the same depositional basin and their correlation (with the possible exception of WSP) to the same stratigraphic bed. All three sites include *Paralia sulcata* and *Melosira westii* among their dominant taxa. The differences between the sites are quite striking, however.

A total of 39 diatom taxa were identified among the three sites, yet only six of these (plus the silicoflagellate *Dictyocha crux*) were found in all three localities. This is not likely to be due solely to undersampling of rare taxa, as abundant and dominant taxa are also among the species that exhibit a limited distribution. For example, *Coscinodiscus radiatus* is dominant at WSP, yet was not identified at either other site. Likewise, *Grammatophora marina* was dominant, and *Terpsinoë americana* abundant, at CCQ yet neither was found in samples from the other localities. *Hyalodiscus laevis* and *Delphineis penelliptica* were dominant or abundant at

two localities and absent at the third. Of the 28 taxa identified from Carmel Church, 13 were found only at that locality. Five taxa were unique to WSP, and two to RMC.

The high degree of apparent endemism is possibly in part an artifact of the small sample sizes used in this study; for example, even though thirteen taxa were only found at CCQ in these samples, all of those taxa have been reported from other Calvert localities in previous studies. However, these data indicate that there are important differences in the relative abundance of diatom taxa between these localities.

The reasons for these abundance differences are not clear. Diatom floras can show significant seasonal fluctuations (Caroppo, 2000). It is also likely that local microenvironments may have varied enough across the Salisbury Embayment to have a measurable effect on the diatom flora. A more detailed and larger-scale comparison of diatom floras between different Chesapeake Group localities will likely produce useful data for developing a detailed environmental model of the Salisbury Embayment.

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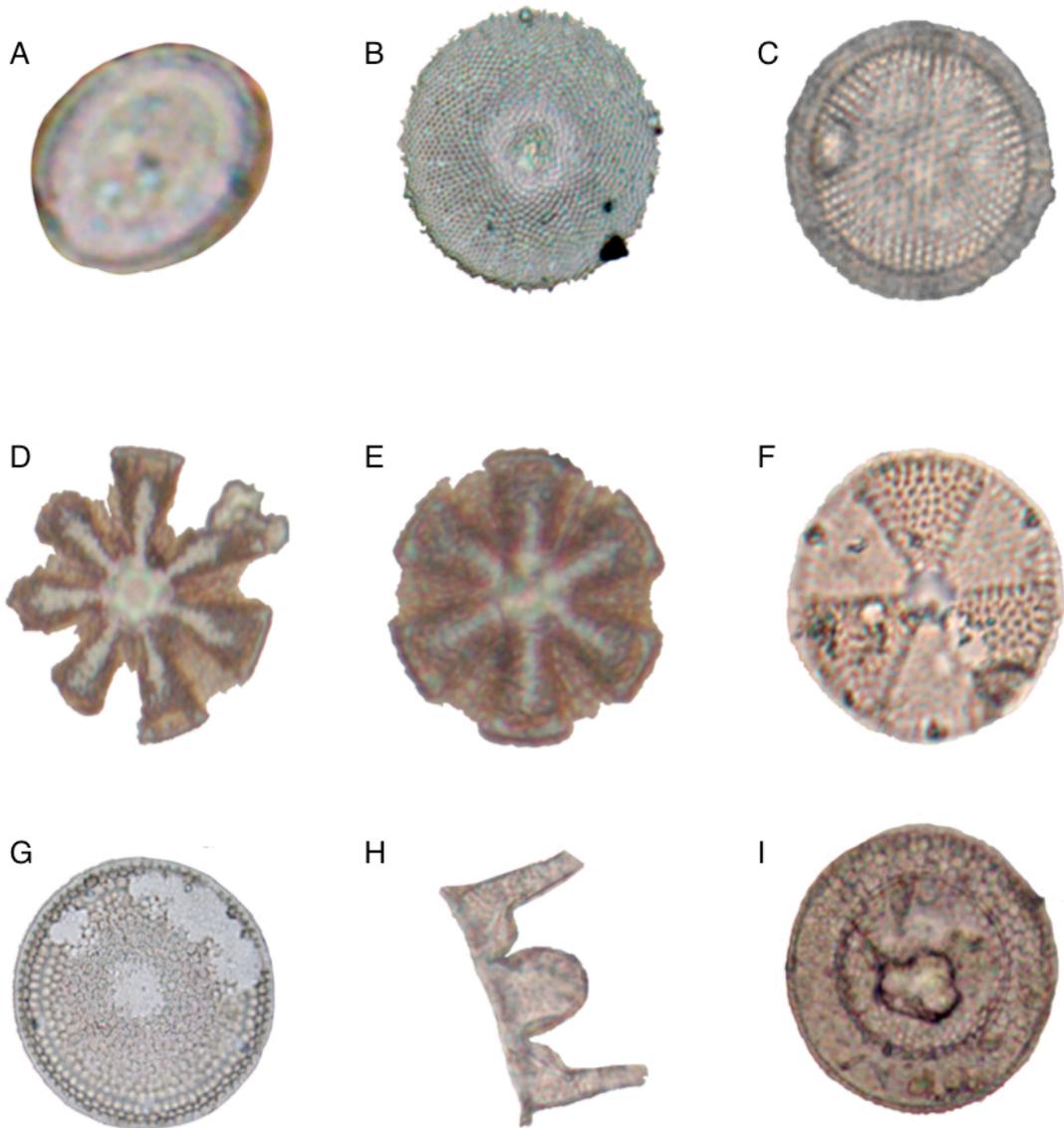


Plate 1. Diatoms from the Carmel Church Quarry (CCQ), Calvert Formation, Plum Point Member, Bed 15. A, *Actinocyclus ellipticus* var. *javanicus*. B, *Actinocyclus octonarius*. C, *Actinocyclus robustus*. D, *Actinoptychus virginicus*. E, *Actinoptychus marylandicus*. F, *Actinoptychus senarius*. G, *Aulacodiscus crux*. H, *Biddulphia toumeyi*. I, *Craspedodiscus coscinodiscus*.

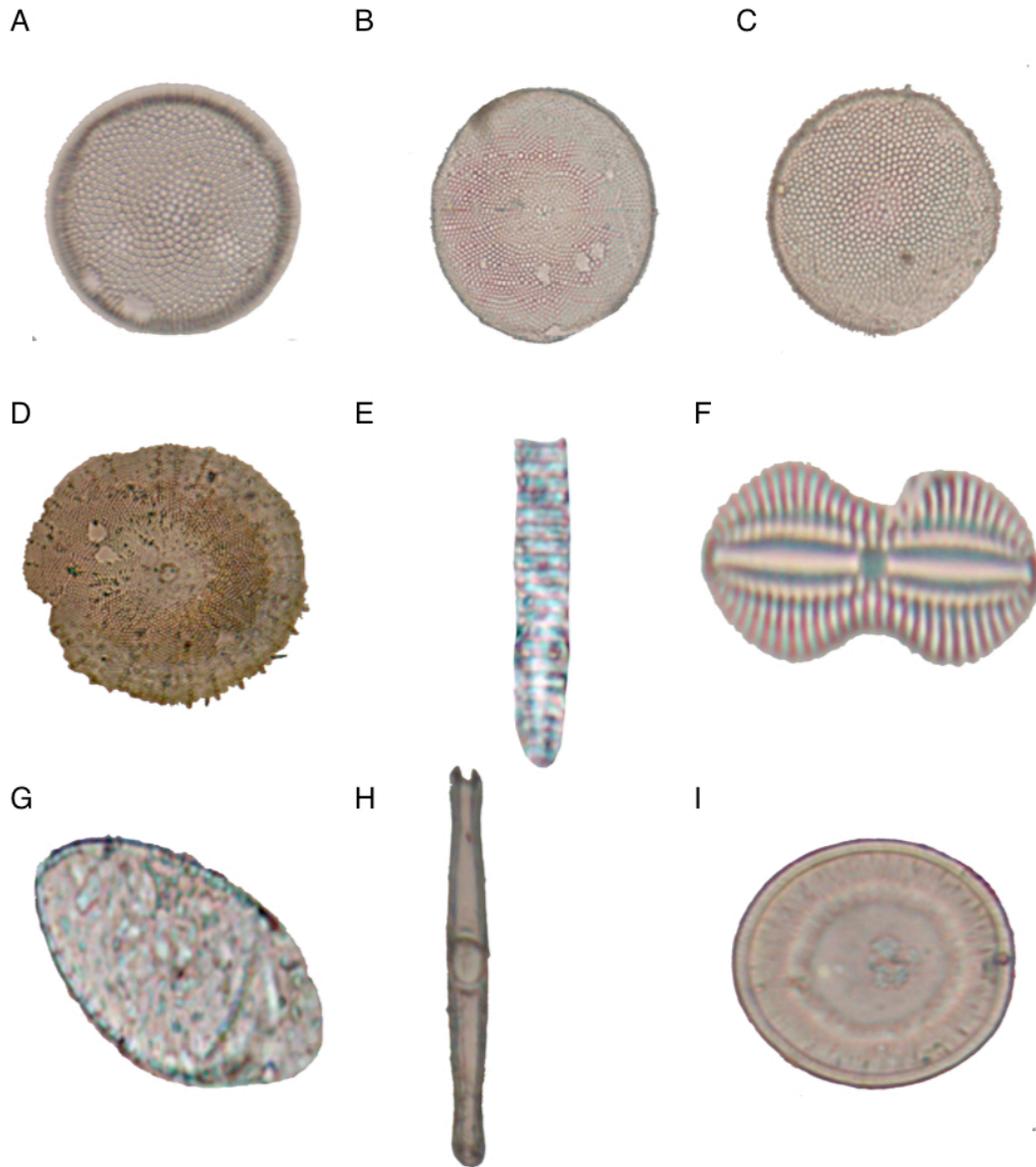


Plate 2. Diatoms from the Carmel Church Quarry (CCQ), Calvert Formation, Plum Point Member, Bed 15. A, *Coscinodiscus marginatus*. B, *Coscinodiscus perforatus* var. *cellulosa*. C, *Coscinodiscus perforatus*. D, *Coscinodiscus rothii*. E, *Delphineis biseriata*. F, *Diploneis crabro*. G, *Goniothecium rogersii*. H, *Grammatophora marina*. I, *Hyalodiscus laevis*.

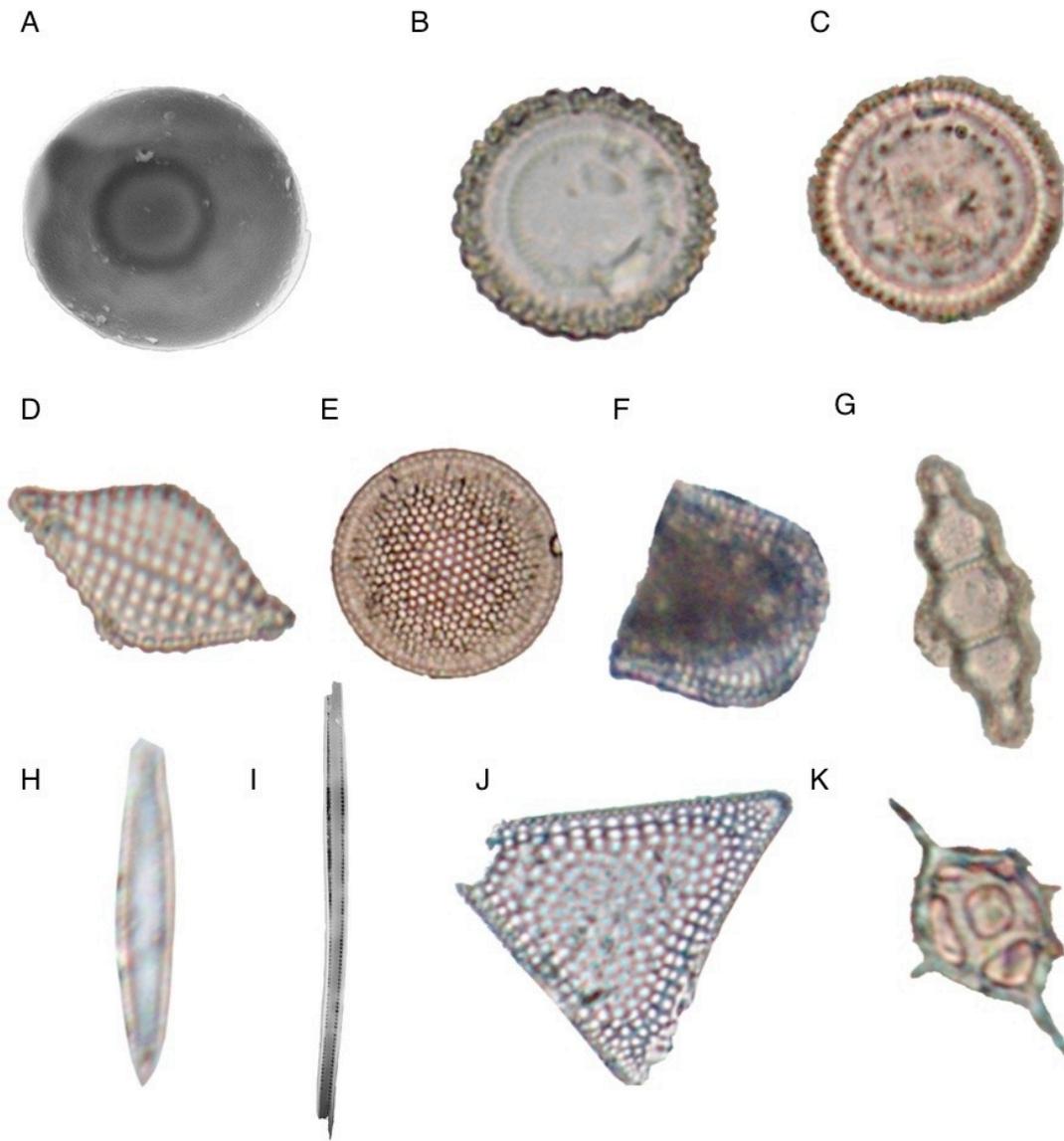


Plate 3. Diatoms and silicoflagellates from the Carmel Church Quarry (CCQ), Calvert Formation, Plum Point Member, Bed 15. A, *Melosira westii*. B, *Paralia sulcata*. C, *Paralia sulcata* var. *coronata*. D, *Rhapsoneis gemmifera*. E, *Stephanopyxis grunowii*. F, *Stephanopyxis turris*. G, *Terpsinoë americana*. H, *Thalassionema obtusa*. I, *Thalassiothrix longissima*. J, *Triceratium condecorum*. K, *Dictyocha crux*.

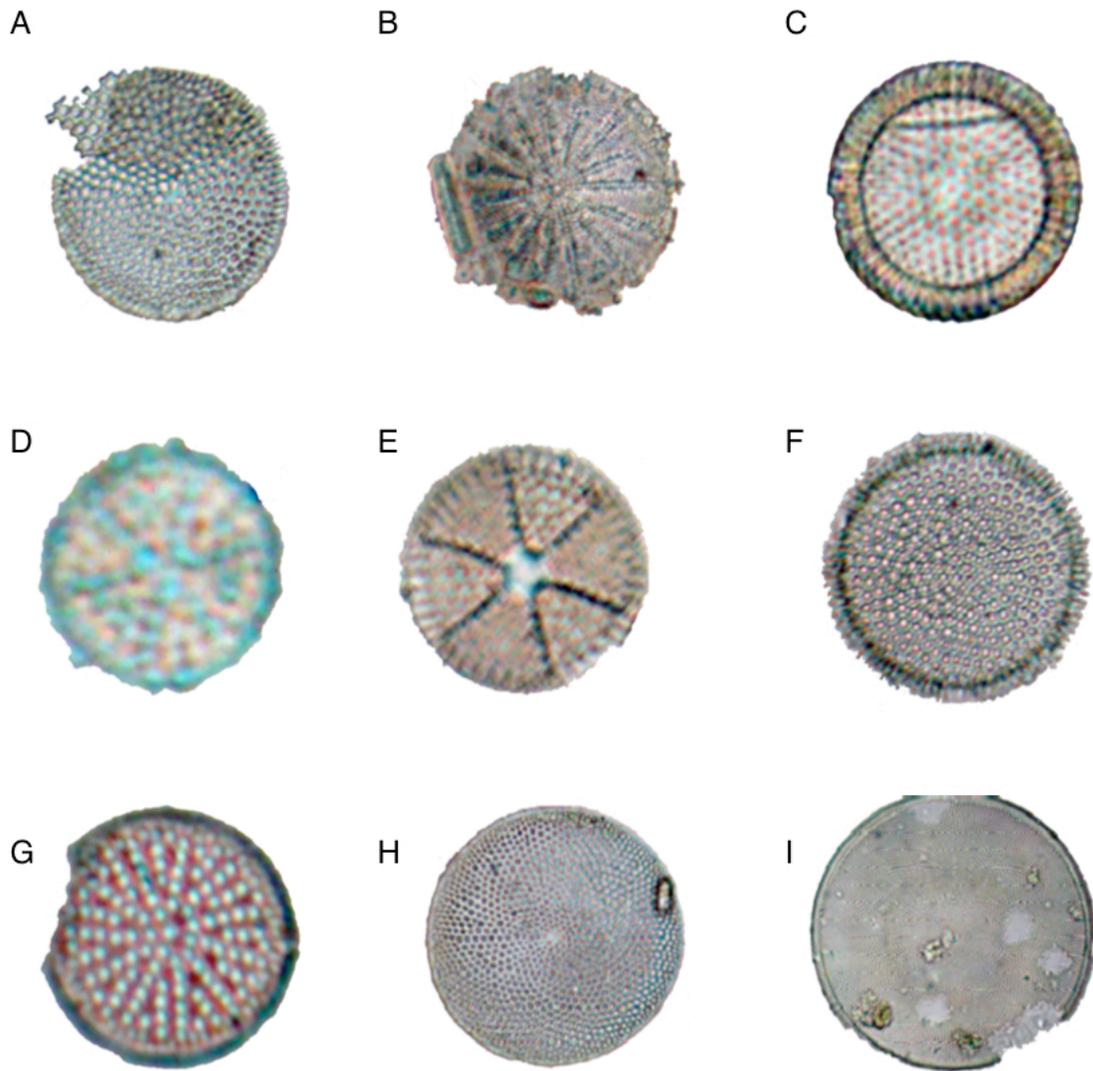


Plate 4. Diatoms from Westmoreland State Park (WSP), Calvert Formation, Plum Point Member, Beds 12-15. A, *Actinocyclus ingens*. B, *Actinocyclus octonarius*. C, *Actinocyclus robustus*. D, *Actinoptychus tenellus*. E, *Actinoptychus senarius*. F, *Coscinodiscus marginatus*. G, *Coscinodiscus praeyabei*. H, *Coscinodiscus radiatus*. I, *Coscinodiscus rothii*.

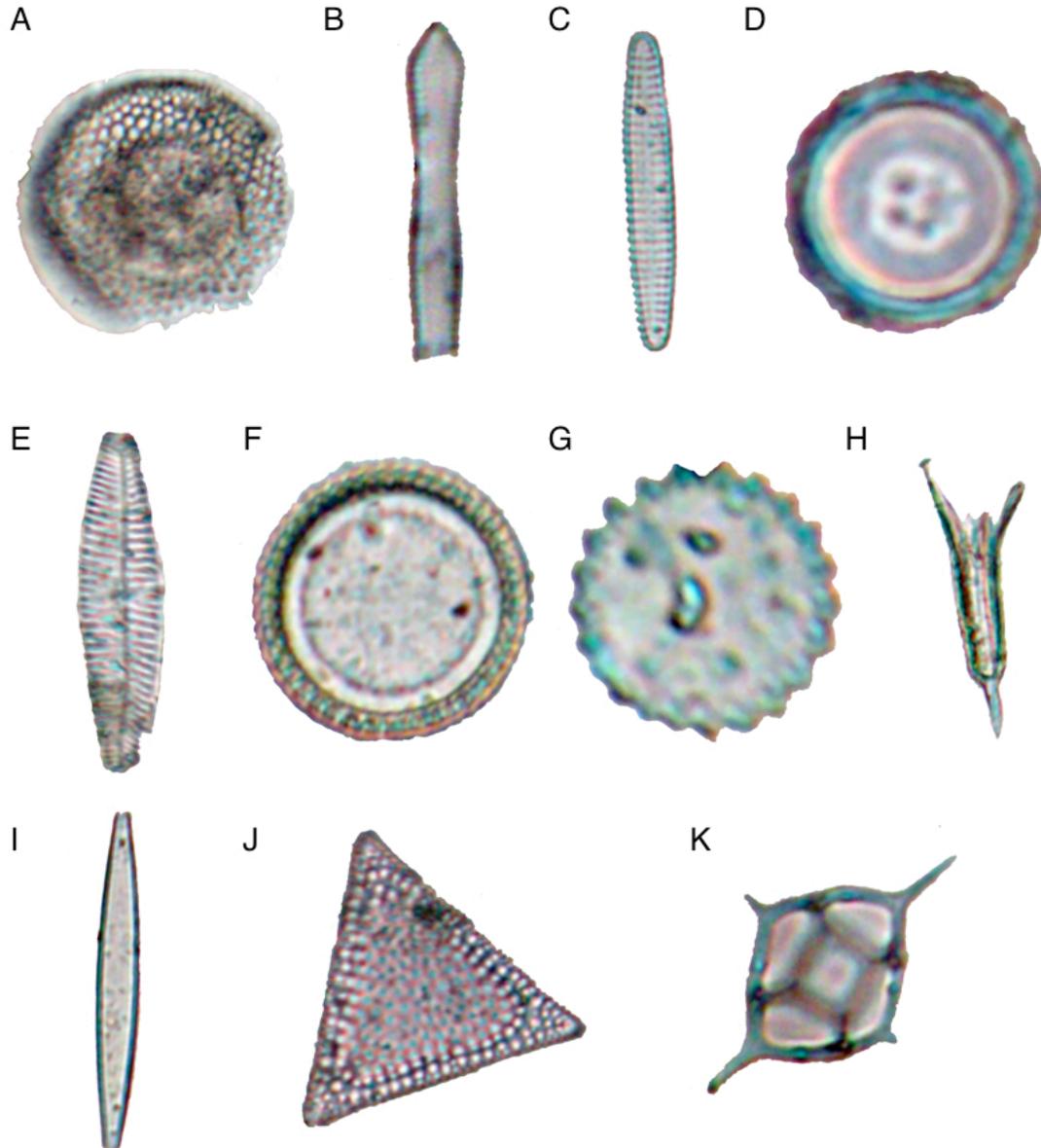


Plate 5. Diatoms and silicoflagellates from Westmoreland State Park (WSP), Calvert Formation, Plum Point Member, Beds 12-15. A, *Craspedodiscus coscinodiscus*. B, *Delphineis novaecaesaraea*. C, *Delphineis penelliptica*. D, *Melosira westii*. E, *Navicula pennata*. F, *Paralia sulcata*. G, *Paralia sulcata* var. *coronata*. H, *Rhizosolenia miocenica*. I, *Thalassionema obtusa*. J, *Triceratium condecorum*. K, *Dictyocha crux*.

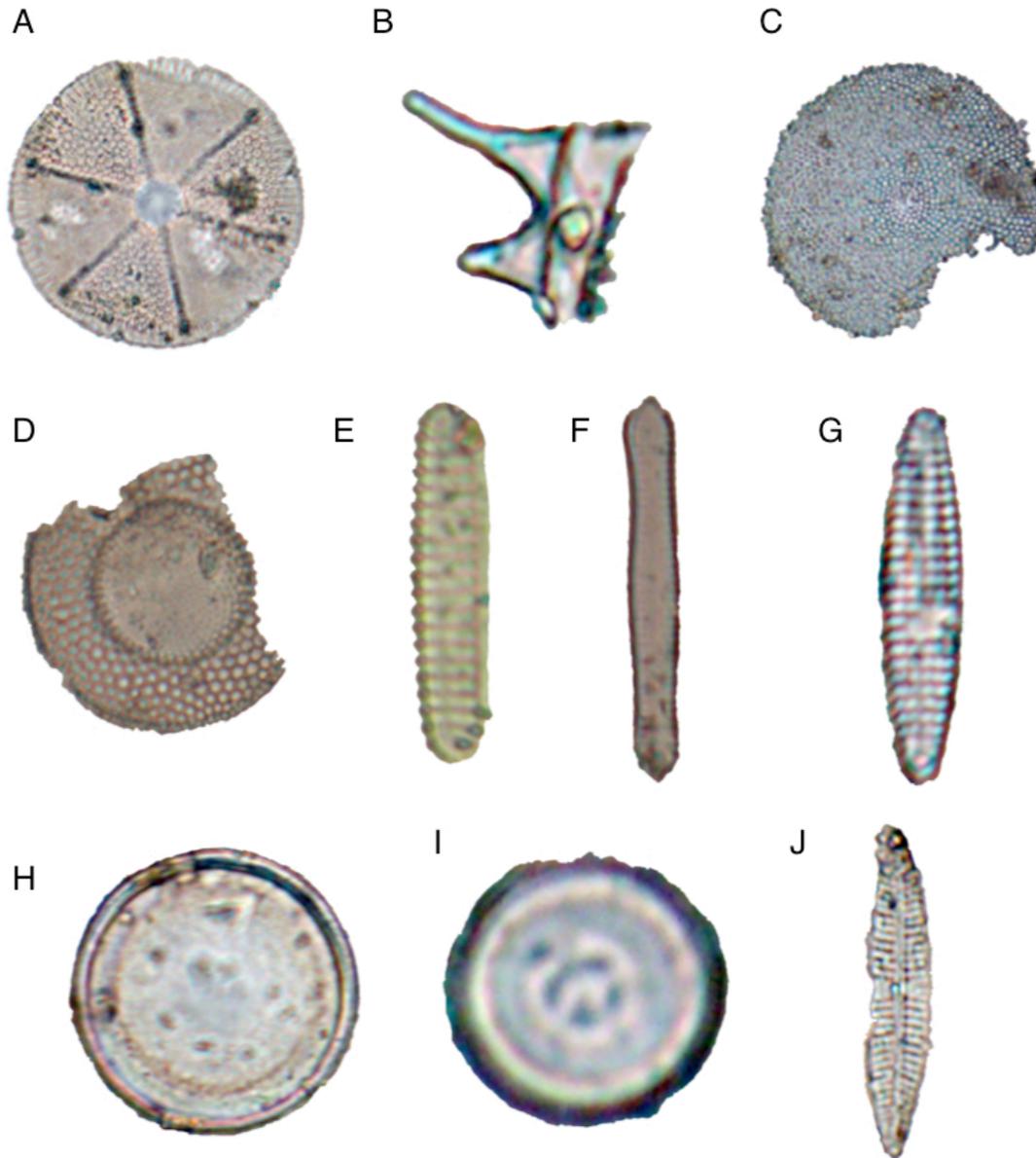


Plate 6. Diatoms from the Rappahannock River in Richmond County (RMC), Calvert Formation, Plum Point Member, Bed 15. A, *Actinoptychus senarius*. B, *Chaetoceros lorenzianum*. C, *Coscinodiscus perforatus*. D, *Craspedodiscus coscinodiscus*. E, *Delphineis biseriata*. F, *Delphineis novaecesaraea*. G, *Delphineis penelliptica*. H, *Hyalodiscus laevis*. I, *Melosira westii*. J, *Navicula pennata*.

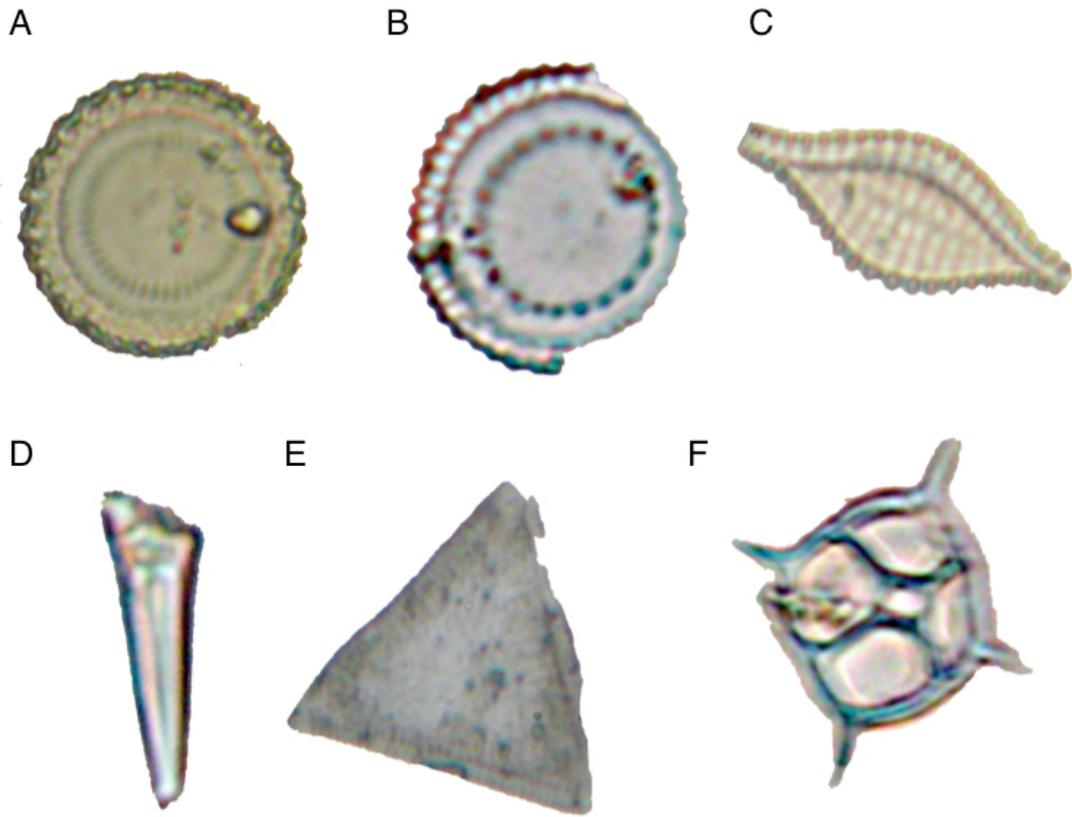


Plate 7. Diatoms and silicoflagellates from the Rappahannock River in Richmond County (RMC), Calvert Formation, Plum Point Member, Bed 15. A, *Paralia sulcata*. B, *Paralia sulcata* var. *coronata*. C, *Rhaphoneis gemmifera*. D, *Rhizosolenia styliformis*. E, *Triceratium condecorum*. F, *Dictyocha crux*.

Parts published to date

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