Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 30

NEW DATA BEARING ON THE STRUCTURAL SIGNIFICANCE OF THE UPPER CHESAPEAKE BAY MAGNETIC ANOMALY

by
Jonathan Edwards, Jr. and Harry J. Hansen

prepared in cooperation
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Maryland Energy and Coastal Zone Administration
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NEW DATA BEARING ON THE STRUCTURAL SIGNIFICANCE OF THE UPPER CHESAPEAKE BAY MAGNETIC ANOMALY

By

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ABSTRACT

Three test borings have been drilled to basement in the upper Chesapeake Bay area of Maryland to clarify the structural significance of a deep, flat, low magnetic anomaly bordered on the southeast by a steep, northeast-striking linear magnetic gradient. This magnetic pattern has previously been modeled as an abnormally thick Coastal Plain half graben bordered on the southeast by a normal or high-angle reverse fault.

Boring HAR-Dg3 was drilled in Harford County on Spesutie Island, west of the linear magnetic feature but within the low magnetic anomaly. Borings CE-Dc2 at Turkey Point and CE-Ec17 on Grove Neck, both in Cecil County, were drilled east of the magnetic gradient in an area dominated by a series of closed high and low magnetic anomalies.

Boring HAR-Dg3 encountered saprolite at an elevation of about -700 feet, which conforms reasonably well to the regional dip of the basement surface as projected from the Fall Zone and does not indicate an unusually deep basin. Boring CE-Ec17, located on the alleged up-thrown block of the proposed fault, penetrated basement at an elevation of about -1,020 feet, again conformable to the regional dip. The average slope of the basement surface between Spesutie Island and Grove Neck is approximately 88 feet per mile, a figure that is incompatible with major vertical offset of the basement surface between the two sites. Boring CE-Dc2 encountered basement about 50 feet higher than estimated from projection of the regional dip. However the unusual thickness of saprolite at this site, about 118 feet, suggests the occurrence of a buried hill on the basement surface.

Data obtained from the Cretaceous Coastal Plain strata indicate that faulting penecontemporaneous with sedimentation seems unlikely insofar as the direction of depositional transport characteristic of palynostratigraphic Zone I (Patuxent Formation) and Subzone IIB (Patapsco Formation) is roughly normal to the trend of the magnetic gradient. Broadly similar lithologic packages occur on both sides of the alleged fault trend without abrupt thinning or lithofacies change. The apparent absence of Zone III (Elk Neck Beds) of the Patapsco Formation west of the anomaly further diminishes any likelihood of a down-faulted Coastal Plain basin at the Spesutie Island test site.

The basal 17 feet of core recovered at Spesutie Island is a coarse-grained felsic gneiss similar to gneisses such as the Port Deposit Gneiss in the adjacent exposed Piedmont. This is overlain by chloritic greenstone and greenstone saprolite which resembles the Gilpins Falls member of the James Run Formation in Cecil County. There is a reasonable possibility that the large, flat low magnetic anomaly beneath the Upper Chesapeake Bay is the magnetic signature of the felsic gneiss cored at Spesutie Island, and that the small-amplitude irregularities associated with the western flank of the low anomaly are caused by infolds of the James Run Formation within the gneiss terrane.

Both of the Cecil County test borings cored schistose rocks in the area east of the linear magnetic feature. These rocks are correlated with the pelitic gneiss facies of the Wissahickon Formation. Ultramafic and mafic rocks may be associated with the high magnetic anomalies elsewhere in this terrane but none were encountered in these two test borings.

Evidence of a post-metamorphic shear zone within the basement was found at Grove Neck where the schist in the core is extensively mylonitized. Mild cataclastic effects are also present in the Spesutie Island core. However, there is no clear-cut relationship of the rocks at these two sites with the linear magnetic gradient beneath the Upper Chesapeake Bay. Fresh bedrock beneath the thick saprolite mantle at Turkey Point showed no evidence of cataclassis, although of the three test borings this was nearest to the alleged fault. It is concluded that the magnetic anomaly pattern in the upper Chesapeake Bay area largely reflects magnetic susceptibility contrasts within the basement complex. Faults undoubtedly exist within the buried basement complex, but there is no evidence of any significant (greater than 50 feet) displacement of the basement surface in this area since the onset of sedimentation in Early Cretaceous time.

INTRODUCTION

On the recently compiled Aeromagnetic Map of Maryland (Zietz and others, 1978), the upper Chesapeake Bay area is characterized by a deep, low magnetic anomaly bordered on the southeast by a steep magnetic gradient (Fig. 1). This gradient extends in a nearly straight line for a distance of about 25 miles from western Kent County to central Cecil County, and is clearly the most prominent magnetic feature of the region. Higgins and others (1974a, p. 75) have proposed that this gradient is a result of "a normal or high-angle reverse fault zone that juxtaposed mafic and ultramafic plutonic rocks on the southeast with Baltimore Gneiss on the northwest." They further proposed "that an abnormal thickness of nonmagnetic sedimentary rocks underlies the upper part of the Chesapeake Bay in the area of the low magnetic anomaly northwest of the fault zone." The absence of distinctive magnetic signatures attributable to diabase or basalt dikes and sills led Higgins and others (1974a, p. 75) to conclude that "a thickened basin of Coastal Plain rocks rather than a Triassic basin" was responsible for the deep magnetic low. In response to comments by Hansen (1974) concerning the age of the fault, Higgins and others (1974b, p. 450) restated their belief that the faulting had offset Coastal Plain sediments and that "continuing movement along the fault zone seems to be a real possibility." Following this argument, they concluded that the course of the ancestral Susquehanna River (the present Upper Chesapeake Bay) was probably predetermined by either continuing movements along the fault zone, differential compaction across the fault zone, or differential erosion along a fault-line scarp.

If the speculations of Higgins and others (1974a, 1974b) are correct, the Upper Chesapeake Bay magnetic anomaly may define a "capable fault" in the engineering sense (U.S. Atomic Energy Commission, 1973, p. 238a). Because "capable faults" influence design criteria for nuclear power plants located within a 200-mile radius, additional ground-truth data were needed to evaluate the structural significance of the anomaly. For this reason, three new test borings were drilled to evaluate the structural implications of the Upper Chesapeake Bay magnetic anomaly. The borings were sited on land, one on the Western Shore and the other two on the Eastern Shore, in a triangular pattern with the legs ranging in length between 3.25 and 3.75 miles (Fig. 2). A closer spacing would have required drilling from barges within a major shipping channel, which would have presented logistical problems exceeding the scope of the project.

The purpose of this drilling program was threefold: (1) to establish, either with cores or geophysical logs, the elevation of the Coastal Plain-basement rock contact at sites on both the up-thrown side and the down-thrown side of the alleged fault, (2) to identify, using biostratigraphic correlations and geophysical logs, any sedimentary or stratigraphic anomalies occurring within the Cretaceous Potomac Group that might be suggestive of penecontemporaneous or later faulting, and (3) to core basement rocks so that the magnetic signatures associated with the linear anomaly could be correlated with lithology. In the authors' judgement these three test borings constitute a fair test of the speculation by Higgins and others (1974a, p. 73) that the Upper Chesapeake Bay magnetic anomaly represents a border fault which separates a down-dropped basin with thickened Coastal Plain section from an up-thrown block of basement rocks.

ACKNOWLEDGEMENTS

The authors' wish to acknowledge the following organizations and persons for services rendered during the Upper Chesapeake Bay area core drilling project: Sprague and Henwood, Inc., test drilling contractor; Elliot Geophysical Company, magnetic susceptibility measurements; Core Laboratories, Inc., acoustic velocity tests; U.S. Geological Survey Water Resources Division, geophysical logging; and Dr. James A. Doyle of the University of California (Davis) for palynological analyses.

The drilling contract was administered through the Maryland Department of General Services with the assistance of Frank Kowalewski. Drilling funds were provided by the Maryland Power Plant Siting Administration, Paul Massicot, Director. Well site logistics were provided by R. Page Jett and Richard Mandle during parts of the project.

Drafts of the report were technically reviewed by Kenneth N. Weaver, John D. Glaser, William P. Crowley, and Karen R. Kuff of the Maryland Geological Survey.

TEST DRILLING PROGRAM

Test boring HAR-Dg2,3 (Table 1) was drilled on the eastern shoreline of Spesutie Island near Sandy Point. The island, which is not outlined on the map of Higgins and others (1974a, Fig. 2), occupies a position within the deep, flat low magnetic anomaly. The drill site itself (elevation about 12 feet[1], lat. 39°26′43″N, long. 76°04′15″W) is located adjacent to the lowest closed magnetic contour, but is not within it.

The drilling operation was begun in August 1976 by Sprague and Henwood, Inc.[2], project drilling contractor, and concluded in November 1976. Because this site was located within the U.S. Army Aberdeen Proving Ground, drilling activity was restricted to the hours between 7:00 a.m. and 4:00 p.m. Boring HAR-Dg2 was abandoned as a false-start at 86.5 feet when the bottom length of casing uncoupled and obstructed the hole. HAR-Dg3 was spudded as a redrill and reached total depth at 777 feet. Six 3″ split-spoon samples were obtained from the Coastal Plain section and were supplemented by drill cuttings and several bit samples (Table 1). Rotary coring commenced at 742 feet with no recovery until 746 feet. At least partial recovery was obtained on each core run thereafter, first using a standard double-tube 3-1/2″O.D. diamond-bit core barrel between 746 and 763 feet and then a NX (1-15/16″I.D.) wire-line core barrel to total depth. Relatively fresh, predominantly gneissic rock was recovered between 757 and 777 feet. Geophysical logs were run by the U.S. Geological Survey (Water Resources Division) from 86 to 767 feet and consisted of both single- and multi-point electrical resistivity logs and an open-hole gama-ray log.

Test boring CE-Dc2 (Table 2) was located in Elk Neck State Park near Turkey Point (elevation about 58 feet, lat. 39°27′16″N , long. 76°00′30″W). The site is on trend with a series of magnetic highs which define the up-gradient edge of the linear magnetic gradient (Fig. 1). Although off-crest, the site is located within an elliptical anomaly with a magnetic closure of about 1,000 gammas.

Drilling took place during December 1976 and January 1977. Seven 3″ split-spoon samples were taken from clayey Coastal Plain beds for microfloral evaluation. In addition, drill cuttings were systematically collected and bit samples were salvaged whenever possible. Rotary core drilling was initiated at 791 feet using a NX wire-line barrel. First recovery occurred at 848 feet in saprolitic schist. Thereafter, generally good recovery was achieved to the total depth of 936 feet with "fresh" schistose rock logged below 900 feet.

A single-point electric log was run by the U.S. Geological Survey in boring CE-Dc2 from 80 to 593 feet and from 825 to 935 feet. Surface casing and a stuck string of drill rods accounted for the missing intervals. A gamma-ray log was run from 6 to 935 feet with a casing-open hole break at 820 feet.

Borings CE-Ec15,16, and 17 (Table 3) were drilled on the northern shoreline of Grove Neck northeast of Grove Point (elevation about 8 feet, lat. 39°24′18″N, long. 76°01′30″W) at a former campground administrated by the Missionary Servants of the Most Holy Trinity. This site lies in a "saddle" which separates two small low magnetic anomalies in the area east of the linear magnetic gradient (Fig. 1).

Drilling took place during February, March, and April of 1977. In addition to four split-spoon samples, two HX (3-1/16″I.D.) wire-line core runs were made above basement in CE-Ec15, both with excellent recovery. The first was between 230 and 296 feet, the second from 500 to 700 feet. Unfortunately, during the retrieval of the lowermost core, the rods struck at 687 feet. Efforts to free the string resulted in a break at 510 feet, forcing an abandonment of the hole. The first redrill (CE-Ec16) was initiated by the Middletown Well Drilling Company under subcontract to Sprague and Henwood, Inc. CE-Ec16 was in turn abandoned at 718 feet in hard red clay when the drill rods twisted off at about 156 feet and "fishing" attempts failed to recover the drill string. The second redrill (CE-Ec17) successfully bottomed out at 685 feet. Middletown then moved off the hole, allowing Sprague and Henwood to set up and run 4″ casing to 687 feet. The hole was then carried to 1,020 feet using a 3-7/8″ tri-cone roller bit. Five 2″ split-spoon samples were selectively obtained within this interval. NX wire-line cor-

[1] Drill site elevations were not determined by leveling, but were estimated by interpolating between contours on U.S.G.S. 7½ minute topographic quadrangles.

[2] Contractors and trade names are identified for the record. No endorsement is intended.

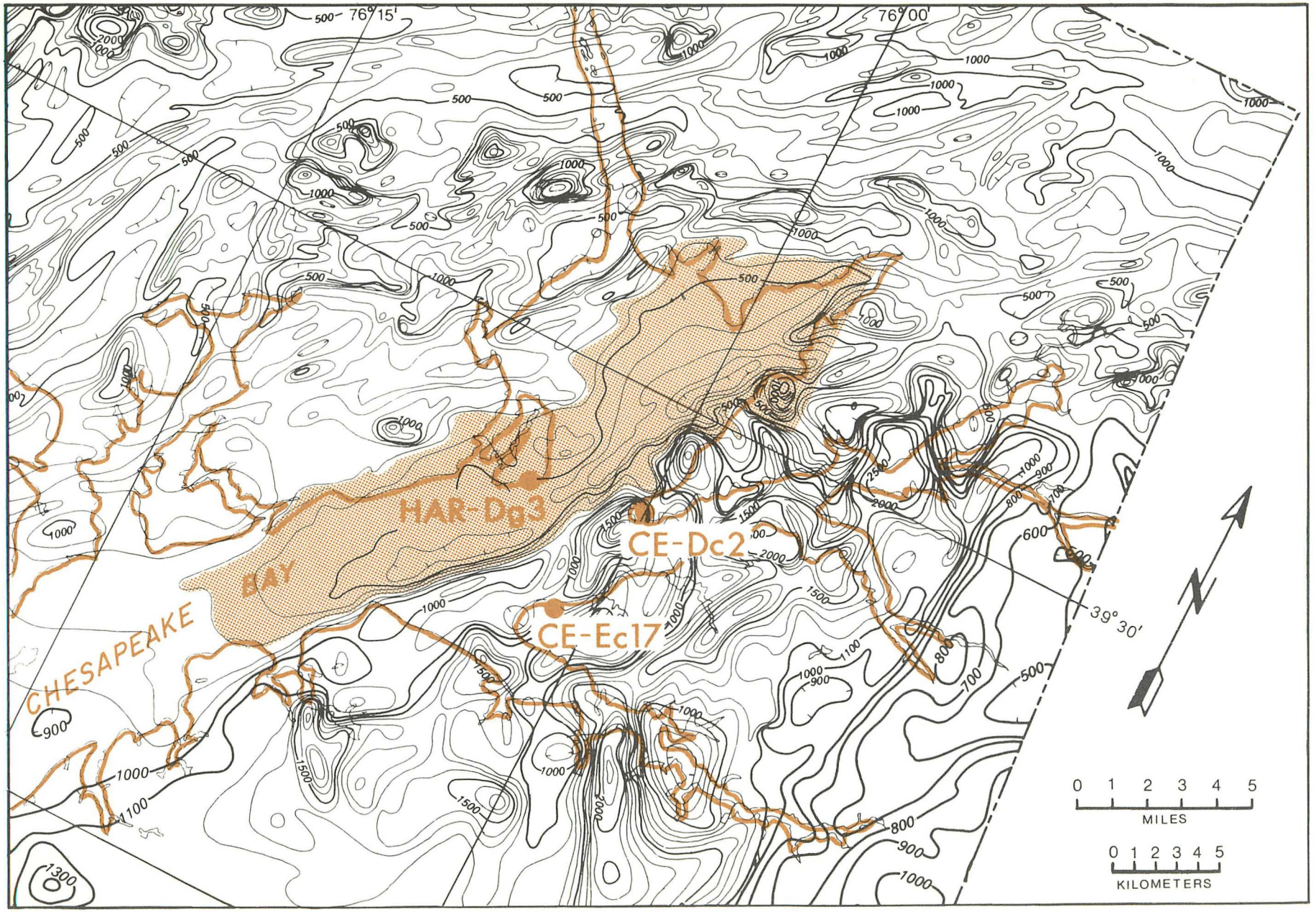


Figure 1. Aeromagnetic map of upper Chesapeake Bay area, showing locations of three test borings (modified after Zietz, Gilbert, and Kirby, 1978). Shaded pattern represents deep magnetic low area (below 700 gammas) of Higgins and others (1974a, Fig. 2).

ing commenced in basal Coastal Plain materials at 1,020 feet and continued to 1,107 feet, the total depth. At 1,028 feet partially decomposed schist, overlain by cobbly sediments, marked the basement contact. Beginning at about 1,080 feet, relatively fresh rock was cored.

A composite single-point electric log was obtained at the Grove Neck site. The first run was made to 686 feet in CE-Ec17 prior to setting casing in the second redrill. The second run logged the interval between 700 and 940 feet. The third run successfully logged 75 feet into the basement rocks before being obstructed at 1,103 feet. The gamma-ray log was run through casing to 686 feet and then open hole to 1,107 feet.

BASEMENT SURFACE

Core Hole Data

Of the three test borings the top-of-saprolite pick is most speculative in HAR-Dg3 chiefly because core recovery was restricted to relatively fresh rock in the basal 31 feet of the hole. The driller logged "sandy clay and small layers of ironstone" from 712 feet to 738 feet; at 738 feet "decomposed rock" was encountered. The driller described these intervals using indirect rig performance criteria, inasmuch as the cutting returns were not diagnostic. The multipoint electric log strongly suggests, however, that the top of saprolite may occur as high as 712 feet (Table 1). The interval 712 feet to 758 feet is dominated by an 8 ohm-meters 64-inch normal resistivity curve, showing little separation from the 16-inch normal. On the other hand, up-hole Potomac Group clays characteristically record at least an 18 ohm-meter base line. Furthermore, in HAR-Dg3 sandy clays in the Potomac group exhibit sufficient textural stratification to cause separation due to mud infiltration or hole diameter effects. It is suspected that if the interval 712 to 738 feet was, in fact, "sandy clay" a similar curve separation would be evident on the electric log. The lack of separation of the 64-inch and 16-inch curves is much more suggestive of the dense, "sticky" greenish-gray, clayey saprolite first cored at 746 feet. The constancy of the electric log response between about 712 and 758 feet suggest strongly that the basal 12 feet are texturally representative of the entire interval. For this reason the top-of-saprolite surface in the HAR-Dg3 boring is picked at approximately 712 feet (elevation -700 feet). Core samples confirm the occurrence of hard, relatively fresh greenstone bedrock at 758 feet.

Saprolite thickness in boring HAR-Dg3 is about 46 feet, a value according closely with average depths of weathering measured in Piedmont rocks by Cleaves (1968, Table 2). The lack of any significant deviation from the average hampers association with a specific topographic element on the basement surface, although it would seem to eliminate a deeply entrenched stream valley or a sharply profiled hill.

In test boring CE-Dc2, the actual contact between sediment and saprolite was not cored, but both gamma-ray and drillers' log data indicate penetration of saprolite at about 785 feet (elevation -727 feet). The contact is evident as a low to high shift on the gamma-ray log. A more obvious kick occurs at 820 feet, but this break is caused chiefly by a change from a cased hole to an open hole. First core recovery at 848 feet shows the saprolite to be an orange-red, highly micaceous, dense clayey material with relict quartz veins. This massive saprolite grades downward into structured material ranging from decomposed to fresh schist. The uniform, relatively high gamma-ray log curve recorded through the massive saprolite, structured saprolite, and fresh rock may be attributed to the consistently micaceous (muscovite-biotite) character of the formation.

Fresh rock was first logged at 898 feet, which correlates reasonably well with a high resistivity kick recorded on the electric log at about 903 feet. These data suggest that the saprolite-decomposed rock which mantles the basement at the Turkey Point site is in the range of 113 to 118 feet thick. Furthermore, much of this section is strongly oxidized which suggests topographic relief during the weathering process. An upland or rounded hilltop setting is implied with saprolitization accentuated, perhaps, along the steeply dipping foliation planes. There is no evidence, however, that the thick saprolite mantle cored in CE-Dc2 is associated with an intensely jointed or faulted zone.

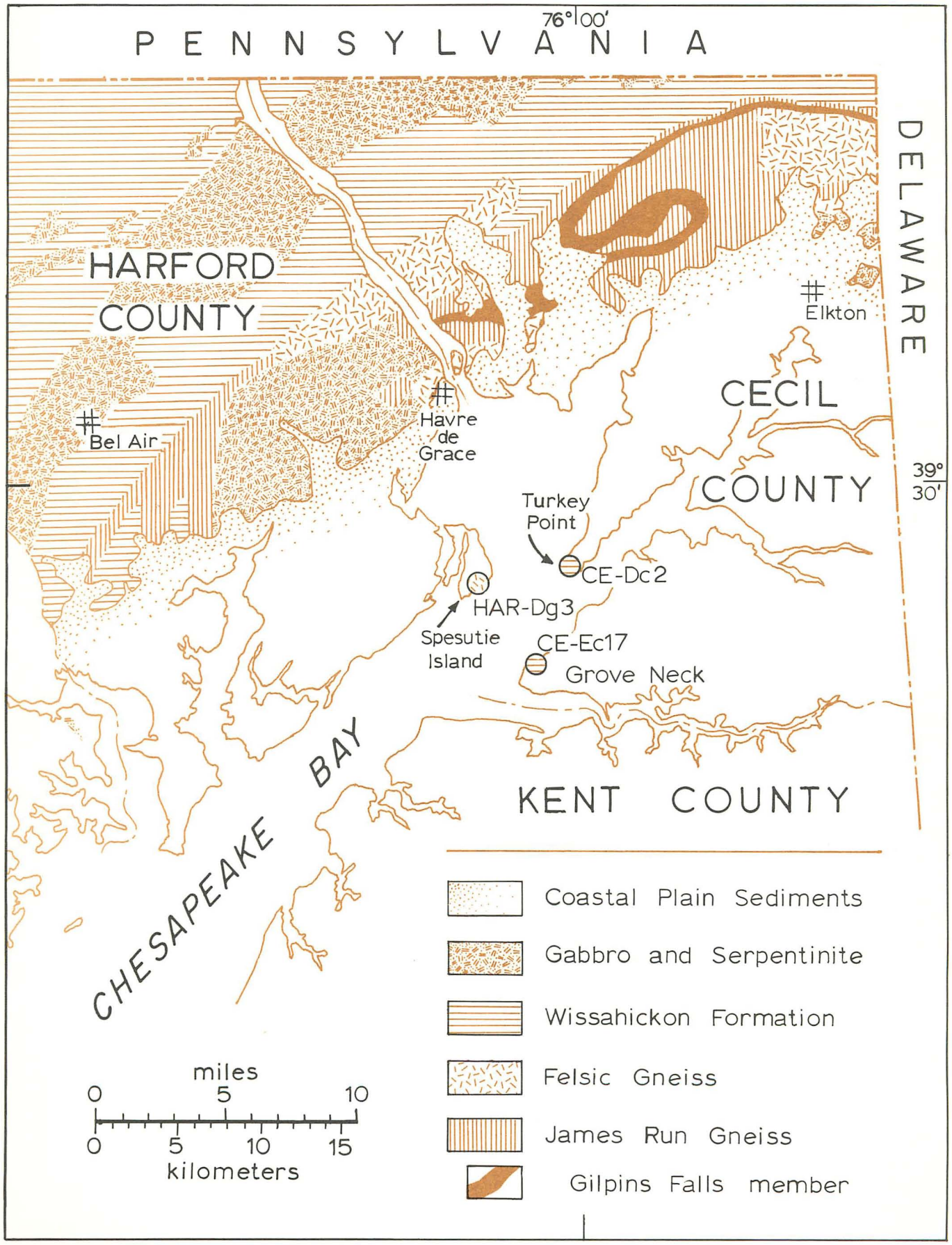


Figure 2. Generalized geologic map of the upper Chesapeake Bay area (modified after Higgins, 1973).

The basement in boring CE-Ec17 was encountered in a core run between 1,026 and 1,032 feet. Sample recovery consisted of four inches of quartzose cobble fragments and eight inches of weathered micaceous schist. The driller picked the contact at 1,028 feet (elevation -1,020 feet) which conforms to high kicks on the gamma-ray and electrical resistivity logs.

The thick clayey mantle of oxidized saprolite characteristic of the basement rocks in CE-Dc2 is not present in CE-Ec17. The occurrence of a six-foot cobbly bed immediately above bedrock suggests a high energy stream channel environment from which saprolite and decomposed rock were eroded. Basement core recovered from the Grove Neck site is strongly sheared and mylonitized which is suggestive of erosively weak rock, perhaps subject to deep channeling. Therefore, the topographic setting during fluvial deposition of the basal Potomac Group may account for the absence of oxidized saprolite in CE-Ec17.

Local Relief

On regional structure contour maps the basement surface near the Fall Zone in Harford County dips southeasterly beneath the Coastal Plain at about 100 feet per mile. East of the Bay the dip flattens to about 75 feet per mile in lower Cecil and Kent Counties (e.g., Brown, Miller, and Swain, 1972, Plate 5). Detailed investigations have shown, however, that the basement surface is locally irregular. For example, Cleaves (1968, p. 26) mapped the buried saprolite surface along the Susquehanna Aqueduct and found local relief of as much as 100 feet beneath Potomac Group (Cretaceous) sediments. Similar observations were made by Owens (1969, p. 80) during construction of Highway I-95. Subsurface studies using bore-hole and/or seismic data have noted similar irregularities on the basement surface. Nutter (1977, Fig. 3a) contoured the thickness of the Coastal Plain in eastern Harford County from water well data and found channel fill sediments at the base of the section locally exceeding 125 feet in thickness. Spoljaric (1973, Figs. 2,3) studied the basement surface underlying a portion of New Castle County, Delaware and interpreted a series of 30- to 100-foot anomalies to be a cross-faulted graben structure. In nearby Kent County, Maryland, a seismic traverse illustrated by Hansen (1978, Fig. 20) exhibits two anomalies at the basement. Across one, the basement reflection appears offset by about 85 feet which the author interpreted as a high-angle fault; the second anomaly is a hummocky, but continuous feature, which is suggestive of an erosional hillock having relief of 50 feet or less.

Thus beneath the Coastal Plain local relief on the basement surface is probably the rule, rather than the exception. Although the above studies suggest that the relief is relatively minor (50 to 100 feet), it can result in locally abrupt changes in dip and strike (Nutter, 1977, Fig. 3a). It should be recognized, however, that the buried basement surface is difficult to map accurately in detail because of the variable thickness (0-150 feet) of weathered rock (saprolite) which mantles the fresh crystalline rock (Cleaves, 1968, Froelich, 1975). Routinely obtained drillers' logs and cuttings should be used with caution because it is often problematic whether the "top-of-rock" pick is, in fact, a cobble bed in the basal Coastal Plain, top of saprolite, resistant material within the saprolite, or top of fresh rock. Cores and geophysical logs are necessary to make these distinctions, as well as to calibrate the complex basement wavelet often observed on seismic reflection records. A series of synthetic seismograms illustrated by Hansen (1978, Fig. 6) suggests that variations in saprolite thickness can generate a complex basement signature capable of lateral attenuation and phasing. For this reason a consistent top-of-saprolite pick is difficult to establish accurately and may lead to the superposition of "pseudo-relief" on regional dip.

Regional Contour Map

A generalized contour map of the basement surface in the upper Chesapeake Bay region (Fig. 3) was prepared incorporating data from the three project core holes. Additional data points were established using published or open-file well records (Bennett and Meyer, 1952; Overbeck and Slaughter, 1958; Nutter and Smigaj, 1975; and Nutter, 1978) and seismic reflection profiles (Hansen, 1978). To contour local relief accurately on the basement surface, closely spaced, "full data" bore holes would be required preferably tied together by a network of calibrated geophysical (e.g., seismic) profiles. Such detailed mapping of the local basement

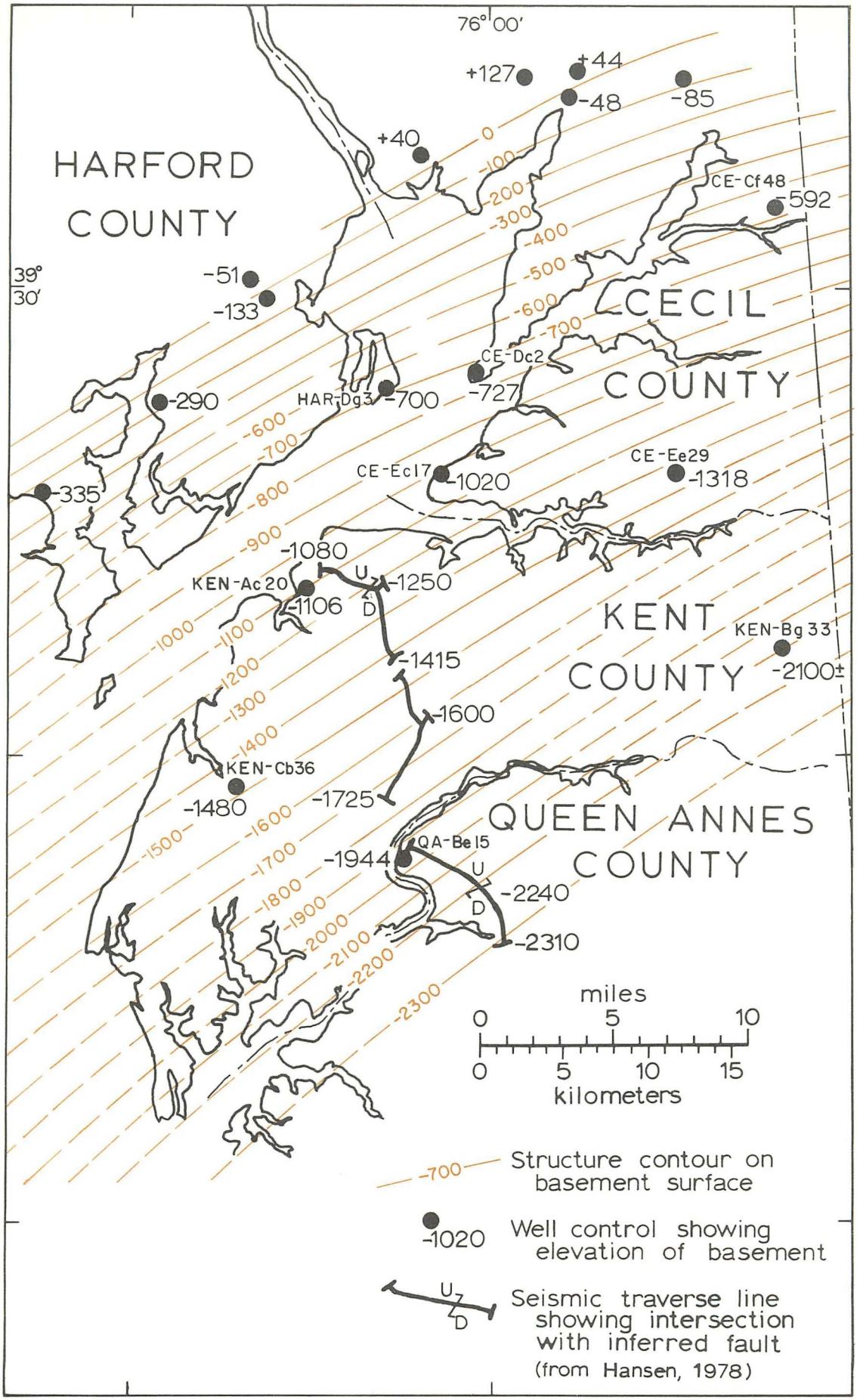


Figure 3. Generalized structure contour map of the upper Chesapeake Bay area showing altitude of the top-of-basement rock surface without faulting.

topography was not considered necessary in order to test whether or not the magnetic anomaly was structurally controlled, because, as Dobrin (1976, p. 535) implies, a magnetic relief of 1,500 gammas would require an offset of considerable magnitude in the basement surface. The authors consider that any offset of the basement surface with a magnitude greater than 50 vertical feet between the three control points would be mappable within the resolution of the data.

A reasonable depiction of the basement surface can be accomplished in the vicinity of the upper Chesapeake Bay magnetic anomaly without recourse to abrupt changes in strike or dip (Fig. 3). Boring HAR-Dg3, located on Spesutie Island, was drilled in a deep magnetic low which Higgins and others (1974a) modeled as an abnormally thick sedimentary basin. However, basement at this site, rather than being unusually deep, conforms reasonably closely to the regional dip of 100 feet per mile projected from the Fall Zone (Fig. 4). Furthermore, boring CE-Ec17, which was sited on the "up-thrown block" of the fault proposed by Higgins and others (1974a), penetrated basement at an elevation of -1,020 feet; hence the down-dip gradient of the top-of-basement surface between Spesutie Island (HAR-Dg3) and Grove Neck (CE-Ec17) is approximately 88 feet per mile, again reasonably conformable to regional dip (Fig. 4). Thus if a thick Coastal Plain basin exists between Spesutie Island and Grove Neck, it must occur as a narrow graben-like structure faulted into crystalline basement without disruption of the overall regional strike and dip, an unlikely structural interpretation in the judgement of the authors.

Admittedly, basement in the Turkey Point boring (Ce-Dc2), was penetrated higher than a simple projection of regional contours would suggest. By itself, however, this should not be accepted as evidence for Coastal Plain faulting. Indeed, the occurrence of a thick, oxidized mantle of clayey saprolite at the site suggests that the boring penetrated a relict hilltop on the lower Cretaceous Piedmont surface. If so, the rather minor deviation of the site from regional trends can be accounted for less speculatively by local relief on the basement surface. If a fault interpretation is inferred from the data, an offset of no more than 25 to 50 feet seems possible (Fig. 5).

POTOMAC GROUP STRATIGRAPHY

Upper Chesapeake Bay Region

The nonmarine Potomac Group of the upper Chesapeake Bay area consists largely of a thick, complexly interbedded sequence of unconsolidated sands and clays. The Potomac Group is the basal Coastal Plain unit in the study area and includes strata of both Lower Cretaceous (Barremian (?), Aptian, Albian) and Upper Cretaceous (Cenomanian) age (Doyle and Robbins, 1977, Fig. 2). As is often characteristic of fluvial sediments, the Potomac Group exhibits great lateral variation which makes lithostratigraphic correlation beyond a single outcrop or cluster of bore holes very difficult (e.g., Jordan, 1970). For this reason recent workers (e.g., Southwick and Owens, 1968; Higgins and Conant, map in prep.) have mapped the Potomac Group undivided rather than using the formational units (Patuxent, Arundel, Patapsco) present in the Baltimore-Washington type region (Brenner, 1963; Hansen, 1968; Crowley, Reinhardt, and Cleaves, 1976). Subdivision of the Potomac Group in its type region is facilitated by the occurrence of the Arundel Clay.

Although the absence of a mappable Arundel Clay northeast of Baltimore County is conceded by most workers, Jordan (1968) has demonstrated that informal lithostratigraphic units based on sand/clay ratios can be recognized in northern Delaware. Similarly, hydrologic studies by Sundstrom and others (1967) and Sundstrom and Pickett (1971) in the same area demonstrated the occurrence of a laterally extensive confining (clayey) bed separating hydraulically discrete aquifers. It is the authors' opinion that similar relationships prevail in adjacent Maryland and that a broad lithostratigraphic zonation is possible, particularly in the subsurface where hundreds of feet of section are available for correlation.

Doyle and Hickey (1976) and Doyle and Robbins (1977), modifying the palynological zonation first offered by Brenner (1967), have subdivided the northern Delaware Potomac Group sequence into several biostratigraphic

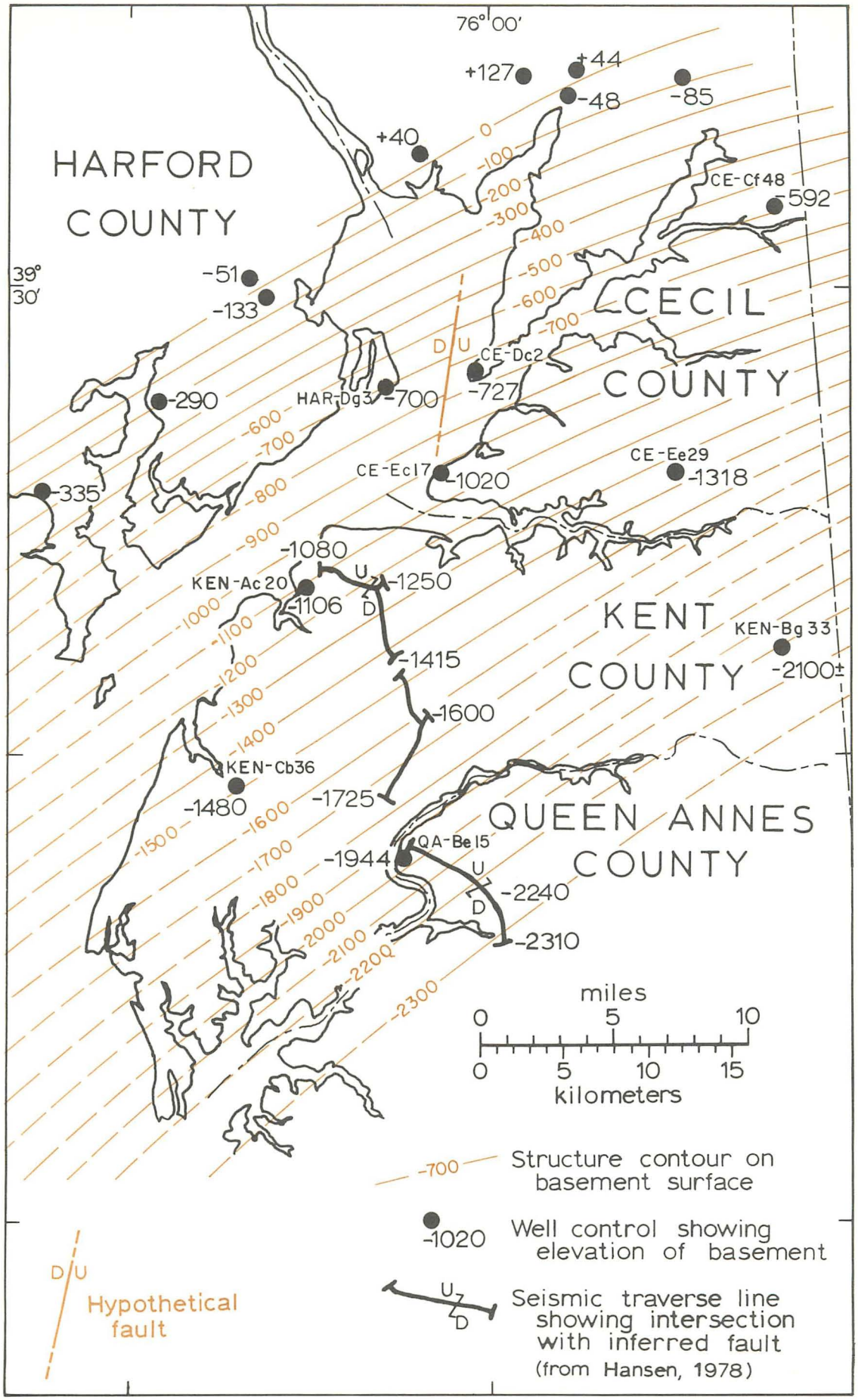


Figure 5. Generalized structure contour map of the upper Chesapeake Bay area showing altitude of the top-of-basement rock surface with fault interpretation.

zones (Fig. 6). Zone I ranges in age from Barremian (?) —Aptian to early Albian and corresponds to the Patuxent Formation and Arundel Clay at their type locality in Southern Maryland. Albian age Subzones IIA and IIB strata in the Delaware section correlate biostratigraphically with the Patapsco Formation of Southern Maryland studied by Brenner (1963). Beds assigned to Subzone IIC (late Albian) and Zone III (early Cenomanian) represent the youngest nonmarine Cretaceous occurring in the upper Chesapeake Bay area. Although still considered part of the Patapsco Formation, these sediments were differentiated by Wolfe and Pakiser (1971) who introduced the name, Elk Neck Beds. Zone IV strata, which include the lower members of the Raritan Formation of New Jersey, have not been identified in the shallow subsurface of Maryland or Delaware (Doyle and Robbins, 1977, Fig. 2).

Doyle and Robbins (1977, Fig. 4) did not attempt to correlate their palynological zones with the informal hydrologic units of Sundstrom and others (1967, Fig. 6); however, certain generalizations seem reasonable using Delaware City wells Ec14-1 and Dc53-7* as tie-points (Fig. 7). Zone I and Subzone IIA are dominated by thicker sand beds which define much of the "lower hydrologic zone." On geophysical logs subzone IIC is a well defined clay-silt bed, exceeding 100 feet in thickness; it appears to be arealy correlative. Subzone IIC probably provides the most effective confining bed separation between Sundstrom's upper and lower hydrologic zones. Zone III contains aquifers assigned to the upper hydrologic zone, but is not a dominantly sandy interval like Zone I.

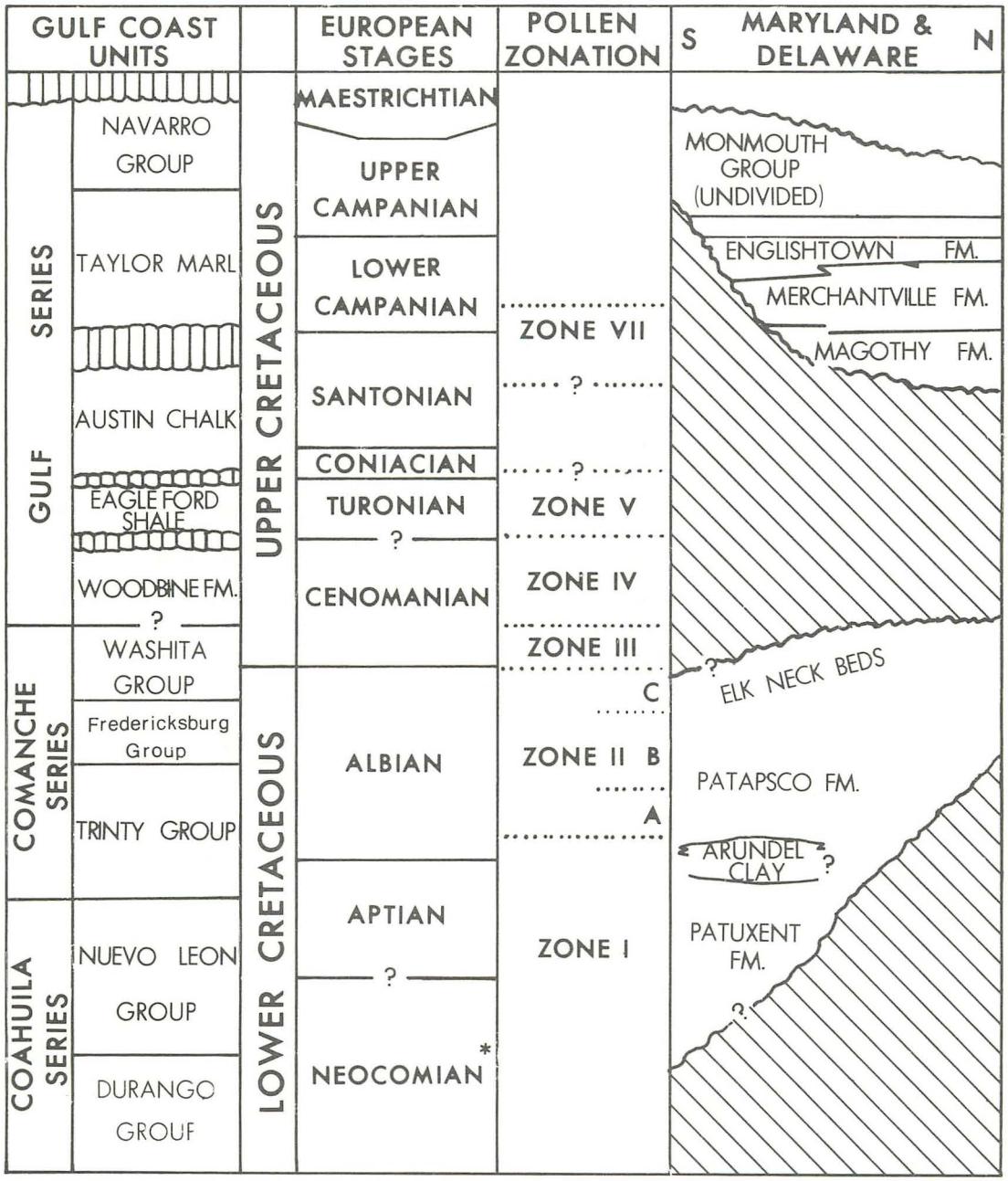
Although recent geologic maps of the northeast Maryland area (Southwick and Owens, 1968; Higgins and Conant, map in prep.) have shown the Potomac group undivided, a review of subsurface data from adjacent Delaware strongly suggests that a zonation is possible in wells that penetrate most of the section. Certainly, broad lithologic correlations seem feasible for at least palynological Zone I and Subzone IIC. In fact Subzone IIC, a thick,largely clay-silt bed of late Albian age (upper Patapsco equivalent), offers the possibility of becoming a shallow subsurface "marker bed" in the upper Chesapeake Bay area.

Doyle (1977) and Doyle and Robbins (1977) generally refer to Ec14-1 and Dc53-7 as Delaware City wells D13 and D12.

On this basis a subdivision of the Potomac group was attempted in each of the three test borings drilled to basement during the project. After erecting a biostratigraphic zonation within the constraints of available data, correlation between wells was made using chiefly electric and gamma-ray logs. To test Higgins and others (1974a) speculation that the Upper Chesapeake Bay magnetic gradient functioned as a capable fault during Potomac Group deposition, zonal correlations were extended across the linear feature. If active movement was occurring during sedimentation, stratigraphic evidence should be present either as changes in thickness or in lithofacies.

Core Hole Data

Driven 2- or 3-inch diameter spoon samples were obtained from clayey beds in the Potomac group at sporadic intervals. Sampling gaps were generally less than 100 feet, but occasionally were greater; supplementary bit samples were also collected (Tables 1, 2 and 3). Two HX wire-line core runs were made in the Grove Neck test boring (CE-Ec17) with excellent recovery of both sands and clays. Emphasis was placed on coring Potomac Group clays because preservation of palynormorphs is much more likely in finer-grained sediments. Unfortunately, about half of the cores consisted of pale gray, red, or mottled clays barren of palynomorphs (Tables 1, 2 and 3). The samples were studied by James A. Doyle and assigned to palynostratigraphic zones according to the scheme of Doyle and Hickey (1976) and Doyle and Robbins (1977) (see Appendix). Because sample density was greatest in CE-Ec17 (Grove Neck), it provided the best pollen stratigraphy. On this basis CE-Ec17 was used as a "standard section" and zonal boundaries were assigned to conform, where possible, with lithologic breaks on the geophysical logs. Even though recovery of pollen-bearing core material was sparse in both HAR-Dg3 (Spesutie Island) and CE-Dc2 (Turkey Point), several palynological zones could be identified. In each boring, zonal boundaries were assigned by correlating geophysical logs into the "standard section" (CE-Ec17). This was acceptable because lithostratigraphic correlations are unlikely to be time transgressive in closely spaced borings.



*Includes Barremian in upper part

(from Doyle and Robbins, 1977)

Figure 6. Chart showing the palynostratigraphic zonation of Cretaceous sediments in Delaware and Maryland (modified after Doyle and Robbins, 1977).

Beds of Barremian-Aptian to Early Albian Age (Zone I): In boring CE-Ec17 Zone I palynomorphs were identified in cores from 780, 939, and 989 feet (Fig. 8). On geophysical logs this interval is characterized by several well defined fining-upward sequences. As reviewed by Fisher and others (1969) and LeBlanc (1972), fining-upward cycles are often exhibited by fluvial sands deposited by meandering streams. Exceptions occur, particularly within the basal beds where complex sand profiles, more reminiscent of multi-story or even braided sequences, occur (Hansen, 1969). Generally speaking, however, stacked sequences of channel lag deposits grading upward into fine overbank clays seem to dominate the lower part of the Potomac Group section. In boring CE-Ec17 this sedimentary package, regionally correlated with the Patuxent and Arundel Formations (undivided) tops out at about 680 feet, but is complicated somewhat by the occurrence of Zone IIA beds in the uppermost cycle. A similar sequence characterizes the lower part of boring HAR-Dg3 between 415 and 712 feet. Although palynological confirmation in HAR-Dg3 is restricted to two badly contaminated bit samples near basement, gamma-ray and electric log correlations between the borings are reasonably persuasive. Each is dominated by three sand sequences exhibiting a fining-upward tendency. These correlations are sufficiently strong to establish the direction of fluvial transport, which by inference subparallels the paleoslope of the lower Cretaceous Coastal Plain. Farther down dip, as at Kings Town (QA-Be15), beds tentatively assigned to Zone I continue to exhibit correlative fining-upward cycles, although the section is thicker. Correlations suggest that Zone I sediments onlapping basement account for this, but palynological evidence is lacking.

Projecting Zone I into CE-Dc2 from HAR-Dg3 and CE-Ec17 is more difficult, but not unexpectedly, inasmuch as log correlations must be made oblique to depositional transport. Although the same fluvial sequences may be present in CE-Dc2, lateral changes in lithofacies prevent a cycle-to-cycle correlation. Some corroboration is provided by the recovery of Zone I palynormorphs from a bit sample near the base of the Coastal Plain (Fig. 7).

An evaluation of Zone I sediments in the three test borings suggests that the predominant direction of depositional transport (i.e. paleoslope) during Barremian (?), Aptian and lower Albian times was roughly normal to the Upper Chesapeake Bay magnetic anomaly. Correlations between HAR-Dg3 and CE-Ec17 suggest that a series of meandering rivers flowed across the anomaly depositing sediments without any abrupt changes in thickness or facies supportive of penecontemporaneous faulting.

Beds of Early to Middle Albian Age (Zone IIA): Subzone IIA is poorly defined in the three upper Chesapeake Bay area core holes. Dateable palynomorphs were found in only one core (520 to 522 ft) from CE-Dc2. Stratigraphically, it occurs within a fining-upwards cycle that appears conformable with the fluvial sequences comprising Zone I. In figures 7 and 8 Zone I and Subzone IIA are assigned to the same lithostratigraphic unit which is correlated regionally with the Patuxent and Arundel Formations (undivided). The rare occurrence (less than 1 percent) of microplanktonic cysts suggests a slight brackish water influence (Doyle, personal commun.). Geophysical log correlations between the three borings are tenuous and were made assuming a thin interval, less than 80 feet, comparable to the Subzone IIA section at Delaware City (Doyle, 1977, Fig. 3).

Beds of Middle to Late Albian Age (Subzone IIB): A wire-line core run between 500 and 700 feet recovered much of Subzone IIB in boring CE-Ec17. Contacts, however, were not cored so that boundaries were, again, assigned at lithologic breaks (Fig. 8). In the upper Chesapeake Bay area borings the sedimentary facies of Zone IIB can be differentiated from Zone I (and IIA) on geophysical logs by a change in thickness and vertical profile of the sand beds. Subzone IIB beds have "blocky" profiles, often broken by thinner, clayey interbeds; the profiles generally fail to exhibit the fining-upward cycle characteristic of Zone I. The bulk lithologic packaging of Subzone IIB is suggestive of an upper delta plain facies still dominated by distributary channel sands. Within the fluviodeltaic framework of Fisher and others (1969, Fig. 59, 60), Zone IIB is suggestive of a transitional facies separating fluvial sands and overbank clays of Zone I from the fine-grained interdistributary deposits found in Subzone II C.

Bed-for-bed correlation of Subzone IIB is not possible, although as a lithologic unit it is identifiable in each of the three test borings. In boring HAR-Dg3 the presence of Zone IIB beds is

suggested, but not confirmed, by scarce palynomorphs recovered from 390 to 393 feet. Several cores from suspected Subzone IIB beds in CE-Dc2 proved to be barren of dateable pollen and spore material. Between Spesutie Island and Grove Neck (Fig. 8) Subzone IIB thickens from about 180 to about 200 feet. Farther down dip, at Kings Town, the unit reaches a thickness of about 295 feet. This progressive, down-dip thickening of Subzone IIB offers little support for penecontemporaneous faulting along the aeromagnetic gradient of Higgins and others (1974a). If faulting was significant during Subzone IIB deposition, one would expect the section to be thinner on the up-thrown block (at Grove Neck) which is demonstrably not the case.

According to convention (Brenner, 1963), Zone IIB is correlated with the middle Patapsco Formation in its type region.

Beds of Late Albian Age (Subzone IIC): In northern Delaware and adjacent parts of Maryland Subzone IIC defines the lower Elk Neck Beds of the Patapsco Formation. Subzone IIC seems to coincide in part with a widely correlative, largely fine-grained, lithostratigraphic unit. It is not a "marker bed" in the sense that kick-for-kick log correlations are possible, but nevertheless provides the best stratigraphic datum in the Potomac Group of northern Delaware. It is recognizable in the three upper Chesapeake Bay area borings, but the introduction of sandy beds into the section diminishes somewhat its usefulness as a stratigraphic datum.

Beginning in Subzone IIC and extending into Zone III clayey beds increase in thickness and begin to dominate the section. Although not as obvious at basin margin sites such as Spesutie Island (HAR-Dg3), the pattern becomes well established down-dip at Grove Neck (CE-Ec17) and Kings Town (QA-Be15). In deep wells farther east Doyle and Robbins (1977, p. 75) have noted the common presence of dinoflagellates and acritarchs in equivalent late Albian and early Cenomanian (Subzone IIB to Zone III) beds, suggestive of an interdistributary delta plain facies increasingly subject to marine or brackish conditions.

Subzone IIC palynomorphs were identified in each of the test borings, providing direct evidence that upper Albian beds occur on both sides of the magnetic anomaly (Fig. 8). Beyond that, correlation between borings must be made using geophysical logs to identify broad lithologic breaks based on sand/clay ratios and vertical sand profiles. On this basis the base of Subzone IIC is tentatively picked at elevations of -450 feet at Grove Neck and -220 feet at Spesutie Island.

Beds of Early Cenomanian Age (Zone III): In the upper Chesapeake Bay area Zone III sediments define the upper Elk Neck Beds of the Patapsco Formation. Palynomorphs from Zone III were recovered in outcrop (elevation +5 feet) near the site of CE-Dc2 on Elk Neck. In this boring the Subzone IIC-Zone III contact is broadly bracketed by the presence of late Albian palynomorphs recovered from 224 to 226 feet. The contact is poorly defined and the Zones are left undivided in CE-Dc2. The contact is more closely bracketed in boring CE-Ec17 (Grove Neck). Here good Subzone IIC and basal Zone III were recovered between 292 and 295 feet and between 248 and 250 feet, respectively. The contact is picked at a lithologic break at about 260 feet. Although palynological confirmation is lacking, it is suspected that Zone III beds occur as shallow as 34 feet where a local channel deposit (Quaternary?) of gravelly sand truncates the unit. In the vicinity of the test boring the Magothy Formation (Zone VII), which crops out along the bluffs of Grove Neck, is apparently missing.

Available data suggest that Zone III beds are either absent or very thin in the Spesutie Island (HAR-Dg3) boring. A core from 188 to 190 feet contained an excellent Subzone IIC assemblage. Geophysical log correlations with CE-Ec17 suggests that the core is from the lower quarter of the subzone. In Figure 4 Subzone IIC beds are shown truncated beneath Quaternary gravel, although a thin wedge of Zone III sediments could conceivably be present. In any event the absence of a reasonably full section of Zone III at the Spesutie Island site does not support the fault speculation of Higgins and others (1974a). As discussed previously, the Spesutie Island site occurs within the magnetic low which they interpreted as a faulted Coastal Plain basin. If significant Coastal Plain faulting had actually occurred, Zone III (or younger) beds, which crop out on Elk Neck, should be present in the subsurface on the down-thrown block. However, they apparently do not occur at Spesutie Island.

Core Data

The test boring on Spesutie Island (HAR-Dg3) encountered the basement surface at a depth of 712 feet (elevation, -700 feet). The interval between 712 and 757 feet is a saprolite zone consisting of dark gray-green, dense, sticky clay with scattered grains of fractured quartz and kaolinized feldspar grains. Bedrock core recovered between 757 and 760 feet is a dark gray-green chloritic greenstone schist with subtle light and dark banding on a scale of 2 to 5 cm. thickness. Large grains of kaolinized or sericitized feldspar occur sporadically. Coarse feldspar grains and several large, rounded and fractured quartz grains are concentrated near the top of the core. In thin section the rock is an epidote-quartz-plagioclase-biotite schist, in which the plagioclase has been partly altered to sericite and the biotite to chlorite (see Appendix for detailed descriptions of thin sections). This greenstone appears to be a metamorphosed basic metavolcanic rock in which the large feldspar and quartz grains represent amygdules. The zone of concentrated feldspar and quartz grains near the top of the core suggests a vesicular flow top or perhaps the vesicular rim of a lava pillow.

Between 760 and 763 feet a greenish-gray to pinkish-gray fine-grained granitic rock was recovered. It was identified in thin section as a microcline-quartz-plagioclase gneiss or granodiorite gneiss. The small percentage of biotite present in the rock is strongly altered to chlorite. Although it possesses a weak gneissic fabric the rock is of igneous origin and in thin section is clearly intrusive into the overlying chloritic greenstone. The rock may have been originally an aplite which has assimilated part of the greenstone, as the small biotite grains in each rock are very similar.

From 763 feet to the bottom of the hole at 777 feet the rock is a coarse-grained felsic gneiss, identified in thin section as a biotite-plagioclase-quartz gneiss. No microcline is present in this rock. Much of the quartz occurs in large, fractured and broken lenticular grains, and all of the minerals show some degree of cataclasis. Between 767 and 768 feet the gneiss contains several fine-grained, laminated schistose inclusions up to 2 cm. thick and 10 cm. long. This interval of core is broken by several joint sets, both inclined and vertical.

The basement surface in the Turkey Point test boring (CE-Dc2) was encountered at 785 feet (elevation, -727 feet). Core recovery began at 870 feet and consists of light yellow-orange to orange-red structured saprolite of mica schist. From 890 to 898 feet the core is a light silvery-gray, clayey and friable, decomposed mica schist. From 898 feet to the bottom of the hole at 936 feet the core consists of fine- to medium-grained mica schist or gneiss. In thin section the rock is a biotite-plagioclase-quartz-muscovite schist (see Appendix), but there is a considerable range in the relative amounts of the constituent minerals throughout the cored section. Minute idioblastic, but strongly corroded, garnets are present in amounts up to 5 percent. Sillimanite is also present. The foliation dips moderately to steeply and in places is vertical. A strong cross-cleavage has refolded the foliation. Below 919.5 feet the cross-cleavage is less distinct. Veins or dikes of quartz and plagioclase occur sporadically, but are more prevalent between 909.5 and 920.5 feet, and again below 925 feet. These veins, which range in thickness between 0.5 and 3 cm., are parallel to the foliation, and have also been refolded by the cross-cleavage.

At Grove Neck (CE-Ec17) basement crystalline rocks were reached at a depth of 1,028 feet (elevation, -1020 feet). No thick oxidized and clayey saprolite zone such as occurs at Turkey Point is present above bedrock in this hole although the rock exhibits varying degrees of alteration by weathering. The core is considerably broken by moderately-dipping to steep joints and shear planes. From 1,028 to 1,063 feet the core is a light to medium silvery-gray chlorite-muscovite-plagioclase-quartz schist or gneiss, strongly decomposed above 1,042 feet. Between 1,042 and 1,051 feet the rock is less altered, although the plagioclase has been kaolinized. Foliation is very steep to vertical and shows crumpling or refolding by cross-cleavage. From 1,051 to 1,063 feet coarse-grained plagioclase-quartz veins penetrate the rock. Graphite-coated shear planes with dips ranging between 50° and 85° are also more prevalent throughout this interval.

Between 1,063 and 1,085 feet the rock was identified in thin section as a biotite-plagioclase-muscovite-quartz schist (see Appendix). The rock has a very strong cataclastic texture with broken, deformed, and granulated mineral grains, and has shear planes dipping from 50° and 80°. Plagioclase is severely altered to sericite. From 1,077 to 1,085 feet the core is broken by steep, intersecting joint sets and is more altered by weathering. Between 1,085 feet and the total depth at 1,107 feet the rock was identified in thin section as a cataclastic biotite-plagioclase-muscovite-quartz schist or mylonite consisting essentially of broken, angular mineral grains surrounded by steep to vertical shear zones with bent, strained, and altered mica grains. Below 1,097 feet intersecting joint sets again are numerous, and below 1,102 feet the rock again is more severely altered, plagioclase going to sericite and biotite to chlorite.

Possible Correlations of Core Samples with Exposed Piedmont Rocks

The greenstone encountered in the Spesutie Island test boring (HAR-Dg3) is very similar to certain members of the James Run Formation as described by Higgins (1971, 1977) in nearby Cecil County (Fig. 2). The Gilpins Falls member of the James Run Formation is in part an amygdular epidote-albite-chlorite schist, locally sheared and streaked (Higgins, manuscript in preparation). This description fits that of the greenstone found in the Spesutie Island core. Metavolcanic rocks are also present in Harford County (Southwick, 1969, p. 53; manuscript in prep.), but rocks similar to the greenstone schist have not been reported there.

Coarse-grained felsic gneiss resembling that in the Spesutie Island core occurs in a number of places in Cecil and Harford Counties. The closest exposures of these to the Spesutie Island test boring are near Havre de Grace in Harford County (Southwick and Owens, 1968; Southwick, 1969; manuscript in prep.), and in the Garrett Island-Perryville area of Cecil County (Higgins, 1973; manuscript in prep.; Higgins and Conant, map in prep.). Other gneisses in the vicinity with descriptions which fit that of the gneiss in the Spesutie Island core are the Port Deposit Gneiss, the gneiss near Elk Mills, and the gneiss near Rolling Mills (Higgins, manuscript in prep.).

Rock recovered from the Turkey Point test boring (CE-Dc2) most nearly resembles the pelitic gneiss facies of the Wissahickon Formation as described by Higgins (manuscript in prep.) in Cecil County. In the samples from the Grove Neck test boring (CE-Ec17) the less-deformed bedrock in the core also resembles the pelitic gneiss of the Wissahickon Formation. There are no reported occurrences of cataclastic rocks in the exposed Piedmont of Cecil or Harford Counties similar to those recovered from the basement at Grove Neck. However, Thompson (1978, p. 88) has described cataclastic rocks associated with the Wilmington Complex in adjacent Delaware.

Contact Relationships of Exposed Piedmont Rocks and the Probability of Faults

The rocks recovered in the core samples from the three test borings are very similar to bedrock exposed in the adjacent Piedmont of Cecil and Harford Counties. It is therefore not unreasonable to assume that they are correlative. How then are the exposed rock formations related spatially to one another, and what evidence is there for faults to account for the juxtaposition of contrasting rock types?

In Harford County, Southwick (1969, p. 46) states that the James Run Gneiss (James Run Formation of Higgins, 1972, p. 1001) seems to conformably overlie pelitic schists which are probably the Wissahickon Formation. Higgins (1971, p. 322) states that the James Run Formation appears to be an eastern volcanic equivalent of the Wissahickon Formation and that in Cecil County the Gilpins Falls member is in conformable, locally gradational, contact with the Wissahickon (Higgins, 1971, p. 323).

The Port Deposit Gneiss and similar, possibly correlative gneisses exposed in Cecil County near Elk Mills and near Rolling Mills, are all in contact with rocks of the James Run Formation, with no indication of a fault relationship (Higgins, manuscript in prep.). Further, Higgins (manuscript in prep.) describes the Port Deposit Gneiss and the James Run Formation as being in gradational contact. In Harford County, the Port Deposit Gneiss (Southwick and Owens, 1968) contains granitoid rocks of diverse origins (Southwick manuscript in prep.) and therefore one might expect to find a wide variety of contact relationships between the Port Deposit and adjacent formations. However, Southwick (manuscript in prep.) does not indicate that any of these contacts are faults.

The coarse-grained gneiss in the Garrett Island-Perryville area of Cecil County (Higgins, 1973; Higgins and Conant, map in prep.) is probably an extension of rocks mapped as Port Deposit Gneiss across The Susquehanna River in Harford County by Southwick and Owens (1968). Higgins (manuscript in prep.) describes this rock as being similar to the fine-grained phase of the diamictite facies of the Wissahickon Formation. No contact relationships of this gneiss with adjacent rock types are described. He adds that insufficient work has been done on this particular body of gneiss to warrant any firm correlation or speculation as to its origin.

Major faults have been described or proposed in the northeastern Maryland Piedmont by Southwick and Owens (1968), Southwick (1969, p. 6) and Crowley (1976, p. 29-30). These faults, for the most part, involve the juxtaposition of ophiolitic and volcanic rocks with metasediments. Moreover, Crowley (personal commun.) considers that these faults, if indeed they do exist, predate the Paleozoic folding and metamorphism of the Piedmont.

In summary, if a major fault underlies the upper Chesapeake Bay as speculated by Higgins and others (1974a, p. 75), it should involve the rock types which were encountered in the test borings: schist, felsic gneiss, and metavolcanic rocks. However, the most recent, detailed geological studies of Cecil (Higgins, manuscript in prep.) and Harford Counties (Southwick, 1969; manuscript in prep.) have shown no indication of the existence of any significant faults between rock types which are possible correlatives with those encountered in the upper Chesapeake Bay test borings. The mutual contacts between the Wissahickon Formation, the James Run Formation, and the several felsic gneisses are described as conformable. These contact relationships as seen in the exposed Piedmont may not eliminate the possiblity of a fault in the buried basement along the trend of the linear magnetic gradient, but neither do they require one. It has been shown here that in order to juxtapose the rock types which were encountered in the test borings it is not necessary to invoke fault displacements of great magnitude. Southwick (1969), p. 7) mentions that many minor faults and dislocations, both pre- and post-metamorphic, are present in Harford County, but no detailed study was made.

Normal faults and high-angle reverse faults in the Coastal Plain have been described or interpreted at several localities in Maryland and adjacent states. In no case, however, has a post-Lower Cretaceous fault been reported as having vertical displacement sufficient to affect the magnetic pattern to the extent shown in the Upper Chesapeake Bay area.

For example, Dryden (1932) described a high-angle reverse fault between Pleistocene and Miocene strata in a roadcut near Upper Marlboro, Prince George's County, about 50 miles to the south of the Upper Chesapeake Bay area. Possible involvment of the basement was not discussed. Subsequent investigations in the area by Glaser (personal commun.) suggests that this phenomenon is due to slumping rather than to tectonic activity. In Washington, D.C., 65 miles to the southwest, Darton (1950, p. 8) observed several basement faults which displaced the overlying Pleistocene gravels by at least 40 feet. Newell and others (1976) and Mixon and Newell (1977) describe high-angle reverse faults along the inner edge of the Coastal Plain in northeastern Virginia, 100 miles to the southwest. Displacements ranging from 15 to 60 meters (50 to 200 feet) were reported.

At Perryman, Maryland, in Harford County about 9 miles west of the area of the steep magnetic gradient, a detailed site survey for a proposed nuclear power generating station (Dames & Moore, 1977) investigated the possibility of faults at the locality. Closely-spaced borings with detailed lithologic and geophysical logs were made throughout the plant site, as well as seismic reflection profiles. Several anomalous features on the top of "seismic basement" (top of fresh, unweathered rock, not top of saprolite) were interpreted to be fault scarps with displacements ranging up to 120 feet (39 meters). The seismic profiles suggest that the Lower Cretaceous sediments immediately overlying basement may have been affected by movement on some of the faults (Dames & Moore, 1977, p. 36-39).

Twenty-five miles to the northeast in the Newark-Wilmington area (Spoljaric, 1972) and Delaware City area (Spoljaric, 1973) of Delaware, topographic irregularities on the buried basement surface were interpreted to be horst and graben structures resulting from movement on normal, reverse and strike-slip faults. However, no data were presented to substantiate these conclusions. Lineaments seen on LANDSAT-1 imagery of the Delmarva peninsula were interpreted by Spoljaric and others (1976) to be geomorphic features related to possible faults in the buried basement; recent earthquakes in northern Delaware were cited indicative of con-

tinuing tectonic activity in that area.

Jacobeen (1972, 1974) identified several high-angle reverse faults in the subsurface in the Brandywine area of Prince George's and Charles Counties, Maryland, 60 miles southwest of the area discussed in this paper. These were determined from a number of deep drill holes with support from seismic profiles. One fault was determined to have at least 250 feet of vertical displacement and offset lower Cretaceous strata. Movement on this fault system is believed to have influenced the development of the Brandywine anticline at least as late as Middle Miocene time (Jacobeen, 1972, p. 16).

On the basis of seismic reflection surveys on the Eastern Shore and in Southern Maryland, Hansen (1978) reported displacements of the basement surface to be either normal or high-angle reverse faults. Faults near Coleman, Kent County, about three miles south of the linear magnetic gradient, between Chestertown and Church Hill in Queen Anne's County, 15 miles to the south, and near Church Hill, 20 miles to the south, have offsets ranging from 80 to 85 feet. Lower Cretaceous strata may have been warped and disturbed, but resolution of the seismic data was insufficient to demonstrate disruption of the overlying Upper Cretaceous and Lower Tertiary strata (Hansen, 1978, p. 28).

Although the authors' of this report do not necessarily question the occurrence of Coastal Plain faulting elsewhere in the Middle Atlantic region, comparable displacements associated with the Upper Chesapeake Bay magnetic gradient were not detected by the three bore holes described herein.

Conversely, the occurrence of cataclastically deformed rocks at Grove Neck and to a lesser degree at Spesutie Island indicates that post-metamorphic faulting has occurred in the basement. However, no determination could be made as to the orientation of the fault or shear surface at Grove Neck, whether the fault displacement was of normal, reverse, or strike-slip nature, or what the magnitude of the displacement was. Furthermore, the location of the test boring is almost two miles southeast of the trend of the linear magnetic gradient, whereas the core from Turkey Point, only a mile southeast of this feature, shows no evidence of cataclasis. Therefore, the relationship between the cataclastic zone at Grove Neck and the magnetic gradient remains obscure.

Interpretation of Aeromagnetic Map

Most discussions of the interpretation of aeromagnetic maps (Dobrin, 1976, p. 534-535; Nettleton, 1971, p. 91-93) attribute the occurrence of a large-scale magnetic gradient to a difference in the magnetic properties of the basement rocks. On the other hand, these same sources demonstrate that the relief of the basement surface, such as may be due to a buried topography or to fault displacement of the basement surface, has only a slight effect on the magnetic contour pattern.

Higgins and others (1974a, p. 75) interpret the large, flat, low magnetic anomaly in the upper Chesapeake Bay area to be a gneiss dome with a core of Baltimore gneiss such as those exposed in the Piedmont 40 miles to the west. It appears, however, that the anomaly is more likely due to an extensive terrane of felsic gneiss such as that cored at Spesutie Island. According to Hopson (1964, p. 48) microcline is an appreciable mineral constitutent of the Baltimore Gneiss. Except for a thin intrusive dike, the gneiss from HAR-Dg2 contained no microcline. The Port Deposit Gneiss and the gneiss in the Garrett Island-Perryville area, exposed in adjacent Harford and Cecil Counties (Southwick and Owens, 1968; Higgins, 1973; Higgins and Conant, map in prep.) are also low in microcline (Southwick, 1969; Higgins, manuscript in prep.). Similar gneisses at Elk Mills and near Rolling Mills in Cecil County (Higgins, manuscript in prep.; Higgins and Conant, map in prep.) may represent the northeasterly extension of this terrane of felsic gneisses along the strike of the low magnetic anomaly.

The area of outcrop of the James Run Formation in Cecil County (Higgins, 1973; Higgins and Conant, map in prep.) is characterized on the aeromagnetic map (Fig. 1) by minor high magnetic anomalies. Similar anomalies interrupt the generally smooth pattern of the large low magnetic anomaly in the vicinity of the Spesutie Island test boring, thus suggesting infolds of the more magnetic James Run Formation within the gneiss terrane. Further evidence in support of this conclusion is provided by the occurrence of metavolcanic rocks in the core samples from HAR-Dg2.

East of the large, flat low magnetic anomaly is a region of closed high and low magnetic

anomalies (Fig. 1). (Indeed, one of the local lows is of greater depth than the large low anomaly west of the gradient.) This pattern is interpreted by Higgins and others (1974a, p. 75) to be a region of mafic and ultramafic rocks. In the course of this project the test borings at Turkey Point (CE-Dc2) and at Grove Neck (CE-Ec17 cored schistose rocks which resemble the pelitic gneiss facies of the Wissachickon Formation. Cuttings of schist also have been recovered from the basement in several deep water well tests in the upper Eastern Shore counties of Maryland (CE-Ee29 at Cecilton and CE-Cf48 near Chesapeake City, both in Cecil County; KE-Ac20 on Stillpond Neck, Kent County; and QA-Be15 at Kings Town, Queen Annes County) (Fig. 3). These appear to define a terrane of schistose rocks.* A magnetic pattern similar to that for this region is present in the Piedmont of Harford and Cecil Counties where rocks of the Wissahickon Formation occur (Figs. 1 and 2).

In laboratory tests the volume magnetic susceptibility of schistose core plugs taken from CE-Dc2 and CE-Ec17 is generally less than the values recorded for gneissic core plugs taken from HAR-Dg3 (see Tables 1, 2, and 3). This is the reverse of what one would expect based on the configuration of the aeromagnetic map (Fig. 1). One possible explanation for this discrepancy is that the schist from the Cecil County test borings has been affected by weathering by which plagioclase and biotite have been slightly to strongly altered prior to deposition of the Coastal Plain sediments. If the magnetite has also been affected by weathering, the rock may have suffered a reduction in its magnetic susceptibility. Another possibility is that the magnetite content of the Wissahickon Formation may vary considerably within short distances and that CE-Dc2 and CE-Ec17 simply were drilled in areas which were deficient in magnetite.

Although lacking laboratory verification the linear magnetic gradient, which borders the deep, flat low magnetic anomaly in the upper Chesapeake Bay region, is nevertheless believed to reflect a magnetic susceptibility contrast along the boundary between adjacent terranes of felsic gneiss and Wissahickon Formation buried beneath the Coastal Plain.

CONCLUSIONS

Three bore holes were drilled to test the speculation of Higgins and others (1974a, 1974b) that a steep, linear magnetic gradient in the upper Chesapeake Bay area (Fig. 1) is a normal or high-angle reverse fault which forms the eastern border of a basin containing an unusual thickness of Coastal Plain sediments. Data from this test boring project do not support their speculation for the following reasons:

(1) A regional map of the basement surface with a contour interval of 100 feet does not reveal any structural anomalies coincident with the magnetic pattern that could not be explained by relict topographic relief on the pre-Coastal Plain surface. The Spesutie Island boring (HAR-Dg3) drilled adjacent to the magnetic low, encountered saprolitized basement rock at an elevation of approximately -700 feet, which is conformable to regional dip projected from control along the Fall Zone. At Grove Neck, which is east of the magnetic gradient, boring CE-Ec17 penetrated weathered rock at elevation -1,020 feet, again conformable with the regional trend. At Turkey Point (CE-Dc2) basement was encountered at -727 feet, which is higher than regional projections would suggest. However, the occurrence at the site of a thick oxidized mantle of clayey saprolite strongly suggests that the boring penetrated a relict hillock on the buried Piedmont surface.

(2) Major faulting, penecontemporaneous with sedimentation, seems unlikely insofar as the direction of depositional transport characteristic of palynological Zone I and Subzone IIB is roughly normal to the trend of the linear magnetic gradient. Broadly similar lithologic packages occur on both sides of the alleged fault without abrupt thinning or changes in lithofacies. In Zone I several fining-

Since the completion of this project, chips of serpentinite have been recovered from the basement in a deep water well test in Kent County, near Fairlee (KE-Cb36). (Fig. 3). This is consistent with the concept that the basement of the upper Eastern Shore of Maryland east of the linear magnetic gradient is a terrane of the Wissahickon Formation, as small bodies of ultramafic rocks as well as amphibolites occur sporadically within the Wissahickon Formation in the exposed Piedmont of Maryland (Crowley, 1976). It is interesting to note that no high magnetic anomalies occur in the vicinity of this well.

upward fluvial cycles correlate across the magnetic gradient; similarly in Subzone IIB a correlative sequence of interbedded sands and clays occurs on both the "up-thrown" and "down-thrown" blocks.

(3) Major post-Cretaceous faulting is doubtful because Zone III (Early Cenomanian) beds at Spesutie Island (HAR-Dg3) are either absent or are very thin. If faulting along the magnetic lineament has occurred with the western block down as proposed by Higgins and others (1974a, 1974b), Zone III beds, which crop out near Bay level on Elk Neck, should be present in the subsurface at Spesutie Island. Instead the stratigraphy at Spesutie Island conforms with an unfaulted, up-dip projection of the palynostratigraphic zones present at Grove Neck (CE-Ec17) (Fig. 5).

(4) The linear magnetic gradient reflects the boundary between different crystalline rock types in the basement. Test boring HAR-Dg3 at Spesutie Island was located west of the gradient and within the deep, flat low magnetic anomaly. The felsic gneiss cored at Spesutie Island probably represents the bedrock associated with the low magnetic anomaly. Small amplitude irregularities within the magnetic low may be caused by infolds of metavolcanic rock such as the rocks similar to the Gilpins Falls member of the James Run Formation which were found overlying the felsic gneiss at Spesutie Island. In contrast, borings CE-Dc2 at Turkey Point and CE-Ec17 on Grove Neck were located east of the steep linear anomaly in a magnetic terrane characterized by a series of ropy-patterned high and low magnetic anomalies. Both borings encountered schistose rocks which resemble the pelitic gneiss facies of the Wissachickon Formation.

The occurrence of sheared and mylonitized rocks at Grove Neck indicates that post-metamorphic faulting has occurred. However, no firm correlation of these rocks with the linear magnetic gradient in the upper Chesapeake Bay area can be made due to the paucity of subsurface control. Contact relationships between possible correlative rock types in the exposed Piedmont suggest that even if a fault or shear zone is present along the trend of the linear magnetic gradient, large-scale displacements are not necessary to juxtapose the rock types present. Furthermore, within the scale of resolution (50 feet) of the data obtained in this project, offset at the base of the Coastal Plain cannot be demonstrated. Thus any fault associated with the shear zone can be dated no younger than Early Cretaceous (pre-Barremian), pending further, more detailed, investigations.

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APPENDICES

MEGASCOPIC DESCRIPTIONS OF BASEMENT CORE

Maryland Geological Survey basement core test hole HAR-Dg3
Aberdeen Proving Ground, Spesutie Island
lat. 30°26″43″N
long. 76°04′15″W

Interval	
757 - 760	Partly decomposed chlorite schist or metabasalt. Sporadic grains of feldspar throughout rock, many grains of quartz concentrated near top.
760 - 763.6	Light pink-gray fine-grained granite.
763.6 - 767	Partly decomposed coarse-grained biotite-quartz-feldspar granite gneiss. Joints dip 60°.
767 - 767.7	Same as above but with sporadic inclusions of fine-grained biotite schist.
767.7 - 777TD	Partly decomposed coarse-grained biotite-quartz-feldspar granite gneiss. Vertical joints.

Maryland Geological Survey basement core test hole CE-Dc2
Elk Neck State Park, Turkey Point
lat. 39°27′16″N
long. 76°00′30″W

Interval	
870 - 879	Pale yellow-orange micaceous saprolite.
879 - 880	White to pale yellow decomposed pegmatite, with kaolinite, quartz and muscovite.
880 - 890	Light yellow-orange micaceous saprolite.
890 - 898	Friable decomposed light-gray mica schist.
898 - 909.5	Gray feldspar-quartz-muscovite-biotite schist. Foliation dips 60° to 75° and is crumpled or refolded by cross-cleavage. A few sporadic veins of quartz. Some joints with 45° dip.
909.5 - 913	Same as above but with veins of quartz and feldspar parallel to foliation.
913 - 920.5	Gray feldspar-quartz-muscovite-biotite schist as above but no quartz-feldspar veins.
920.5 - 925	Same as above but cross-cleavage is weak to absent.
925 - 936TD	Same as above but with a few thin veins of quartz. Foliation dips 50° to 70° and is refolded by cross-cleavage.

Maryland Geological Survey basement core test hole CE-Ec17
Camp Trinity, Grove Neck
lat. 39°24′18″N
long. 76°01′30″W

Interval	
1022 - 1028	Gravel composed of translucent to opaque, light gray to white pebbles and cobbles of quartz and quartzite.
1028 - 1042	Decomposed light gray muscovite-biotite-feldspar-quartz schist. Feldspar altered to kaolinite. Rock highly fractured and broken.
1042 - 1051	Same as above but less fractured. Foliation vertical to 70° dip.
1051 - 1063	Sheared gray muscovite-biotite-feldspar-quartz schist or gneiss. Banded with feldspar-rich pegmatitic layers and mica-rich layers. Feldspar strongly altered to kaolinite. Streaks and veinlets of graphite along shears. Also some pyrite.

1063 - 1077	Gray muscovite-biotite-feldspar-quartz schist with some veinlets of feldspar. Feldspar strongly altered to kaolinite. Rock is broken by graphite-coated shear planes. Dip of shears vertical to 45°, average 60°. Some refolding of foliation by shear planes.
1077 - 1085	Partly decomposed, sheared, and brecciated graphitic mica schist, strongly broken by closely-spaced shear planes.
1085 - 1097	Compact, brecciated and mylonitized mica schist or gneiss composed of crushed and broken mineral grains and rock fragments. Many graphitic streaks and shears with dips vertical to 80°. Foliation dips 10° to 20°, strongly refolded.
1097 - 1102	Same as above but rock is broken along shears and is more decomposed.
1102 - 1107TD	Sheared chlorite-mica schist or mylonite. Many closely-spaced shears with dips vertical to 80°.

THIN-SECTION DESCRIPTIONS OF BASEMENT CORE

Maryland Geological Survey basement core test hole HAR-Dg3
Aberdeen Proving Ground, Spesutie Island
lat. 39°26′43″N
long. 76°04′15″W

758 feet

Biotite 42%	Ragged xenoblastic grains 0.2 to 0.01 mm; pleochroic from pale greenish-yellow to brownish-green; moderately altered to chlorite (pennine).
Plagioclase 37%	Oligoclase; xenoblastic grains 0.1 to 0.05 mm; moderately to severely altered to sericite; twinning obscured.
Quartz 10%	Xenoblastic grains 0.5 to 0.01 mm; moderately strained and fractured.
Epidote 9%	Idioblastic to xenoblastic grains 0.5 to 0.01 mm; alteration product associated with plagioclase and biotite.
Sphene 1%	Corroded idioblastic to xenoblastic grains 0.1 to 0.05 mm; partly altered to leucoxene.
Opaques 1%	(probably magnetite)
Apatite Tr.	
Calcite Tr.	
Fabric:	Schistose, lepidoblastic, porphyroblastic, fine-grained (rock specimen contained sericitic blebs, probably remains of feldspar phenocrysts, which in the thin section are vacant holes)
Rock:	*Epidote-quartz-plagioclase-biotite schist*

763 feet

Type #1

Plagioclase 45%	Oligoclase; xenoblastic grains 1.5 to 0.05 mm; albite and pericline twins obscured; strongly altered to sericite, muscovite, and epidote.
Quartz 29%	Xenoblastic grains 1.0 to 0.01 mm; strongly strained and fractured; sutured and granulated borders.
Microcline 19%	Xenoblastic grains 1.5 to 0.1 mm; polysynthetic twinning; poikiloblastically enclose quartz and plagioclase.
Biotite 5%	Ragged xenoblastic grains 0.5 to 0.01 mm; Pleochroic from pale brown to dark greenish-brown; strongly altered to chlorite.
Muscovite 1%	Idioblastic grains 0.5 to 0.01 mm; associated with plagioclase.
Epidote 1%	Idioblastic to xenoblastic grains 0.5 to 0.01 mm; alteration product associated with plagioclase and biotite.
Apatite Tr.	
Zircon Tr.	
Fabric:	Granoblastic, porphyroblastic, fine-grained.
Rock:	*Microcline-quartz-plagioclase gneiss* (granodiorite gneiss)

Type #2

Biotite 42%	Xenoblastic grains 0.75 to 0.01 mm; pleochroic from pale brown to very dark brownish-green; preferred orientation; moderately to strongly altered to chlorite.
Plagioclase 34%	Oligoclase; xenoblastic grains 0.1 to 0.01 mm; strongly altered to sericite; twinning obscured.
Quartz 14%	Xenoblastic grains 0.2 to 0.01 mm; moderately strained and fractured.
Epidote 10%	Xenoblastic grains 0.5 to 0.01 mm; alteration product associated with biotite and plagioclase.
Fabric:	Schistose, lepidoblastic, non-porphyroblastic, fine-grained.
Rock:	*Epidote-quartz-plagioclase-biotite schist*

770 feet

Quartz 51%	Xenoblastic grains 14.0 to 0.01 mm; strongly to severely strained and fractured, sutured and granulated borders.
Plagioclase 36%	Albite to oligoclase; xenoblastic grains 1.5 to 0.05 mm; occur in lenticular masses up to 1.2 cm long; albite, pericline, and Carlsbad twins; moderately to strongly altered to sericite and epidote.
Biotite 9%	Ragged xenoblastic grains 1.0 to 0.05 mm; pleochroic from pale greenish-brown to very dark greenish-brown; moderately altered to chlorite.
Epidote 3%	Idioblastic to xenoblastic grains 0.75 to 0.01 mm; alteration product associated with plagioclase and biotite.
Opaques 1%	(probably magnetite)
Apatite Tr.	
Zircon Tr.	
Fabric:	Gneissose, granoblastic, non-porphyroblastic, cataclastic, fine- to medium-grained.
Rock:	*Biotite-plagioclase-quartz gneiss*

775.5 feet

Quartz 41%	Xenoblastic grains 6.0 to 0.01 mm; strongly to severely strained and fractured; sutured borders.
Plagioclase 40%	Albite to oligoclase; xenoblastic grains 1.5 to 0.05 mm; occur in lenticular masses up to 1 cm long; albite, pericline, and Carlsbad twins; moderately to strongly altered to sericite and epidote.
Biotite 12%	Xenoblastic grains 1.0 to 0.05 mm; pleochroic from pale brown to very dark brown and very dark greenish-brown; moderately altered to chlorite.
Epidote 6%	Idioblastic to xenoblastic grains 0.5 to 0.01 mm; alteration product associated with plagioclase and biotite.
Apatite Tr.	
Zircon Tr.	
Calcite Tr.	Fracture filling.
Opaques 1%	(probably magnetite)
Fabric:	Gneissic, granoblastic, non-porphyroblastic, cataclastic, fine- to Medium-grained.
Rock:	*Biotite-plagioclase-quartz gneiss*

Maryland Geological Survey basement core test hole CE-Dc2
Elk Neck State Park, Turkey Point
lat. 39°27′16″N
long. 76°00′30″W

903 feet

Quartz 32%	Xenoblastic grains 4.0 to 0.05 mm; strongly strained and fractured; sutured borders.
Muscovite 26%	Idioblastic to xenoblastic grains 3.5 to 0.05 mm; preferred orientation; strong cross-foliation.
Plagioclase 25%	Oligoclase; xenoblastic grains 0.5 to 0.05 mm; poikiloblastically enclose biotite, quartz, and garnet; albite twins obscured; strongly to severely altered to sericite; some grains lost in preparation of thin section.
Biotite 10%	Ragged xenoblastic grains 1.0 to 0.01 mm; pleochroic from pale yellow to reddish-brown; poikiloblastically enclose zircon with pleochroic halos and magnetite; moderately altered to chlorite.

Garnet 5%	Idioblastic to rounded and embayed xenoblastic grains 1.5 to 0.01 mm; fractured; poikiloblastically enclose quartz, muscovite, biotite, and magnetite; moderately to strongly altered to chlorite and sericite.
Opaques 2%	(probably magnetite)
Apatite Tr.	
Zircon Tr.	
Pyrite Tr.	
Fabric:	Schistose, lepidoblastic, prophyroblastic, fine-grained.
Rock:	*Garnetiferous biotite-plagioclase-muscovite-quartz schist*

909.5 feet

Quartz 45%	Xenoblastic grains 9.0 to 0.01 mm; strongly strained and fractured; sutured borders; largest grains occur in veins.
Muscovite 24%	Idioblastic grains 3.0 to 0.05 mm; preferred orientation; slightly altered to chlorite.
Plagioclase 16%	Oligoclase; xenoblastic grains 1.5 to 0.05 mm; poikiloblastically enclose quartz and biotite; albite twins obscured; strongly altered to sericite.
Biotite 14%	Ragged xenoblastic grains 2.5 to 0.05 mm; pleochroic from pale yellow to reddish-brown; poikiloblastically enclose zircon with pleochroic halos and magnetite; slightly altered to chlorite.
Garnet 1%	Rounded xenoblastic grains 0.5 to 0.05 mm; fractured, poikiloblastically enclose quartz and muscovite; moderately altered to chlorite and sericite.
Apatite Tr.	
Zircon Tr.	
Sillimanite Tr.	
Opaques Tr.	(probably magnetite)
Pyrite Tr.	
Fabric:	Schistose, lepidoblastic, porphyroblastic, fine-grained.
Rock:	*Garnet-bearing biotite-plagioclase-muscovite-quartz schist*

916.5 feet

Muscovite 38%	Idioblastic to xenoblastic grains 4.0 to 0.1 mm; poikiloblastically enclose garnet, biotite, pyrite, magnetite, and apatite; preferred orientation; slightly altered to chlorite.
Quartz 25%	Xenoblastic grains 8.0 to 0.05 mm; strongly strained and fractured; sutured grain borders; largest grains occur in veins cutting rock.
Plagioclase 22%	Oligoclase; xenoblastic grains 11.0 to 0.1 mm; albite and pericline twins; poikiliblastically enclose quartz and muscovite; moderately altered to sericite; largest grains occur in veins with quartz.
Biotite 8%	Xenoblastic grains 1.5 to 0.05 mm; pleochroic from pale yellow to reddish-brown; poikiloblastically enclose zircon with pleochroic halos; preferred orientation; slightly altered to chlorite.
Garnet 5%	Rounded xenoblastic grains 4.0 to 0.05 mm; fractured; poikiloblastically enclose quartz, feldspar, biotite, and magnetite; slightly altered to sericite and chlorite.
Opaques 1%	(probably magnetite)
Apatite Tr.	
Zircon Tr.	
Pyrite Tr.	
Fabric:	Schistose, lepidoblastic, porphyroblastic, fine-grained.
Rock:	*Garnetiferous biotite-plagioclase-quartz-muscovite schist*

918 feet

Muscovite 35%	Idioblastic to xenoblastic grains 4.0 to 0.1 mm; poikiloblastically enclose biotite, magnetite, and pyrite; preferred orientation with cross-foliation.
Quartz 32%	Xenoblastic grains 7.0 to 0.01 mm; strongly strained and fractured; sutured grain borders; largest grains occur in a small vein.
Plagioclase 16%	Oligoclase; xenoblastic grains 4.5 to 0.1 mm; albite and pericline twins; poikiloblastically enclose quartz and biotite; myrmekitic where adjacent to quartz vein; moderately altered to sericite.
Biotite 14%	Xenoblastic grains 1.5 to 0.05 mm; pleochroic from pale yellow to reddish-brown; poikiloblastically enclose zircon with pleochroic halos and magnetite; preferred orientation; slightly altered to chlorite.
Garnet 2%	Xenoblastic grains 2.0 to 0.05 mm; fractured; poikiloblastically enclose quartz, muscovite, biotite, and magnetite; slightly altered to sericite and chlorite.
Opaques 1%	(probably magnetite)
Apatite Tr.	
Zircon Tr.	
Pyrite Tr.	
Fabric:	Schistose, lepidoblastic, porphyroblastic, fine-grained.
Rock:	*Garnet-bearing biotite-plagioclase-quartz-muscovite schist*

921 feet

Quartz 39%	Xenoblastic grains 4.5 to 0.05 mm; moderately to strongly strained and fractured.
Plagioclase 38%	Oligoclase; xenoblastic grains 5.0 to 0.1 mm; albite and pericline twins; poikiloblastically enclose quartz and biotite; moderately altered to sercite.
Biotite 15%	Xenoblastic grains 2.0 to 0.05 mm; pleochroic from pale yellow to reddish-brown; poikiloblastically enclose zircon with pleochroic halos, pyrite, and magnetite; preferred orientation; slightly altered to chlorite.
Muscovite 6%	Idioblastic to xenoblastic grains 2.0 to 0.05 mm; poikiloblastically enclose biotite, pyrite, and magnetite; preferred orientation with weak cross-foliation.
Garnet 1%	Idioblastic to rounded xenoblastic grains 0.5 to 0.05 mm; fractured; slightly to moderately altered to sericite and chlorite; poikiloblastically enclose plagioclase, quartz, biotite, and magnetite.
Pyrite 1%	Xenoblastic masses and grains 3.0 to 0.01 mm.
Zircon Tr.	
Apatite Tr.	
Opaques Tr.	(probably magnetite)
Fabric:	Schistose, lepidolbastic, porphyroblastic, fine-grained.
Rock:	*Garnet-bearing muscovite-biotite-plagioclase-quartz schist.*

926.5 feet

Muscovite 41%	Idioblastic to xenoblastic grains 5.0 to 0.05 mm; poikiloblastically enclose quartz, biotite, and garnet; preferred orientation with weak cross-foliation.
Quartz 32%	Xenoblastic grains 5.0 to 0.05 mm; moderately to strongly strained and fractured; large grains poikiloblastically enclose plagioclase, muscovite, and biotite.
Plagioclase 12%	Oligoclase; xenoblastic grains 1.0 to 0.1 mm; moderately to severely altered sericite; some grains lost in preparation of thin section; twinning obscured by alteration.
Biotite 10%	Xenoblastic grains 1.0 to 0.05 mm; pleochroic from pale yellow to reddish-brown; poikiloblastically enclose zircon with pleochroic halos; slightly altered to chlorite.
Garnet 3%	Idioblastic to rounded and embayed xenoblastic grains 1.5 to 0.3 mm; fractured; poikiloblastically enclose quartz, plagioclase, biotite, muscovite, zircon, and magnetite; slightly altered to sericite and chlorite.

Opaques 1%	(probably magnetite)
Sillimanite Tr.	Minute, needle-shaped crystals associated with muscovite.
Apatite Tr.	
Zircon Tr.	
Pyrite Tr.	
Fabric:	Schistose, lepidoblastic, porphyroblastic, fine-grained.
Rock:	*Garnet-bearing biotite-plagioclase-quartz-muscovite schist*

930.5 feet

Quartz 38%	Xenoblastic grains 2.5 to 0.1 mm; moderately strained and fractured.
Muscovite 20%	Elongate idioblastic to xenoblastic grains 5.0 to 0.1 mm; poikiloblastically enclose biotite, garnet, quartz, hornblende, and magnetite; strong preferred orientation with weak cross-foliation.
Plagioclase 16%	Oligoclase; xenoblastic grains 1.0 to 0.1 mm; slightly to moderately altered to sericite; albite twins.
Biotite 15%	Idioblastic to xenoblastic grains 2.0 to 0.05 mm; pleochroic from pale yellow to reddish-brown; poikiloblastically enclose zircon with pleochroic halos and magnetite; preferred orientation; slightly altered to chlorite.
Sillimanite 5%	Minute, needle-like crystals associated with muscovite.
Garnet 4%	Idioblastic to rounded and embayed xenoblastic grains 3.0 to 0.05 mm; fractured; poikiloblastically enclose quartz, muscovite, biotite, and magnetite; slightly altered to chlorite.
Opaques 1%	(probably magnetite)
Hornblende Tr.	Xenoblastic grains 0.3 to 0.05 mm; pleochroic from pale green to dark olive-green.
Leucoxene Tr.	
Zircon Tr.	
Pyrite Tr.	
Fabric:	Schistose, lepidoblastic, porphyroblastic, fine-grained.
Rock:	*Garnet- and sillimanite-bearing biotite-plagioclase-muscovite-quartz schist.*

931 feet

Plagioclase 31%	Oligoclase; xenoblastic grains 1.5 to 0.05 mm; moderately altered to sericite; albite, pericline, and Carlsbad twins; poikiloblastically enclose small blebs of quartz and biotite.
Quartz 31%	Xenoblastic grains 2.5 and 0.05 mm; strongly strained and fractured; slightly sutured; poikiloblastically enclose biotite and muscovite.
Muscovite 17%	Idioblastic to xenoblastic grains 3.5 to 0.05 mm; poikiloblastically enclose garnet, biotite, pyrite, and leucoxene; preferred orientation, slightly altered to chlorite.
Biotite 17%	Xenoblastic grains 4.0 to 0.05 mm; pleochroic from pale yellow to reddish-brown; poikiloblastically enclose garnet, pyrite, and zircon with pleochroic halos; preferred orientation; slightly altered to chlorite.
Garnet 3%	Idioblastic to rounded xenoblastic grains 1.0 to 0.05 mm; fractured; slightly altered to sericite and chlorite.
Opaques 1%	(probably magnetite)
Chlorite Tr.	
Leucoxene Tr.	
Zircon Tr.	
Pyrite Tr.	
Fabric:	Schistose, leipdoblastic, porphyroblastic, fine-grained.
Rock:	*Garnet-bearing biotite-muscovite-quartz-plagioclase schist*

Maryland Geological Survey basement core test hole CE-Ec17
Camp Trinity, Grove Neck
lat. 39°24′18″N
long. 76°01′30″W

1069 feet

Quartz 38%	Xenoblastic grains 3.0 to 0.01 mm; strongly to severely strained and fractured; grain borders sutured.
Muscovite 25%	Elongate idioblastic to xenoblastic grains 1.0 to 0.01 mm; preferred orientation, strained.
Plagioclase 20%	Severely altered to sericite; most grains lost during preparation of thin section and represented only by voids.
Biotite 13%	Xenoblastic grains 1.0 to 0.01 mm; pleochroic from pale brown to reddish-brown; preferred orientation; poikiloblastically enclose zircon with pleochroic halos.
Garnet 2%	Idioblastic to xenoblastic grains 1.5 to 0.05 mm; severely fractured.
Pyrite 1%	
Apatite Tr.	
Zircon Tr.	
Leucoxene Tr.	
Calcite Tr.	Secondary fracture-filling.
Opaques Tr.	(probably magnetite and/or graphite*)
Fabric:	Schistose, lepidoblastic, porphyroblastic, cataclastic, fine-grained, Rock is cut by many shear planes.
Rock:	*Biotite-plagioclase-muscovite-quartz schist*

*Graphite was identified megascopically in the core sample.

1076 feet

Quartz 45%	Xenoblastic grains 3.5 to 0.01 mm; strongly to severely strained and fractured; grain borders sutured and granulated.
Muscovite 25%	Idioblastic to xenoblastic grains 1.0 to 0.01 mm; preferred orientation; strained.
Biotite 15%	Elongate xenoblastic grains 2.0 to 0.05 mm; paleochroic from pale yellow to reddish-brown; preferred orientation; strained.
Plagioclase 11%	Severely altered to sericite; most grains lost during preparation of thin section and represented only by voids.
Opaques 2%	(probably magnetite and/or graphite*)
Pyrite 1%	
Sillimanite Tr.	
Apatite Tr.	
Zircon Tr.	
Fabric:	Schistose, lepidoblastic, non-porphyroblastic, cataclastic, fine-grained. Rock is cut by many closely-spaced shear planes.
Rock:	*Plagioclase-biotite-muscovite-quartz schist.*

*Graphite was identified megascopically in the core sample.

1087 feet

Plagioclase 39%	Oligoclase; xenoblastic grains 4.0 to 0.05 mm; faint albite twins; poikiloblastically enclose quartz; moderately to strongly altered to sericite; strained and fractured.
Quartz 34%	Xenoblastic grains 4.0 to 0.01 mm; strongly to severely strained and fractured; sutured and granulated borders.
Muscovite 16%	Ragged xenoblastic grains 1.0 to 0.01 mm; partially altered to sericite; bent and distorted.

Biotite 10%	Ragged xenoblastic grains 3.0 to 0.05 mm; weak preferred orientation; pleochroic from pale brownish-green to dark olive-green; strongly strained and bent.
Opaques 1%	(probably magnetite and/or graphite)
Zircon Tr.	
Pyrite Tr.	
Fabric:	Granoblastic to cataclastic, non-porphyroblastic, fine-grained.
Rock:	*Biotite-muscovite-quartz-plagioclase gneiss.*

*Graphite was identified megascopically in the core samples.

1090.5

Quartz 54%	Xenoblastic grains 1.0 to 0.05 mm; strongly strained; sutured borders.
Plagioclase 33%	Oligoclase; xenoblastic grains 0.3 to 0.05 mm; albite twins obscured; moderately to strongly altered to sericite.
Biotite 7%	Ragged elongate xenoblastic grains 1.0 to 0.5 mm; pleochroic from pale brownish-green to dark olive-green; preferred orientation.
Chlorite 3%	Pennine; xenoblastic grains 1.0 to 0.01 mm; alteration product of biotite; associated with shear planes.
Garnet 2%	Corroded idioblastic to rounded xenoblastic grains 0.3 to 0.05 mm; fractured.
Tourmaline 1%	Radiating masses of minute, needle-like crystals; associated with shear planes.
Sphene Tr.	
Leucoxene Tr.	
Apatite Tr.	
Zircon Tr.	
Opaques Tr.	(probably magnetite and/or graphite*)
Fabric:	Granoblastic, weakly schistose, lepidoblastic, non-porphyroblastic, cataclastic, fine-grained.
Rock:	*Garnet-bearing biotite-plagioclase-quartz gneiss* to *quartzite.*

*Graphite was identified megascopically in the core sample.

1095.5 feet

Quartz 41%	Xenoblastic grains 3.0 to 0.01 mm; strongly to severely strained and fractured; sutured and granulated grain borders.
Muscovite 28%	Elongate xenoblastic grains 0.5 mm to microcrystalline; larger grains strained and bent, smaller grains occur in aggregates along shear planes.
Plagioclase 21%	Oligoclase; xenoblastic grains 4.0 to 0.05 mm; weak albite twins; moderately altered to sericite; strained.
Biotite 9%	Ragged elongate xenoblastic grains 0.7 to 0.01 mm; pleochroic from pale brown to dark olive-green; moderately altered to chlorite.
Garnet Tr.	
Apatite Tr.	
Zircon Tr.	
Leucoxene Tr.	Alteration product of ilmenite.
Ilmenite (?) Tr.	
Pyrite Tr.	
Fabric:	Granoblastic, weakly schistose, lepidoblastic, non-porphyroblastic, cataclastic, fine-grained.
Rock:	*Biotite-plagioclase-muscovite-quartz gneiss*

1105 feet

Muscovite 42%	Xenoblastic grains 3.0 mm to microcrystalline; large grains bent and strained, small grains occur in large aggregates.
Quartz 22%	Lenticular xenoblastic grains 3.0 to 0.01 mm; severely strained and fractured; sutured and granulated borders.
Biotite 19%	Ragged elongate xenoblastic grains 0.5 to 0.05 mm; pleochroic from pale yellow-brown to dark olive-green; severely altered to chlorite.

Plagioclase 12%	Oligoclase; xenoblastic grains 6.0 to 1.05 mm; weak albite twins; poikiloblastically enclose biotite, muscovite, and quartz; some quartz myrmekitic; moderately altered to sericite.
Garnet 2%	Xenoblastic grains 8.0 to 0.05 mm; fractured; poililoblastically enclose quartz, plagioclase, muscovite, biotite, and magnetite; moderately altered to chlorite.
Opaques 2%	(probably magnetite and/or graphite*)
Leucoxene Tr.	
Apatite Tr.	
Zircon Tr.	
Epidote Tr.	
Pyrite Tr.	
Fabric:	Schistose, cataclastic, non-porphyroblastic, fine- to medium-grained; originally granoblastic.
Rock:	*Plagioclase-biotite-quartz-muscovite schist*

*Graphite was identified megascopically in the core sample.

PALYNOSTRATIGRAPHIC ZONATION

by
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Occurrences of taxa identified in samples from the Spesutie Island, Grove Neck, and Turkey Point wells are recorded in Table 4. Taxonomic treatment of the fern spores and gymnosperm pollen follows Brenner (1963), except for taxa not seen by Brenner and some cases where Brenner's species have been subsequently transferred to other genera; here the name used by Brenner is indicated in parentheses. Taxonomic treatment of the angiosperm pollen follows Doyle and Robbins (1977), where illustrations of most identified types may be found. The expression "cf." before a name indicates that the identification is somewhat uncertain because of either slight morphological differences from the original material or insufficient information. The expression "aff." indicates that the specimens in question appear to be closely related to the species named, but show sufficient differences from it that they could probably be described as a distinct new species.

Rapid counts were made to determine relative abundances of taxa in the Grove Neck (CE-Ec15, 17) and Turkey Point (CE-Dc2) wells, but the sample size (100-150 grains) is not considered large enough to justify citing percentage figures. The counts are summarized in Table 4 using the following convention: $\leqslant$ 1%=R (rare), 2-5%=O (occasional), 6-20%=C (common), 21-50%=A (abundant), > 50%=D (dominant). Except for sample HAR-Dg3 23.5-25′, counts were not made for the Spesutie Island well; R, O, and C here are purely subjective estimates of relative abundance and cannot be compared directly with the data from the other wells.

In the following commentary, inferred ages of each sample are given first in terms of the zonational scheme of Doyle and Robbins (1977), which follows Brenner (1963) for Zone I, Subzone II-A, and all but the upper limit of Subzone II-B; then in terms of the standard European stage sequence; and finally in terms of sample depths in Delaware City wells D12 (Dc53-17) and D13 (Ec14-1). Detailed studies of the morphology and stratigraphic distribution of angiosperm species in the Delaware wells have resulted in considerable subdivision and refinement of Brenner's zonational units (Doyle and Robbins, 1977); the usefulness of these wells as standard reference sections has been illustrated in correlation of outcrop localities (Doyle and Hickey, 1976) and deep wells in the Salisbury Embayment (Doyle and Robbins, 1977). Except where noted otherwise, assignments to European stages and substages are based on arguments presented in Doyle and Robbins (1977) for palynological correlation of the Potomac sequence with assemblages described from faunally dated deposits elsewhere in North America and in Europe.

Presences and absences of species are discussed in greater than usual detail in Subzone II-B of Grove Neck well CE-Ec 15, since there is evidence that sampling of this interval is more complete here than in the Delaware City wells, and this information may hence be valuable in future zonation of samples from other wells or the outcrop. The order of appearance of new species going up in the Grove Neck section is consistent with that in the Delaware wells, but some samples seem intermediate between sampled horizons in the Delaware wells in possessing some but not others of the species which appear at the younger horizon. If these were isolated spot samples, there would be no way to judge whether or not the absences were significant, but when the species in question appear at immediately succeeding levels in the same well, it is reasonable to suggest that a previously unknown intermediate level is represented.

SPESUTIE ISLAND WELL HAR-Dg3

HAR-Dg3 719′ (bit sample)

AGE: Lower Zone I (Barremian-Aptian?); pre-D12-745′; older than any samples in well D13.

This sample is severely contaminated with Quaternary pollen (probably not Recent, since most of the grains concerned are flattened and colored like fossils). However, the bulk of the assemblage is clearly of Early Cretaceous age.

In evaluating the age of Potomac samples where there is evidence of up-hole contamination, it is important to bear in mind that the prevailing pattern in the Potomac sequence is the appearance of new types rather than the disappearance of old ones (cf. Brenner, 1963; Doyle, 1977; Doyle and Robbins, 1977). Thus most species found in Zone I continue into Zone II and even younger horizons, although usually they decrease in abundance. This means that Zone I samples must often be recognized as such on the absence of Zone II "index" species and the greater abundance of those forms which decrease in Zone II, rather than on the presence of species restricted to Zone I. Hence, when Zone I samples are contaminated by Zone II material, special care is needed to recognize them as Zone I rather than Zone II.

Most of the spores and gymnosperm pollen taxa in the present sample range throughout the Potomac Group. The association of tricolpate species listed is restricted to Subzone II-B and Subzone II-C (middle and late Albian?). However, the abundance of Schizaeaceae, *Concavissimisporites, Pilosisporites, Trilobosporites,* other large spores, *Exesipollenites,* and *Classopollis* is more suggestive of Zone I. More conclusive evidence that the well had penetrated Zone I, in fact its lower portion, is the presence of representatives or close relatives of three species restricted to basal Zone I horizons (770′, 765′) in Delaware well D12 and apparent pre-Arundel localities in the Maryland-Virginia outcrop belt (cf. Doyle and Hickey, 1976): the angiosperms *Liliacidites* sp. B and *Stellatopollis* sp. and the small bisaccate aff. *Decussosporites* sp.

The age of lower Zone I can be bracketed as Barremian-Aptian on the presence of reticulate angiospermous monosulcates, whose oldest dated occurrences are in the Barremian of England *(Clavatipollenites hughesii, Retimonocolpites* and *Stellatopollis* species), and the absence of upper Zone I forms such as *Retimonocolpites* aff. *dividuus* and *Tricolpites* aff. *crassimurus,* close relatives of which appear in the lower Albian of England (cf. Doyle and Robbins, 1977). The presence of *Retimonocolpites peroreticulatus* (not known from all Zone I outcrop localities) may help narrow down the age of the present sample to Aptian, since recent data of Hughes (1977) indicate that this species appears at the base of the marine Aptian in England.

HAR-Dg3 685-686′ (bit sample)

AGE: Lower Zone I (Barremian-Aptian?); pre-D12-745′; older than any samples in well D13.

Although poorer in species and in preservation, this assemblage is essentially similar to that from 719′, and the same arguments presented above apply to it. Again, the presence of *Stellatopollis* sp. and aff. *Decussosporites* sp. strengthens correlation with the lower part of the zone.

HAR-Dg3 614′ (bit sample)

AGE: Zone I or Zone II (Barremian-Albian).

This sample is poor in pollen and spores and heavily contaminated by Quaternary material. Although most of the spores and gymnosperm pollen are found in both Zone I and Zone II, there are no forms characteristic of Zone I, as was the case in lower samples. The tricolpates in association would indicate a middle or upper Subzone II-B or Subzone II-C age (middle or late Albian); in addition, one of Brenner's (1963) Zone II index spores is present *(Apiculatisporis babsae).* However, in view of the rarity of Early Cretaceous pollen and spores as a whole, the obvious up-hole contamination, the fact that the Subzone II-B or II-C species could be derived from the same horizons as the contamination in the demonstrable Zone I samples from 719′ and 685-686′, and the low stratigraphic position, it is quite possible that the entire Potomac element represents contamination from higher in the section. Hence, the palynological data serve only to indicate that Potomac sediments had been penetrated.

HAR-Dg3 390-393′ (bit sample)

AGE: Subzone II-B or II-C? (middle or late Albian?); post-D12-615′, pre-D12-285′; post-D13-640′, pre-D13-370′.

Because of the relative scarcity of pollen and the obvious contamination, this sample suffers from many of the same problems of interpretation as that from 614′. Again, there is no sign of a diagnostic Zone I component. The fern-gymnosperm "background" is suggestive of Subzone II-B or II-C, with fewer spores and *Classopollis* than usually occur in Zone I, no *Exesipollenites*, and more abundant *Araucariacites* and *Inaperturopollenites dubius*. *Apiculatisporis babsae* and *Verrucatosporites chaloneri* are "index" species that enter at the base of Zone II and continue to higher horizons; *Taurocusporites spackmani* and *Pilosisporites brevipapillosus* enter in Subzone II-B, while *Trilobosporites humilis* is most common above Subzone II-A. The *Tricolpites, "Retitricolpites,"* and *Striatopollis* species identified are all consistent with either a middle or upper Subzone II-B or Subzone II-C age; however, *Tricolporoidites* cf. *subtilis* is a Subzone II-C (and younger) index species. This assemblage could represent a true middle or upper Subzone II-B flora (middle or early late Albian?) slightly contaminated by Subzone II-C material, but the absence of the abundant and distinctive middle and upper Subzone II-B species *"Retitricolpites" vermimurus* leaves open the possibility that the whole Potomac assemblage consists of contamination from Subzone II-C.

HAR-Dg3 188-190′ (core)

AGE: Subzone II-C (latest Albian?); post-D12-465′, pre-D12-285′; post-D13-510′, pre-D13-370′.

This is the only fossiliferous Potomac sample from the Spesutie well which is not contaminated by younger material. The excellent flora allows it to be correlated securely with Subzone II-C (i.e., equivalents of the lower part of the Maryland-Delaware "Raritan Formation" or Elk Neck beds).

As is typical of Subzone II-C, the bulk of the flora consists of elements continuing from Subzone II-B and lower horizons. Many are forms which range throughout the Potomac; some appear at the base of Zone II (*Apiculatisporis babsae,* several tricolpates) or in Subzone II-B (*Neoraistrickia robusta, Pilosisporites brevipapillosus, Taurocusporites spackmani, Stellatopollis barghoornii, Tricolpites* cf. *minutus, "Retitricolpites"* aff. *prosimilis, T.* cf. *georgensis*). However, *Tricolporoidites* cf. *subtilis, T.* cf. *minimus,* and *"Tricolporopollenites"* cf. *distinctus* are all restricted to Subzone II-C and younger beds. Furthermore, although *Granulatisporites dailyi, Lycopodiacidites triangularis,* and *Taurocusporites spackmani* occur below Subzone II-C, they are most common in this interval. The upper age bracket is based on the absence of the larger and more triangular tricolporates and distinctive tricolpate species which enter in Zone III. It may be noted that *Tricolporoidites* cf. *subtilis* is one of the elements used to correlate Subzone II-C with the latest Albian of western Canada and England (Doyle and Robbins, 1977).

HAR-Dg3 23.5-25′ (core)

AGE: Quaternary, Pleistocene interglacial or Holocene.

This assemblage represents an essentially modern flora made up of trees, shrubs, and herbs typical of deciduous forests of the eastern United States today. The diversity of Compositae and other herbaceous groups rules out the possibility of a Miocene age. A temperate, inter- or post-glacial rather than glacial climate is indicated by the dominance of hardwoods (especially oak) and pine, as in the Coastal Plain today, and the extreme rarity of spruce. The isolated grain of *Ephedra,* a desert shrub, may have been blown in from the western U.S.; such occurrences are not uncommon in Quaternary samples. The presence of several aquatics (*Sagittaria, Sparganium* or *Typha,* water lilies) and grasses and sedges suggest a pond or marsh environment, with the forest elements wind- or water-transported an unknown distance. More detailed analysis would undoubtedly permit more precise conclusions on the age and environment of this sample.

CE-Ec17 989-989.5′ (core)

AGE: Lower Zone I (Barremian-Aptian?); pre-D12-745′, older than any samples in well D-13.

This sample contains very little pollen, and a significant portion of this consists of Quaternary or Recent and younger Potomac contaminants *(Neoraistrickia robusta,* tricolpates, and *Clavatipollenites* cf. *tenellis*, together suggestive of a source horizon in Subzone II-B). However, the bulk of the spore and pollen flora is consistent with a Zone I age, while aff. *Decussosporites* sp. and *Monosulcites* aff. *glottus* are restricted to the lowest Zone I samples in Delaware well D12 (D12-770′,-765′). The rare marine plankton pose a problem, since no marine or brackish-water sediments are known to have been penetrated higher in the section (except perhaps the Magothy, though no other obvious Magothy elements have been observed), and since there is no evidence of marine influence elsewhere in the lower Potomac Group except in deep wells in the Salisbury Embayment (cf. Doyle and Robbins, 1977).

CE-Ec17 939-940′ (core)

AGE: Lower Zone I (Barremian-Aptian?); pre-D12-745′; older than any samples in well D13.

Besides lacking the Zone II index species of Brenner (1963) and such forms as *Retimonocolpites* aff. *dividuus* and *Tricolpites* aff. *crassimurus* which appear near the top of Zone I, this sample contains several forms which have been observed only in Zone I: *Liliacidites* sp. A, *L.* sp. B, aff. *Decussosporites* sp., and *Monosulcites* aff. *glottus* (large), of which the latter two are restricted to basal Zone I in well D12 and inferred lower Zone I outcrop localities. As noted above, the presence of *Retimonocolpites peroreticulatus* may indicate an Aptian vs. Barremian age.

CE-Ec17 890′ (bit sample)

AGE: Zone I or Zone II (Barremian-Albian).

Pollen and spores are too rare in this sample to justify listing in Table 4, and the majority are obvious Quaternary or Recent contaminants (*Betula, Alnus, Juglans, Quercus, Liquidambar,* Compositae, grasses, etc.). The Cretaceous element consists of long-ranging forms *(Cyathidites, Gleicheniidites, Cicatricosisporites, Laevigatosporites gracilis, Classopollis, Inaperturopollenites dubius, Vitreisporites pallidus),* plus a few forms which circumstantial evidence would indicate are derived from higher in the section (small tricolpates, *Pilosisporites brevipapillosus*), and indicates only that Potomac sediments had been penetrated.

CE-Ec17 780′ (core)

AGE: Zone I, probably middle or upper portion (Aptian-early Albian?); post-D12-765′, pre-D12-615′; pre-D13-730′.

As is often a problem in Zone I, especially its middle and upper portions, this sample contains no species which are restricted to any zone, and its assignment to Zone I must be based on general quantitative composition and the absence of species which appear at the base of Zone II. Although the flora is largely dominated by *Gleicheniidites* and *Inaperturopollenites dubius,* spores and pollen, including angiosperms, are common enough to be reasonably sure that tricolpate angiosperms and other Zone II index forms would have been seen if that zone were represented. Similarly, it is significant that there is no indication of those species that are restricted to the base of Zone I. *Clavatipollenites* aff. *hughesii* is of the broad type prevalent above D12-765′, and aff. *Decussosporites* sp. has been replaced by *D. microreticulatus,* as occurs above D12-765′. Although such latest

Zone I and younger species as *Retimonocolpites* aff. *dividuus* and *Tricolpites* aff. *crassimurus* have not been seen, their absences cannot be used to rule out a latest Zone I age, since they are rare and occur only in some upper Zone I samples in the reference section.

CE-Ec15 660-670′ (core)

AGE: Probably basal Subzone II-B (middle Albian?); post-D12-615′, pre-D12-525′; post-D13-695′, pre-D13-600′.

This very rich sample can be readily assigned to Zone II on the presence of *Cingulatisporites caminus, Lycopodiacidites irregularis, Verrucatosporites chaloneri, Perotriletes pannuceus,* and several species of tricolpate angiosperm pollen. Its general quantitative composition would be consistent with either Subzone II-A or lower Subzone II-B: codominance of the gymnosperms *Inaperturopollenites dubius* (subordinate in Zone I), *Exesipollenites tumulus,* and *Classopollis torosus* (both declining higher in Zone II); diversity of sculptured pteridophyte spores, many with possible lycopsid affinities; tricolpate angiosperms present but still very subordinate (less than 1%). Although none of Brenner's (1963) Subzone II-B index species have been observed, there are several other species which first appear or reach a particular level of morphological advancement at the same horizons as the first Subzone II-B index species in the Delaware wells (D13-600′ or -640′, D12-590′): *Appendicisporites jansonii, Asteropollis asteroides, Stellatopollis* aff. *barghoornii, Tricolpites* cf. *micromunus, T.* cf. *sagax, "Tricolpopollenites"* cf. *parvulus, "Retitricolpites"* aff. *fragosus,* and aff. *Nemejcipollis* sp. (not reported in Doyle and Robbins, 1977). A few other complexes, however, do not seem to have reached the level of advancement seen at D13-660′ and D12-590′ (*Tricolpites* aff. *georgensis, T.* aff. sp. B). The "borderline" Subzone II-B character of this sample suggests that it may correlate with the interval between 695′ and 660′ in the D13 reference section, especially considering the assemblage from the next sample. The more conservative younger age bracket given is based on the absence of several forms which appear at D13-600′ and the fact that *Clavatipollenites* aff. *minutus* and *"Retitricolpites"* aff. *fragosus* resemble representatives of those complexes in D13-660′, D13-640′, and D12-590′ more than those at D13-600′ and younger horizons.

CE-Ec15 620-630′ (core)

AGE: Lower Subzone II-B (middle Albian?); post-D12-615′, pre-D12-525′; post-D13-695′, pre-D13-600′.

This sample is very similar to that from 660-670′, and most of the arguments used to place that sample near the Subzone II-A/II-B boundary apply here, allowing for slight differences in the suite of Zone II index species (e.g., *Apiculatisporis babsae*). However, several additional elements place this sample more solidly in Subzone II-B and nearer Delaware well samples D13-660′, D13-640′, and D12-590′: Brenner's (1963) Subzone II-B index species *Podocarpidites epistratus,* more typical *Tricolpites* cf. sp. B, *"Retitricolpites"* aff. *prosimilis,* and the first clearly tricolporoidate members of the *T. micromunus* complex. The presence of more typical *Stellatopollis barghoornii* and of one grain of *Striatopollis* sp. A, both first seen in D13-600′, could mean that the sample is younger than D13-640′, but this is somewhat speculative, since both species are sporadically distributed in the reference section.

CE-Ec15 589-590′ (core)

AGE: Lower Subzone II-B (middle Albian?); post-D12-590′, pre-D12-525′; post-D13-640′, pre-D13-595′.

This sample is readily assignable to Subzone II-B on the presence of Brenner's (1963) index species *Neoraistrickia robusta* and *Podocarpidites epistratus,* as well as several taxa first seen at 660′ or 640′ in well D13 (*Appendicisporites jansonii,* most of the angiosperm species cited under CE-Ec15 620-630′, and the new species *"Foveotricolpites"* aff. *concinnus* and *Tricolpites* aff. *geranioides).* The angiosperm

element shows a slight but perceptible differentiation over lower samples in the same well and D13-640′ and D12-590′ at Delaware City, with an increased relative abundance of tricolpates (ca. 5%), greater numbers of tricolporoidate variants in the *Tricolpites micromunus* and *T. minutus* complexes, and the first occurrence of several forms which enter in middle Subzone II-B (600′ or 595′) in Delaware well D13: *Tricolpites* cf. *minutus*, *"Retitricolpites"* cf. *magnificus*, and the first typical members of the *"R." fragosus* and *"R." prosimilis* complexes, plus a middle II-B gymnosperm, *Ephedripites* sp. A. At the same time, this sample apparently lacks several other species which are conspicuously present for the first time in D13-600′ or D13-595′ and at 522-524′ or 510-513′ in this well (*Liliacidites* sp. F, *L.* aff. sp. D, *"Retitricolpites" vermimurus*, and *Dicotetradites* aff. sp. A), and a few complexes are morphologically closer to their representatives in D13-640′ than those in D13-600′ or CE-Ec15 522-524′ (*Clavatipollenites* aff. *minutus* is still larger than *C.* cf. *minutus* from D13-600′ onward; the *"Retitricolpites" fragosus* complex does not include the very smooth variants first seen in D13-600′). Hence it is a good guess that the age of this sample falls between D13-640′ and D13-600′, but I have placed the younger age bracket more conservatively below D13-595′, where the middle II-B assemblage is first completely developed.

CE-Ec15 522-524′ (core)

AGE: Middle Subzone II-B (late middle Albian?); post-D12-590′, pre-D12-520′; post-D13-600′, pre-D13-560′.

This sample is readily assigned to Subzone II-B on the presence of Brenner's (1963) index species *Neoraistrickia robusta*, *Cicatricosisporites patapscoensis*, *Pilosisporites brevipapillosus*, and *Taurocusporites spackmani*, all but the first appearing for the first time in this well. Correlation with the post-D13-600′ portion of Subzone II-B is based on the continued decline of *Exesipollenites tumulus*, the increase in tricolpates and especially tricolporoidates (ca. 12% combined), the presence of the same post-D13-640′ angiosperm species noted in CE-Ec15 589-590′ (*Tricolpites* cf. *minutus*, *"Retitricolpites"* cf. *fragosus*, *"R."* cf. *magnificus*, and *"R."* cf. *prosimilis*), and two new species, *Liliacidites* aff. sp. D and *"Retitricolpites" vermimurus*, which first occur at 595′ in well D13. A latest Subzone II-B age is ruled out by the presence of the *Asteropollis-Stephanocolpites* complex, which disappears above 545′ in well D13 and 485′ in well D12. This younger age bracket is tentatively lowered further on the absence of three species which appear at D12-520′ and D13-560′: typical *Liliacidites* sp. D, *Tricolpites* cf. *geranioides*, and *Penetetrapites mollis*, the first two of which occur in the next sample from this well.

Many of the forms used to establish the maximum age bracket for this sample are among those used (Doyle, 1977; Doyle and Robbins, 1977) to correlate Delaware City samples D12-520′ and -515′ with the late middle Albian palynoflora described from the Fredericksburgian of Oklahoma by Hedlund and Norris (1968). However, since several other species used for correlation with Oklahoma are absent here (e.g., *Striatopollis paraneus*, *Tricolpites geranioides*, *Penetetrapites mollis*), but two of them do appear in the next sample, it is possible that the present sample is slightly older than the Oklahoma flora.

CE-Ec15 510-513′ (core)

AGE: Middle Subzone II-B (late middle Albian?); post-D12-525′, pre-D12-465′; post-D13-590′, pre-D13-540′.

This assemblage is similar in general aspect to that from CE-Ec15 522-524′, and it contains all but two of the index species used to correlate that sample with post-D13-600′, pre-D13-540′ interval, plus the middle II-B and younger species *Ephedripites* sp. A, *Liliacidites* sp. F, and *Dicotetradites* aff. sp. A. However, it also contains four new angiosperms which suggest it is younger than D13-590′ or D12-525′: typical coarsely reticulate *Liliacidites* sp. D and *Striatopollis* cf. *paraneus*, first seen in D13-580′ and D12-520′; typical *T.* cf. *geranioides*, first seen in D13-560′ and D12-515′; and a monoporoidate form (*Retimonocolpites* sp. C, not reported in Doyle and Robbins, 1977) which occurs only at D12-485′. The only anomaly is the absence of *Penetetrapites mollis*, which could of course be fortuitous. The addition of *S.* cf. *paraneus* and *T.* cf. *geranioides* allows this sample to be correlated even more closely with the late middle Albian of Oklahoma.

CE-Ec15 493′ (bit sample)

AGE: Middle Subzone II-B (late middle Albian?); post-D12-525′, pre-D12-465′; post-D13-590′, pre-D13-540′.

This rather peculiar assemblage differs from the underlying ones in the unusual abundance of large spores and pinaceous or podocarpaceous conifer pollen and the relative rarity of *Inaperturopollenites dubius* and angiosperm pollen (less than 1%). These anomalies are probably results of sedimentary sorting factors. However, it contains several Subzone II-B index species *(Cicatricosisporites patapscoensis, C. subrotundus, Appendicisporites jansonii, Neoraistrickia robusta, Pilosisporites brevipapillosus, Reticulatisporites arcuatus, Taurocusporites spackmani, Rugubivesiculites reductus),* while the association of *Asteropollis asteroides, Liliacidites* aff. sp. E (very close to forms in D12-515′), *Retimonocolpites* sp. C, and apparent abortive specimens of *Tricolpites* cf. *geranioides* confirm its assignment to the same post-D13-590′, pre-D13-540′ interval as the underlying sample.

CE-Ec15 292-295′ (core)

AGE: Subzone II-C (latest Albian?); post-D12-405′, pre D12-285′; post-D13-480′, pre-D13-370′.

Definitive evidence of a post-Subzone II-B age for this sample is the presence of *Rugubivesiculites rugosus* and *Tricolporoidites* cf. *subtilis,* which appear at 480′ in well D13 and 405′ in well D12, and typical *"Tricolporopollenites"* cf. *triangulus,* which appears at D13-435′ and hence suggests that the sample lies somewhat above the base of Subzone II-C. Subsidiary evidence for a Subzone II-C or Zone III age is the relative conspicuousness of the *Granulatisporites dailyi-Lycopodiacidites-Taurocusporites* complex. At the same time, none of the distinctive tricolpates or tricolporoidates which enter at the base of Zone III (D13-370′) have been observed. As is typical for Subzone II-C but less true for Zone III, this assemblage otherwise resembles a depauperate late Subzone II-B flora, with continuing representatives of many of Brenner's (1963) Zone II and Subzone II-B index species (*Apiculatisporis babsae, Cicatricosisporites patapscoensis, C. subrotundus, Pilosisporites brevipapillosus, Taurocusporites spackmani)* and such typical upper II-B angiosperms as *Penetetrapites mollis, Dicotetradites* sp. A, and the tricolporoidate *Tricolpites micromunus-minutus-albiensis* complex, but without certain larger and/or more sculptured Subzone II-B angiosperms such as *"Retitricolpites" vermimurus* and *Tricolpites* cf. *geranioides.*

It may be noted that the first three species listed are among those used to correlate Subzone II-C with the latest Albian of western Canada and England (Doyle and Robbins, 1977).

CE-Ec15 248-250′ (core)

AGE: Basal Zone III (earliest Cenomanian?); post-D12-405′; post-D13-390′, pre-D13-340′.

In addition to forms which entered in Subzone II-C, such as *Rugubivesiculites rugosus, Tricolporoidites* cf. *subtilis, "Tricolporopollenites"* cf. *distinctus,* and *"T"* cf. *triangulus,* this sample contains several new tricolpate and tricolporoidate species which first appear at the base of Zone III in the Delaware wells (D13-370′, D12-285′): *Tricolpites* aff. *nemejci, T.* cf. *vulgaris, Tricolporoidites* sp. B, and *Tricolporopollenites* sp. B. Also consistent with a Zone III age is the presence of several longer-ranging complexes which disappear or become very rare in the Potomac area in Subzone II-C, but which reappear, sometimes slightly changed in morphology, at or near the base of Zone III: *Liliacidites* sp. F, *L.* aff. sp. D, *Tricolpites* aff. *crassimurus, "Foveotricolpites"* aff. *concinnus,* and *Ajatipollis* sp. A. The continued presence of *Striatopollis* cf. *paraneus,* which is last seen at 370′ in well D13 and 275′ in well D12, suggests that this sample lies near the base of Zone III. This is supported by the presence of typical members of the *Tricolpites micromunus* and *T. minutus* complexes, which tend to be replaced by morphologically somewhat different forms higher in Zone III. The presence of *Dicotetradites* sp. A and *Tricolpites* cf. *albiensis* hence seems anomalous, since neither occurs above Subzone II-C in the Delaware wells. However,

since *T.* cf. *albiensis* occurs in outcrop samples confidently assigned to Zone III (e.g., Turkey Point) and *D.* sp. A is very sporadic, I do not consider the "tops" of these species to have much stratigraphic significance.

The association of tricolpates such as *Tricolpites* cf. *vulgaris* and *T.* aff. *nemejci* with small, smooth, often triangular tricolporoidates such as *"Tricolporopollenites"* cf. *triangulus* and *T.* sp. A allows Zone III to be correlated with independently dated lower Cenomanian deposits in western Canada, Minnesota, Oklahoma, England, and Czechoslovakia (cf. Doyle and Robbins, 1977).

TURKEY POINT WELL CE-Dc2

CE-Dc2 791′ (bit sample)

AGE: Lower Zone I (Barremian-Aptian?); pre-D12-745′; older than any samples in well D13.

This sample presents many of the same problems of interpretation due to contamination as HAR-Dg3 719′ and 685-686′ and CE-Ec17 989-989.5′. Although it contains several species which first appear at horizons ranging from upper Zone I to Subzone II-C *(Retimonocolpites* cf. *dividuus, Clavatipollenites* cf. *tenellis,* all the tricolpates and tricolporoidates, *Rugubivesiculites rugosus,* and probably *Appendicisporites jansonii* and *Cingulatisporites caminus),* the presence of *Liliacidites* sp. B, aff. *Stellatopollis* sp., *Monosulcites* aff. *glottus,* and aff. *Decussosporites* sp. indicates that lower Zone I horizons had been penetrated by this depth. The longer-ranging ferns and gymnosperms which make up the bulk of the flora are consistent with derivation from lower Zone I. Evidence for the Barremian or more likely Aptian age of such floras is summarized above.

CE-Dc2 710′ (bit sample)

AGE: Probably Zone I (Barremian-early Albian).

This sample contains very little pollen, much of it obvious Subzone II-B and Recent contamination (e.g., *Tricolpites* cf. *micromunus, "Retitricolpites"* cf. *prosimilis,* Compositae, grasses). The remaining elements (e.g., *Cyathidites, Gleicheniidites, Laevigatosporites, Classopollis, Exesipollenites, Inaperturopollenites dubius,* bisaccate conifers, etc.) could be derived from anywhere in the Potomac Group, but their relative abundance is most consistent with Zone I.

CE-Dc2 520-522′ (core)

AGE: Subzone II-A (early middle Albian?); post-D12-695′, pre-D12-590′; pre-D13-660′.

The presence of three of Brenner's (1963) Zone II index species *(Ceratosporites parvus, Verrucatosporites chaloneri, Perotriletes pannuceus),* the three species of small tricolpates, and probably *Clavatipollenites* cf. *tenellis* place this sample securely above Zone I. The codominance of the conifers *Inaperturopollenites dubius, Alisporites* sp., *Classpollis torosus,* and Exesipollenites *tumulus,* and the highly subordinate role of tricolpate angiosperms (ca. 1-2%) give the flora a Subzone II-A or lower Subzone II-B aspect, like that noted for Grove Neck sample CE-Ec15 660-670′. However, whereas CE-Ec15 660-670′ contained several angiosperms and ferns which enter in basal Subzone II-B in the Delaware City wells (D13-660′, -640′; D12-590′), no such forms have been observed here. These absences and the specific affinities of the tricolpates — three poorly differentiated complexes suggestive of but not clearly assignable to Subzone II-B species, as in Subzone II-A samples D13-730′, -725′, and -695′, and D12-615′ —indicate a Subzone II-A age for this sample.

The appearance at the base of the marine middle Albian of England of small reticulate tricolpates and one of Brenner's Zone II index spores *(Apiculatisporis babsae,* not seen here but present in D13-730′) has been used as evi-

dence that Subzone II-A lies near or above the early-middle Albian boundary (Doyle and Robbins, 1977).

The presence of microplanktonic cysts is of interest in indicating slight marine or brackish influence at this level.

CE-Dc2 224-226′ (core)

AGE: Probably Subzone II-C (latest Albian?); post-D12-465′, pre-D12-285′; post-D13-510′, pre-D13-370′.

This rather poor sample illustrates the difficulties in distinguishing Subzone II-C from Subzone II-B when only a small number of species are present. All the spores and gymnosperm pollen range throughout the Potomac Group, and all but the last two angiosperm species would be consistent with a late Subzone II-B age. In fact, *Liliacidites* sp. F, *Stellatopollis barghoornii,* and *"Retitricolpites"* aff. *fragosus* are more suggestive of Subzone II-B than II-C, since they are rare or absent in Subzone II-C. However, since the first two reappear in Zone III and since the one specimen of *"R."* aff. *fragosus* is smaller and thinner-walled than typical II-B forms, they are believed to have less stratigraphic significance than *Tricolporoidites* cf. *subtilis,* which appears at D13-480′ and D12-405′ and is considered a primary index species for Subzone II-C and younger rocks, and a specimen close to *T. minimus,* which enters at D13-435′. A Subzone II-C age is also consistent with a tendency seen here for morphological overlap of the *Tricolpites micromunus* and *T. minutus* complexes.

TP-O (Turkey Point outcrop sample)

AGE: Probably upper Zone III (early Cenomanian?); post-D12-275′; post-D13-285′, pre-D13-100′.

In addition to long-ranging forms and several species which entered in Subzone II-C *(Rugubivesiculites rugosus, Tricolporoidites* cf. *subtilis, "Tricolporopollenites"* cf. *distinctus, "T."* cf. *triangulus),* this sample contains a large number of angiosperm species which are not known below Zone III (D13-370′, D12-285′). Of these, some range throughout Zone III: *Tricolpites* aff. *nemejci, T.* cf. *vulgaris, Tricolporopollenites* sp. B, and *Ajatipollis* sp. A. Several additional features suggest an age younger than lower and middle Zone III: the presence of species first seen at D13-290′ or -285′ *(Striatopollis* sp. B, typical *Tricolporoidites* cf. *bohemicus)* and D13-220′ through -210′ *(Asteropollis* cf. sp. A, *Tricolpites* cf. *nemejci, Stephanocolpites tectorius,* and aff. *Tricolporopollenites* sp. E); the absence of *Striatopollis* cf. *paraneus* (last seen at D13-370′ and D12-275′); and significant morphological divergence of several angiosperm (and fern!) complexes from the Zone II species with which they are compared *(Tricolpites* aff. *albiensis, T.* aff. *micromunus, T.* aff. *minutus, Clavatipollenites* aff. *minutus, C.* aff. *tenellis).* However, some features are anomalous for upper Zone III: the rarity of the *Tricolpites vulgaris-T. barrandei* complex, dominant from 220′ to 165′ in well D13, and the presence of typical *"Retitricolpites"* cf. *prosimilis* and relatives of *Tricolpites albiensis,* not known above Subzone II-C in well D13. Whether these anomalies have any stratigraphic significance is unclear, since relations between facies effects and genuine stratigraphic trends are less well understood in Zone III than in any other interval of the Potomac section.

Tricolpites cf. *vulgaris, T.* cf. *nemejci, Tricolporidites* cf. *bohemicus, Tricolporopollenites* sp. B, and *Stephanocolpites tectorius* are important members of the association that allows Zone III to be correlated with dated lower Cenomanian units of Minnesota, Oklahoma, and Czechoslovakia (cf. Doyle and Robbins, 1977).

MARYLAND GEOLOGICAL SURVEY

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Figure 4. — Geologic cross-section extending from near Aberdeen Proving Ground to near Grove Point, Maryland

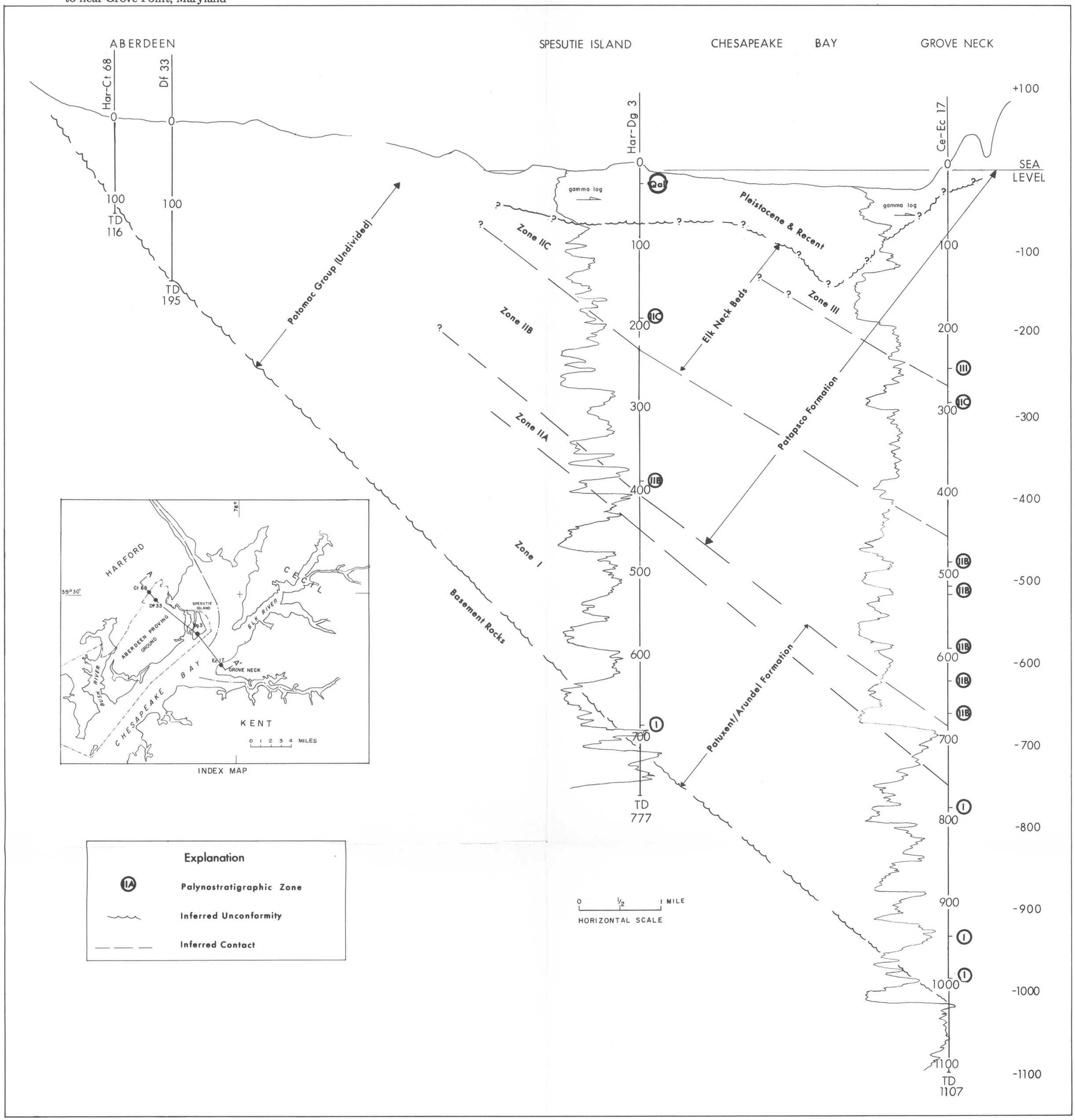


Figure 7. — Stratigraphic cross-section extending from Spesutie Island, Maryland to near Delaware City, Delaware

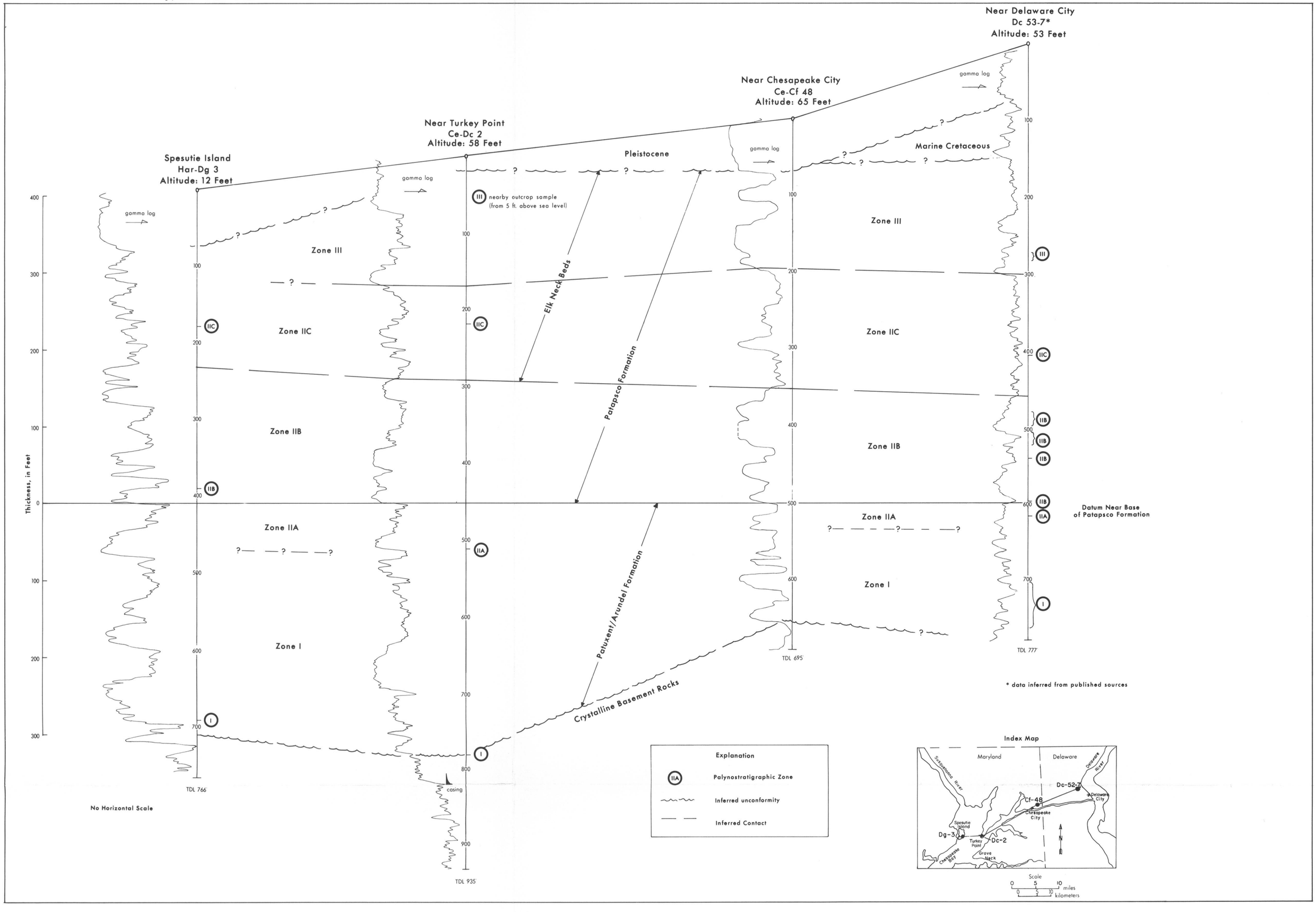


Figure 8. — Stratigraphic cross-section extending from Spesutie Island to near Chestertown, Maryland

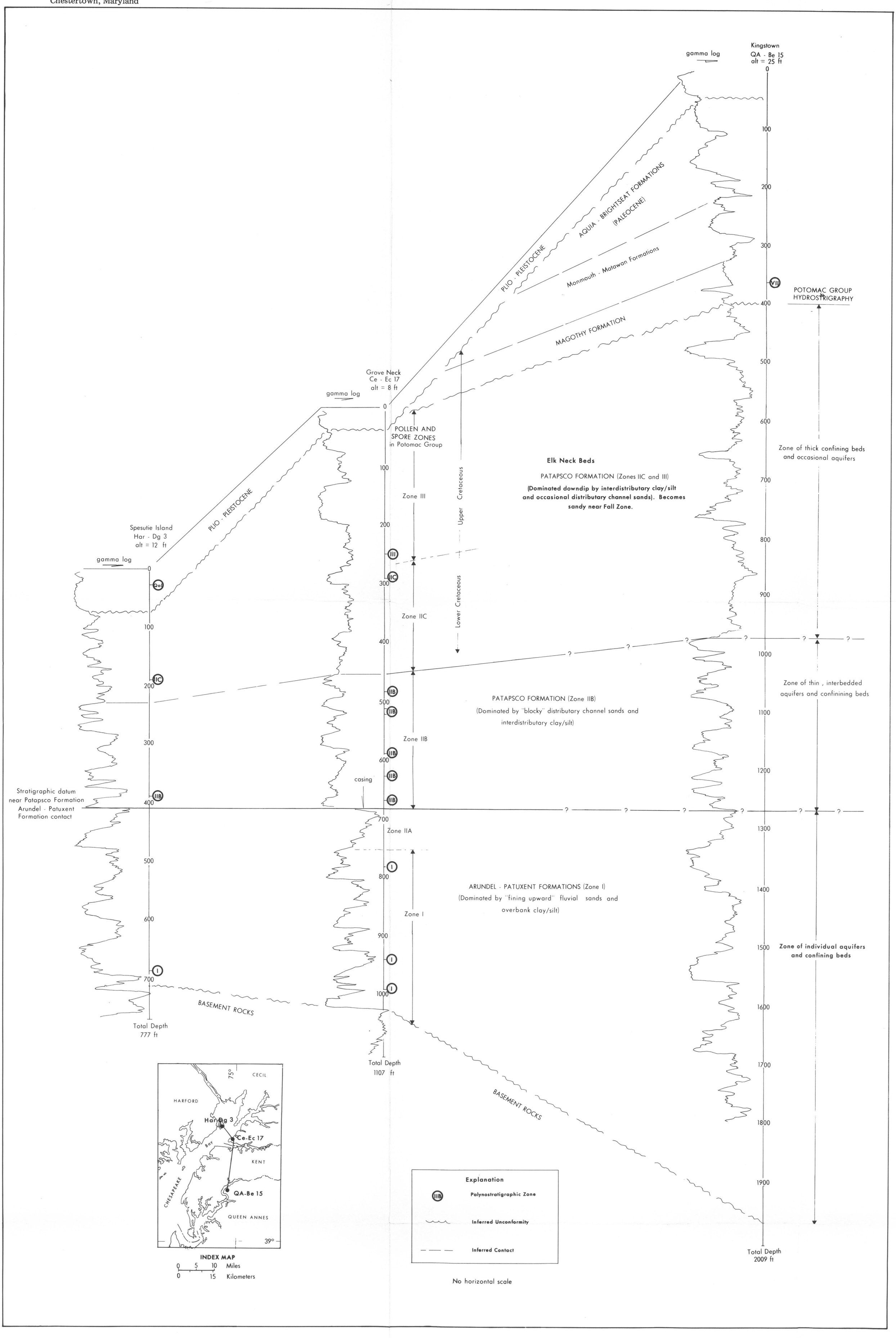
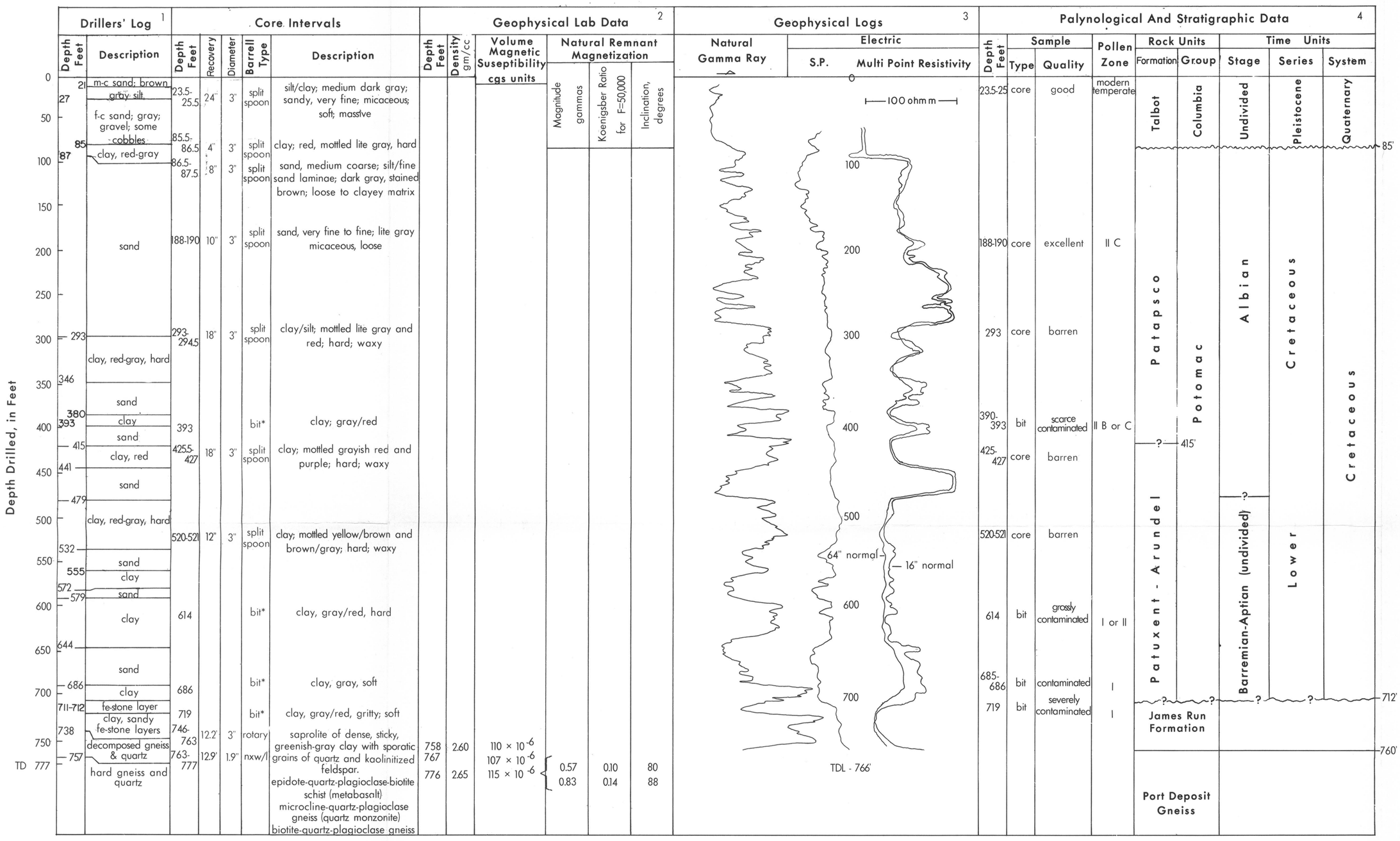


Table 1. — Geologic data compilation for the Spesutie Island boring (HAR-Dg3)

Spesutie Island
HAR-Dg 3
76°04'15'' W
39°26'43'' N
Altitude: 12 Feet

SOURCES OF DATA

1. Sprague and Henwood, Inc.
2. Elliot Geophysical Company
3. U.S. Geological Survey (WRD)
4. Dr. James A. Doyle, University of California, Davis



*bit samples are subject to up-hole contamination

*core unoriented

Table 2. — Geologic data compilation for the Turkey Point boring (CE-Dc2)

Elk Neck, near Turkey Point
Ce-Dc 2
76°00'30'' W
39°27'16'' N
Altitude: 58 Feet

SOURCES OF DATA

1. Sprague and Henwood, Inc.
2. Elliot Geophysical Company
3. Core Laboratories, Inc.
4. U.S. Geological Survey (WRD)
5. Dr. James A. Doyle, University of California, Davis

Drillers' Log [1]

Depth, Feet	Description
76	sand, gravel, & some cobbles
126	clay, red & gray
208	sand & fine gravel
212	sand, fine, brown
220	sand & gray clay
227	clay, gray
273	sand, fine, gray-brown
303	clay, hard, red & gray
325	sand, fine, brown
338	sand, fine; clay seams
360	clay, red & gray
390	sand & clay layers
457	sand
477	clay, sandy, brown & gray
489	clay & sand layers
518	sand
528	clay
551	sand
567	clay
571	clay & sand
590	clay, sandy, red-gray
642	clay, red & gray
644	ironstone
708	sand & gravel
725	clay, sandy, gray
739	sand
764	sand with clay layers
772	clay
785	sand, ironstone layers
898	schist, mica, decomposed
TD 936	schist, mica, hard

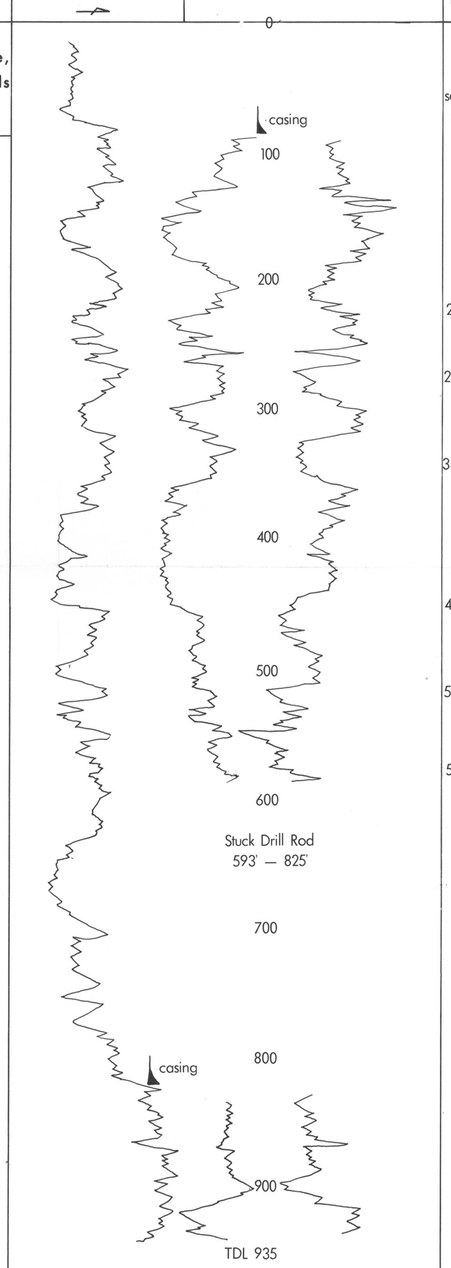
Core Intervals

Depth, Feet	Recovery	Diameter	Barrell Type	Description
80-82	20"	3"	split spoon	clay; mottled red & lite gray; dense
224-226	18"	3"	split spoon	clay; brown-gray & silt, lite gray with irregular laminations of very fine sand
277-279	24"	3"	split spoon	clay, mottled red & lite gray; dense; pockets of lite gray very fine sand & silt
344-346	24"	3"	split spoon	clay; plastic; mottled red, lite gray with cross-cutting seam of limonitic clay
459-461	24"	3"	split spoon	clay; mottled red-lite gray laminae of very fine sand & lite gray silt
520-522	18"	3"	split spoon	clay; grayish black; dense & massive
578-580	18"	3"	split spoon	silt/clay; lite gray; choatically seamed with brownish red very fine sand
710			bit*	clayey mix; soft; gray
791			bit*	clayey mix; very gritty; micaceous; reddish gray
848-936	64.5'	1.9"	nxw/l	Dense, brown, highly-micaceous clayey saprolite with relict quartz veins. Grades downward into structured saprolite of decomposed schist & fresh bedrock. biotite-plagioclase-muscovite-quartz schist with small porphyroblasts of garnet. Sillimanite-bearing in places. Foliation in schist has been re-folded or crinkled by slip cleavage.

Geophysical Lab Data [2,3]

Depth, Feet	Density gm/cc	Volume Magnetic Susceptibility cgs units	Natural Remnant Magnetization: Magnitude, gammas	Natural Remnant Magnetization: Koenigsber Ratio for F=50,000	Natural Remnant Magnetization: Inclination, degrees	Porosity	Acoustic Velocity Data: Effective Overburden Pressure psi	Acoustic Velocity Data: Transit Time, micro-seconds per foot
898	2.64	< 33 × 10^-6				9.0%	188 — 1500	124 — 111
902								
916	2.64	< 37 × 10^-6	2.37	0.52	-35			
927	2.74	92 × 10^-6	0.27	0.059	31			
930		79 × 10^-6						
932						1.1%	188 — 1500	61 — 62

Geophysical Logs [4]



Palynological And Stratigraphic Data [5]

Depth, Feet	Sample: Type	Sample: Quality	Pollen Zone	Rock Units: Formation	Rock Units: Group	Time Units: Stage	Time Units: Series	Time Units: System
				Talbot	Columbia	Undivided	Pleistocene	Quaternary
+5 sed level	outcrop	good	upper zone III			Cenomanian	Upper Cretaceous	
80-82	core	barren						
224-226	core	poor	zone II C	Patapsco				
277-279	core	barren						
344-346	core	barren				Albian		
459-461	core	barren			Potomac			
520-522	core	good	zone II A					
578-580	core	barren		Patuxent - Arundel (Undivided)			Lower Cretaceous	Cretaceous
710	bit	grossly contaminated	?			Barremian - Aptian (Undivided)		
791	bit	contaminated	lower zone I					785'
				Wissahickon schist ?				Cambro-Ordovician ?

Depth Drilled, in Feet: 0, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, TD 936

* bit samples are subject to up-hole contamination

Table 3. — Geologic data compilation for the Grove Neck borings (CE-Ec15, 17)

GroveNeck
Ce-Ec 15,17
76°01'30'' W
39°24'18'' N
Altitude: 8 Feet

SOURCES OF DATA

1. Sprague and Henwood, Inc.
2. Elliot Geophysical Company
3. U.S. Geological Survey (WRD)
4. Dr. James A. Doyle, University of California, Davis

Depth Drilled, in Feet

Drillers' Log [1]

Depth, Feet	Description
0–34	sand, fine-coarse brown; gravel
34–40	clay, tan & sand
40–50	sand, fine, brown
50–74	sand, fine, brown & thin clay layers
74–95	clay, red & gray
95–199	sand
199–208	clay, red & gray
208–230	sand, with clay layers
230–247	clay, red & gray
247–260	clay, gray
260–270	clay, sandy & clay
270–282	clay, gray, red trace
282–290	sand, brown
290–296	sand, clay, ironstone
296–350	sand
350–370	clay, red & gray
370–407	sand & clay layers
407–428	clay, red & gray
428–440	sand & clay layers
440–488	sand
488–518	clay, gray, sandy
518–526	clay, red & gray
526–580	clay, gray with sand layers
580–590	clay, red & gray
590–620	sand & sandy clay
620–630	clay, gray
630–668	clay & sand, gray
668–670	sand, clayey
670–680	clay, gray
680–740	sand
740–764	clay, red & gray
764–771	sand
771–779	sand & gravel
779–805	sand
805–817	sand, fine, gray & gray clay
817–844	sand, fine gray
844–848	clay, red & gray
848–857	sand
857–889	clay
889–894	sand
894–904	clay, sandy, gray
904–927	sand & clay layers
927–939	sand
939–963	clay
963–974	clay, gray
974–984	clay & sand layers
984–1011	sand & basal ironstone
1011–1022	sand, lite gray
1022–1028	sand & ironstone
1028–1063	cobbles, quartz
1063–TD 1,107	schist; mica; decomposed
	schist; mica; weathered rock

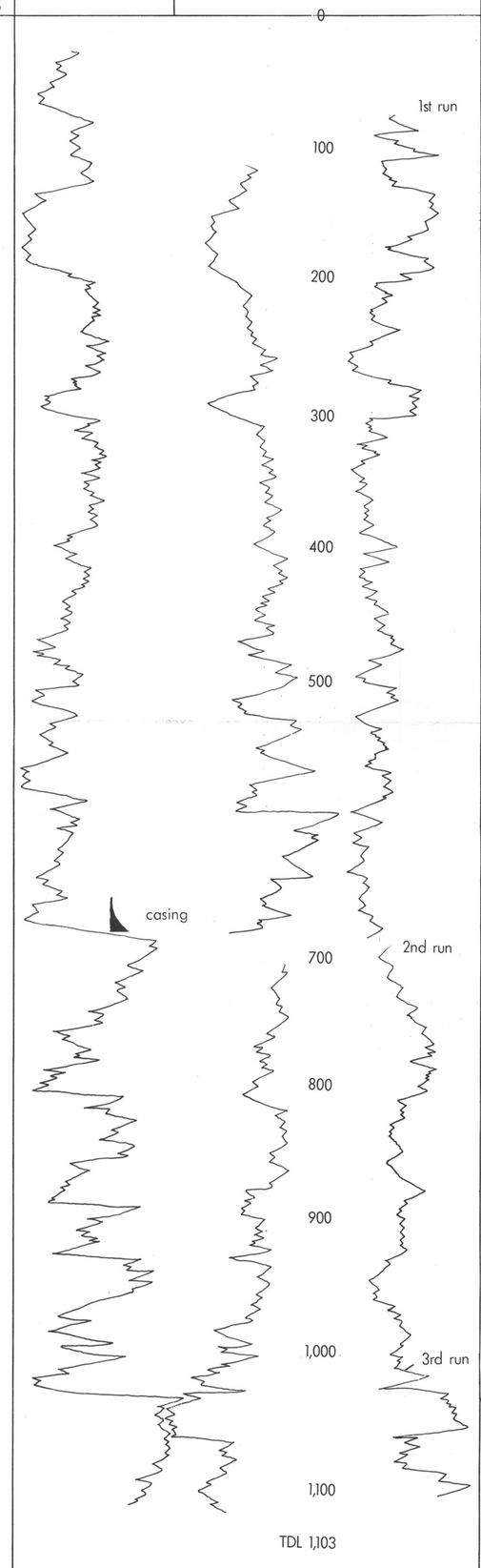
Core Intervals

Depth, Feet	Recovery	Diameter	Barrell Type	Description
76-78	24"	3"	split spoon	clay; grayish purple, mottled orange & red
203-205	24"	3"	split spoon	clay; medium gray, streaked & mottled dark redish brown
231-232	12"	2.8"	hxw/l	clay; as above
248-250	24"	2.8"	hxw/l	clay; brown-gray to dark gray with gray laminae
293-295	36"	2.8"	hxw/l	sand; very fine, medium dark gray thin lignitic streaks & blebs
350-352	24"	3"	split spoon	clay; dusky red with yellowish gray mottling
414-416	24"	2"	split spoon	clay; as above
493			bit	clay; dark gray
510-513	36"	2.8"	hxw/l	sand; fine medium gray with lignitic blebs
520-522	24"	2.8"	hxw/l	clay; medium dark gray with lite gray silty seams; lignitic blebs
589-590	12"	2.8"	hxw/l	clay; medium dark gray, with lite gray clay laminae; lignitic partings
620-630	84"	2.8"	hxw/l	clay; dark gray with seams of lite gray silt; lignitic & micaceous blebs
660-670	8"	2.8"	hxw/l	sand, fine-medium; clayey; dark gray; lignitic & micaceous
690-700	96"	2.8"	hxw/l	clay; dark reddish brown; some lite gray mottling
779-780	12"	2"	split spoon	sand; very fine-fine; lite gray; clay laminae, medium gray
818-820		2"	split spoon	clay/silt to very fine sand; lite gray
890			bit	clay; medium gray
939-940	14"	2"	split spoon	clay; dark gray
989	6"	2"	split spoon	sand; fine; very micaceous; lite gray
1,022-1,028	12'	1.9"	nxw/l	gravel; broken quartzose clasts
1,028-1,107	67.7'	1.9"	nxw/l	plagioclase-biotite-muscovite quartz schist; biotite-plagioclase-muscovite quartz gneiss; garnet-bearing biotite-plagioclase-quartz gneiss or quartzite. (all rock types are cataclastic)

Geophysical Lab Data [2]

Depth, Feet	Density gm/cc	Volume Magnetic Susceptibility cgs units	Resistivity ohm/meters
1,051	2.70	80×10^{-6}	130
1,077	2.47	$<30 \times 10^{-6}$	80
1,092	2.66	110×10^{-6}	160
1,105	2.76	$1,480 \times 10^{-6}$	180

Geophysical Logs [3]



Palynological And Stratigraphic Data [4]

Depth,	Sample Type	Sample Quality	Pollen Zone	Rock Units: Formation	Rock Units: Group	Time Units: Stage	Time Units: Series	Time Units: System
				Talbot	Columbia	Undivided	Pleistocene	Quaternary
76-78	core	barren		Patapsco	Potomac	Cenomanian	Upper Cretaceous	Cretaceous
203-205	core	barren						
231-232	core	barren	lower zone III					
248-250	core	good						
292-295	core	good	zone IIC					
350-352	core	barren						
414-416	core	barren						
493	bit	good	zone IIB			Albian	Lower Cretaceous	
510-513	core	excellent	zone IIB					
522-524	core	excellent	zone IIB					
589-590	core	excellent	zone IIB					
620-630	core	excellent	zone IIB					
660-670	core	excellent	zone IIB					
690-700	core	barren		Patuxent-Arundel (Undivided)				
780	core	fair	zone I			Barremian - Aptian (Undivided)		
818-820	core	barren						
890	bit	not datable						
939-940	core	good	lower zone I					
989	core	scarce	lower zone I					
				Wissahickon Schist ?				Cambro-Ordovician ?

Table 4. — Distribution of spore and pollen taxa in the Spesutie Island, Grove Neck, and Turkey Point wells

	Har-Dg3					Ce-Ec15,17													Ce-Dc2			
	719'	685-686'	614'	390-393'	188-190'	23.5-25'	989-989.5'	939-940'	780'	660-670'	620-630'	589-590'	522-524'	510-513'	493'	292-295'	248-250'	791'	520-522'	224-226'	TP-O
PTERIDOPHYTE AND BRYOPHYTE SPORES																					
Apiculatisporis asymmetricus							R			R	R	R	R	R					R		
Apiculatisporis aff. asymmetricus																R		R			
Apiculatisporis babsae			R	R	R					R	R		R	R	R						
Appendicisporites jansonii	O									R	R	R		R	R			R			
Appendicisporites potomacensis	O			O	O			R		R	R	R	R	R	R		R	O	R		R
Appendicisporites segmentus												R									
Appendicisporites sp.			R							R		R	R	R					R		
Camarozonosporites sp. (Lycopodiac. cerniidites)													R		R		R				
Ceratosporites parvus												R		R	O	R			R		
Chomotriletes sp.											R		R			R			R		
Cicatricosisporites hallei		C		O	O					R	R	R	O	R	O	O		R	R		
Cicatricosisporites patapscoensis													R	R	R	R					
Cicatricosisporites subrotundus															R	R					
Cicatricosisporites sp.	C	C	O	C	C		O	O	R	O	O	O	O	R	C	C		C	O		
Cingulatisporites caminus											R					R		R			
Cingulatisporites distaverrucosus							R			R	R	O				R			R		R
Cingulatisporites reticingulus										R		R	R	R					O		R
Cingulatisporites sp.					R			R			R		R		R	R	R		R		R
Cirratriradites spinulosus					R					R	R	R	R	R	R						
Concavissimisporites punctatus		O								R			R	R	O		R		R		
Concavissimisporites variverrucatus	O	O						R													
Concavissimisporites sp. (smooth)	O	O					R	R	R	R	R	R	R	R	O	O	R	R	R	R	R
Converrucosisporites proxigranulatus										R	R	R	R	R	R	R					
Crybelosporites (Perotriletes) striatus	O	O								R				R				R			
Cyathidites minor	C	C	O	C	C		C	A	O	C	C	O	O	C	C	C	C	A	C	C	O
Cyathidites sp. (larger)	O	O		O	O		R	O		R	R	R	R	R	R	O	R	R	O	R	
Densoisporites microrugulatus										R	R		R	R	R				R		
Densoisporites perinatus	O	O								R		R	R	R	R	R	R	R	R		R
Foveotriletes subtriangularis								R		R						R					
Gleicheniidites apilobatus	O																				
Gleicheniidites sp.	C	C	O	O	C		C	A	D	R	R		R	R	R	O	A	O	R	R	O
Granulatisporites dailyi					O		R			R	R	R	R			O	R		R		R
Inaperturopollenites pseudoreticulatus							R	R				R	R			R	R			R	R
Klukisporites sp.				R				O		R	R	R	R	R					R		R
Laevigatosporites gracilis	C	O	O	C	C		C	C	R	R	R	R	O	O	O	O		R	O	R	O
Lycopodiacidites ambifoveolatus								R		R	R	R				R					
Lycopodiacidites aff. ambifoveolatus					R										R						
Lycopodiacidites cristatus										R					R						
Lycopodiacidites intraverrucatus												R			R		R				
Lycopodiacidites irregularis										R	R	R									
Lycopodiacidites triangularis	R				O					R	R	R	R			R	R		R		R
Lycopodiumsporites austroclavatidites														R			R				
Lycopodiumsporites aff. austroclavatidites					O			R													
Lycopodiumsporites cf. dentimuratus													R			O					
Marattisporites sp.																		R			
Matonisporites sp.															R	O					
Microreticulatisporites crassiexinous										R		R		R		R					
Neoraistrickia robusta					R		R					R	R	R	R	R					
Osmundacidites sp.	C	C		O											R						
Peromonolites cf. allenensis					O					R				R			R				
Perotriletes pannuceus										R		R	R						R		
Pilosisporites brevipapillosus				O	O								R	R	R	R	R				
Pilosisporites trichopapillosus	O	O										R	R	R	R	R		R			
Pilosisporites aff. trichopapillosus																					R
Psilatriletes circumundulatus										R	R	R	R	R	R	R	R		R		
Psilatriletes aff. circumundulatus																					R
Reticulatisporites arcuatus															R	R					
Rouseisporites sp. (Cingu. cf. eukirchensoides)	O				O					R	R	R	R	R	R		R		R		R
Sphagnumsporites antiquasporites	R													R				O			
Taurocusporites reduncus											R	R	R			O	R		R		R
Taurocusporites segmentatus					R					R	R	R	R			R	R		R		R
Taurocusporites spackmani				O	O								R	R	R	R					
Trilobosporites humilis				O	O									R				R			
Trilobosporites marylandensis	O	O					R	R	R	R								R			R
Verrucatosporites (Monosulcites) chaloneri				R						R	R	R	R	R					R		R
GYMNOSPERM POLLEN																					
Abietineaepollenites sp.	C	C	C	O	C			O		O	O	O	O	O	A	C	O	C	O	R	O
Alisporites sp.								R			R	R					R		C		R
Abietineaepollenites and Alisporites undiff.							O		O												
Araucariacites australis	R		R	O	O		R			R	R	R	R	R	O	R	R	R	O		R
Classopollis torosus	O	C		O	O		O	R	O	C	C	C	C	O	R	R	R	O	C		C
Decussosporites microreticulatus					R				R	R		R	R	R			R		R		
Aff. Decussosporites sp. (small bisaccate)	O	R					R	R										R			
Entylissa nitidus	O	O					R	R	O	R	R	R	R	R	R			O	O		R
Entylissa aff. nitidus																R	R			R	
Ephedripites sp. A (7-8 thick, twisted muri)												R		R	R						
Ephedripites sp.	R	R					O			R	R	R	R		R				R		R
Eucommiidites minor														R							
Eucommiidites sp.	O	O	O	O	O		O	R		R	R	R	R	R	O	O	R	R			
Exesipollenites tumulus	C	C	O		O		O		R	C	C	C	R	R	R	R			C	R	
Inaperturopollenites dubius	O	O	C	C	C		A	C	A	D	A	D	D	A	O	C	R	C	A	D	O
Laricoidites sp.	O	O								R	R	R	R	R	R	R			R		R
Monosulcites glottus	O	O	O	O	O		R	R	R	R	R	R	R	O	R	R	R	O			R
Monosulcites aff. glottus (large)							R	O										R			
Monosulcites aff. glottus (foveolate)								R													
Monosulcites aff. scabrus																	R				
Parvisaccites rugulatus	O	O																R			
Parvisaccites sp.					O		R	R	R	R	R		R		O			R	R		
Phyllocladidites sp.							R								R	R				R	R
Podocarpidites epistratus											R	R		R							
Podocarpidites sp.	O	O							R		R				R	R		R	R		
Rugubivesiculites reductus															R	R	R				R
Rugubivesiculites rugosus																O	R	R			R
Tsugaepollenites mesozoicus	R	R										R						R	R		
Vitreisporites pallidus	O	O			O		O	R	R	R	R	R	R	R			R	O	R		R
Zonalapollenites dampieri														R	R	R					
ANGIOSPERM POLLEN																					
Ajatipollis sp. A	R	R															R				R
Ajatipollis aff. sp. A													R								
Asteropollis asteroides										R	R	R	R	R	R						
Asteropollis cf. sp. A																					R
Clavatipollenites cf. hughesii	O	O						R										R			
Clavatipollenites aff. hughesii									R	R	R		R	R	R	R	R		R		
Clavatipollenites cf. minutus				O									R	R	R		R				
Clavatipollenites aff. minutus	O	O						R	O	R	O	R						O	R		R
Clavatipollenites cf. tenellis				O			R			O	R	R	R	R	R		R	R	R		
Clavatipollenites aff. tenellis					O																R
Clavatipollenites sp. A		R					O	R										R			
Clavatipollenites aff. sp. A				R						R											
Clavatipollenites sp. (medium-sized, tectate)	O																				
Dicotetradites sp. A																R	R				
Dicotetradites aff. sp. A														R							
"Foveotricolpites" aff. concinnus												R	R	R			R				R
Liliacidites sp. A								R													
Liliacidites sp. B	R							O										R			

	Har-Dg3					Ce-Ec15,17													Ce-Dc2			
	719'	685-686'	614'	390-393'	188-190'	23.5-25'	989-989.5'	939-940'	780'	660-670'	620-630'	589-590'	522-524'	510-513'	493'	292-295'	248-250'	791'	520-522'	224-226'	TP-O
ANGIOSPERM POLLEN (cont'd.)																					
Liliacidites sp. D														R							
Liliacidites aff. sp. D													R				R				
Liliacidites aff. sp. E (unbranched sulcus)													R	R	R						
Liliacidites sp. F														R			R			R	
Aff. Nemejcipollis sp. (hexaporate)											R		R		R						
Penetetrapites mollis																R	R				
Retimonocolpites cf. dividuus				R		R					R	R		R	R	R	R	R			
Retimonocolpites peroreticulatus	C	C				R	O	O	R	R			R	R		R	R	C			R
Retimonocolpites aff. peroreticulatus (finer)						O															O
Retimonocolpites sp. B (coarse, columellar)													R	R		R					
Retimonocolpites sp. C (monoporoidate)														R	R		R				
"Retitricolpites" cf. fragosus	R				R								R	R	R			R			
"Retitricolpites" aff. fragosus				R							R									R	
"Retitricolpites" cf. magnificus													R	R							
"Retitricolpites" cf. prosimilis	R			R	R								R	O	R	R	O				R
"Retitricolpites" aff. prosimilis						R						R						O		R	
"Retitricolpites" vermimurus							R							R	R	R					
Stellatopollis barghoornii						R						R	R	R	R	R				R	
Stellatopollis aff. barghoornii											R										
Stellatopollis sp.			O																		
Aff. Stellatopollis sp. (less crotonoid)	O	R																	R		
Stephanocolpites fredericksburgensis													R	R	R						
Stephanocolpites tectorius																					R
Striatopollis cf. paraneus				R	R										R						
Striatopollis sp. A												R									
Striatopollis sp. B																					R
Tricolpites cf. albiensis					O		O				R	R	O	R		R	R				
Tricolpites aff. albiensis																			R		R
Tricolpites cf. crassimurus										R	R	R	R	R							
Tricolpites aff. crassimurus			R														R				
Tricolpites cf. georgensis	R				O							R	R	R		R					R
Tricolpites aff. georgensis										R											
Tricolpites cf. geranioides															R	R					
Tricolpites aff. geranioides													R	R				R			R
Tricolpites cf. micromunus	O	O	O	C	C		R			R	R	O	O	O		O	R	R		C	
Tricolpites aff. micromunus																			R		O
Tricolpites cf. minutus			R	O	O							R	O	O		O	A	R		R	
Tricolpites aff. minutus																					O
Tricolpites cf. nemejci																					R
Tricolpites aff. nemejci (thinner)																	R				C
Tricolpites cf. sagax										R	R	R	R	R	R						
Tricolpites aff. sagax																R			R		
Tricolpites cf. variabilis			O	C	C																
Tricolpites cf. vulgaris																	R				R
Tricolpites sp. B							R				R	R	R	R	R						R
Tricolpites aff. sp. B (fine)										R											
Tricolpites aff. sp. B (small)					R										R	O					O
Tricolpites (very small, open reticulate)																					O
"Tricolpopollenites" cf. parvulus				R						R	R	R	R		R	R				R	C
Tricolporoidites cf. bohemicus																					O
Tricolporoidites cf. minimus					R															R	
Tricolporoidites cf. subtilis				R	O											O	C	R		R	C
Tricolporoidites sp. B																	R				
"Tricolporopollenites" cf. distinctus					O												R				R
"Tricolporopollenites" cf. triangulus																R	R				
Tricolporopollenites sp. B																	R				R
Tricolporopollenites aff. sp. E																					R
Tetrad of small reticulate tricolpates										R	R										
MICROPLANKTON																					
Dinoflagellates								R													
Glassy spherical acritarchs																			R		
Micrhystridium sp.																			R		
Pterospermopsis sp.								R													
Schizosporis reticulatus	R																R				
QUATERNARY OR RECENT ELEMENTS																					
Sphagnum sp.						R															
Lycopodium clavatum group						R															
Lycopodium lucidulum group						R															
Botrychium sp.						R															
Osmunda sp.						R															
Polypodiaceae undifferentiated						O															
Abies sp.						R															
Ephedra sp.						R															
Picea sp.						R															
Pinus sp.	R	R		R		C	R														
Tsuga sp.						R															
Cyperaceae undifferentiated						O															
Gramineae undifferentiated	O	R	R	O		C															
Sagittaria sp.						R															
Sparganium or Typha sp.						R															
Acer sp.						R	R														
Alnus sp.	R			R	O	O															
Ambrosia sp.				R	R	O															
Artemisia sp.						R															
Betula sp.	O	R	O	C		O	R														
Betulaceae undifferentiated	R	R	R				R														
Carpinus or Ostrya sp.						O															
Carya sp.	R			R		R															
Castanea sp.			R			R															
Chenopodiaceae or Amaranthaceae undiff.	O	R				R	R														
Compositae undifferentiated	O		O			C	O													R	
Corylus sp.						R															
Dianthera-type						R															
Ericaceae undifferentiated				R	R																
Ilex or Nemopanthus sp.	R				R	R															
Juglans sp.				R	R																
Liquidambar sp.	R			R	R		R														
Morus sp.						R															
Myrica sp.						R															
Nuphar sp.						R															
Nymphaea sp.						R															
Nyssa sp.			R			R															
Plantago sp.						R															
Polygonum lapathifolium-type						R															
Quercus sp.	O	R	R	C		A														R	
Rosaceae undifferentiated						R															
Salix sp.						R															
Thalictrum sp.						R															
Tilia sp.				R		R															
Ulmus sp.						R															
Umbelliferae undifferentiated				R																	
Vitis sp.						R															
Undetermined tricolporates			O			R															
Undetermined inaperturates						O															

Table 1. — Geologic data compilation for the Spesutie Island boring (HAR-Dg3)

Spesutie Island
HAR-Dg 3
76°04'15" W
39°26'43" N
Altitude: 12 Feet

	Drillers' Log [1]		Core Intervals				
	Depth Feet	Description	Depth Feet	Recovery	Diameter	Barrell Type	Description
0	21	m-c sand; brown	23.5-25.5	24"	3"	split spoon	silt/clay; medium dark g sandy, very fine; micac soft; massive
	27	gray silt					
50		f-c sand; gray; gravel; some cobbles					
	85		85.5-86.5	4"	3"	split	clay; red, mottled lite gray
	87	clay, red-gray					

New Data Bearing On The Structural
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