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Postdepositional Alteration of Surface and Near-Surface Minerals in Selected Coastal Plain Formations of the Middle Atlantic States

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1067-F



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By JAMES P. OWENS, MELODIE M. HESS, CHARLES S. DENNY,
and EDWARD J. DWORNIK

SURFACE AND SHALLOW SUBSURFACE GEOLOGIC STUDIES IN THE
EMERGED COASTAL PLAIN OF THE MIDDLE ATLANTIC STATES

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1067-F

*Methods for studying the effects of weathering
are outlined—formations range from late
Miocene to middle Wisconsinan*



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SURFACE AND SHALLOW SUBSURFACE GEOLOGIC STUDIES
IN THE EMERGED COASTAL PLAIN OF THE MIDDLE ATLANTIC STATES

**POSTDEPOSITIONAL ALTERATION OF SURFACE AND NEAR-SURFACE
MINERALS IN SELECTED COASTAL PLAIN FORMATIONS OF
THE MIDDLE ATLANTIC STATES**

By JAMES P. OWENS, MELODIE M. HESS, CHARLES S. DENNY, *and*
EDWARD J. DWORNIK

ABSTRACT

The depth and intensity of postdepositional subaerial weathering were examined in several Coastal Plain formations from New Jersey to Virginia. This region was divided into three study areas: (1) west of Chesapeake Bay, (2) between Chesapeake and Delaware Bays (Delmarva Peninsula), and (3) northeast of Delaware Bay. The mineralogy of well-drained sandy beds from 12 sites in these three areas was compared to ascertain compositional maturity (defined, for example, for clay-sized material as the presence of iron and aluminum oxides or hydrated silicates) in relation to the age of the formation containing the sand.

Three categories of weathering profiles were recognized. In the first, the clay-mineral type and the degree of intrastratal solution of sand minerals seemed reasonable relative to the age of the formation on which the weathering profile was developed. In the second, the mineralogy appeared too young relative to the age of the formation on which the weathering profile had developed. This type of unit is most common west of Chesapeake Bay. The relationship is interpreted as resulting from local tectonics. In the third, the weathering mineralogy appeared too old relative to the age of the unit. The overmature minerals in these units were either reworked into these units during a marine transgression or introduced into a sandy unit as loess and subsequently distributed throughout the dominantly sandy units by illuviation.

In summary, most of the weathering-age relationships followed a predictable pattern. The use of this technique to determine relative ages and uplift patterns in this region is in its initial stage but holds much promise. The existence of some anomalies, however, points to the need to obtain a detailed geologic history of a given deposit before this weathering-age technique can be applied.

INTRODUCTION

Studies of subaerial alteration in unconsolidated sediments as a method of establishing the age of these sediments has been attempted in many regions. Such a technique has been widely utilized, for example, in the midcontinent glacial deposits, where the depth of leaching of calcium carbonate or the degree of develop-

ment and thickness of soil zones have been used as methods of establishing the relative ages of these deposits.

As an adjunct to the mapping of surficial sediments in the Coastal Plains of the Middle Atlantic States (New Jersey to Virginia), 12 sites were sampled to determine whether the degree and depth of weathering, as compared with the stratigraphic age of a deposit, could be used as an age indicator in this terrane. The method was tested by determining the weathering effects developed on deposits of a variety of ages (Early Cretaceous to late Pleistocene) and lithologies. The weathering mineral model proposed by Jackson (1965) was used initially as a standard to determine the sequence of weathering products (minerals) relative to time.

Like some glacial drift, the Coastal Plain formations are suitable for studying weathering because, in addition to their high porosity, they contain an abundance of easily weatherable minerals—mostly feldspar, calcareous materials, and, to a lesser degree, glauconite, micas, and ferromagnesian minerals. The formations selected for study are all well-drained sands or gravelly sands, locally containing thin to thick beds of compact clay or clay-silt. Because a major objective of this study was to assess the effects of mineral alteration during leaching, only the interstitial clay-silt fractions in the sands were analyzed. The much higher porosity of the sands in comparison with the less permeable beds of clay or clay-silt was the principal reason for this sampling procedure. It was reasoned that any alteration effects would be accelerated and therefore more readily detectable in the fine-grained fraction of the sands. Assessing the effects of leaching or weathering over a broad region on a variety of formations resulted in a study of

many lithologies. Most of the Coastal Plain sample sites were in units mapped by us or by coworkers. The ages of these units have been determined by biostratigraphic and radiometric methods.

One complicating factor in our study was postdepositional stripping, which, in places, has interrupted or destroyed the upper leached or weathered zone. Although we made an effort to collect samples from areas where this effect had been minimal, we were forced to collect some of our samples from dug pits on remnant knobs high in the landscape. Therefore, a degree of uncertainty exists as to the results obtained from these sites.

As the study progressed, it became apparent that a knowledge of the depositional history of each deposit was essential to a proper evaluation of the laboratory results. Simply stated, the effect of inherited (detrital) clay minerals from source lands or reworked (multicycle) clay minerals from underlying units had to be determined before any analysis of postdepositional weathering effects could be made.

Additionally, because of the very large area encompassed in our investigation and the relatively small number of sites examined in detail, our results can be considered only as a prelude to a more detailed study.

METHOD OF STUDY

Most of the samples were collected from freshly dug pits. Some of the sites were natural exposures that had recently eroded or slumped, and exposed fresh sediments. Within the stratigraphic framework worked out in the study areas (Owens and Minard, 1975, 1979; Owens and Denny, 1979; Minard, 1980; Force and Moncure, 1977; present field studies in southeastern Virginia; Wayne Newell, written commun., 1978), the formations sampled included a wide variety of lithologies; thus, many mineral combinations (lithofacies) were analyzed.

The sand minerals were separated into two classes: those having a specific gravity of greater than 2.85 (the "heavy" minerals) and those having a specific gravity of less than 2.85 (the "light" minerals). These minerals were then examined under the petrographic microscope to determine provenance, the degree of reworking from other units (first-cycle as opposed to multicycle sediments), and, perhaps more important, the effects of intrastratal solution. Only light minerals in the 0.077- to 0.177-mm size range were identified under the petrographic microscope. The ratios of these light minerals (largely quartz and feldspar), therefore, are not representative of the entire sand fraction but tend to be biased in favor of feldspar, which, because of its good cleavage, tends to be concentrated in the finer size fractions during transport.

The clay minerals were identified by standard X-ray techniques. Only the minerals having well-ordered crystal structures were detected. Other amorphous forms such as allophanes were not recognized and are disregarded in our discussion. Supplemental studies of some samples by transmission electron microscopy and scanning electron microscopy were made because the X-ray analyses indicated the presence of minerals (such as halloysite) that have excellent crystal morphology. The scanning electron microscope was equipped with an energy-dispersive X-ray analyzer, which gave qualitative elemental analyses. This capability helped in distinguishing the anhedral forms of aluminum oxides (gibbsite) from aluminum silicates (vermiculite, illite, and feldspars).

Individual clay minerals were identified and classified by the technique described by Reynolds and Hower (1970). Their terminology differs from that used by other mineralogists, particularly in the classification of clays having large unit-cell dimensions (for example, montmorillonites of other workers are classified here as mixed-layer illite-smectite). Only the untreated patterns are illustrated in our report. The specific determinations listed were based on samples treated by standard clay-identification techniques (chemical or heating).

PREVIOUS INVESTIGATIONS

Within the area of our investigation, all the early studies of mineral alteration in surficial sediments were made by soil scientists. These investigations for the most part examined the mineralogy of the upper 1.5 m of the surficial beds. Many of these studies were conducted by the Agronomy Department of Rutgers University in New Jersey (Tedrow, 1954; Krebs and Tedrow, 1957; Novak and others, 1971). These investigations were usually site specific and did not represent a comprehensive study of a soil or a group of soils over a large area.

Weathering studies based in part on these agronomic studies were conducted by Lodding (1961, 1972) and Bowman (1966) on the Pensauken Formation, as shown on the geologic map of New Jersey (Johnson, 1950). Bowman's studies were the most detailed, concentrating on the Coastal Plain between Camden and Jamesburg, N.J. Generally, he found that gibbsite and locally metahalloysite were most abundant at depth and that clay mica (illite-muscovite mixed layering) and chlorite increased toward the top of the profile. Perhaps Bowman's greatest contribution was recognizing the widespread distribution of gibbsite in the Pensauken Formation and the depths at which it was present. Because he adopted the age assigned to this unit on the New Jersey geologic map, he thought that the mineral assemblages that he reported were Pleistocene.

Outside New Jersey, particularly in Alabama and Georgia, Clarke (1971) described several weathering profiles in the Coastal Plain sediments. He concluded that the gibbsite-bearing rocks in this region were pre-Pleistocene in age, developed on sediments derived from the feldspar-rich metamorphic and igneous rocks of the Appalachian Mountain system.

In the field of agronomy, weathering sequences related to environment, intensity, and time were outlined by Jackson (1965). This oft-cited paper is used as a model to define weathering sequences in a variety of terranes. Jackson proposed three major weathering categories: mild, intermediate, and intensive. We are concerned in our study only with those minerals discussed in each of these categories in well-drained topographic positions. The mild category is characterized by chloritized vermiculite, allophane, and quartz. The intermediate category contains kaolinite, halloysite, chloritized vermiculite, and montmorillonite. The intensive mineral assemblage (referred to as laterization) includes hematite, goethite, anatase, gibbsite, boehmite, kaolinite, and allophane. We will elaborate on the model in the conclusions to this paper.

REGIONAL GEOLOGY AND SAMPLE LOCALITIES

Figure 1, a generalized geologic map of the Coastal Plain sediments, shows the localities from which samples were collected in the Middle Atlantic States.

As this figure shows, the Coastal Plain lies between the Atlantic Ocean on the east and the Piedmont physiographic province on the west. The rocks of the Piedmont province are largely metamorphic and crystalline and were the source of large quantities of weatherable (labile) minerals in the Coastal Plain sediments (that is, feldspar, chlorite, biotite, and muscovite) in addition to contributing the readily alterable clay mineral, illite-smectite.

The formations comprising the Coastal Plain of the Middle Atlantic States are shown in figure 2. The sampling program did not follow a prescribed sequential stratigraphic plan but was dictated in large part by the availability of fresh cutbanks or slump blocks. The typically unconsolidated nature of the Coastal Plain sediments and the ephemeral nature of natural outcrops forced us to follow such a sampling procedure.

The Coastal Plain formations in the study area are comprised of unconsolidated sediments and were deposited in a wide variety of paleoenvironments: (1) fluvial (channel fill and overbank principally), (2) estuarine-barrier-back barrier, and (3) marine (inner shelf and perhaps middle shelf). Therefore, the weathering effects on a large number of lithofacies and lithologies (feldspathic, glauconitic, and micaceous sands) were studied. Some of the sands were first cycle

(notably, the most feldspathic sands), whereas others were multicycle and contained fewer weatherable minerals.

Twelve sites were studied in detail; their general locations are shown in figure 1. Particulars for each are given in the appendix. The data given in the main body of the report typically refer to a single formation only. The conclusions drawn from each formation were checked at other localities within the formation to see if the data thus obtained had regional continuity. (They did.)

LOCALITIES STUDIED

The sample sites in this paper will be discussed by geographic area (fig. 1) rather than in stratigraphic order. The three main areas are (1) west of the Chesapeake Bay, (2) between Chesapeake Bay and Delaware Bay, and (3) northeast of Delaware Bay. The stratigraphic position of a formation can be determined by referring to figures 1 and 2.

WEST OF CHESAPEAKE BAY

West of Chesapeake Bay, three localities were selected for detailed study: the Hayfield site (beds of Early Cretaceous age), the Bowling Green site (beds of early to middle Pliocene age), and the Round Bay site (beds of middle Miocene and late Paleocene age).

HAYFIELD, VA.

"UPLAND GRAVELS" AND POTOMAC FORMATION, LOCALITY NO. ANNA 1

A columnar section showing the geology at the Hayfield, Va., site is illustrated in figure 3. Two formations are exposed: the "upland gravels" of probable Pliocene age and the Potomac Formation of early Cretaceous (Barremian Stage) age. A large time gap is represented by the unconformity between the two units.

The "upland gravels" at this site have been removed for aggregate and were not sampled. The mineralogy of probable equivalent upland beds will be discussed in the Bowling Green site description.

Approximately 12 m of the Potomac Formation is well exposed at this locality. The formation consists of interstratified thick beds of sand and clay-silt. The sand is loose, extensively cross stratified, typically medium grained, and moderately well sorted and has subangular to angular grain shapes. The angularity of the grains suggests that this deposit is probably a first-cycle sediment. Two sand beds are present, separated by a clay-silt bed (fig. 3). The upper sandy bed is typically a light gray but is stained a dark yellowish orange (10 YR 6/6) in the upper 1.5 m. There is no pronounced clay accumulation in this sand; specifically, it does not have a well-developed B horizon. In fact, the soil-forming processes

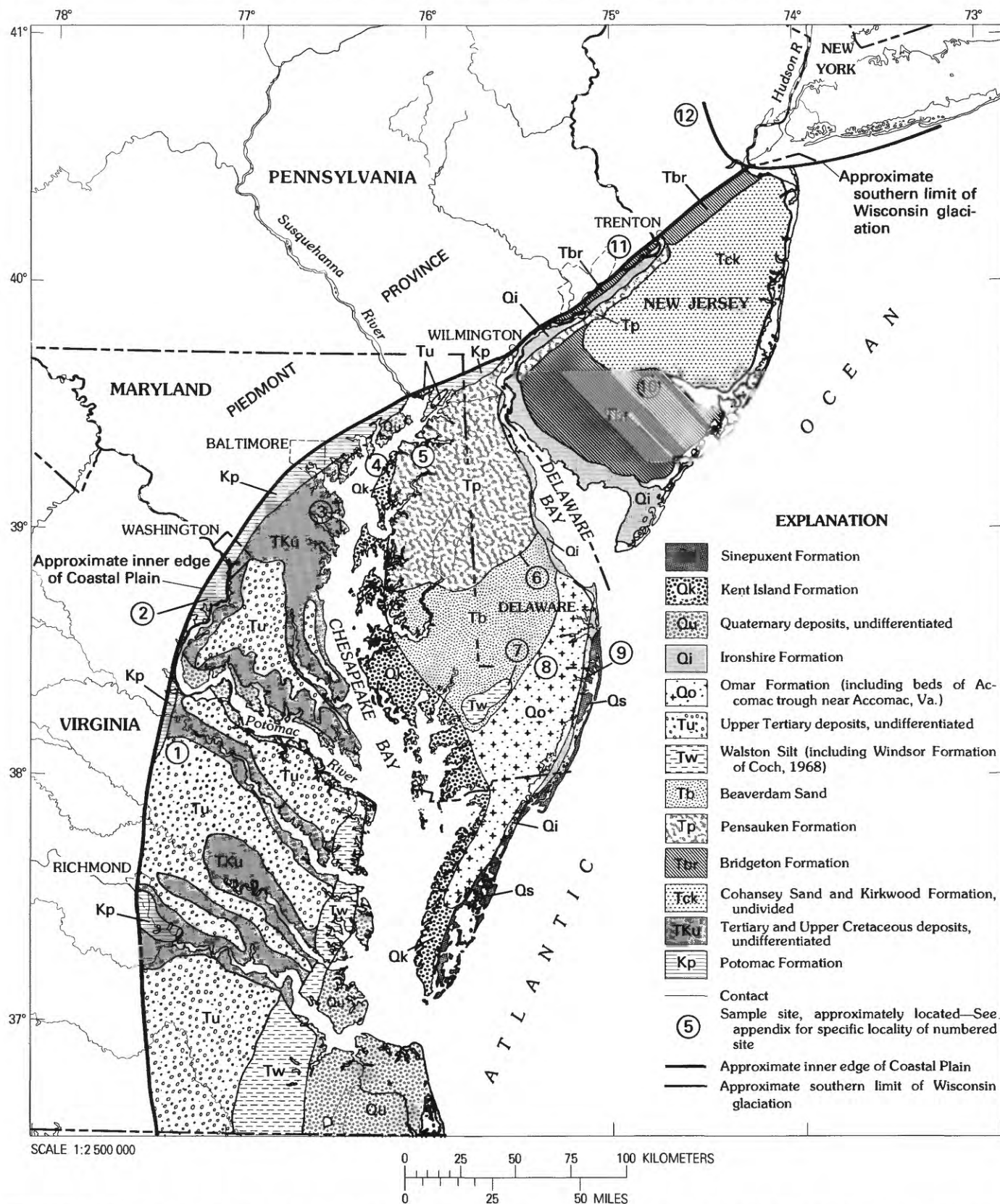


FIGURE 1.—Generalized geology in the Coastal Plain of New Jersey, Pennsylvania, Delaware, Maryland, and Virginia. Formation boundaries are only approximate, and some units have been deleted to emphasize others. Sample sites are shown by number but are only approximately located. Specific sample localities are given in the appendix. The locality numbers shown in the figure are 1, Bowling Green 1, Bowling Green, Va.; 2, Anna 1, Hayfield, Va.; 3, R.B. 51, Round Bay, Md.; 4, Hanesville 1, Worton Point, Md.; 5, Bet. 3, Betterton, Md.; 6, Harr. 5, Houston, Del.; 7, Pitt. 8, Pittsville, Md.; 8, Wh. 1A, Whaleyville, Md.; 9, Ber. 2, Germantown, Md.; 10, Newtonville 1, Hammonton, N.J.; 11, TWA 15A, Van Sciver Lake, Pa.; 12, Bern. 1, Bernardsville, N.J.

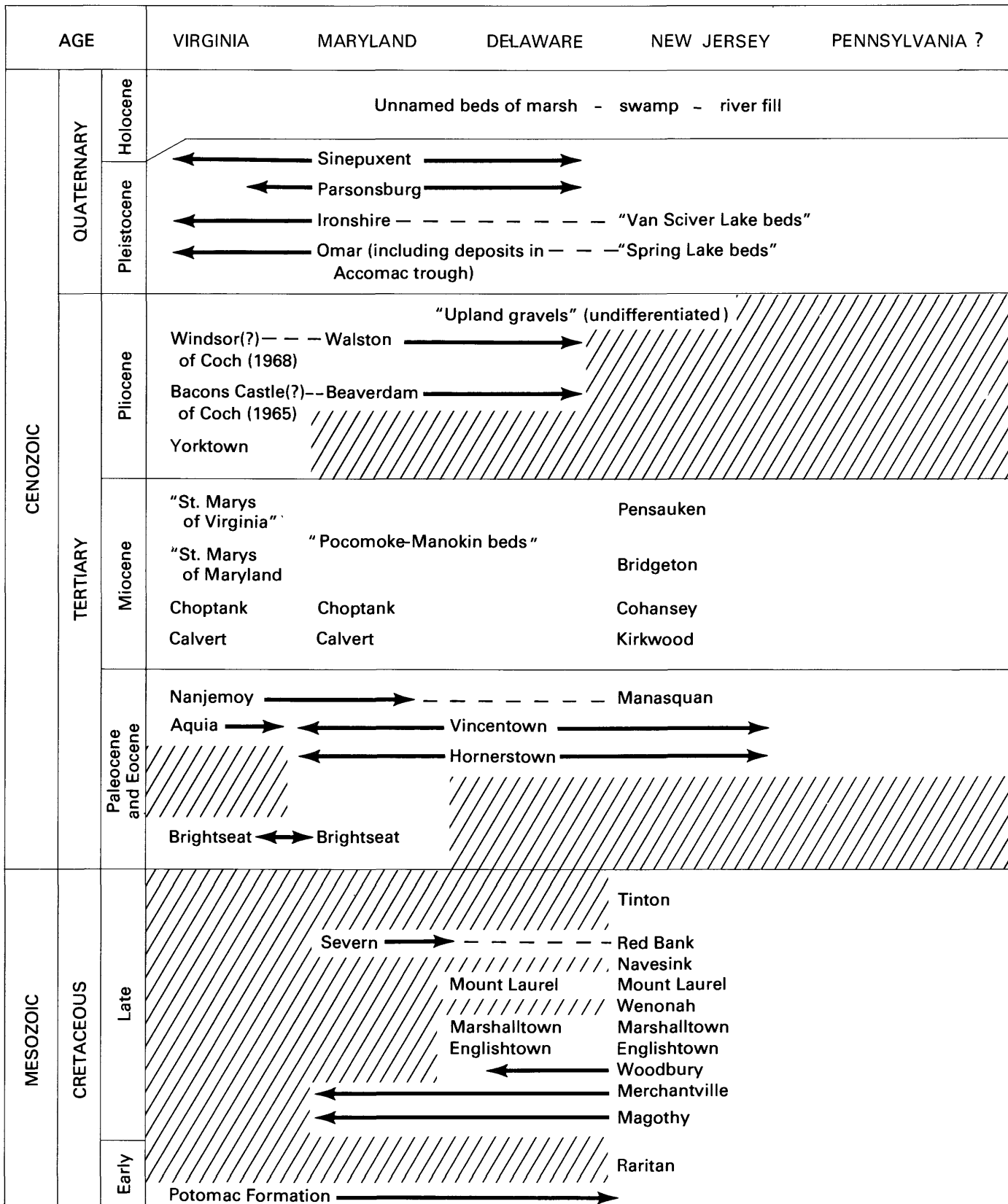


FIGURE 2.—Formations and informally named units cropping out or occurring in shallow subsurface in the Coastal Plain of Virginia, Maryland, Delaware, and New Jersey (Pennsylvania?). Diagonal lines indicate absence of a unit.

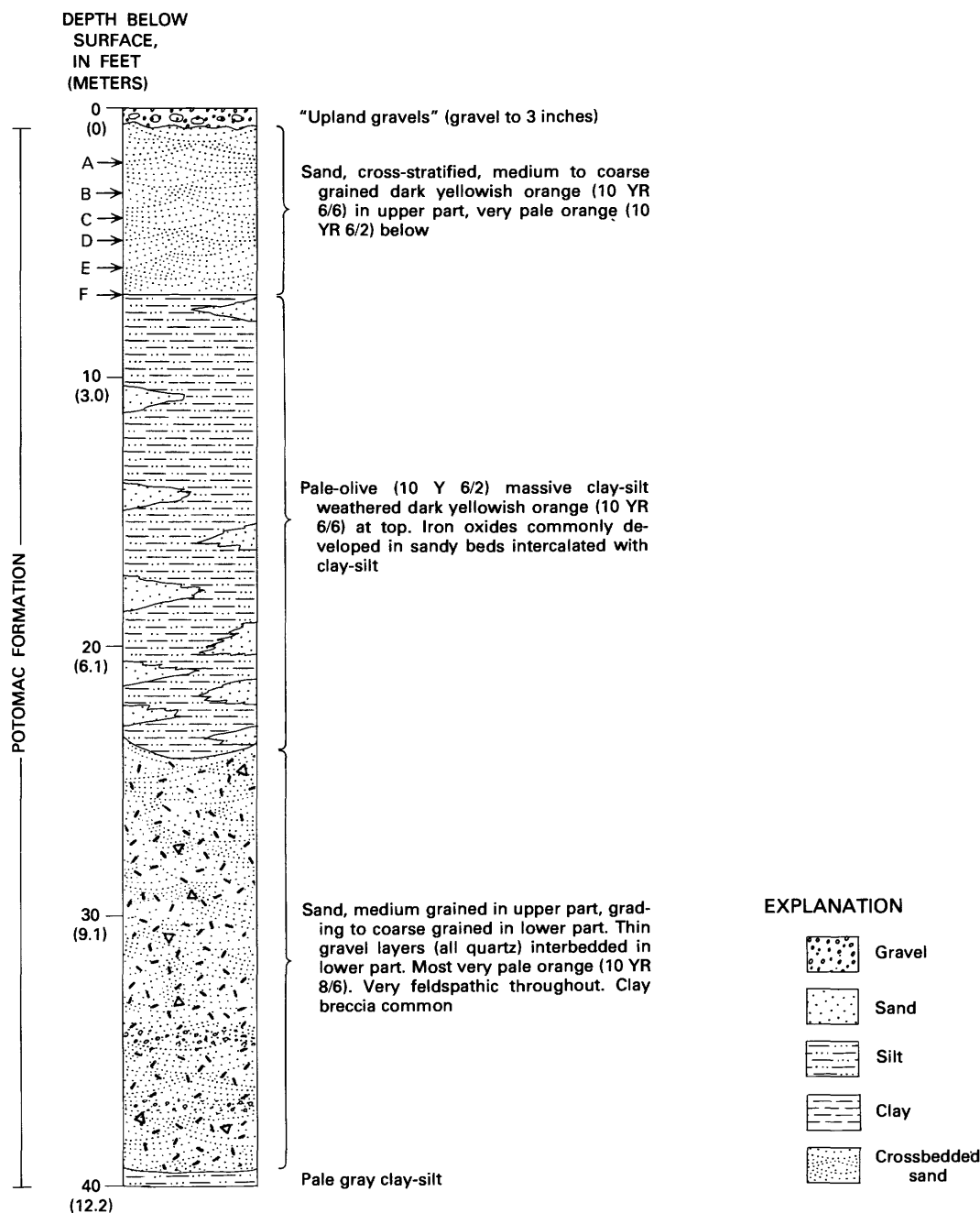


FIGURE 3.—Columnar section showing the stratigraphy in a pit and an adjacent gully at Hayfield, Va., 5 km (3.1 mi) south of Alexandria in the Annandale 7.5-minute quadrangle. Locality no. Anna 1. Arrows indicate sample locations in profile. Surface elevation is 64 m (210 ft) above sea level.

have not destroyed the cross-stratification in the upper zones of iron oxide staining.

The underlying, generally massive clay-silt is pale gray to pale olive and approximately 4.6 m thick. Thin beds or laminae of fine-grained to very fine grained sand are interbedded with the clay-silt. Iron oxide staining is common along the sandy laminae.

Another sand bed approximately 4.6 to 6.0 m thick underlies the clay-silt. The sand in this bed is unconsolidated, moderately sorted, and extensively cross-stratified, like that in the near-surface sand bed. The trough style of crossbedding is essentially the same as that in the upper sand. In general, the sand is coarse grained and gravelly in the lower part of this bed and

becomes finer upward to the clay-silt boundary. Taken in conjunction with the clay-silt, the sand forms an upward-fining cycle. For the most part, the sand is a pale orange locally stained by thin layers of iron oxide. The overall sedimentary structures and upward-fining sequences of the deposit indicate this formation to be fluvial in origin.

SAND MINERALOGY

Light minerals.—The light minerals compose nearly all the sand fraction in the Potomac Formation. A binocular examination of these minerals revealed that most have subangular to angular shapes and hence are probably first-cycle sediment. The light minerals in the very fine sand fractions were studied under the petrographic microscope, and the results are shown graphically in figure 4A. Quartz is the major mineral, although feldspar (largely K-feldspar) is also very abundant.

It has long been known that feldspar is relatively unstable in a strongly oxidizing environment for any extended period of time. As figure 4 shows, there is no significant decline in the total percentage of feldspar throughout the entire section. Nevertheless, the feldspars in the upper meter of the profile are more weathered than those below. The K-feldspars in the upper beds are very turgid, and the plagioclase crystals are extensively embayed. A binocular examination of the grains also reveals that most of the feldspar grains have a dull white coating, which suggests at least some surface alteration of the grains.

Heavy minerals.—Zircon and small amounts of tourmaline are the major heavy minerals present (fig. 5A). Because these minerals are commonly thought to be some of the most resistant to subaerial oxidation, they could not be used to determine the effects of postdepositional weathering on these beds. Much smaller amounts of epidote and staurolite are also present, along with even smaller amounts of garnet and kyanite. The epidote, staurolite, and kyanite typically are altered, but whether the weathering was a provenance effect or a postdepositional effect is unknown. Regardless, the heavy-mineral assemblages in the Potomac Formation would be considered a mature assemblage.

CLAY-SILT MINERALOGY

X-ray studies of the clay-silt fraction in the upper sand bed are summarized in figure 6. In general, illite-smectite dominates the lower, less weathered part of the section and decreases upward into the orange-brown zone, where kaolinite and, to a lesser degree, illite become more abundant. About 1.2 m from the surface, both illite and kaolinite appear to decrease. There, dioctahedral vermiculite becomes prominent and accounts

for the kaolinite-illite decrease. Figure 7 shows the mineral distribution throughout the upper sand beds and, although it is not quantitative, illustrates the clay mineral changes upward through this section, particularly the change from illite-smectite to more stable clay minerals (kaolinite and dioctahedral vermiculite).

INTERPRETATION

The Potomac Formation at the Hayfield site appears to be a first-cycle sediment derived from a very feldspathic, coarse crystalline metamorphic or igneous rock. The close proximity of the Occoquan Granite to the Potomac Formation suggests that this rock is the major source for the Potomac sediments. The Potomac Formation does not, however, contain the high percentage of plagioclase reported by Seiders and others (1975) to be characteristic of the Occoquan Granite. If they are correct, then a large amount of plagioclase was lost during the chemical and mechanical disintegration of the adamellite. Nevertheless, the relatively fresh state of the feldspar in the Potomac Formation and the especially abundant illite-smectite in a zone of strong subaerial oxidation are incompatible with the Cretaceous age of these sediments. Perhaps these beds were exhumed in recent times. The near-surface position of the relatively unweathered beds of Cretaceous age in this region probably came about as a result of faulting described by Mixon and Newell (1977) or is perhaps related to Quaternary eustatic sea-level changes known to have affected this area.

The principal factors involved in positioning these beds at the surface are not particularly relevant to our study. What is important are the character or degree of weathering of the sediments and the length of time necessary to produce the degree of mineral alteration at the Hayfield site.

Alteration of minerals in the Potomac Formation appears to be minimal. Some weathering of the feldspars was observed optically, but the only significant change in the clay minerals was the alteration of some of the illite-smectite to kaolinite and dioctahedral vermiculite in the uppermost beds. This slight degree of alteration in well-drained sands under the present climatic conditions in this area (particularly the relatively high rainfall and humidity) suggests a very youthful weathering profile. The best guess is that the weathering could have begun in the middle Pliocene but is probably much younger.

BOWLING GREEN, VA.

YORKTOWN FORMATION, LOCALITY NO.

BOWLING GREEN 1

The upper Coastal Plain of Virginia is mantled by a widespread cover of gravelly sands (fig. 1), which for a

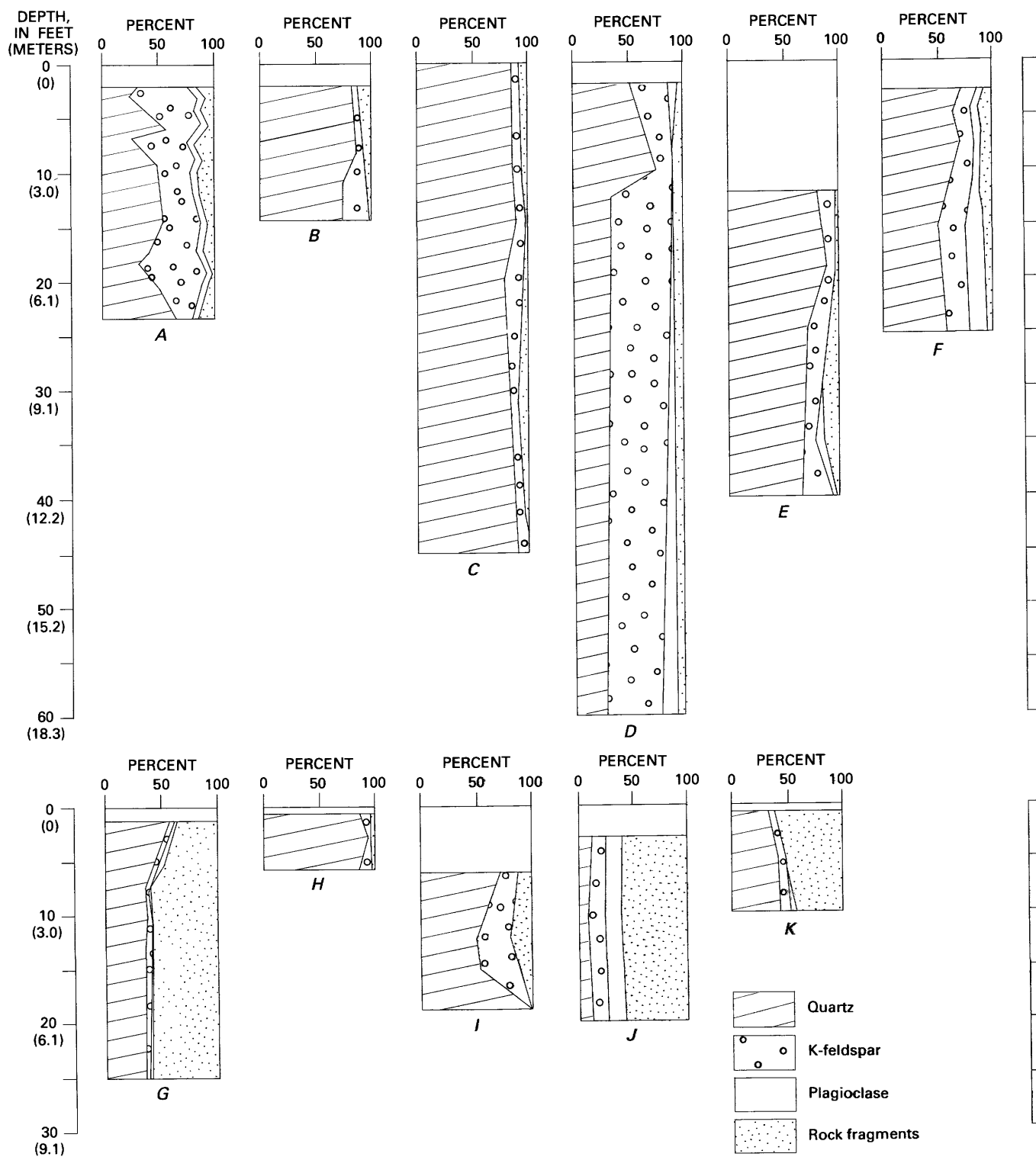


FIGURE 4. — Distribution of light minerals (<2.85 specific gravity) in formations in the study area. The size fraction studied is from 0.177 to 0.074 mm (fine-grained to very fine grained sand). A, Hayfield, Va.; B, Bowling Green, Va.; C, Round Bay, Md.; D, Betterton, Md.; E, Whaleysville, Md.; F, Germantown, Md.; G, Worton Point, Md.; H, Pittsville, Md.; I, Hamonton, N.J.; J, Bernardsville, N.J.; K, Van Sciver Lake, Pa.

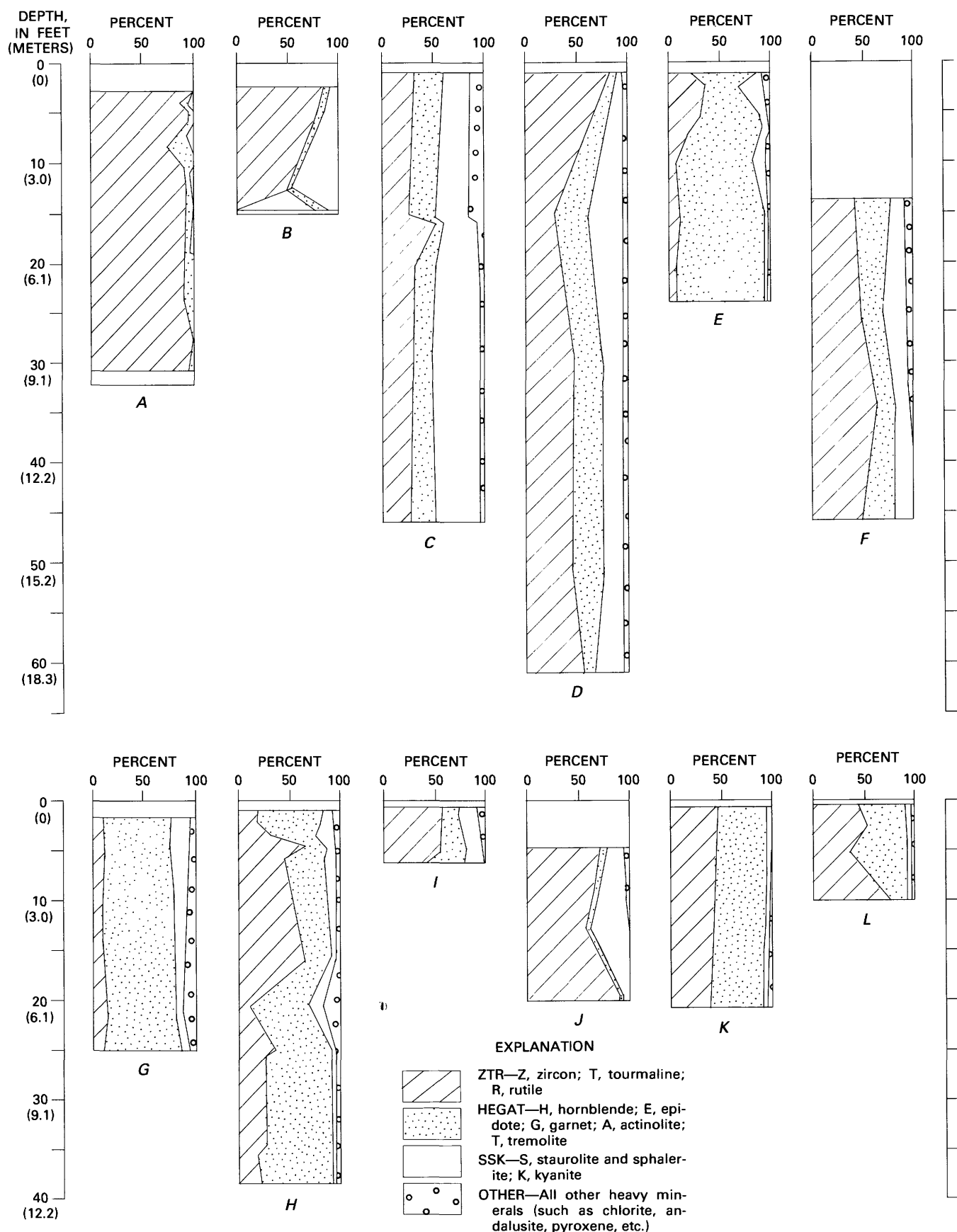


FIGURE 5.—Distribution of heavy minerals (>2.85 specific gravity) in formations in the study area. The size fraction studied is from 0.177 to 0.074 mm (fine-grained to very fine grained sand). A, Hayfield, Va.; B, Bowling Green, Va.; C, Round Bay, Md.; D, Betterton, Md.; E, Houston, Del.; F, Whaleyville, Md.; G, Germantown, Md.; H, Worton Point, Md.; I, Pittsville, Md.; J, Hammonton, N.J.; K, Bernardsville, N.J.; L, Van Sciver Lake, Pa.

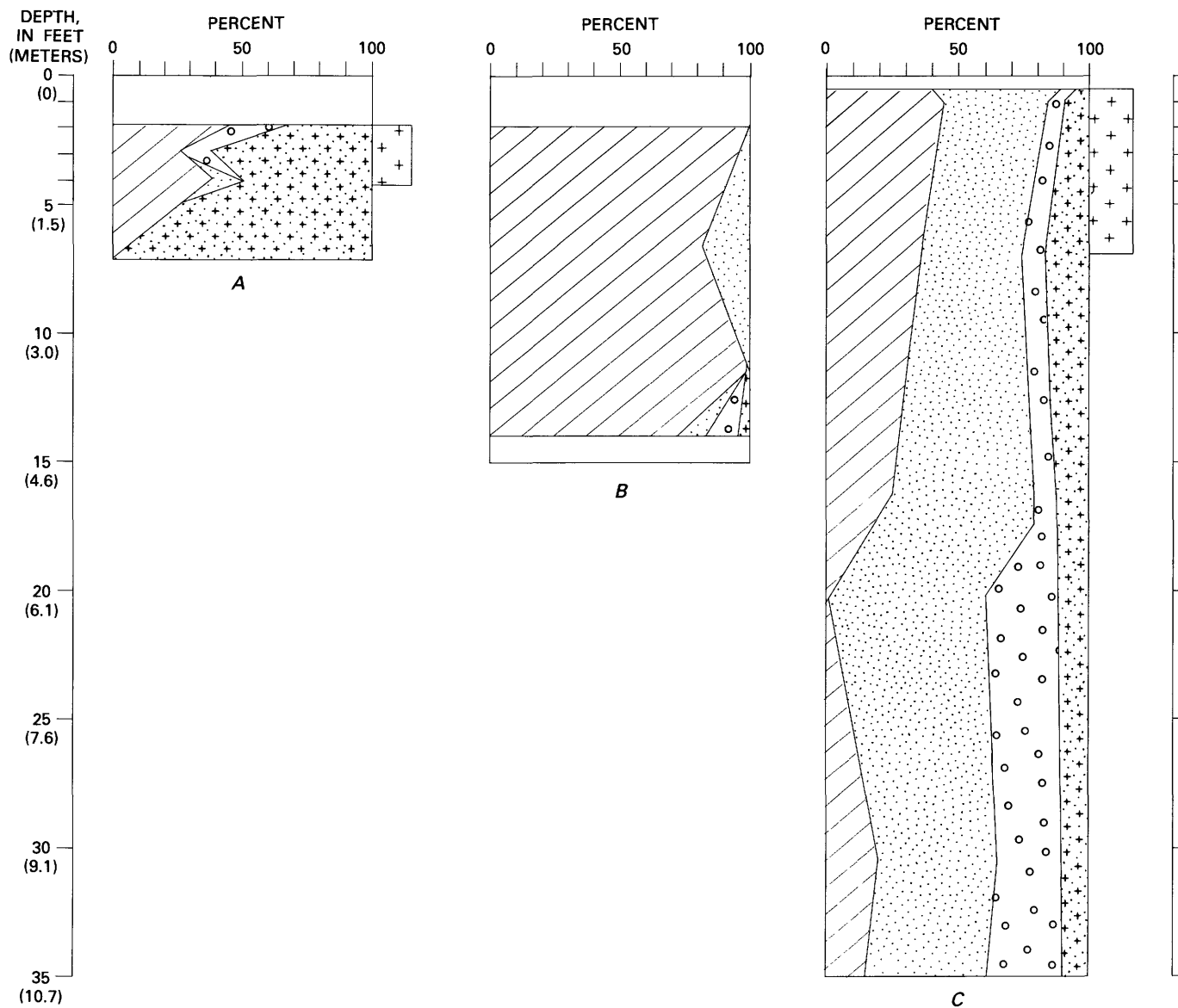
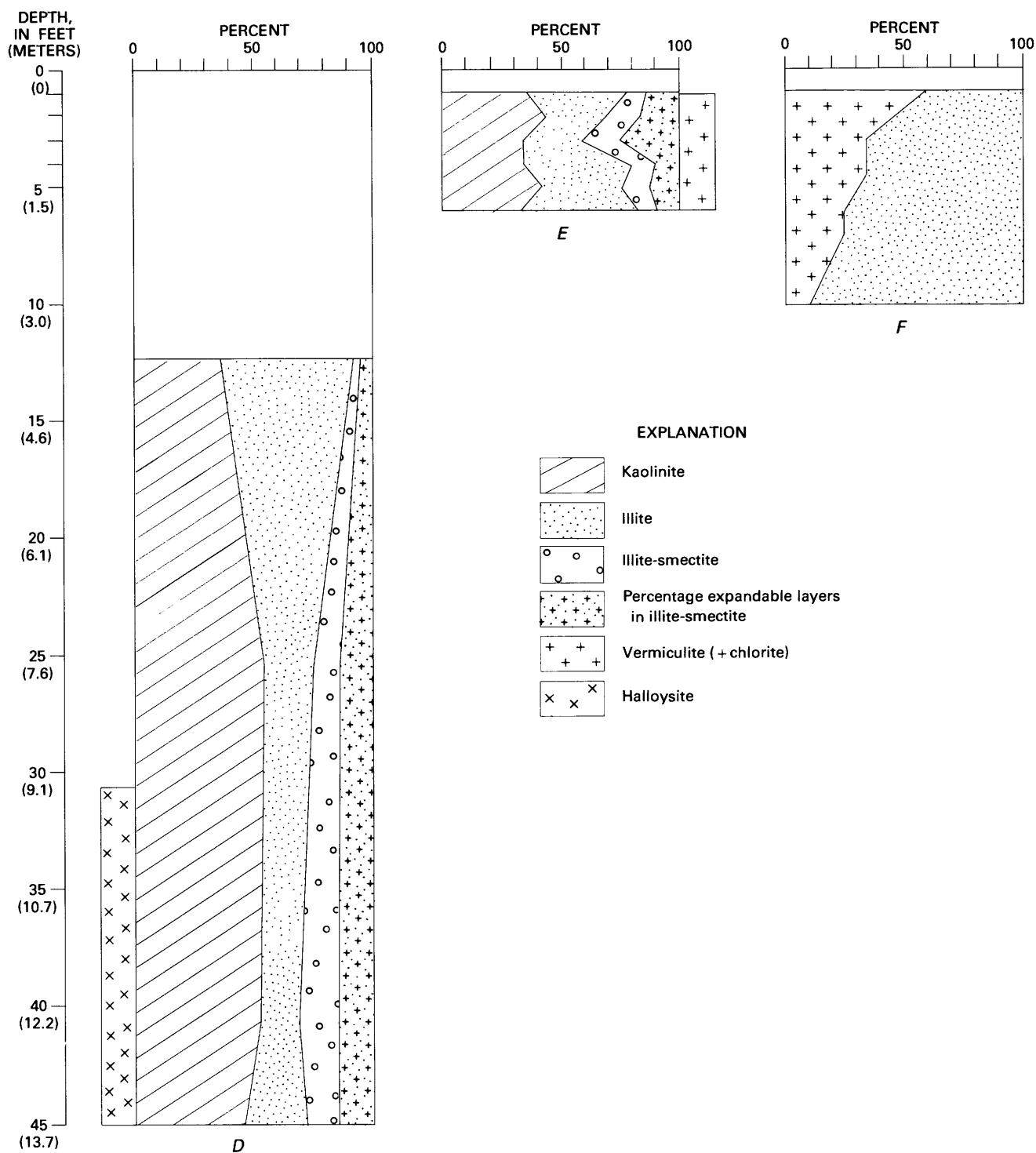


FIGURE 6.—Calculated clay mineral concentrations in some formations in the study area. Vermiculite, halloysite, and gibbsite were not calculated with the other clays because no method has been devised to determine, with any degree of assurance, the amount of these minerals in a sample. Therefore, those samples that contained significant concentrations of these minerals are not shown in this type diagram. A, Hayfield, Va.; B, Bowling Green, Va.; C, Round Bay, Md.; D, Whaleysville, Md.; E, Pittsville, Md.; F, Van Sciver Lake, Pa. (vermiculite estimated on the basis of peak height).



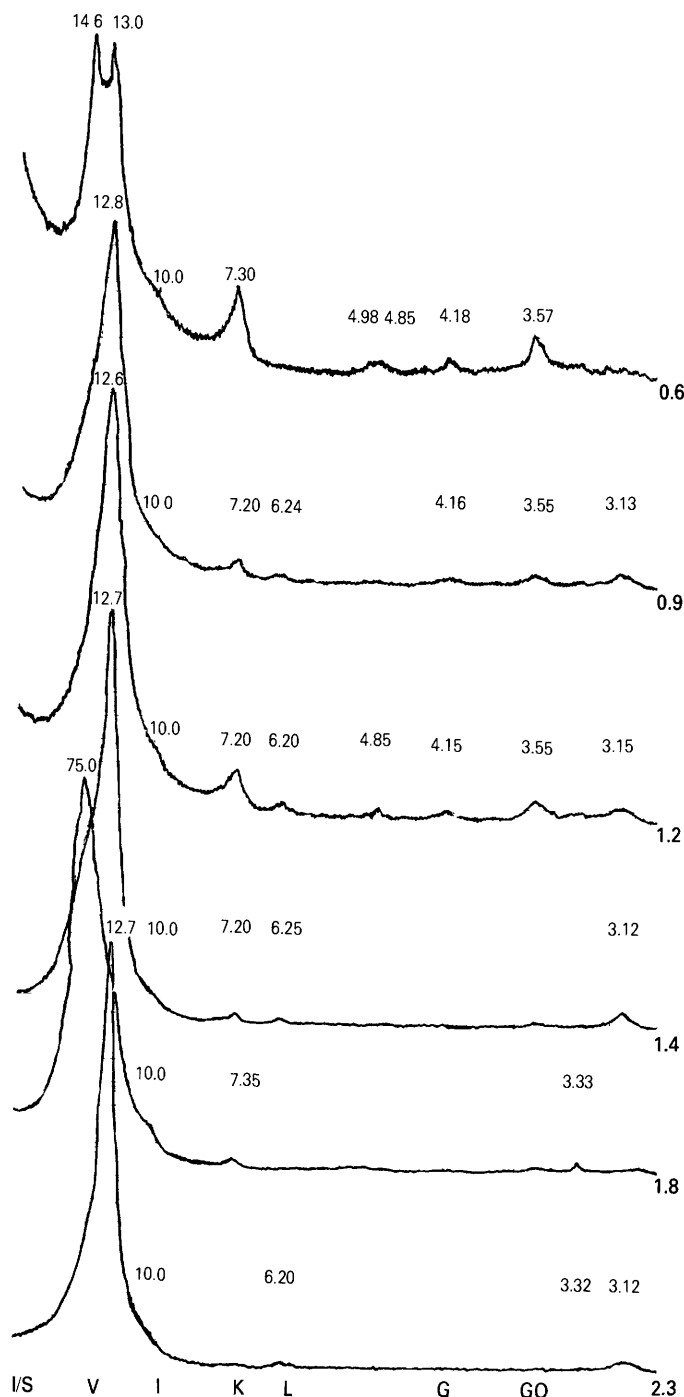


FIGURE 7.—X-ray traces of the <2- μ fraction in sand of the Potomac Formation at Hayfield, Va. (locality no. Anna 1). Traces illustrated are of unoriented and untreated clay. This untreated type of clay pattern is used for other units throughout the report. The X-ray identification discussed in the text, however, was data derived after the clay had been subjected to the standard series of heating and chemical tests. Measurements of peaks in the X-ray traces are in angstroms. Depths of samples are given in meters. V is vermiculite, I is illite, K is kaolinite, L is lepidocrocite, G is gibbsite, GO is goethite, and I/S is illite-smectite.

long time was considered to be a single unit ("upland gravels" or Brandywine Formation, Pliocene?). These beds could be equivalent to the "upland gravels" at the Hayfield site. Detailed field studies near the Rappahannock River, however, have shown that these "upland gravels" are of more than one age and were deposited in many environments (Wayne Newell, written commun., 1978). The gravels at Bowling Green (fig. 1) are mapped as Yorktown Formation (lower and middle(?) Pliocene). The lithology of the upper part of this unit as exposed in a roadcut is shown in figure 8. The most obvious lithic characteristics of this unit are abundant gravel and sand, poor stratification, extensive but irregularly distributed iron oxide staining, and the presence of relatively large *Ophiomorpha* burrows. In general, the deposits appear to be well-drained, permeable sand.

SAND MINERALOGY

Light minerals.—Figure 4B shows the light-mineral distribution in the sand fraction at this locality. The bulk of the sand fraction is quartz. K-feldspar totals about 25 percent of the sand fraction at depth and decreases to about 7 percent near the surface. All of the K-feldspar grains examined, irrespective of depth, appear to be altered to some degree (turgid and ragged edged). A few rock fragments are also present in the light-mineral fraction. Most of these fragments appear to be medium-grained gneiss. The subangularity of most of the grains suggests that they are first-cycle material. Compositionally, the sands at this locality are subarkose to proto-quartzite.

Heavy minerals.—The heavy-mineral assemblages in this unit are dominated by the more stable forms: zircon, tourmaline, and rutile (ZTR group) (fig. 5B). Zircon is especially abundant in this group of minerals. The next most abundant minerals are the SSK group (staurolite, sillimanite, and kyanite). Staurolite is the most abundant in this group, kyanite being the next most common.

The least abundant mineral group present, HEGAT (hornblende, epidote, garnet, actinolite, and tremolite), accounts for up to 7 percent of the heavy-mineral concentrate. This group contains minerals considered to be the least stable in strongly oxidizing environments. There is no consistent pattern to the distribution or concentrations of these minerals in the profile studied. Surprisingly, hornblende, considered to very unstable in oxidizing zones, occurs as fresh grains in the sample collected nearest the surface.

CLAY-SILT MINERALOGY

Figure 6B shows the distribution of the clay minerals in the profile sampled. In this profile, kaolinite is by far the most abundant clay mineral. Illite occurs in small

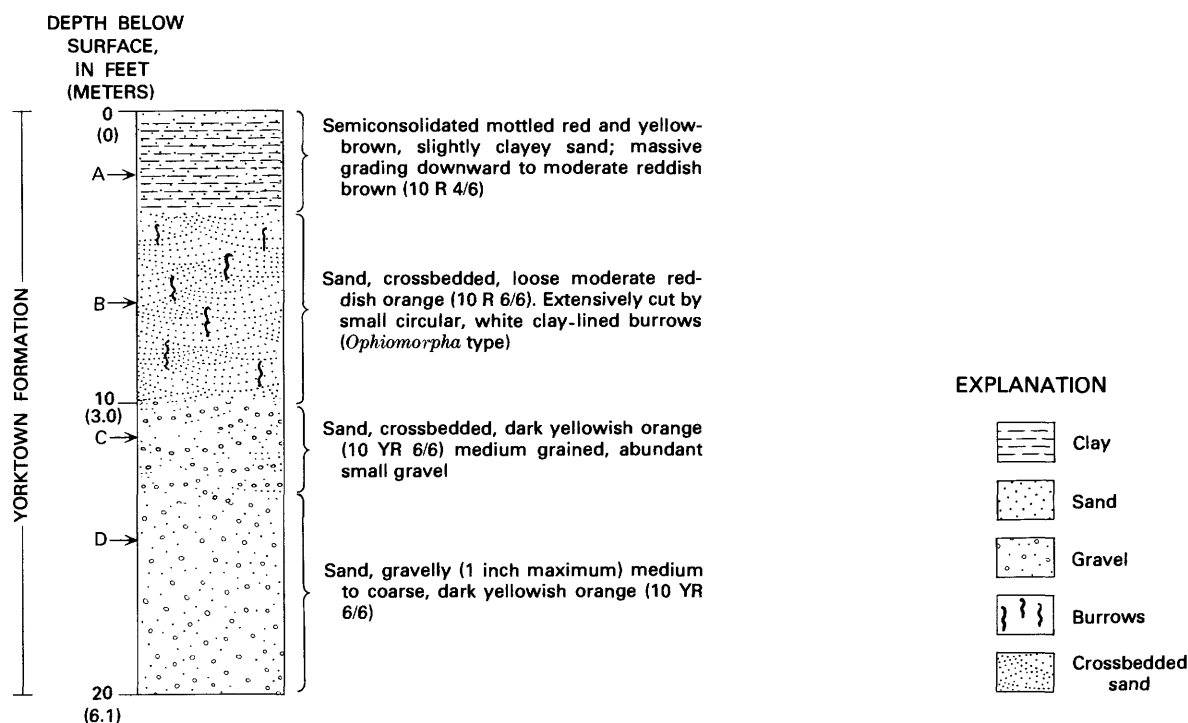


FIGURE 8. — Columnar section showing the geology at Bowling Green, Va. Exposure is in a roadcut on State Route 2, 0.6 km (0.4 mi) northeast of Bowling Green in the Bowling Green 7.5-minute quadrangle. Locality no. Bowling Green 1. Arrows indicate sample locations in profile. Surface elevation is 64 m (210 ft) above sea level.

amounts throughout the profile, and illite-smectite occurs only in the lowest beds. Vermiculite is present throughout.

Figure 9 shows the X-ray traces of untreated samples from this profile. There appears to be very little variation in the peak heights of the minerals in this profile, except for a tendency for vermiculite to increase toward the surface. Free aluminum oxides were not detected, but small amounts of iron oxides (goethite) occur at depth.

INTERPRETATION

In general, the clay mineral content (kaolinite dominant) and the decrease in feldspar and the increase in the stable heavy-mineral assemblages (ZTR) toward the surface indicate that the Yorktown Formation at this locality has been subjected to weathering of intermediate intensity.

Samples also were obtained from the capping gravels near the Fall Line at Fredericksburg, Va. These beds lie at higher elevations than those at Bowling Green and are farther updip. These gravels are considered to be the fluvial facies of the Yorktown Formation (again lower and middle(?) Pliocene) (Wayne Newell, written commun., 1978). In general, the clay minerals in the sand at Fredericksburg are very similar to those at Bowling Green—that is, kaolinite and vermiculite dominant and

no illite-smectite. Again, the supermature weathering minerals, gibbsite and hematite, were not observed at this locality.

It would appear, therefore, that, in this part of the Virginia Coastal Plain, feldspathic surficial sand of early and middle(?) Pliocene age is weathered but has not reached compositional maturity or, if it has, that the deposits have undergone undetected stripping or resiliification or both.

ROUND BAY, MD. CALVERT AND AQUIA FORMATIONS, LOCALITY NO. R.B. 51

A series of samples were collected from a section on the northern bank of the Severn River, about 1.44 km (0.9 mi) south of Round Bay and about 8 km (5 mi) west of Annapolis, Md. This locality is a naturally cut bank approximately 24.3 m high that is gradually retreating and thus exposing relatively fresh material. This area has been mapped recently (Minard, 1980); the stratigraphy at this site is shown in figure 10. Two formations are present, the Calvert Formation of early and middle Miocene age and the Aquia Formation of early(?) and late Paleocene age. Samples were collected from the Calvert and the upper part of the Aquia to a depth shown in figure 10.

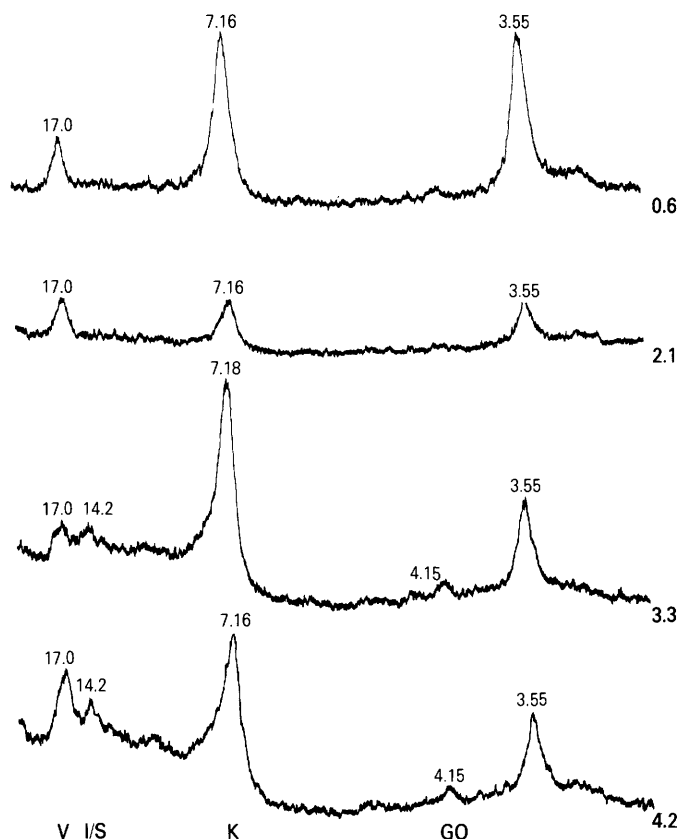


FIGURE 9.—X-ray traces of clay minerals in the Yorktown Formation at Bowling Green, Va. (locality no. Bowling Green 1). The intensity of the kaolinite (K) reflection (7 Å) is apparent in this diagram. The increase in dioctahedral vermiculite (V) (14.6 Å) in samples taken nearest the surface also can be seen. I/S is illite-smectite, and GO is goethite. Measurements of the peaks of the X-ray traces are in angstroms. Depths of samples are in meters.

SAND MINERALOGY

Light minerals.—The light-mineral fraction in both these formations is shown in figure 4C. In both these units, quartz is the major light mineral. Not shown, however, is glauconite, which is particularly abundant (a major sand constituent) in the Aquia Formation. K-feldspar averages about 10 percent of the size fraction examined, and plagioclase occurs only in trace amounts. Most of the rock fragments in these beds are gneiss. The feldspar content in these two formations is considerably less than that in the Potomac Formation at the Hayfield site and about the same as that in the Yorktown Formation at the Bowling Green site. The feldspar content does not decline toward the surface in either the Aquia or the Calvert. In both units, the K-feldspar grains all appear to be altered to some degree, their general appearance being turgid.

Heavy minerals.—The heavy-mineral content at this locality is shown in figure 5C. All the assemblages except OTHER (which includes all common heavy minerals

such as chloritoid, andalusite, and pyroxene) are present in major amounts. In the HEGAT group, epidote and garnet compose nearly the entire fraction. No hornblende, actinolite, or tremolite was found in any samples. In the ZTR group, zircon is the major mineral, and, in the SSK group, staurolite is the major mineral. In the OTHER group, chloritoid is the major mineral.

Like the light minerals, the heavy-mineral assemblages of the Calvert and Aquia Formations are very similar. There is no significant variation in the percentages of the heavy-mineral assemblages, irrespective of depth within the formation. The one notable exception is at the top of the Aquia Formation, where the most stable of the heavy-mineral groups (ZTR) is unusually abundant. One explanation is that this particular zone represents a paleosol formed on the upper beds of the Aquia (upper Paleocene) before Calvert (lower and middle Miocene) deposition.

The heavy-mineral assemblages in these two formations have much less zircon than those in the Potomac Formation. There is a marked increase in the HEGAT (notably, epidote), SSK (notably, staurolite), and OTHER (notably, chloritoid) contents. Clearly, the sediments in these formations had a provenance different from that of the sediments of the Potomac Formation (Lower Cretaceous) at Hayfield or the "upland gravels" (lower and middle Pliocene) at Bowling Green.

CLAY-SILT MINERALOGY

The clay mineral distribution at this locality is summarized in figure 6C. In general, there is a decrease in illite-smectite upward through the section and a concomitant increase in kaolinite. In addition, vermiculite and chloritized vermiculite are developed in the upper part of the Calvert Formation. Illite shows no marked changes in concentration upward through the section.

X-ray traces showing the distribution of clay-sized minerals at this locality are shown in figure 11. The overall crystallinity of the minerals in both formations is poorer than that at the previously described localities. Mixed layering is very common, and glauconite is present in the Aquia Formation. Differentiating between illite and glauconite in X-ray traces is particularly difficult. For that reason, part of the illite percentage shown in figure 11 in the Aquia Formation is probably glauconite.

INTERPRETATION

The Calvert and Aquia Formations were originally protoquartzite in composition. They had, therefore, a feldspar content considerably lower than that of the Potomac Formation at Hayfield. Because the heavy and light minerals in the Calvert and Aquia Formations do

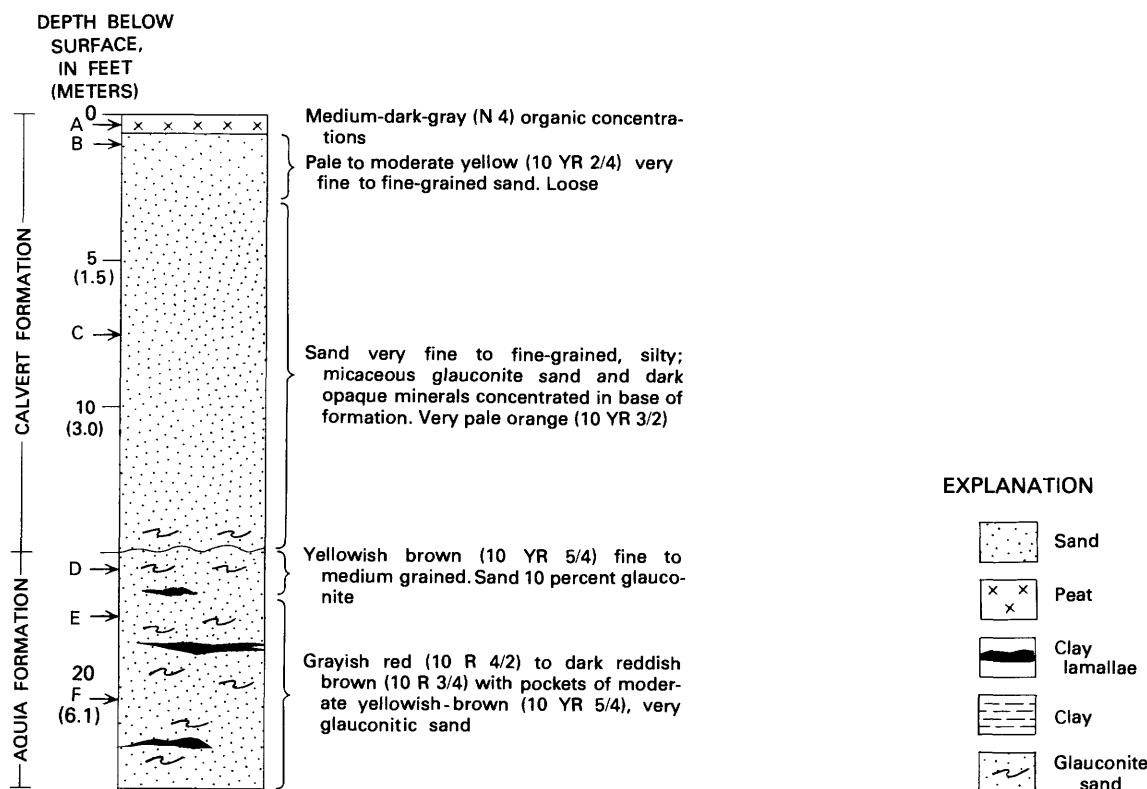


FIGURE 10.—Columnar section showing the geology at Round Bay, Md. Exposure in the northern bank of the Severn River, 1.44 km (0.9 mi) south of Round Bay, Md., and 8 km (5 mi) west of Annapolis, Md., in the Round Bay 7.5-minute quadrangle. The lower part of the lower and middle Miocene Calvert Formation and the upper part of the lower(?) and upper Paleocene Aquia Formation are exposed at this locality. Locality no. R.B. 51. Arrows indicate sample locations in profile. Surface elevation is about 30 m (100 ft) above sea level.

not show any pronounced variation from the top to the base, these beds may not have been subjected to any prolonged subaerial oxidation in relatively recent time.

The data from the clay minerals, however, show a trend toward more compositional maturity from the lowermost part of the Aquia to the uppermost part of the exposed Calvert. Kaolinite and dioctahedral vermiculite increased toward the surface, and the percentage of illite-smectite shows an inverse relationship decreasing in the same direction. The compositional maturity of the clays, however, appears to be only in the aluminous silicates, not in the aluminum oxides. The resultant difference in the clay mineralogy of the Calvert and Aquia Formations and that of the Potomac Formation may be related the original lower feldspar content in the Calvert and Aquia Formations rather than to the effects of subaerial oxidation.

SUMMARY OF WEATHERING EFFECTS WEST OF CHESAPEAKE BAY

In the three sample localities west of Chesapeake Bay, the weathering effects were studied on the surface and near the surface of formations ranging in age from Ear-

ly Cretaceous to middle Pliocene. The weathering effects indicated by the mineral assemblages (clay and sand) present in near-surface beds varied between sites, but none approached the maturity that might be predicted for deposits of this age from Jackson's (1965) weathering model. All the surfaces seem to be stripped postdepositionally, but how much and when?

The Yorktown Formation (Bowling Green site) appears to have the most mature profile if the concentration of illite-smectite in the clay assemblage is interpreted to reflect a strongly oxidizing near-surface environment. By the same criterion, the Calvert Formation appears to be more weathered than the Potomac Formation. In general, the weathering, as described by the Jackson model, would range from mild (Potomac) to intermediate (Yorktown).

Sand minerals show the effect of weathering less than clay minerals. The quartz-feldspar ratios show a base-to-surface decrease that is best seen in the Yorktown Formation. This preferential loss of feldspar relative to quartz upward through a section is to be expected in a well-developed weathering profile. Marked changes in the quartz-feldspar ratios were not evident in the Calvert and Potomac Formations; therefore, these

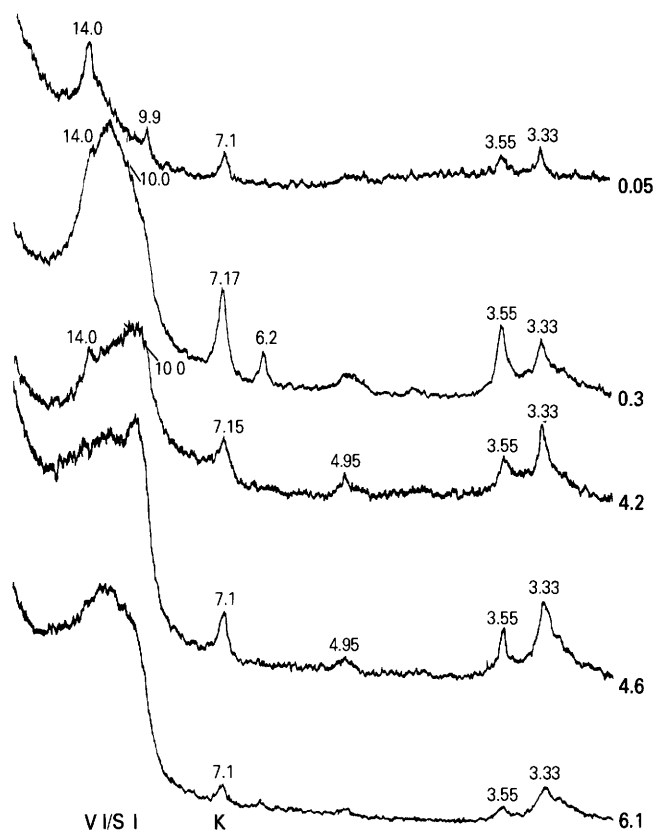


FIGURE 11.—X-ray traces of untreated, unoriented specimens in samples of the Calvert (0.05, 0.3, and 4.2 m) and Aquia (4.6 and 6.1 m) Formations at Round Bay, Md. (locality no. R.B.51). The preponderance of minerals in the high-angle range is characteristic of both formations. Mineralogic trends are difficult to see in these traces because of extensive mixed layering, but, in general, vermiculite (V) (14 Å) increases toward the surface. Other minerals present are illite-smectite (I/S), illite (I), and kaolinite (K). Measurements of peaks in the X-ray traces are in angstroms. Depths of samples are given in meters.

minerals could not be used to detect any effects of weathering superimposed on these formations.

The heavy minerals followed much the same mineral trends as the light minerals. In the Yorktown Formation, the ZTR assemblage (the most resistant minerals) increases from the base to the top. In the Calvert and Potomac Formations, no such trend is evident.

In conclusion, the weathered profiles tested in this region are less mature (younger) than the formations on which they were developed. Additionally, the fact that formations are weathered to different depths and varying intensities suggests a different rate of erosion at each site. The interpretation that we favor for the lack of compositional maturity is that these deposits have been uplifted postdepositionally, the result being that the uppermost weathered beds have been stripped from much of this area.

BETWEEN CHESAPEAKE AND DELAWARE BAYS

Six sites were sampled between Chesapeake and Delaware Bays.

BETTERTON, MD.

PENSAUKEN FORMATION, LOCALITY NO. BET. 3

A series of high bluffs borders the Sassafras River in the northwestern part of the Delmarva Peninsula. Exposed in a few of these bluffs are broad channels filled with yellow gravelly sand that has cut into the older Cretaceous formations. This gravelly sand has been assigned to the Pensauken Formation (upper Miocene) (Owens and Minard, 1979). Figure 12 shows a section through a channel just west of Betterton, Md., that was sampled for study. Just over 18 m of the channel is exposed, from which six samples were collected for analysis.

The channel fill is composed of cross-stratified, moderately sorted, medium- to coarse-grained sand and horizontally stratified, poorly sorted gravelly sand. No trace fossils are present. The fill in these channels appears very permeable. Iron oxide staining and locally weak cementation occur throughout the entire section, although most of the iron oxides are in the upper beds of the channel fill (fig. 12).

SAND MINERALOGY

Light minerals.—The light-mineral distribution in the sand fraction is shown in figure 4D. In the size fraction studied (0.177 to 0.074 mm), K-feldspar is more abundant than quartz, although the relationship is reversed in the coarser and more abundant size fractions. Smaller amounts of plagioclase (mostly oligoclase), rock fragments, mica, and glauconite are also common constituents. In general, almost all the feldspar grains are weathered to some degree. Compositionally, the Pensauken Formation at this locality is an arkose unit, similar in this respect to the Potomac Formation at Hayfield, Va.

Heavy minerals.—The heavy-mineral assemblage in the Pensauken Formation at this locality is immature, as its high percentage of HEGAT minerals shows (fig. 5D). The formation here has high concentrations of actinolite in comparison with the formation in other parts of the Delmarva Peninsula. Otherwise, the Pensauken heavy-mineral assemblages are very similar throughout the Delmarva Peninsula. Studies of the heavy minerals upward through the section at Betterton show a general decline in the more labile constituents, although the feldspar content relative to quartz remains about the same.

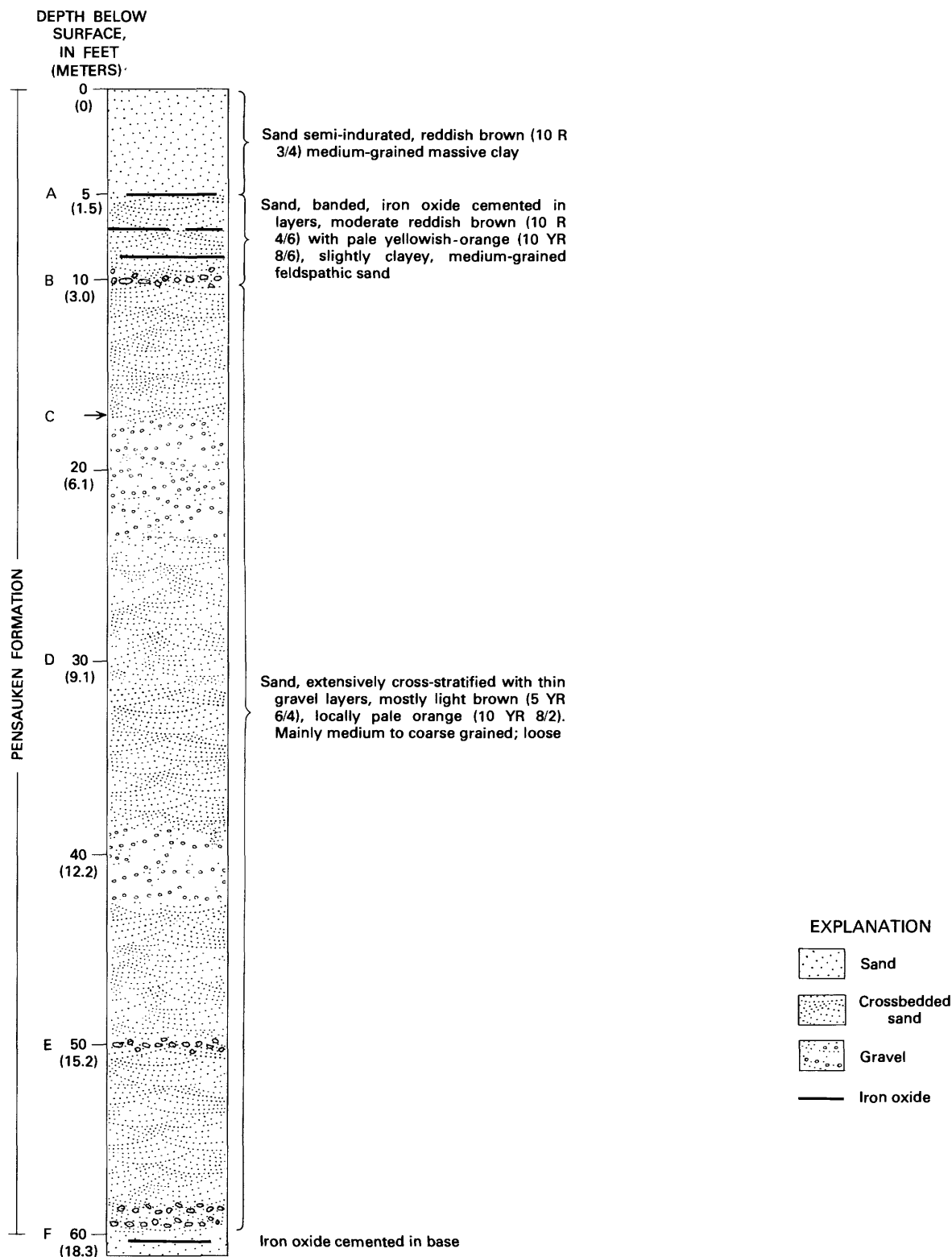


FIGURE 12.—Columnar section showing the geology as exposed in a bluff along the southern side of the Sassafra River 0.5 km (0.9 mi) west of Betterton, Md., in the Betterton 7.5-minute quadrangle. Locality no. Bet. 3. Arrows indicate sample locations in profile. Surface elevation is 24.4 m (80 ft) above sea level.

CLAY-SILT MINERALOGY

The clay minerals interstitial to the sand of the Pensauken Formation are shown in figure 13. At a depth of 18.3 m below the surface, these minerals are poorly crystalline. The assemblage at this level appears to be characterized by quartz, halloysite, goethite, and feldspar. At 15.2 m, halloysite increases in crystallinity and apparent concentration. Detectable amounts of gibbsite and dioctahedral vermiculite also make their first appearance in this assemblage dominated by halloysite. From this level to the surface, gibbsite and, particularly, vermiculite increase, and halloysite tends to decrease. Small amounts of illite are also present 1.5 to 4.6 m below the surface.

TEM plates illustrating the morphology of the minerals at various levels in the formation are shown in figure 14. In the two basal samples (figs. 14E, F), halloysite tubes are abundant and very well formed. Thin, transparent plates (kaolinite) are scattered throughout these samples. In figure 14D, most of the well-formed halloysite tubes are not present. At this level, unrolled halloysite tubes are the major form, and the thin anhedral plates are more common than they are below. In figure 14C, none of the well-developed halloysite tubes are present, and the bulk of the sample is the unrolled tubes and anhedral plates. In figure 14A, the platy minerals (vermiculite, kaolinite, and perhaps gibbsite) are the major phase, and only a few poorly formed tubes are present.

INTERPRETATION

The Pensauken Formation contains large concentrations of feldspar and thus resembles the arkosic Potomac Formation at Hayfield. Samples taken from the Pensauken at Betterton throughout its entire thickness are stained by iron oxides to varying degrees, an indication that the Pensauken is much more leached than the Potomac at Hayfield. The occurrence of abundant halloysite and especially gibbsite in the Pensauken, but not in the Potomac, indicates that the Pensauken has been intensively leached. Additionally, a comparison of the Pensauken with its near-age equivalent (the Yorktown Formation at Bowling Green) shows that both these upper Tertiary formations have widespread iron oxide staining, which superficially indicates a comparable degree of subaerial alteration. This weathering equivalency is not borne out in the mineralogy, however. All the mature weathering products—gibbsite or halloysite or both—are present in the Pensauken but are notably absent in the Yorktown. Perhaps these mineralogic differences are related to the fact that the original feldspar content in the Pensauken was higher than that

in the Yorktown, but, at present, we favor the interpretation that the Pensauken is much more intensely weathered. In summary, the Pensauken is an intensely leached unit, the first formation discussed thus far that contains significant amounts of the supermature weathering mineral gibbsite.

HOUSTON, DEL.

BEAVERDAM SAND AND PENSUKEN FORMATION,
LOCALITY NO. HARR. 5

At the Houston, Del., locality, the Pensauken Formation (upper Miocene) is overlapped by the Beaverdam Sand (upper Pliocene) (fig. 15). The upper beds of the Beaverdam in turn are extensively dissected and overlain by younger, much more quartzose sand apparently derived from a reworking of the Beaverdam Sand. The Pensauken and Beaverdam are equally feldspathic units (arkose to subarkose).

The Pensauken at this locality is lithologically similar to the beds at Betterton (cross-bedded sand, local gravel beds, extensive iron oxide staining, and local cementation). Near the contact with the overlying Beaverdam, the Pensauken is cemented irregularly by iron oxides into a hard ironstone. This ironstone forms a highly irregular surface in the Pensauken. The much lighter colored sand in the overlying Beaverdam is characterized by small- to large-scale crossbedding and by an upward-fining sequence. The sand is typically a light gray but is normally stained by iron oxides along some of the cross-strata. The light red staining of the upper 30 cm of the formation suggests that the original weathered surface of this unit is not intact. Apparently, the upper part of the Beaverdam was removed before the deposition of the younger quartz sand that overlies the Beaverdam here.

SAND MINERALOGY

Light minerals.—No mineral counts of the Beaverdam or Pensauken were made at this locality. Spot checks of the mineralogy in the sand indicate that both units are very feldspathic (mostly K-feldspar) and have about the same feldspar content. The Beaverdam, like the Pensauken, is therefore an arkose unit.

Heavy minerals.—The heavy-mineral assemblages in the Beaverdam and Pensauken at this locality have a high HEGAT (immature) content (fig. 5E). Within this HEGAT group, hornblende is especially abundant. The ZTR content of the Beaverdam is higher than that of the Pensauken, and the Beaverdam thus is probably a more mature assemblage. The hornblende content (high) in the Pensauken differs markedly from the hornblende concentration in the Pensauken at Betterton (low).

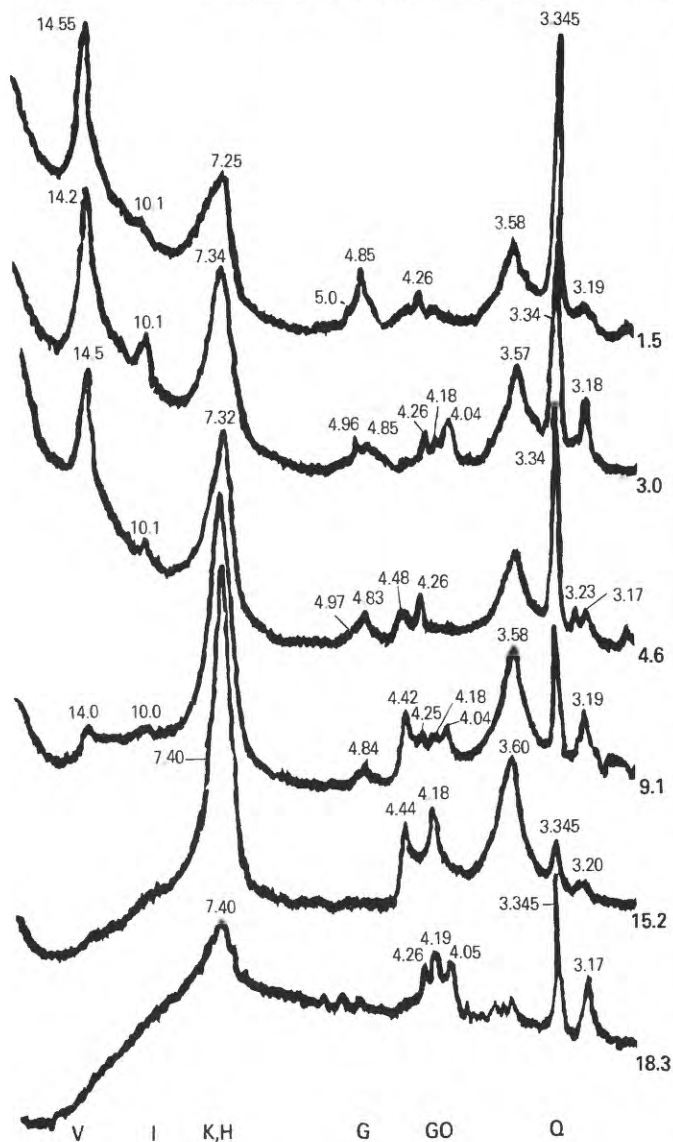


FIGURE 13.—X-ray traces showing clay minerals in sand of the Pensauken Formation at Betterton, Md. (locality no. Bet. 3). In this profile, kaolinite + halloysite (K,H) decreases in concentration from base to top. Vermiculite (V) increases in abundance in the uppermost beds, as does gibbsite (G), although this mineral is less abundant than vermiculite in these upper beds. Illite (I) occurs only in a few samples and then only in small amounts. Goethite (GO) is a common constituent in all samples, as is quartz (Q). Measurements of peaks in the X-ray traces are in angstroms. Depths of samples are given in meters.

CLAY-SILT MINERALOGY

The clay minerals in the sand of the Beaverdam and Pensauken are shown in figure 16. Generally, X-ray patterns of the Pensauken at 3.2 m are similar to those of the Beaverdam at 2.7 m. The uppermost sample of the Pensauken at 4.2 m is more poorly crystalline than either of the two samples mentioned above. The 1.5-m sample has significantly higher concentrations of goethite (iron oxide). This result can be expected

because the sample came from the iron oxide zone shown in figure 15. Overall, several trends can be seen in figure 16. The general increase in vermiculite content upward through the weathering profile is found at many of the previously described localities. Gibbsite appears to increase from the base to the top, but this trend is less pronounced than the vermiculite increase. Illite also shows an increase upward through the section and appears to combine with vermiculite to form a mixed-layer clay in the sample taken nearest the surface.

INTERPRETATION

Mineralogic studies of the Beaverdam Sand and the Pensauken Formation at this locality confirm field observations that the unit nearest the surface, the Beaverdam, has been stripped postdepositionally. After this stripping (probably in the late Quaternary on the basis of general field relations throughout the Delmarva Peninsula), a second weathering profile developed on the Beaverdam; during this phase, vermiculite and, to a lesser degree, illite were formed in the uppermost beds. Gibbsite formed during a previous weathering cycle appears to have been relict in these beds. The presence of gibbsite in the nonvermiculite-illite beds of the Pensauken and through the Beaverdam favors such an interpretation.

The heavy-mineral suite and, to a lesser degree, the feldspar percentages indicate that neither the Beaverdam nor the Pensauken has undergone intensive subaerial oxidation after stripping. Hornblende in heavy-mineral assemblages is particularly soluble in mild to intensive subaerial oxidation. This mineral is very abundant even in the Beaverdam sample taken nearest the surface. The fact that feldspar percentages do not show any significant decline in the upper beds again attests to the relatively mild leaching of these formations.

Therefore, our interpretation of this section would be that the Beaverdam (upper Pliocene) and the Pensauken (upper Miocene) have been through at least two cycles of weathering. In the earlier phase, the assemblage kaolinite-gibbsite-goethite was formed. The Beaverdam was reexposed, and the uppermost intensely weathered bed (characterized by a thick, upper, red-colored zone) was stripped. A second weathering cycle began producing a vermiculite-illite-amorphous iron oxide(?) assemblage in the upper beds.

This last weathering cycle has hardly affected the underlying Pensauken. The clay minerals in this part of the section tend to resemble those in the more weathered parts of the Pensauken at Betterton (fig. 13), especially those beds between 1.5 and 4.6 m (kaolinite-gibbsite-goethite assemblage). The only exception is the

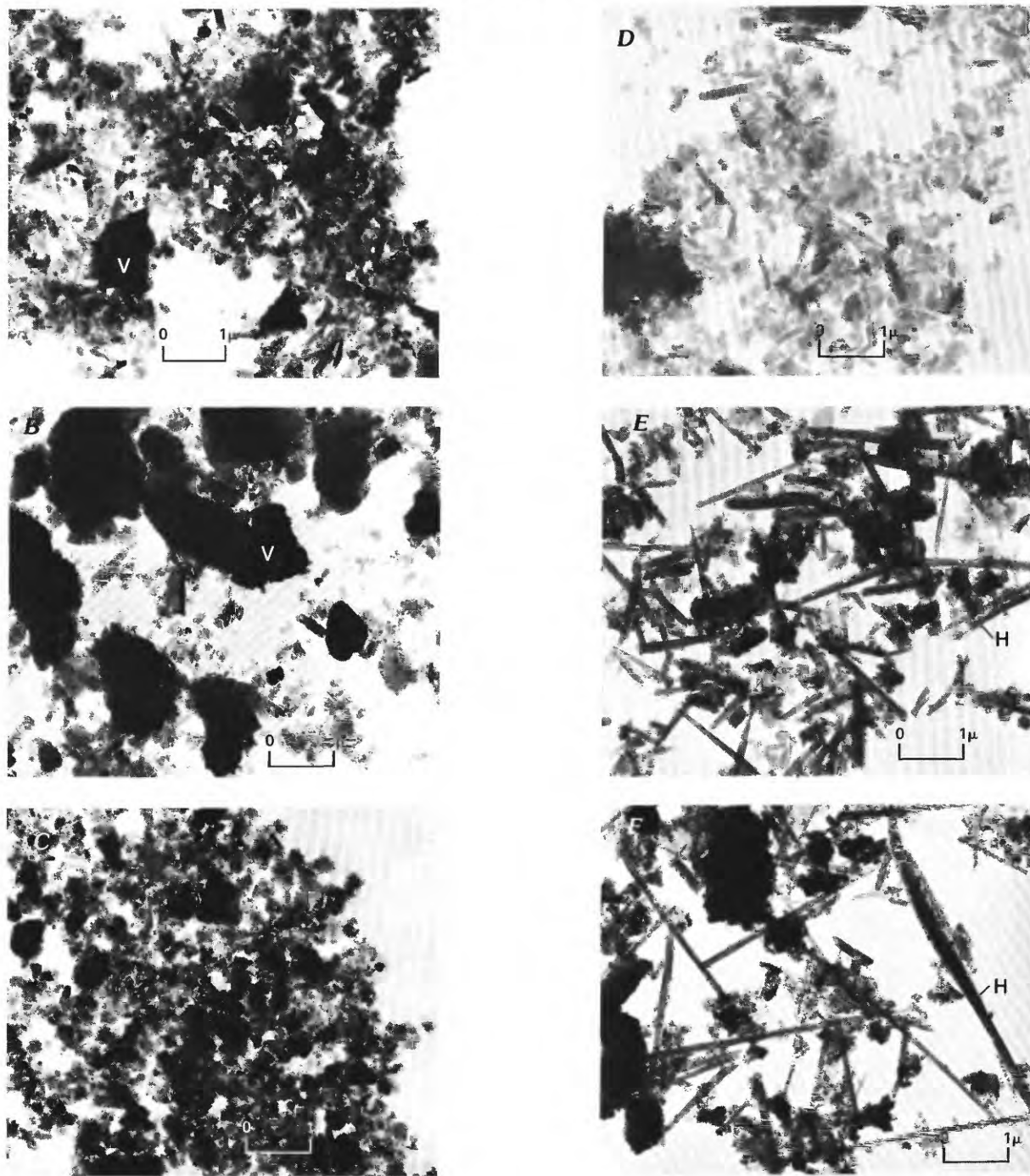


FIGURE 14.—Transmission electron microscope photomicrographs of the $<2\text{-}\mu$ fraction in sand of the Pensauken Formation at Betterton, Md. (locality no. Bet. 3). Depths of samples are as follows: A, 1.5 m; B, 3 m; C, 6.1 m; D, 9.1 m; E, 15.2 m; F, 18.3 m. Letters correspond to sample designations in figure 12. V is vermiculite, and H is halloysite.

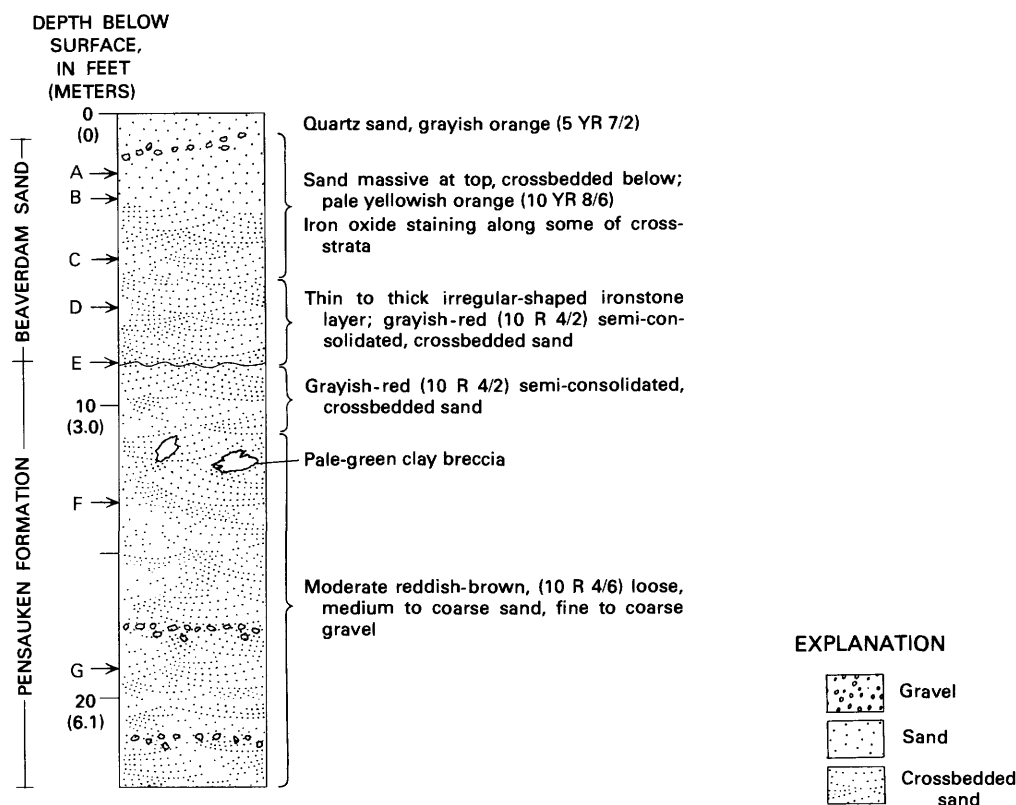


FIGURE 15.—Columnar section showing the geology in a pit on the northern side of the Murderkill River 8 km (5 mi) northeast of Houston, Del., in the Harrington 7.5-minute quadrangle. Locality no. Harr. 5. As interpreted here, three units are present: an upper, very quartzose unit; a middle, light-colored, very feldspathic sand (Beaverdam Sand); and a lower, moderate-reddish-brown-stained unit (Pensauken Formation). Arrows indicate sample locations in profile. Surface elevation is 9.1 m (30 ft) above sea level.

vermiculite-illite assemblage apparently superimposed on the older weathered beds.

WHALEYSVILLE, MD.
OMAR FORMATION AND BEAVERDAM SAND,
LOCALITY NO. WH. 1A

One of the most widespread coastal units in the Delmarva Peninsula is the Omar Formation (Owens and Denny, 1979). This formation occurs at elevations of 9 to 15 m above sea level. The unit was deposited in a marginal marine environment and characteristically consists of several lithofacies. Drill holes through the unit at several localities show that the unit typically has the same types of lithofacies stacked in a vertical sequence. A thin (as much as 1 m thick) basal brown peat to peaty clay is overlain by a massive, black, very clayey silt to silty clay (commonly containing the oyster *Crassostrea virginica*) that grades upward into a massive, white, slightly clayey and silty sand. Macro-

fossils here include *Merceneria* sp. (clam), *Ensis* sp. (clam), *Donax* sp. (clam), and *Busycon* sp. (snail). Commonly, the upper beds are a medium-dark-gray, weathered, silty, fine-grained sand.

In general, this assemblage indicates saline water deposition (open bay to shallow shelf). The dark-gray sand is overlain by a light-colored, extensively cross-bedded sand indicative of a barrier-to-beach depositional site.

The Omar beds are characteristically more the lagoonal or back-barrier muddy sediments in the Maryland part of the Delmarva Peninsula, whereas the Omar beds near Accomack, Va., are a shallow shelf-barrier (sandy) complex.

The Whaleysville samples taken at Longridge, Md., just west of Whaleysville, are from the Omar-type sediments. At this locality, both the Omar and the underlying Beaverdam were sampled (fig. 17). In all, four samples were analyzed, two from the Omar (one sand and one clay-silt) and two from the Beaverdam (both sand).

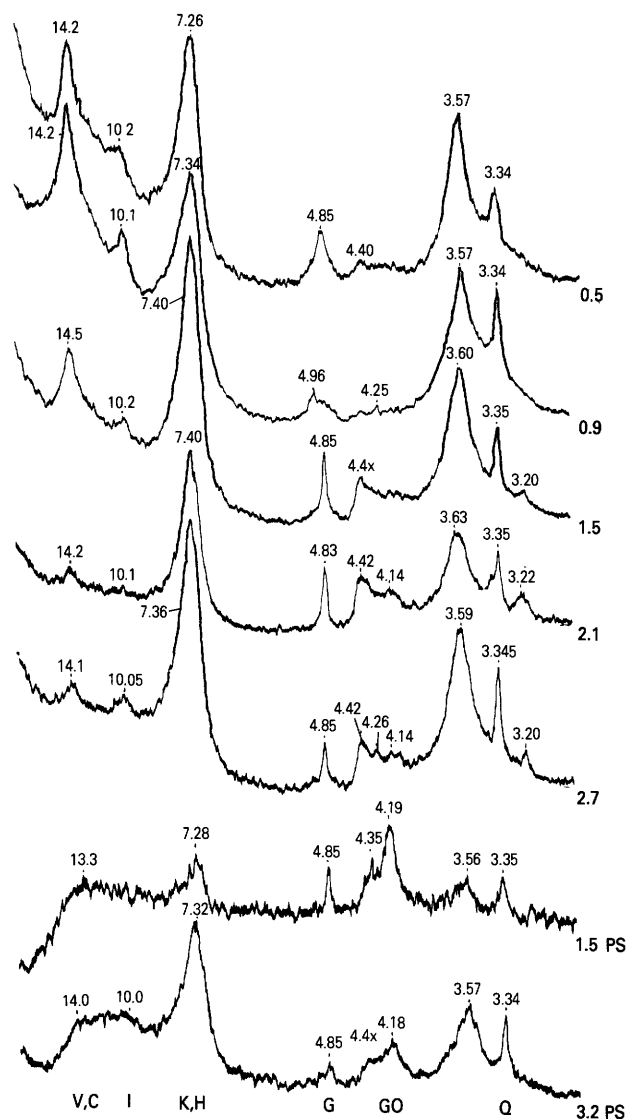


FIGURE 16.—X-ray traces of clay minerals in the Beaverdam Sand and the Pensauken Formation northeast of Houston, Del. (locality no. Harr. 5). Vermiculite (V) shows typical near-surface increase in concentration in the upper part of the Beaverdam between 0.5 and 1.5 m below the surface. Kaolinite (+halloysite) (K,H) and gibbsite (G) seem little changed in concentration throughout both formations. Goethite (GO) (4.19 Å), on the other hand, is present only in the Pensauken (PS) and is absent or poorly developed in the Beaverdam. C is chlorite, Q is quartz, and I is illite. Depths (in meters) are keyed to columnar section. Measurements of peaks in the X-ray traces are in angstroms.

SAND MINERALOGY

Light minerals.—The bulk of the sand in the Omar Formation is quartz (fig. 4F). K-feldspar, largely microcline, is the next most abundant mineral. No plagioclase was observed in the Omar at this locality. Rock fragments are a small but persistent constituent in all of the Omar samples. Compositionally, the Omar is protoquartzite.

The Beaverdam Sand, on the other hand, has, in general, more feldspar than the Omar, although quartz is still the major light mineral. K-feldspar is the major feldspar, but plagioclase (oligoclase) is present in small amounts. The Beaverdam at Whaleysville is an arkose unit, similar to the Beaverdam at the Houston site.

Heavy minerals.—The heavy minerals in both units are somewhat similar, although the Omar is slightly less mature (fig. 5F). Field relationships (Beaverdam deeply eroded prior to the emplacement of Omar beds) suggest that the Omar at this site may have been derived largely from the Beaverdam—hence, the general mineral similarity in both assemblages. The HEGAT assemblage in both units has low hornblende content relative to tremolite and actinolite. The heavy-mineral assemblages in both units are considered to be moderately immature because the more labile constituents such as amphibole are present in only small amounts. In the samples examined, no selective removal of the more labile constituents by intrastratal solution was observed. However, no very near surface samples were analyzed from this locality. Farther southwest, however, such near-surface sand was examined from the Omar beds. As at Whaleysville, no selective removal of the more labile heavy minerals could be discerned.

CLAY-SILT MINERALOGY

Four samples of the clay-silt fraction in the sand from this locality were X rayed. Two samples were from the Omar (3.7 to 4.6 m and 7.6 to 9.1 m), and two samples were from the Beaverdam (10.7 to 12.2 m and 12.2 to 13.7 m). The two assemblages are different (fig. 6D). The Beaverdam assemblage is mainly halloysite (+kaolinite) and smaller amounts of illite and illite-smectite (fig. 6D). The overlying Omar has much more illite and less kaolinite and illite-smectite than the underlying Beaverdam. The Omar sample taken nearest the surface also has vermiculite (fig. 18). Like the sand fraction, the clay mineral assemblages in both formations are moderately immature.

INTERPRETATION

The effects of subaerial oxidation on the Omar Formation near Whaleysville are slight. Except for the appearance of vermiculite in the sample taken nearest the surface, the Omar appears relatively unweathered. At this site (the only one studied in the Omar), however, the upper 3.6 m of the formation was not analyzed, so that the weathering effects in this interval are not known.

It appears, therefore, that subaerial oxidation has had little effect on the part of the Omar Formation sampled. The underlying Beaverdam also shows few visual alteration effects in drill cuttings (no iron oxide formation),

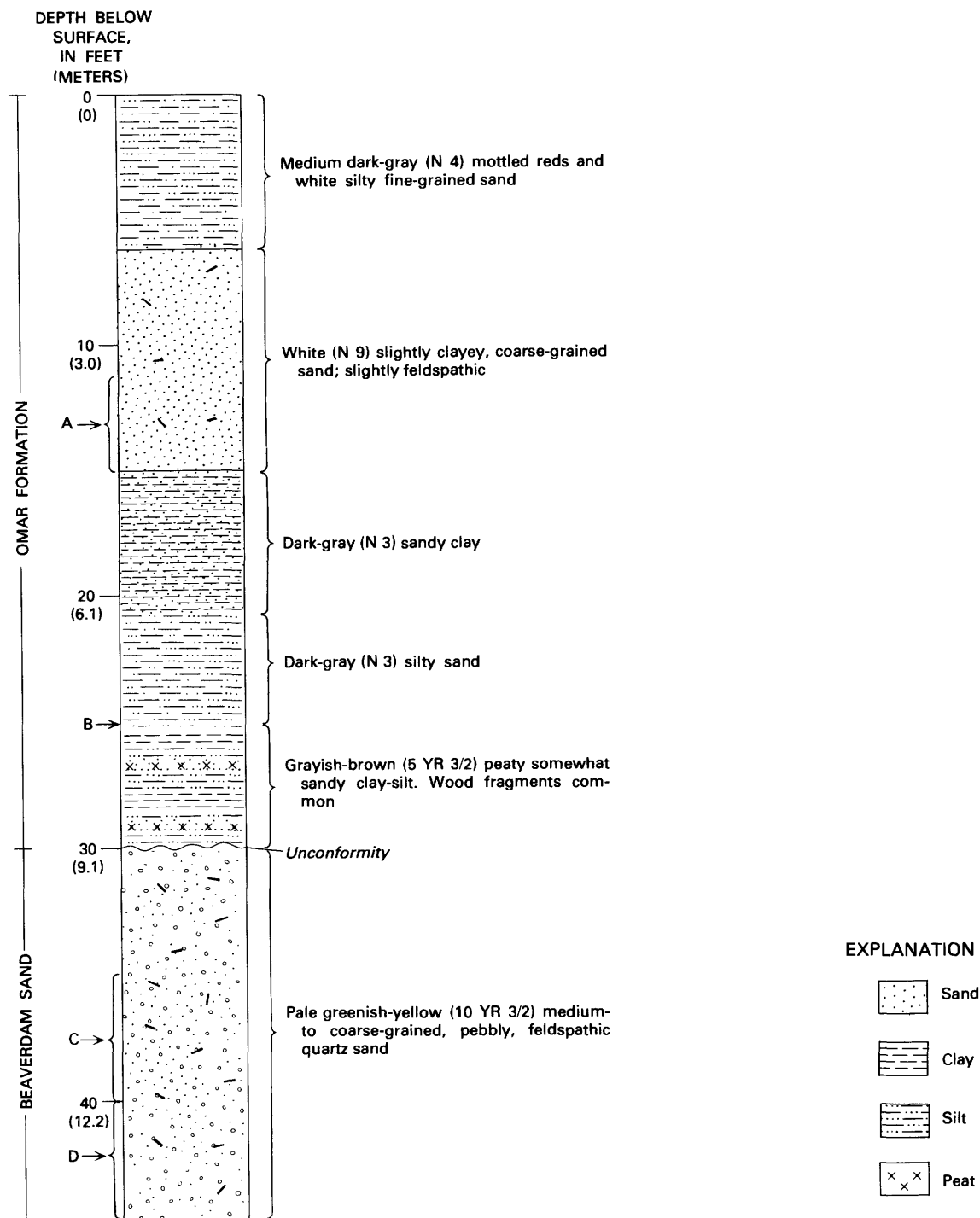


FIGURE 17.—Columnar section in an auger hole at Longridge 2 km (1.3 mi) west of Whaleysville, Md., in the Whaleysville 7.5-minute quadrangle of Maryland and Delaware. Locality no. Wh. 1A. The Omar Formation and the Beaverdam Sand are present in this auger hole. Arrows indicate sample locations in profile. Surface elevation is 10.6 m (35 ft) above sea level.

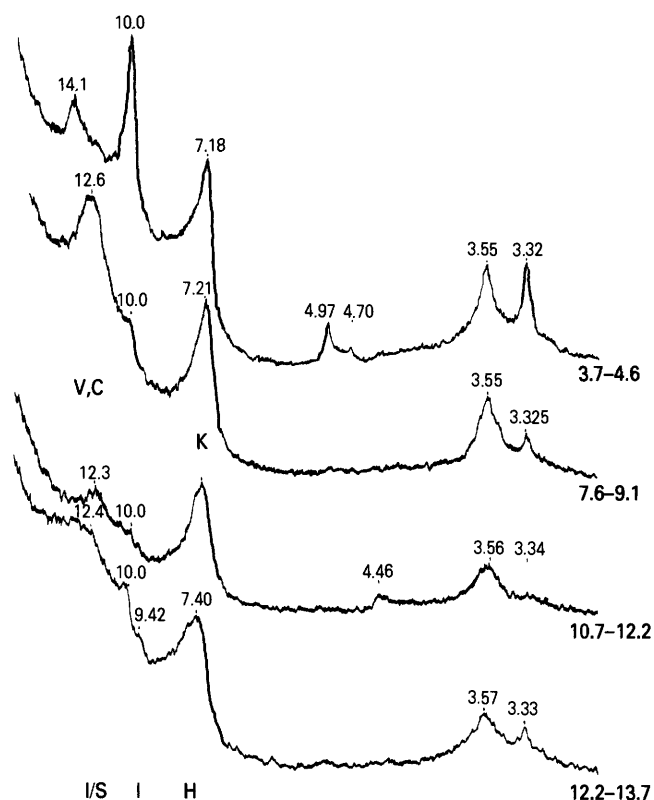


FIGURE 18.—X-ray diffractograms of the untreated <2- μ fraction in sand of the Omar Formation and the Beaverdam Sand at Whaleyville, Md. (locality no. Wh. 1A). I/S is illite-smectite, I is illite, H is halloysite, K is kaolinite, and V,C is vermiculite (+chlorite). Measurements of peaks in the X-ray traces are in angstroms. Depths of samples are given in meters.

but the X-ray traces indicate that the clay mineral assemblage (halloysite dominant) in this unit is more weathered than that in the Omar. Although the Beaverdam Sand near Whaleyville is weathered, it is less altered than the Beaverdam at Houston. One explanation is that the Beaverdam beds at Whaleyville are a less weathered zone lying below the weathering level represented by the Beaverdam at Houston. The upper, more weathered beds of the Beaverdam were stripped during emplacement of the Omar Formation.

The point to be made at this locality is that the upper Pleistocene Omar Formation (about 190,000 years old) is much less altered than the Beaverdam (Pliocene) or the Pensauken (Miocene).

GERMANTOWN, MD.
IRONSHIRE FORMATION, UPPER PLEISTOCENE,
LOCALITY NO. BER. 2

The Omar Formation has been eroded into and overlapped along its eastern margin by a dominantly sandy unit called the Ironshire Formation (Owens and Denny, 1979). Along the Atlantic Coast, this unit occurs

as a narrow band of sand having elevations of as much as 10 m above sea level (fig. 1).

Figure 19 is a stratigraphic section typical of many seen in exposures of the sand. The Ironshire Formation consists of three lithofacies distinguished primarily by the type of cross-stratification. The lower unit is a loose, well-sorted sand having long, gently inclined crossbeds. Black, heavy-mineral laminae are abundant and commonly cut by numerous short, circular borings. This unit is overlain by a loose, poorly sorted gravelly (quartz clasts) sand in which the scale of the trough crossbedding is very large. Locally, this sand has a large number of *Callianassa* burrows. This unit grades up into another sandy unit. The sand is extensively crossbedded (trough type), but the cross sets are much smaller than those in the gravelly sand below. Only a few burrows were observed in this facies.

Overall, the Ironshire Formation appears to have the lithofacies found in a regressive beach sequence (beach, tidal channel, and tidal flat (ridge and runnel)). To the south, all of the sand is overlain by a back-barrier silty clay. This formation is considered to be late Sangamon (about 60,000 to 80,000 years) in age (Owens and Denny, 1979).

SAND MINERALOGY

Light minerals.—Seven samples from this site were analyzed. Quartz is the major sand constituent, and K-feldspar, plagioclase, and rock fragments (mica gneiss) are less abundant (fig. 4F). The feldspar content in the fraction analyzed is about 25 percent. K-feldspar is the most abundant, but plagioclase is very common. In the sampled pit, plagioclase shows the most marked trend, decreasing from the base to the top; quartz increases upward in the same interval. Compositionally, the Ironshire sand is a subarkose unit.

Heavy minerals.—The heavy-mineral assemblage in this unit is noteworthy because of the large number of well-rounded grains in all the samples examined. Hornblende is particularly abundant (fig. 5G) and appears exceptionally fresh, even in the samples taken nearest the surface. Pyroxene (hypersthene) is a common constituent in the sample taken nearest the surface, but these grains have a “washed out” appearance (weathered). This mineral is the only indication in the heavy-mineral assemblage that any chemical weathering of these beds has taken place.

CLAY-SILT MINERALOGY

The X-ray results from this unit were very surprising because of the large concentrations of gibbsite in many of the traces (fig. 20). The trace from the lowermost sample (7.3 m) is almost totally gibbsite. This

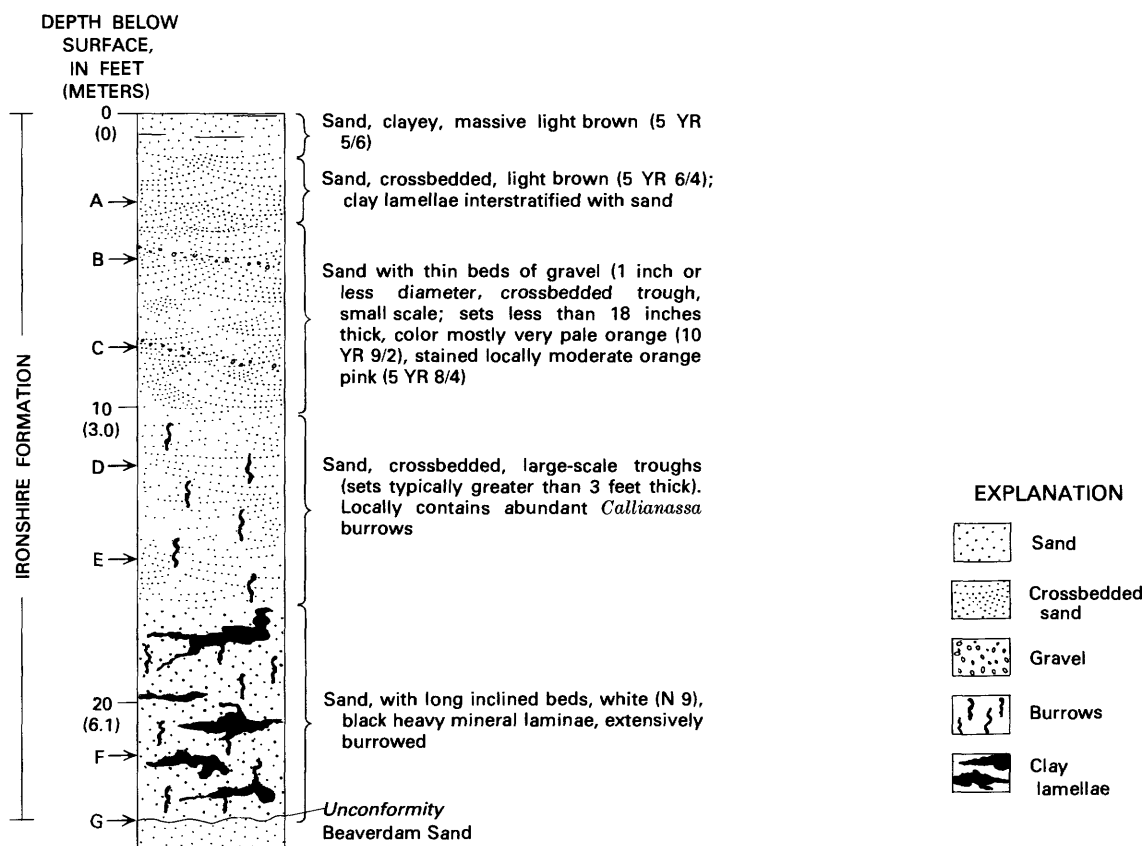


FIGURE 19.—Columnar section showing the geology in a pit near Berlin, Md., 0.4 km (0.6 mi) east of Germantown, Md., in the Berlin 7.5-minute quadrangle. Locality no. Ber. 2. The Ironshire Formation and the Beaverdam Sand are exposed in this pit. The Ironshire is typically a sandy unit bevelled into the underlying Beaverdam along the coast. Arrows indicate sample locations in profile. Surface elevation is 9 m (30 ft) above sea level.

mineralogy persists to within 3.7 m of the surface. Above this interval, the clay minerals show a marked change; vermiculite, illite, and kaolinite are present in fair abundance from here to the surface. Gibbsite is still a major constituent at 3.7 m but decreases in abundance (or crystallinity or both) above this level.

One of the most difficult minerals to identify morphologically under the electron microscope is gibbsite. Because of the unusual concentration of this mineral in the base of the Ironshire, a series of SEM pictures were taken at various magnifications to ascertain what morphologies were present (fig. 21). The dominant shapes are what appear to be unrolled tubes of halloysite (fig. 21A). At increased magnification (fig. 21B), halloysite and the other major shapes (thin anhedral plates) are better displayed. SEM-EDAX analyses of this form revealed it to be almost all aluminum and some traces of silica and thus confirmed the X-ray analyses of these samples.

INTERPRETATION

The overall lithology of the Ironshire (feldspathic sand and a very immature heavy-mineral suite) suggests a fresh first-cycle sediment. The presence of abundant amphiboles and smaller amounts of pyroxene throughout the formation favors such an interpretation. In outcrop, the formation appears to be somewhat weathered in the upper beds, as evidenced by iron oxide staining in the upper 2.4 m (8 ft).

The distribution of clay minerals in the formation is unusual, however. The lower half of the outcrop is characterized by an abundance of gibbsite, whereas the upper half shows the soil development noted at other localities—that is, a general increase in vermiculite, illite, and possibly kaolinite from about 2.4 to 0.9 m below the surface (intermediate weathering).

Thus, the clay minerals in the upper half of the profile appear to belong to the normal weathering profile observed at all the sites described previously. The gibb-

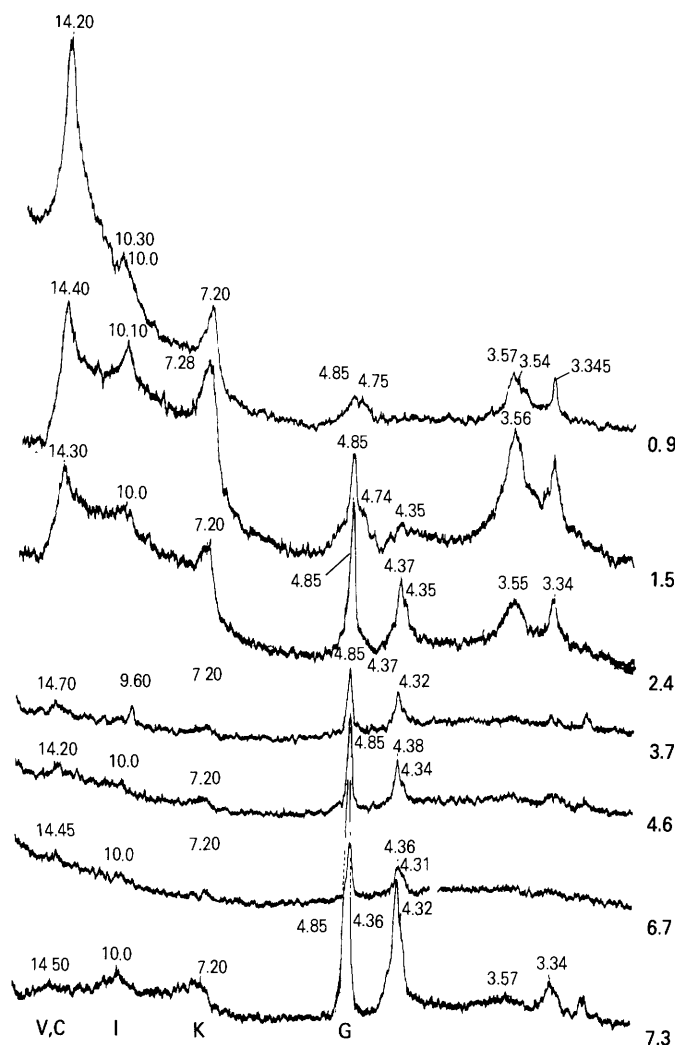


FIGURE 20.—X-ray traces of clay minerals in the Ironshire Formation at Germantown, Md. (locality no. Ber. 2). The lower half of the profile is dominated by gibbsite (G) (4.85 Å), a mature weathering mineral. The upper half is characterized by progressive development of vermiculite (V) (14.2 Å) and, to a lesser degree, of illite (I) and kaolinite (K), which suggest a less mature weathering profile. C is chlorite. Measurements of peaks in the X-ray traces are in angstroms. Depths of samples are given in meters.

site, however, presumably a more mature weathering mineral, seems out of place in the profile. The fact that this mineral is most abundant in the basal sample suggests derivation from an intensely weathered terrane and is present as a detrital weathering product rather than as an in-place weathering product. At this locality, the Ironshire has bevelled into the Beaverdam Sand (upper Pliocene) and the Omar Formation (upper Pleistocene). As illustrated earlier, the Beaverdam, which has significant concentrations of gibbsite at Houston, Del., probably was the source for gibbsite in the Ironshire. The clay minerals in the Ironshire, therefore, show that knowledge of the geologic history

of a deposit is necessary before its clay mineral content can be interpreted.

WORTON POINT, MD.
KENT ISLAND FORMATION, UPPER PLEISTOCENE,
LOCALITY NO. HANESVILLE 1

The eastern side of Chesapeake Bay is flanked by a flat surface or terrace that slopes gently from north to south. In the northern Chesapeake Bay area near the mouth of the Susquehanna River, this terrace is very dissected but has maximum elevations of 12 to 15 m (40–50 ft). The Chesapeake Bay has cut into this terrace at Worton Point, Md. (fig. 1) and exposed about 12 m (40 ft) of section. The lithologies in this bluff are shown in figure 22. The section includes two clay-silt units separated by a gravel and sand unit. Pollen studies from the clay-silt beds indicate that two palynomorph zones are present, the upper dominated by a cool assemblage (pine-hemlock) and the lower by a warm assemblage (oak-hickory) (L. A. Sirkin, written commun., 1975). A thick gravel and sand layer separating the two silt beds suggests an unconformity, and we conclude that two formations are present. Such a two-bed configuration (cool flora–warm flora) also has been seen at Kent Island in Chesapeake Bay and possibly includes Omar or Ironshire Formation equivalents (warm) as mapped in the lower bay region (Owens and Denny, 1979). Wood obtained from the lower silt was dated at more than 45,000 years B.P. (U.S. Geological Survey Radiocarbon Laboratory Sample W-1920) (Meyer Rubin, written commun., 1973). The upper unit is possibly middle Wisconsinan (about 30,000 years B.P.), whereas the underlying unit is either about 60,000 years (Ironshire equivalent) or 190,000 years (Omar equivalent). The sediments at Worton Point, therefore, are probably late Pleistocene in age.

SAND MINERALOGY

Light minerals.—Figure 4G shows the light minerals observed at this locality. The concentrations of light minerals in this unit are different from those in units described heretofore. Rock fragments, typically micaceous gneiss or schist, are the major light minerals observed. Quartz and feldspar, both K-feldspar and plagioclase, are also very common sand constituents. At a few localities, such as the mouth of the Susquehanna and as far south as Kent Island, coarse gravel is particularly abundant. The gravel suite is heterogeneous and contains many different rock types, mostly crystalline and metamorphic. This heterogeneity and the closeness of Worton Point to the source of these rocks (the Piedmont province) explain the high content of rock fragments in the sand. Compositionally, the beds at Worton Point are a high-rank graywacke.

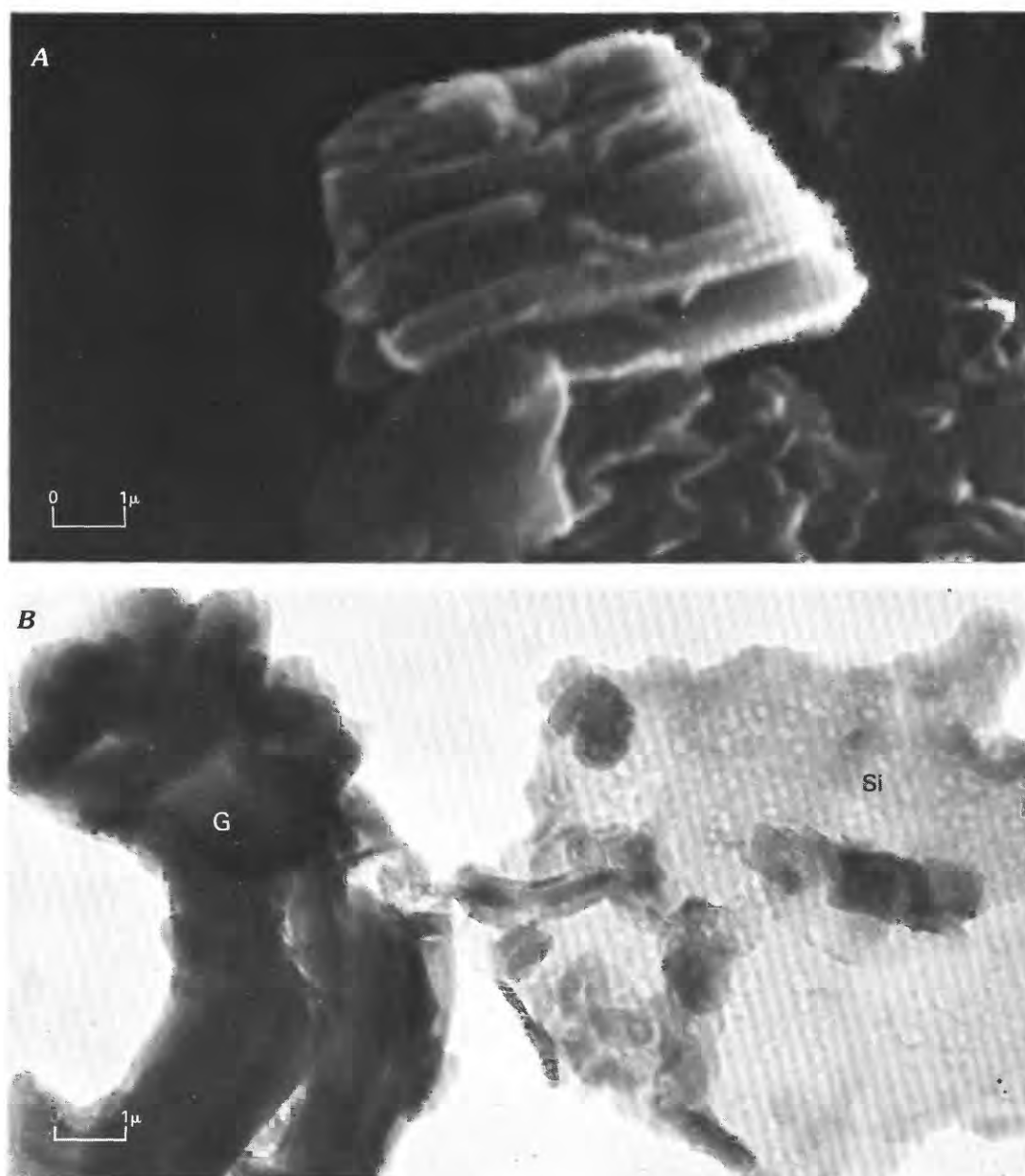


FIGURE 21.—Scanning electron microscope (A) and transmission electron microscope (B) micrographs of gibbsite (G) from the $<2\text{-}\mu$ fraction in sand of the Ironshire Formation 7.3 m (24 ft) below the surface at locality no. Ber. 2. Siliceous film, Si. Scale is $1\text{ cm} = 1\text{ }\mu$.

The apparent lack of any significant variation in feldspar content from top to bottom in this sample suggests only slight postdepositional mineral alteration here.

Heavy minerals.—The heavy-mineral assemblages in the beds at this locality (fig. 5H) are immature. In the nonopaque fraction, highly weatherable amphiboles, notably hornblende, are abundant and fresh throughout the section. Pyroxenes, mostly orthopyroxene (hypersthene), are relatively abundant in these beds, quite comparable to the abundance in the Pleistocene units (Omar and Ironshire Formations) along the Atlantic

Coast. In the opaque fraction, magnetite as well as ilmenite is very abundant throughout the sampled section.

As was true of the light minerals, there is little variation in the heavy-mineral assemblages throughout this section.

CLAY-SILT MINERALOGY

The clay mineral assemblage in the Worton Point beds consists of vermiculite, illite, and kaolinite. Vermiculite is particularly abundant in all the samples examined, irrespective of depth or palynomorph zone. In this

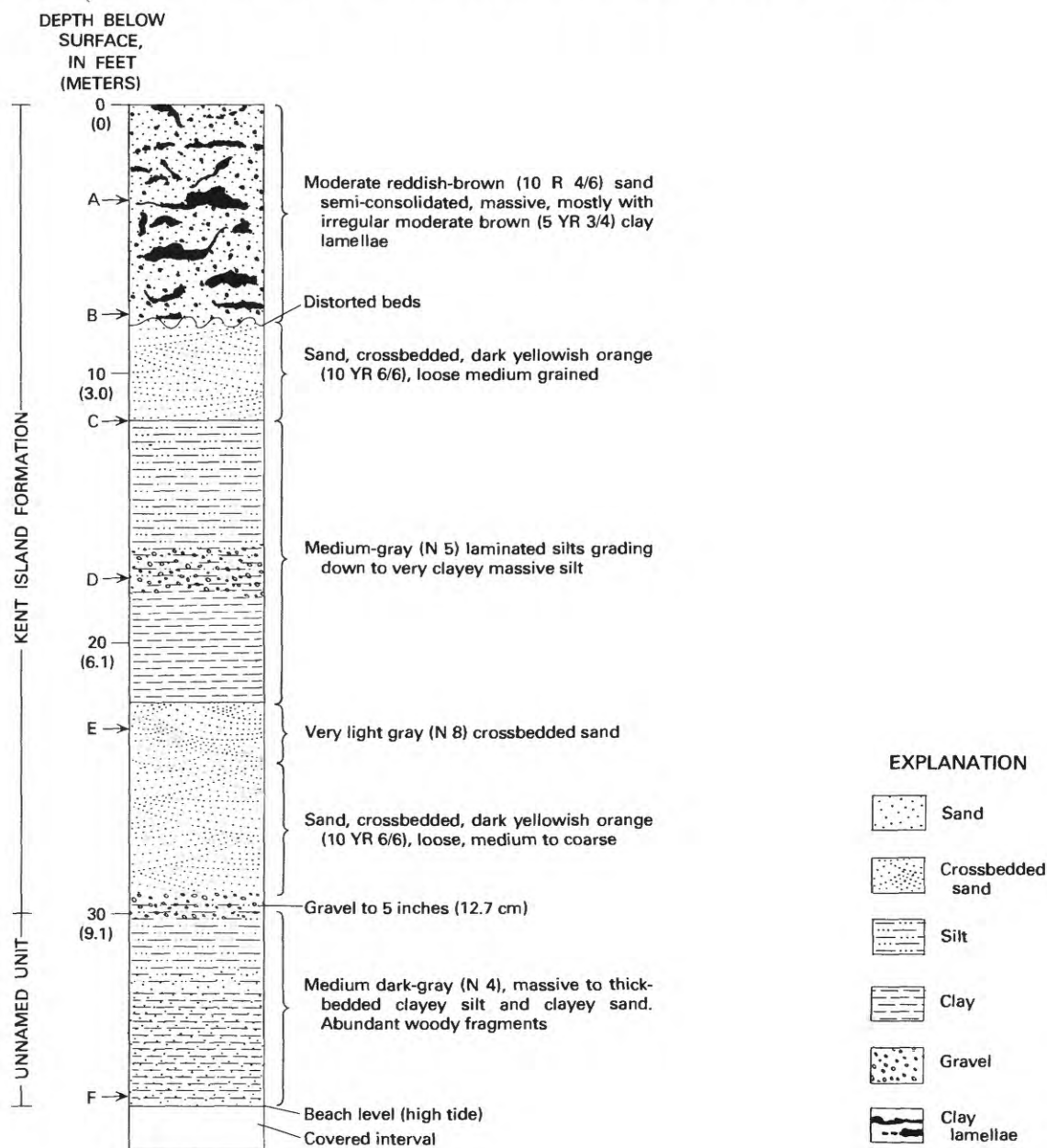


FIGURE 22.—Columnar section showing the Kent Island Formation at Worton Point, Md. The section was measured in a bluff on the eastern side of Chesapeake Bay 3.5 km (2.2 mi) northwest of Newtown, Md., in the Hanesville 7.5-minute quadrangle. Locality no. Hanesville 1. Arrows indicate sample locations in profile. Surface elevation is 12.2 m (40 ft) above sea level.

respect, the Worton Point beds differ from all the deposits discussed to this point.

As we observed for the heavy- and light-mineral assemblages, there is little or no variation in the clay mineral assemblage throughout the section (fig. 23).

Figures 24A and 24B are electron micrographs from the Worton Point beds. Figure 24A shows the platy but otherwise anhedral forms of vermiculite. Figure 24B shows a kaolinite-dominant sample in which the hex-

agonal edges of the plates are well defined. Neither sample, however, has tubular halloysite.

INTERPRETATION

The beds of the Kent Island Formation at Worton Point compositionally show only minor subaerial alteration effects, as suggested by the general absence of iron oxide staining. One of the more common clay minerals

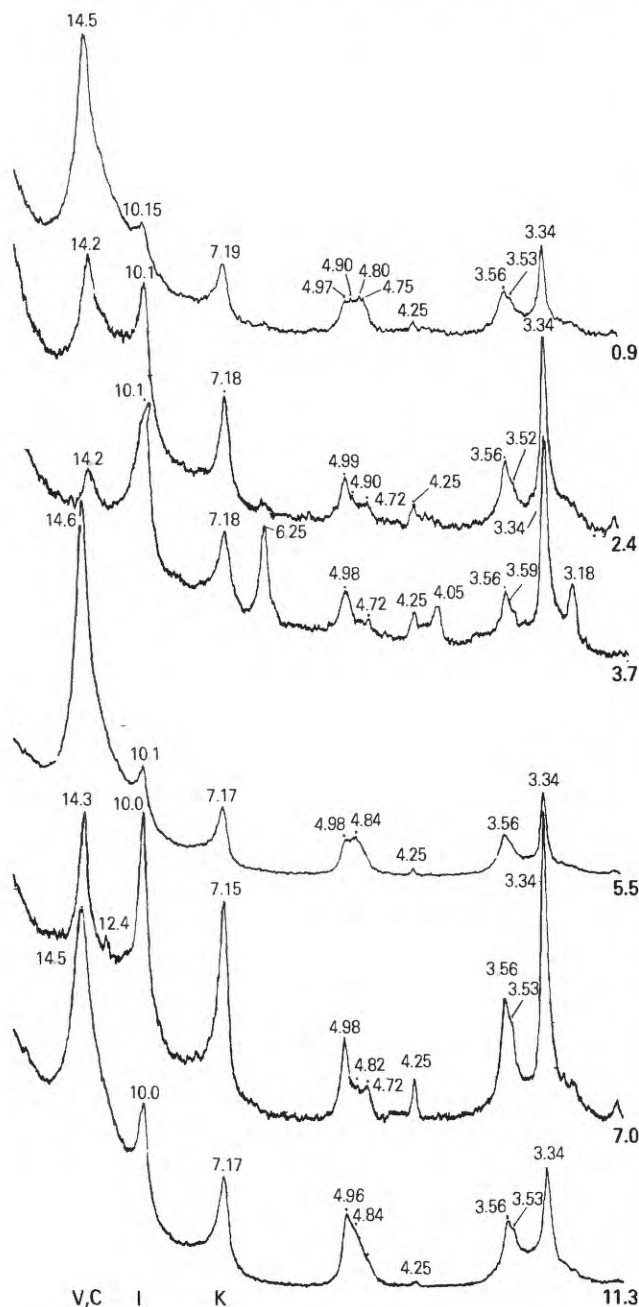


FIGURE 23.—X-ray traces of the clay fraction in sand of the Kent Island Formation at Worton Point, Md. (locality no. Hanesville 1). The most conspicuous feature of these patterns is the persistence of vermiculite (+ chlorite) (V,C) throughout the profile. In addition, kaolinite (K) and illite (I) are persistent minerals throughout the section. There is very little evidence of significant subaerial oxidation reflected in clay minerals at this locality. Measurements of peaks in X-ray traces are in angstroms. Depths of samples are given in meters.

formed in the upper zone of alteration at most of the other sites discussed is vermiculite. The abundance of this mineral throughout an entire 11.2-m (37 ft) Worton Point section suggests that this mineral is detrital

rather than authigenic. Apparently, the concentration of the mineral here is because of the close proximity of the Worton Point beds to probable source rocks (metamorphic and crystalline) in the nearby Piedmont province. The biotite and chlorite in the metamorphic rocks were probably weathered to vermiculite before stripping, transportation, and deposition in the Coastal Plain. The fact that downbay age equivalents of the Worton Point beds contain considerably less vermiculite suggests that this mineral was deposited rapidly by rivers after they entered the Coastal Plain or that the percentages were reduced because of the addition of clay minerals from other sources, such as the reworked Coastal Plain sediments.

If the Kent Island beds at Worton Point are late Pleistocene in age, as interpreted, and are in part either Ironshire or Omar Formation equivalents, a correlation of the weathering effects in the Ironshire and Omar Formations with the Worton Point beds is not possible. In the coastal beds of late Pleistocene age, subaerial alteration is expressed by the development of vermiculite and illite. Both these minerals appear to be original depositional components in the Kent Island beds at Worton Point; therefore, weathering effects could not be detected because of the original mineralogy in these beds.

The heavy and light sand minerals, however, can be used to determine the intensity of subaerial oxidation in this unit. The heavy and light sand minerals show few alteration effects from the base to the top of the section. Intensive weathering or leaching (intrastratal solution) does not appear to have been an important factor in the postdepositional history of this unit. Therefore, this unit is only mildly weathered, or, simply stated, the weathering profile here is compatible with the age of the upper beds.

PITTSVILLE, MD.

PARSONSBURG SAND (UPPER PLEISTOCENE) (COULD INCLUDE PLIOCENE TO HOLOCENE SAND DEPOSITS),
LOCALITY NO. PITT:8

Large parts of the Delmarva Peninsula are underlain by a thin to thick blanket of sand called the Parsonsborg Sand (Denny and Owens, 1979). The age of these sand deposits is uncertain in many areas but could be as old as late Pliocene. Most of the sand, however, was deposited in late Wisconsinan time (Sirkin and others, 1977).

Some of these sand deposits occur on the higher elevations in the southern Delmarva Peninsula, called by some "the Parsonsborg high" (Rasmussen and Slaughter, 1955). One of the sandy bodies on this high was sampled (fig. 25). Only 1 m of section was available for study, but a drill hole showed the deposit to be approximately 8.2 m thick. The exposed beds of the deposit

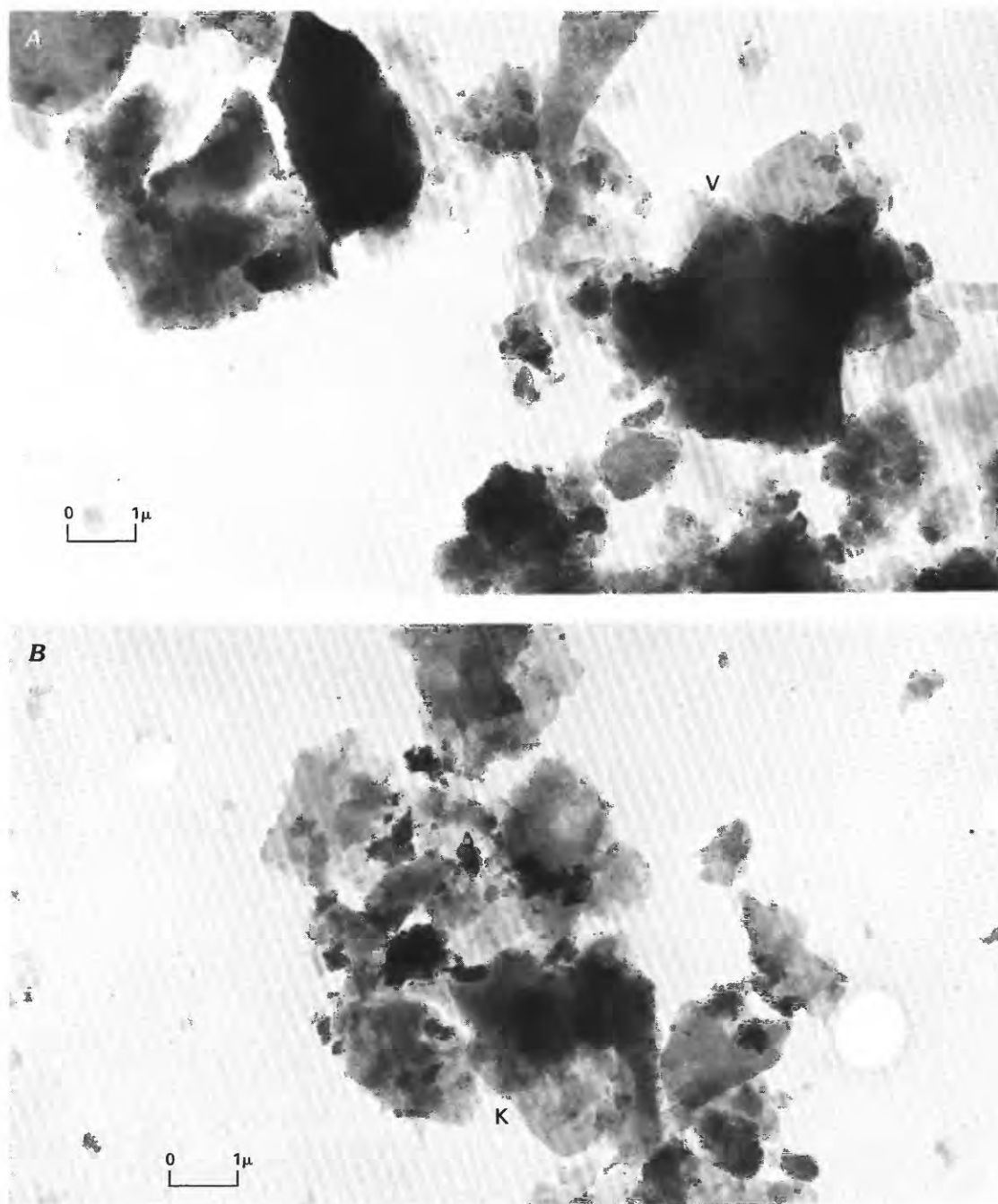


FIGURE 24.—Electron micrographs of clay fractions from the Kent Island Formation at Worton Point, Md. (locality no. Hanesville 1), showing (A) vermiculite flakes (V) from a depth of 2.7 m and (B) characteristic hexagonal kaolinite aggregates (K) from a depth of 3.35 m. Both of these forms are readily identifiable on the basis of morphology, and their presence is corroborated in X-ray traces.

typically are a massive, loose, medium-grained sand. Many of the grains are rounded to well rounded and have a frosted or pitted surface. The upper meter is stained by iron oxide, but there is no well-developed B horizon having a pronounced clay accumulation. Below this iron oxide zone, accumulations of stained, irregular, thin, wiggly brown clay (clay lamellae of other workers) are present. Clay lamellae are common throughout the Parsonsburg Sand in the Delmarva Peninsula.

SAND MINERALOGY

Light minerals.—The light minerals in the 0.074- to 0.177-mm fraction are shown in figure 4H. Quartz and lesser amounts of K-feldspar comprise nearly this entire fraction. No plagioclase was found in any samples. Minor amounts of rock fragments too small to be shown in figure 4 were detected in most samples.

The quartz-feldspar ratio showed very little variation in the section sampled. The feldspar content of

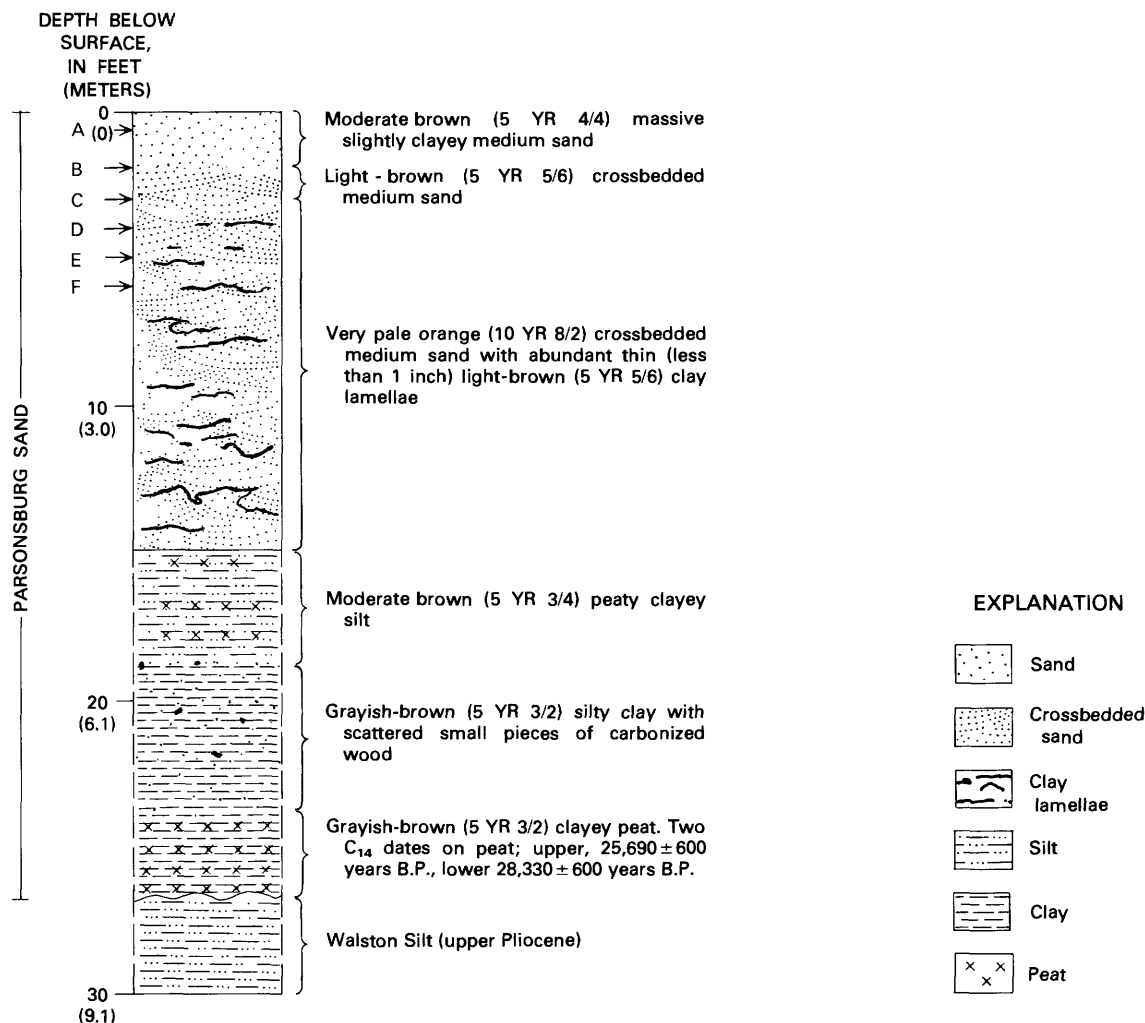


FIGURE 25.—Columnar section of the Parsonsburg Sand near Pittsville, Md., about 11.2 km (7 mi) east of Salisbury, Md., in the Pittsville 7.5-minute quadrangle. Locality no. Pitt. 8. Solid lines show the section seen in outcrop; dashed lines indicate lithologic data obtained from an auger hole at the outcrop site. Arrows indicate sample locations in profile. Surface elevation is 24 m (80 ft) above sea level.

samples from the base of the unit in the subsurface (15 percent) was much larger than that of samples from the upper beds (less than 5 percent). The Parsonsburg Sand here is protoquartzite, a composition typical of most Parsonsburg samples from other localities.

Heavy minerals.—The heavy minerals in the 0.074- to 0.177-mm fraction are shown in figure 5I. The ZTR minerals are the most common; the HEGAT and SSK minerals are present in about equal but lesser amounts. In a vertical section, the ZTR minerals show a small tendency to increase toward the surface, whereas the HEGAT minerals tend to decrease slightly toward the surface. The heavy-mineral assemblage in the Parsonsburg Sand is moderately mature.

CLAY-SILT MINERALOGY

The X-ray traces of the clay minerals in this unit are shown in figure 26. There is no dramatic change in the clay mineralogy vertically in the section sampled. In general, vermiculite and kaolinite are the major minerals in the profile. Gibbsite, illite, and locally goethite are minor minerals. Gibbsite appears to increase toward the surface, whereas kaolinite and illite decrease upward.

INTERPRETATION

The Parsonsburg Sand at this locality yielded radiocarbon ages of 26,000 to 30,000 years B.P. The

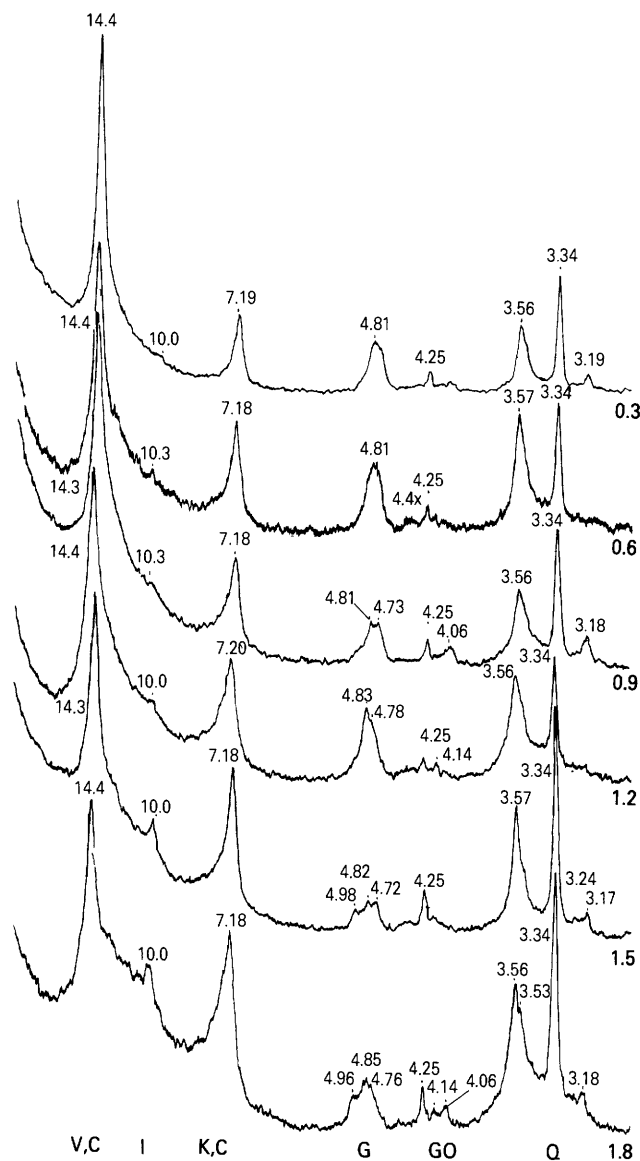


FIGURE 26.—X-ray traces of the clay-silt fraction in the Parsonsburg Sand near Pittsville, Md. (locality no. Pitt. 8). In general, the clay mineral assemblage is mature (gibbsite bearing) and changes little throughout the sampled section. In view of the very young late Pleistocene age of this unit, such an assemblage is unusually mature. V,C is vermiculite (+ chlorite), I is illite, K,C is kaolinite (+ chlorite), G is gibbsite, GO is goethite, and Q is quartz. Measurements of peaks in the X-ray traces are in angstroms. Depths of samples are given in meters.

composition of the sand and its probable aeolian origin suggest that it was derived from the nearby Beaverdam Sand. The Parsonsburg, therefore, is at least a second-cycle sediment, and its sand mineral assemblage (both light and heavy) is more mature than that of the underlying Beaverdam.

The clay minerals are unusual in comparison with the others discussed thus far in this paper because of a small variation in a vertical profile. The clay mineral assemblage is also unusual, in view of the late Wisconsin

age of the deposit, because of its relative compositional maturity (moderate percentage of gibbsite and no illite-smectite). The percentage of gibbsite in the Parsonsburg is similar to that found in the upper beds of the Beaverdam at the Houston, Del., site (Harr. 5) but not found in Quaternary sediment at the Worton Point or Whaleysville sites, for example. It seems likely that most of the Parsonsburg gibbsite is detrital, similar to that found in the base of the Ber. 2 sample (fig. 19). Whereas the gibbsite at Berlin was derived from the Beaverdam in an aqueous environment, the gibbsite in the Parsonsburg probably was introduced as loess. The gibbsite-bearing clay lamellae common in the Parsonsburg probably are loess translocated through this dominantly sandy deposit by illuviation.

SUMMARY OF WEATHERING EFFECTS BETWEEN CHESAPEAKE AND DELAWARE BAYS

In this general region, six sites ranging in age from late Pleistocene to late Miocene were examined. A variety of formations were sampled, some from the surface down and others only at depth. Some sections contained more than one formation in the vertical sequence.

The clay mineral assemblages in the formations seem to follow a normal sequence in most places, the older formations having the more mature assemblages. At Betterton, for example, the Pensauken Formation (upper Miocene) has a profile characterized by aluminous silicates (kaolinite, halloysite, and vermiculite) and, to a lesser degree, by aluminous oxides (gibbsite). Illite-smectite is notably absent, even 18 m below the surface. In contrast, at Worton Point, the upper Pleistocene beds have a much more diverse assemblage consisting of vermiculite, chlorite, illite, and only small amounts of kaolinite. Even smaller amounts of gibbsite are possibly present at the surface. The Worton Point clay assemblage is much less mature than the Pensauken clay assemblage but does show some degree of weathering.

The light and heavy sand minerals in those units thought to have relatively in-place authigenic clay mineral assemblages follow the same trend toward mineralogic maturity from the base to the top of the unit. At Betterton, feldspar declines upward through the section, and the ZTR assemblage increases upward in the Miocene Pensauken Formation. At Worton Point in the Pleistocene Kent Island beds, the feldspar decreases from the base to top, but the heavy minerals show no significant change in the same interval. Apparently, the geochemical conditions necessary to break down the feldspars did not affect the heavy minerals in any significant manner during this time interval.

The Beaverdam (Harr. 5) and Omar (Wh. 1A) sites represent sections in which the upper original

weathered surface was either stripped away or was not sampled. In the upper Pleistocene Omar Formation, the clay mineral assemblage is unweathered, but the upper 3.7 m was not sampled. However, any weathering effects in this upper 3.7-m section obviously do not extend to a depth as great as that of subaerial oxidation in the Beaverdam at Houston, Del. At the Houston site, the upper Pliocene Beaverdam is overlain by a Pleistocene quartz sand and, therefore, has been stripped postdepositionally. The Beaverdam, nonetheless, is weathered throughout to a significant degree (the presence of gibbsite throughout indicates an intensive weathering history before the deposition of the quartz sand). Additionally, the fact that the underlying Pensauken was bevelled before Beaverdam deposition suggests a similar intensive weathering history before emplacement of the Beaverdam. The light and heavy sand minerals seem to follow the same weathering pattern noted in the Worton Point and Betterton beds.

Two of the sampled sites have clay mineral assemblages that are unusual relative to their age. Abundant gibbsite is the only clay mineral in the base of the Ironshire Formation, and its concentration decreases upward to the surface. The distribution of this mature weathering mineral suggests that it was derived from the reworking of the underlying Beaverdam Sand during the transgression associated with the Ironshire Formation. A similar case can be made for the presence of gibbsite in the Parsonsburg Sand (a 30,000-year-old deposit). This unit is, in large part, a dune deposit that, for the most part, overlies deeply weathered (gibbsite-bearing) surfaces. The presence of gibbsite (as an aerosol product) in such young deposits is attributed to wind action. These two sites and their unusual clay mineral assemblages indicate that clay mineral maturity should be used cautiously as a guide in determining the age of a deposit.

The effects of weathering deduced from the dissolution of feldspar could be determined only in the Ironshire. In this unit, there is a general decrease in plagioclase and, to a lesser degree, in K-feldspar from the base to the top. Apparently, the weathering shown by the clay mineral assemblage at the top was sufficient to partially remove some of the feldspar. No such relationship is evident in the Parsonsburg Sand, possibly because of the youthfulness of its beds. The heavy minerals in both these units seem little affected by the intensity of the subaerial oxidation to which both have been subjected.

NORTHEAST OF DELAWARE BAY

Three sites were sampled from this general region, two containing materials thought to be Quaternary and one containing material thought to be late Miocene.

HAMMONTON, N.J.

BRIDGETON FORMATION, UPPER MIOCENE, LOCALITY NO. NEWTONSVILLE 1

Much of southern New Jersey and part of the Salem-Amboy valley along the inner edge of the New Jersey Coastal Plain are mantled by gravelly deposits called the Bridgeton Formation (Owens and Minard, 1979). This gravelly sand varies in thickness from area to area but may be as much as 30 m thick. All exposures of this formation are weathered to some degree. Not uncommonly, the upper beds are deep red, massive, and very clayey and typically have a thick B horizon.

One site was sampled in Hammonton, N.J.; figure 27 is a columnar section showing the geology. The sand beneath the massive B horizon is cross-stratified. Platelets centered by iron oxide are common in some of the sand; all the sand beds are stained by iron oxides. Locally small, roughly circular black masses are scattered throughout the sand below the B horizon.

SAND MINERALOGY

Light minerals.—Most of the Bridgeton Formation throughout the outcrop belt is sand. The sand grains, particularly quartz, are subangular to subrounded. The feldspar grains, which are abundant, are more angular than the quartz grains, and all are coated by a dull white film. Mica, mostly muscovite, is present locally, especially southwest of Philadelphia, Pa. Glauconite is a common sand constituent in the Bridgeton between Amboy and Camden, N.J.

The light-mineral distribution at the Hammonton site is shown in figure 4I. The lowest sample, taken 5.4 m (18 ft) below the surface, is from the Cohansey Sand of probable early to middle Miocene age. This unit is typically an orthoquartzite (Owens and Sohl, 1969). In the basal Bridgeton samples, there is a marked increase in feldspar and rock fragments. This section, in fact, illustrates one of the easier methods for distinguishing between the Cohansey Sand and the Bridgeton Formation. No plagioclase was observed in the Bridgeton in this sample or in any of the southern New Jersey samples from this formation. Plagioclase, however, is common in samples from this formation near New York, N.Y. Feldspar shows a general decline from the base to the top in figure 4I.

The high concentrations of feldspar are characteristic of the Bridgeton throughout its outcrop. The composition of this unit varies from a subarkose to an arkose and, in this report, is similar to the samples of the Pensauken, Beaverdam, and Potomac discussed earlier.

Heavy minerals.—Heavy minerals in the Bridgeton, for the most part, account for less than 0.5 percent of the sand fraction. The distribution of these minerals is

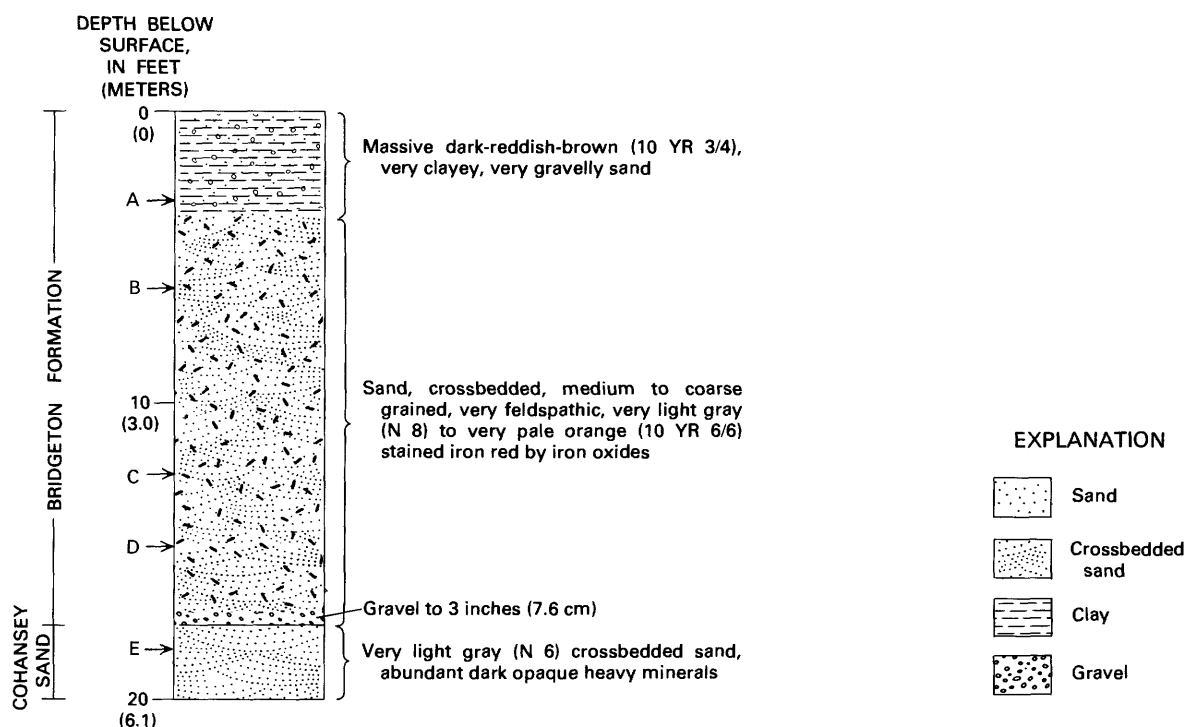


FIGURE 27.—Columnar section showing the geology in a borrow pit at Hammonton, N.J., 3 km (1.9 mi) northeast of Folsom, N.J., in the Newtonsville 7.5-minute quadrangle. Locality no. Newtonsville 1. Most of the exposure is the Bridgeton Formation. The Cohansey Sand (Miocene) is locally exposed in the base of the pit. Arrows indicate sample locations in profile. Surface elevation is 36.5 m (120 ft) above sea level.

remarkably uniform throughout the outcrop. In comparison with the relatively immature light-mineral assemblage, the heavy minerals are strikingly more mature (fig. 5J). The ZTR assemblage is the major group, SSK being the next most abundant. The more labile HEGAT mineral group is relatively unimportant throughout.

In the Hammonton section, the more stable ZTR minerals increase from the base to the top, and the SSK minerals decrease proportionally. The trend evident in the light minerals, therefore, exists here as well; that is, the stable constituents are more abundant in the intensely weathered upper beds.

CLAY-SILT MINERALOGY

The clay minerals in the Bridgeton perhaps illustrate best the effects of prolonged leaching. The mineralogy of this fine fraction is shown in figure 28. Vermiculite and gibbsite increase from the base to the top in this profile. Kaolinite + halloysite decreases somewhat, as does illite. The widespread occurrence of gibbsite as a major clay-sized phase characterizes the Bridgeton throughout its outcrop more than any other formation sampled in our study. A few samples of the silt fraction also show

that gibbsite is even more abundant in this size range than figure 28 shows. The iron oxides in the Bridgeton also deserve some mention. Goethite occurs as a major iron oxide mineral in many of the X-ray traces of the Bridgeton Formation. The particular iron oxide phase also is accompanied locally by significant concentrations of hematite not shown in figure 28. The presence of hematite in significant concentrations in the soil zone appears to be unique to the Bridgeton.

Figure 29 is a set of a TEM micrographs showing the morphology of the clays in the Bridgeton and the Cohansey. The presence of halloysite in the Cohansey is anomalous because this unit is an orthoquartzite (no feldspar). Apparently, the halloysite migrated downward from the base to the Bridgeton, where halloysite is abundant. Upward through the section, halloysite tubes give way to more amorphous forms, which, according to the X-ray results, are mainly gibbsite and vermiculite. The bulk of the sample shown in figure 29A consists of anhedral plates. Some halloysite tubes persist into this level.

SEM micrographs of the same samples (fig. 30) show the minerals in three dimensions. The tubular nature of the halloysite is particularly striking in this series of photographs (figs. 30A, B).

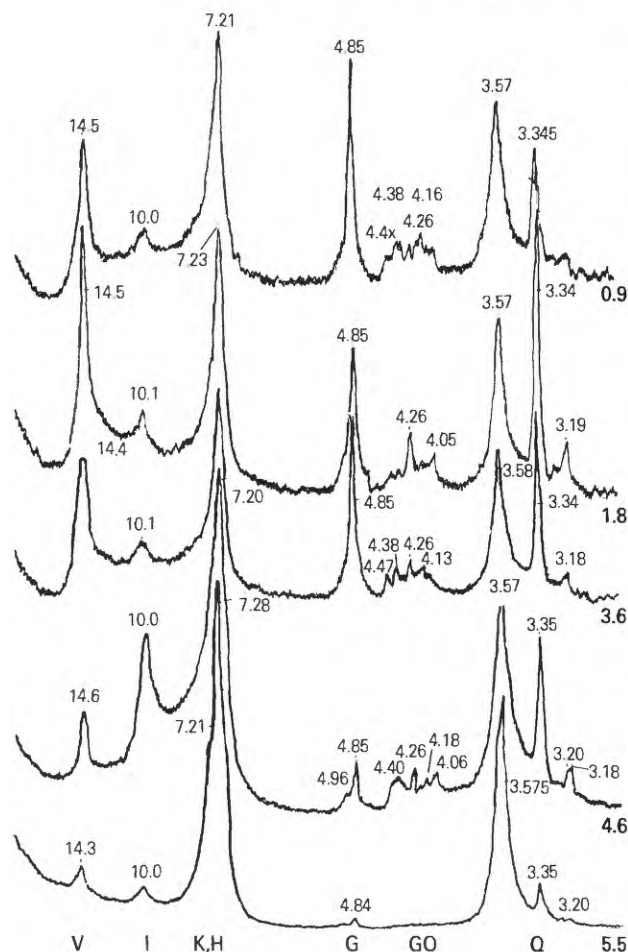


FIGURE 28.—X-ray traces of the clay-silt fraction in the Bridgeton Formation at Hamonton, N.J. (locality no. Newtonsville 1). Gibbsite (G) and vermiculite (V) increase in abundance from base to top. Kaolinite (K) decreases in the same interval. I is illite, K,H, is kaolinite (+halloysite), GO is goethite, and Q is quartz. The clay mineral assemblage is mature, the most mature, in fact, of any discussed in this report. Measurements of peaks in the X-ray traces are in angstroms. Depths of samples are given in meters.

INTERPRETATION

For a long time, the Bridgeton was considered to be Pleistocene in age. The deeply weathered nature of this deposit, taken in conjunction with the reported presence of gibbsite, led Owens and Minard (1975) to postulate a late Tertiary age (Miocene and Pliocene?) for this unit. Mapping in the southern Delmarva Peninsula later showed that the Pensauken (which is unconformable on the Bridgeton) was late Miocene in age (Owens and Denny, 1979). It was then apparent that the Bridgeton was pre-Pleistocene, in fact, pre-Pliocene. The mature clay mineralogy and the thick B horizon in this unit, therefore, are readily understandable. The assemblage gibbsite-goethite-hematite-halloysite, the alteration toward iron and aluminum oxides, and the degradation

of kaolinite to halloysite all suggest leaching over a long period of time. The development of dioctahedral vermiculite, a complex ferroaluminum, does not follow this leaching (that is, the stripping of silica from basic sheet or chain crystal structures). The mineral, in effect, increases in abundance toward the surface, a situation noted in most other profiles.

When the other, very feldspathic formations are compared, the weathering of the Bridgeton is seen to resemble that of the Beaverdam and the Pensauken. The Bridgeton has a more mature clay mineral assemblage, which we interpret to indicate a longer period of subaerial oxidation. The weathering of the Bridgeton certainly is much more mature than that of the equally feldspathic Potomac Formation, this maturity again pointing to the deeper weathering of the pre-Quaternary feldspathic deposits east of Chesapeake Bay.

The sand minerals in the Bridgeton also show the effects of interstratal solution. In both the light- and the heavy-mineral fractions, concentrations of the more weatherable minerals decrease from the base to the top of the section. Thus, both the clay and the sand minerals exhibit the effects of prolonged leaching in a thick vertical section through this unit.

BERNARDSVILLE, N.J.

PLEISTOCENE, ILLINOIAN(?), LOCALITY NO. BERN. 1

Scattered bodies of glacial deposits south of the Wisconsin terminal moraine in New Jersey appear to be more weathered than the Wisconsin deposits (Minard and Rhodehamel, 1969). Nearly everyone who has discussed these deposits considers them to be pre-Wisconsinan and most commonly Illinoian. All that can be determined, however, with any degree of assurance is that they are pre-Wisconsinan in age.

Overall, these deposits are very gravelly in the upper part where the samples were collected. However, the surface of this deposit has high relief, and the sampled section was not from the highest surface.

All the exposed beds of the Bernardsville deposit have a general yellowish cast, unlike the typical light to medium gray of the Wisconsin deposits or the red of the Miocene deposits. The feldspathic gravel in this unit was saprolitized throughout the 6 m (20 ft) of section that we studied. Figure 31 is a columnar section of the lithology at the Bernardsville site between Basking Ridge and Bernardsville, N.J.

SAND MINERALOGY

Light minerals.—The light minerals in this unit are mostly rock fragments and smaller amounts of K-feldspar and plagioclase (fig. 4J). Free quartz grains are notably few in all the samples studied. The fact that

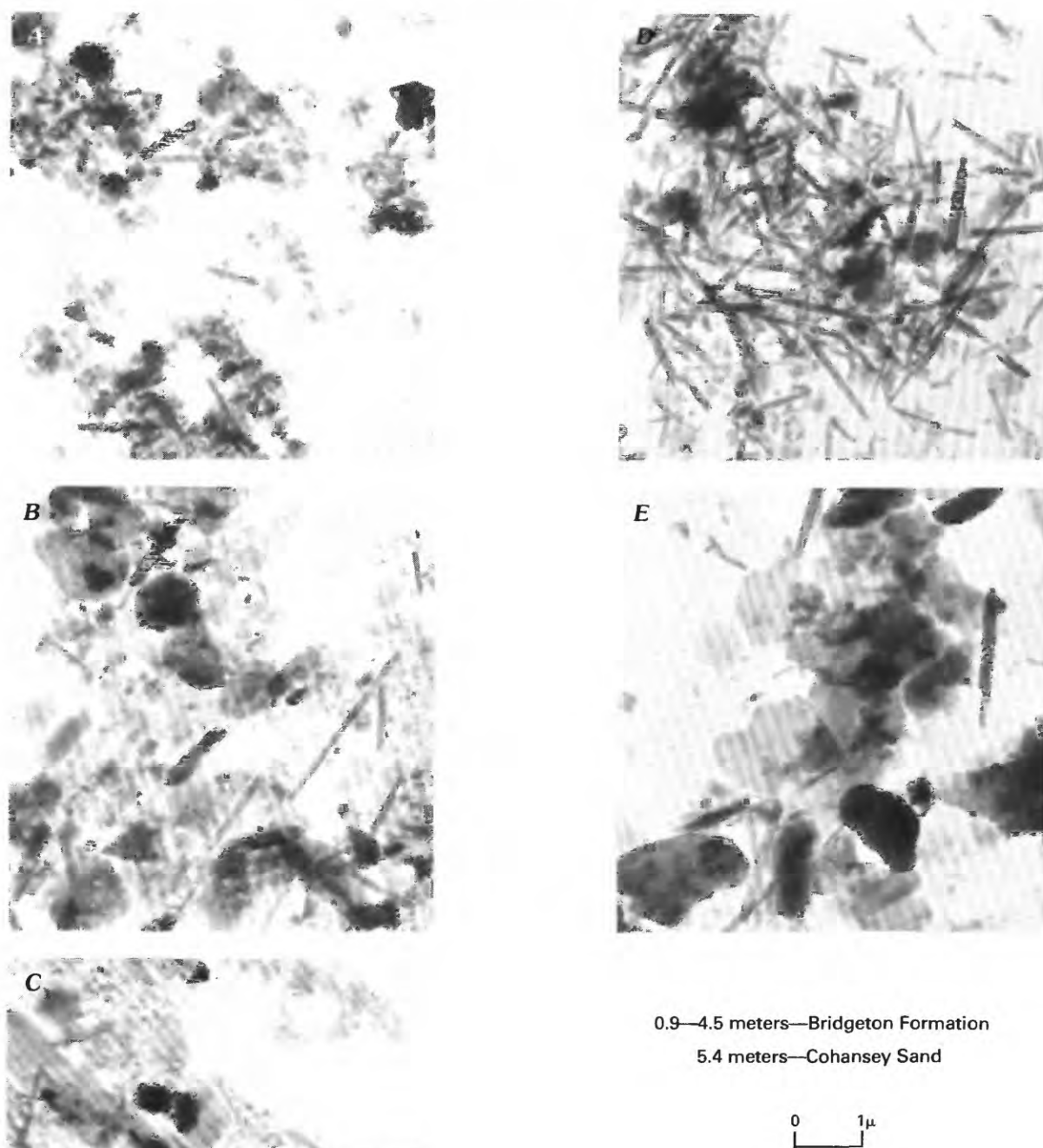


FIGURE 29.—Transmission electron microscope micrographs of the clay fraction of sand of the Bridgeton Formation (*A–D*) and the Cohansey Sand (*E*) at Hammonton, N.J. (locality no. Newtonsville 1), showing the morphology of the minerals. Abundant well-developed halloysite tubes in the base of the Bridgeton (*D*) gradually decrease upward through the section (*C* and *B*). The presence of small amounts of halloysite in the Cohansey sample (*E*) is probably the result of downward migration from the overlying Bridgeton. Depths of samples are as follows: *A*, 0.9 m; *B*, 1.8 m; *C*, 3.6 m; *D*, 4.9 m; *E*, 5.4 m.

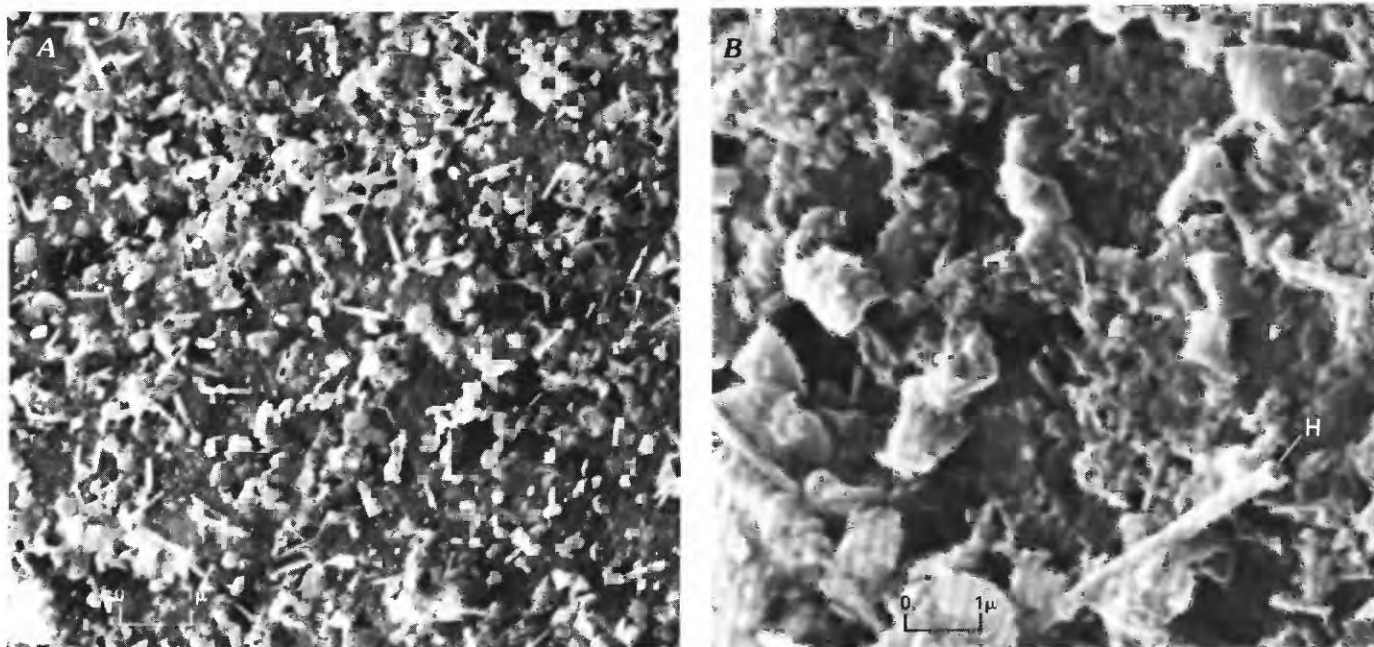


FIGURE 30. — Scanning electron microscope micrographs of the clay fraction of the Bridgeton sand at Hammonton, N.J. (locality no. Newtonsville 1). The halloysite tube at H is hollow; platy vermiculite is present in both A and B.

the rock fragments are typically micaceous or feldspathic suggests derivation from metamorphic or igneous rocks. The very high rock-fragment content in this unit is somewhat similar to that in the Worton Point beds near the mouth of the Susquehanna River. The high percentage of rock fragments plus the feldspar indicates that this sand is a high-rank graywacke in composition. A binocular examination of the sand grains reveals that they are subangular to angular, and they are thus interpreted as being a first-cycle sediment. The light minerals show very little variation from the top to the bottom of the exposed section; hence, no intensive weathering effects are indicated.

Heavy minerals. — The heavy-mineral assemblages in this unit have nearly equal amounts of the HEGAT and ZTR groups. Minerals of the SSK group are present in only small amounts (fig. 5K). In the HEGAT group, hornblende is especially abundant, and epidote is also very common. Zircon dominates the ZTR group. The heavy-mineral assemblage overall is immature.

The heavy-mineral assemblage suggests derivation from a largely granitic terrane. The low amounts of staurolite, sillimanite, and kyanite show the small contribution from metamorphic rocks. The heavy minerals show very little variation through the section sampled.

CLAY-SILT MINERALOGY

The clay minerals in the sand fraction are shown in figure 32. Kaolinite (+ halloysite) and illite are the major

minerals and are more or less present in the same abundance throughout the section. The kaolinite (+ halloysite) appears to be poorly ordered. Vermiculite is not present in the lowest sample (6 m) but is present at 3 m and is very abundant in the upper samples (0.9 m). These three minerals are the only ones present in the X-ray traces.

TEM plates were prepared for the three samples to examine the morphology of the clay minerals. Figure 33, from the basal sample, shows that the bulk of the sample is transparent, thin, anhedral plates. Small, incipient(?) halloysite tubes are also abundant. There is no apparent change in the morphology of the clay minerals from the base to the top of the unit.

INTERPRETATION

Weathering in the pre-Wisconsinan deposits in New Jersey seems intermediate. No pronounced changes in the light- or heavy-mineral assemblages were observed. The clay minerals, however, show some evidence of surficial subaerial oxidation, notably the development of vermiculite in the upper beds. The kaolinite (+ halloysite) appears little affected throughout the profile; that is, no distinct upward change takes place. In fact, although the X-ray traces indicate that the aluminum silicates of the kaolinite family are disordered (poorly crystalline), halloysite tubes are few. The persistence of disordering in the kaolinite formation from the base to the top of the unit suggests that this mineral

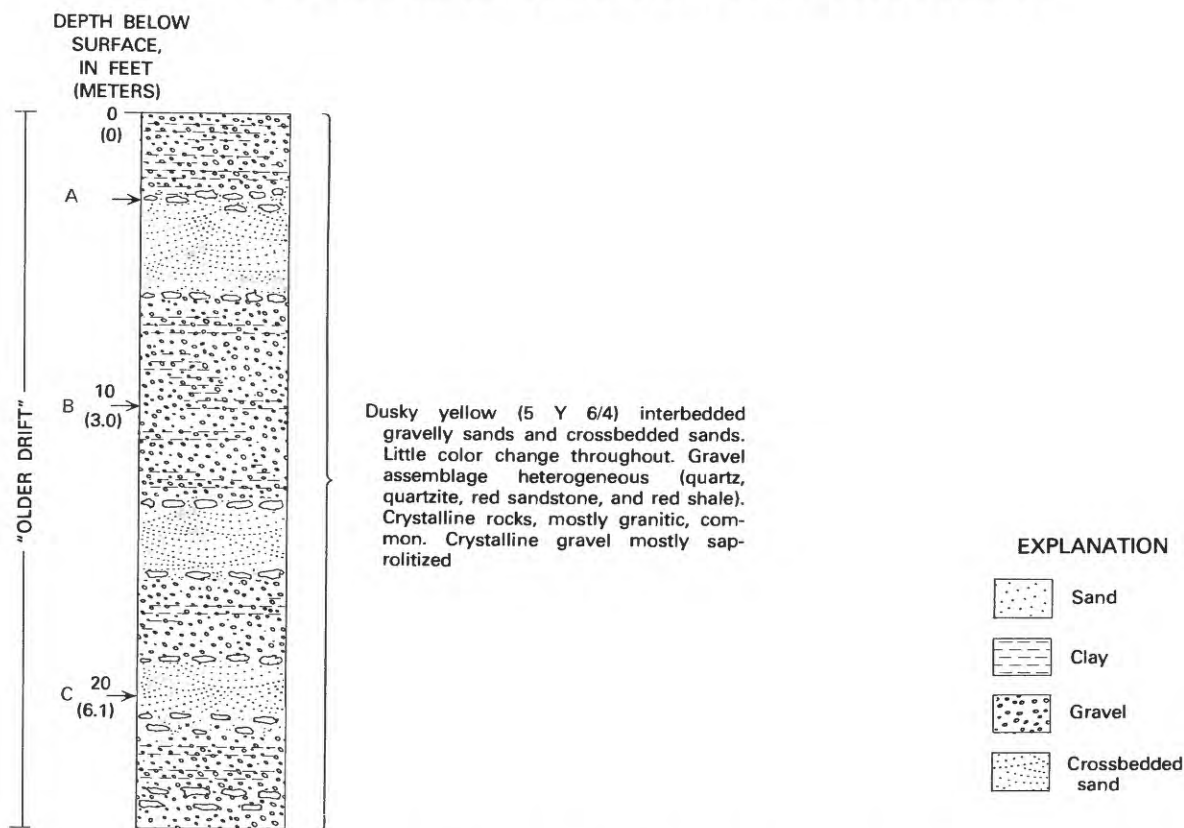


FIGURE 31.—Columnar section showing the geology in a roadcut near Bernardsville, N.J., on the northern side of Interstate 287 between Bernardsville and Basking Ridge, N.J., in the Bernardsville 7.5-minute quadrangle. Locality no. Bern. 1. Arrows indicate sample locations in profile. Surface elevation is 121 m (400 ft) above sea level.

is detrital rather than diagenetic. Whatever the case, the pre-Wisconsinan (Illinoian?) beds sampled in this area are not intensely altered. If these beds are mostly intact, then, in this region, the profile of the pre-Wisconsinan drift (which is about 200,000 years old) is considerably different from that of the pre-Sangamon beds in the Delmarva Peninsula. Novak and others (1971), discussing beds similar in appearance and interpreted to be Illinoian drift elsewhere in New Jersey (Rockport Soil Series), reported a mineralogy somewhat different from ours (more chlorite and no halloysite, for example). They did, however, report that vermiculite and kaolinite are major minerals in samples taken very near the surface; thus, an overall similarity exists between this mineralogy and that at Bernardsville.

"VAN SCIVER LAKE BEDS"
SANGAMON(?), LOCALITY NO. TW 15A

A thick deltalike mass of unconsolidated coarse gravelly sands and sandy gravel occurs where the Delaware River leaves the Piedmont physiographic province and enters the Coastal Plain at Trenton, N.J. Parts of these beds are included with the "Van Sciver

Lake beds" by Owens and Minard (1979). These beds lie beneath a broad, relatively undissected terrace that has surface elevations near 6.1 m (20 ft) above sea level. Extensive mining of the terrace for its sand and gravel content has provided abundant fresh exposures of this unit.

A profile showing a typical lithology in this unit is presented in figure 34. As shown, this unit consists of light- to medium-gray, horizontally bedded gravels and thinner crossbedded sands. No evidence of iron oxide staining was observed in these beds. The gravel in this unit is heterogeneous, containing quartz and many rock types: quartzite, granite, gneiss, schist, and, less commonly, limestone. A coating of calcium carbonate on some of the gravels suggests at least partial solution of some of the limestone clasts. Another feature of this formation is the abundant boulders, some as much as 1.5 m in maximum dimensions. In this respect, this unit resembles the beds near the mouth of the Susquehanna River in Chesapeake Bay.

The formation is considered to be Sangamon (about 60,000 to 80,000 years) in age, probably the fluvial equivalent, at least in part, of the Ironshire Formation at the coast and the lower part of the Worton Point beds in the upper Chesapeake Bay region.

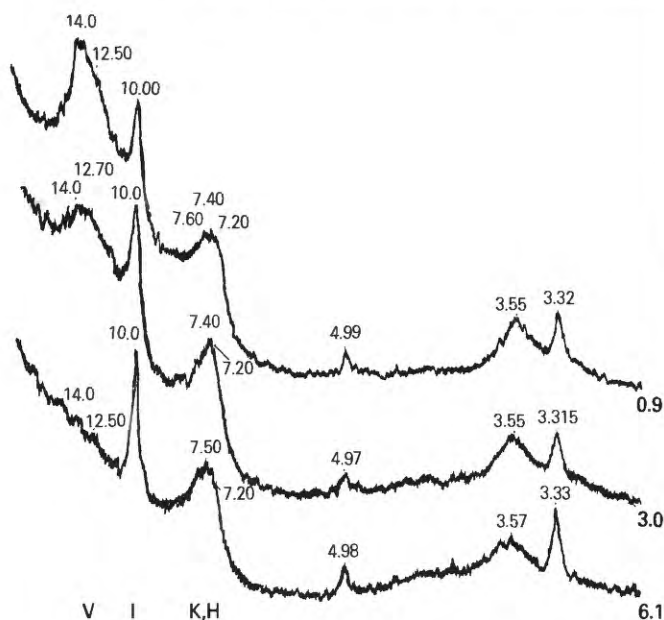


FIGURE 32.—X-ray traces of three samples collected from a road-cut near Bernardsville, N.J. (locality no. Bern. 1). The most significant weathering effect seen in this profile is the increase in dioctahedral vermiculite (V) (14 Å) from base to top. I is illite, and K,H is kaolinite (+halloysite). Measurements of peaks in the X-ray traces are in angstroms. Depths of samples are given in meters.

SAND MINERALOGY

Light minerals.—The light minerals in this unit are mostly rock fragments (mostly granitic gneiss) and quartz (fig. 4K). Two feldspars (K-feldspar and plagioclase) are present, but they comprise only a small percentage of the light-mineral fraction. Compositionally, the “Van Sciver Lake beds” are a high-grade graywacke. There is no marked increase or decrease in the various light minerals of this assemblage in a vertical section.

Heavy minerals.—The heavy-mineral assemblages have nearly equal proportions of ZTR and HEGAT minerals (fig. 5L). The SSK and OTHER minerals are only minor constituents. In the HEGAT assemblage, hornblende is very abundant, and hypersthene is present in the OTHER group. The heavy-mineral assemblage in this unit is immature and shows little variation throughout the studied profile.

CLAY-SILT MINERALOGY

The clay minerals in this unit are shown in figure 6F. Basically, the only minerals present in varying abundance are chlorite, illite, and vermiculite. Illite-smectite and kaolinite were not found in the samples analyzed. Vermiculite is present throughout the profile. Chlorite increases in concentration toward the top. In the upper beds, chlorite is probably interlayered to some degree

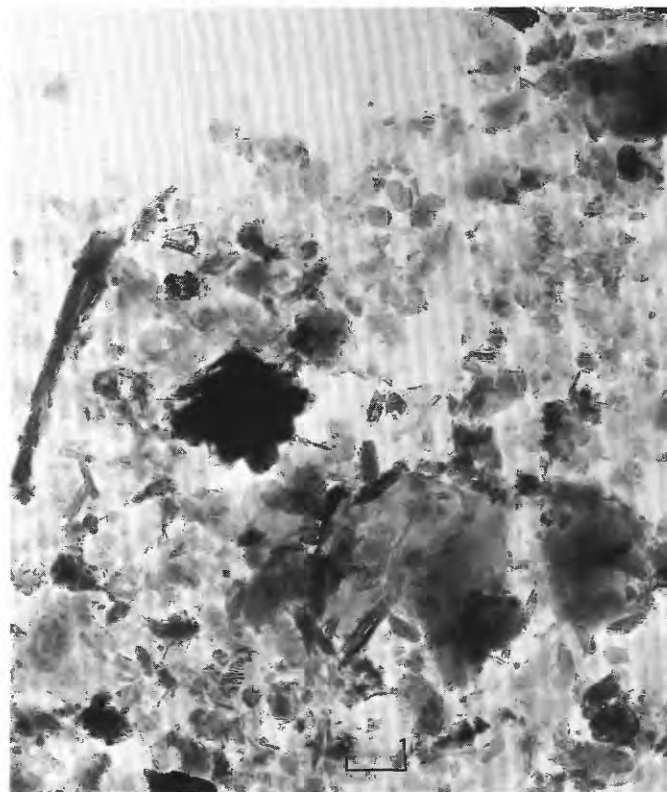


FIGURE 33.—Transmission electron microscope micrograph of the clay-silt fraction in the sand of the “older drift” at Bernardsville, N.J. (locality no. Bern. 1). The elongate, incomplete halloysite tubes are believed by some investigators to be intermediate in the transformation of halloysite from allophane. The broadened peak in the X-ray trace at the characteristic spacing for halloysite is also indicative of poor crystallinity.

with vermiculite. Illite shows a general decrease from the base to the top.

X-ray patterns showing these trends are given in figure 35. The decrease in illite, especially in the (001) and (002) reflections, is especially pronounced. Vermiculite, as evidenced by the 14-Å peak, shows the upward increase in the concentration of this mineral.

The presence of chlorite and the absence of the more mature aluminous silicates (kaolinite, for example) indicate that this assemblage is very immature.

Figure 36 is an SEM micrograph of the clay minerals. These samples were studied by electron microscope because they presumably represent relatively unweathered clays introduced into the Coastal Plain from the source lands. The anhedral clay morphologies in this unit contrast markedly with the clay forms in the Bernardsville sample (fig. 33) and especially with those in the Bridgeton sample (fig. 30). Essentially, the dominant form in all the samples is thin anhedral plates. The SEM micrograph emphasizes the platy or tabular nature of the minerals. Because there is no evidence of halloysite-type minerals in these samples, the results obtained by the X ray are confirmed.

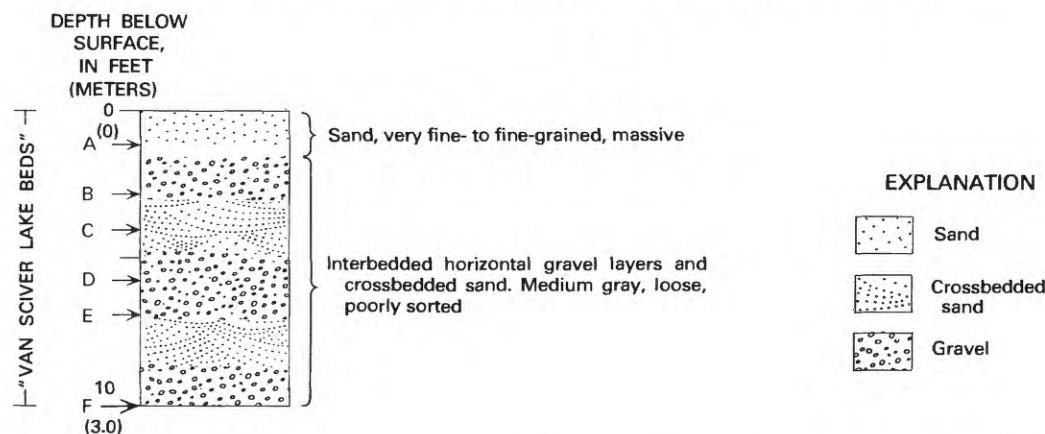


FIGURE 34.—Columnar section showing the geology in the pits at Van Sciver Lake, Pa. Pit is 3 km (1.9 mi) south of Morrisville, Pa., in the Trenton West 7.5-minute quadrangle of New Jersey and Pennsylvania. Locality no. TW 15A. Arrows indicate sample locations in profile. Surface elevation is 6 m (20 ft) above sea level.

INTERPRETATION

In outcrop, the beds comprising this unit do not appear to have any obvious weathering except for the redeposition of calcite on some of the siliceous clasts. The heavy- and light-mineral assemblages show no evidence of alteration through the sampled section. The clay minerals, however, change, as the increase in vermiculite and decrease in illite upward through the profile show. Apparently, illite in this profile is transformed into vermiculite. It is difficult to determine what is happening to the chlorite in this section, but the suggestion is that part of the vermiculite is a vermiculite-chlorite mixed-layer clay.

Novak and others (1971) studied the clay mineralogy in the B horizon in Wisconsinan drift in New Jersey (Nassau Soil Series). Their clay mineral assemblage is a mica (illite?)-kaolinite-chlorite mixed-layer clay and vermiculite, in that order of abundance. Except for the presence of kaolinite, a concentration of vermiculite probably greater than that in our samples, and a lesser abundance of illite, the two assemblages are somewhat similar. The weathering profiles of the "Van Sciver Lake beds" and those of their age equivalent at the coast (Ironshire Formation) appear to be compatible again, except for the development of kaolinite in the Ironshire Formation. Another point to be mentioned regarding the clay minerals is the persistence of vermiculite throughout the section. The distribution of this mineral in these beds is similar to its distribution in the Worton Point beds. Essentially, the vermiculite in the "Van Sciver Lake beds" suggests that a high percentage of this mineral is detrital. Like that at Worton Point in the Chesapeake region, the high concentration of vermiculite appears to be a function of proximity to rocks of the Piedmont province.

SUMMARY OF WEATHERING EFFECTS NORTHEAST OF DELAWARE BAY

The three sites studied northeast of Delaware Bay include two units that are relatively young (Pleistocene) and close to each other in age (the "Van Sciver Lake beds" and the "older drift" at Bernardsville) and one unit (Bridgeton Formation) that is much older (Miocene). All seem to follow what is considered a normal weathering pattern relative to the age of the deposits.

The Bridgeton Formation of southern New Jersey has the most mature weathering profile of any unit studied. We would interpret this profile as indicating that the Bridgeton is the oldest sampled unit in which the original surface is still relatively intact.

The clay mineral assemblage in this unit is characterized by the increase of the supermature weathering minerals from the base of the section to the top. Halloysite-endellite and vermiculite are also main minerals in the upper Bridgeton beds. Feldspar (K-feldspar) decreases from the lower part of the formation to the upper part; in the heavy minerals, the SSK minerals show a decline, and the more stable ZTR minerals increase upward through the section. Overall, the Bridgeton would be interpreted as being intensely weathered.

The "older drift" beds at Bernardsville (middle Pleistocene?) are much less weathered than the beds at the Bridgeton. The clay minerals in the unit are characterized by halloysite, vermiculite, and illite. The extensive halloysite suggests an intermediate intensity of weathering. The heavy and light minerals in this unit show few weathering effects under this type of leaching regime.

The youngest unit sampled (the "Van Sciver Lake beds," probably late Pleistocene, Sangamon, in age) is less weathered than other units sampled northeast of Delaware Bay. The clay minerals are characterized by

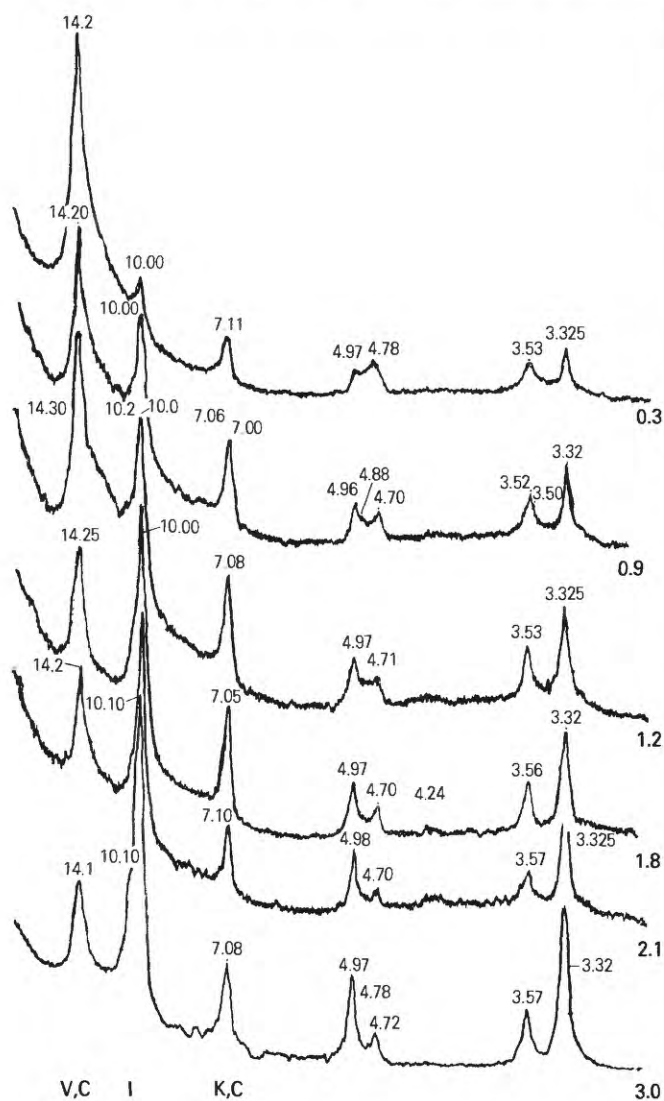


FIGURE 35.—X-ray traces of untreated samples in the "Van Sciver Lake beds" (locality no. TW 15A) showing the upward increase in vermiculite (V) concentration. A decrease in the illite (I) content is also apparent. K,C is kaolinite (+ chlorite). This assemblage suggests that vermiculite is detrital but that subsequent weathering increases the amount of this mineral in the upper beds. Measurements of peaks in the X-ray traces are in angstroms. Depths of samples are given in meters.

vermiculite, chlorite, and illite. Much of the vermiculite at this locality is detrital but generally increases toward the surface. This increase in vermiculite concentration upward in the section is thought to be the best indicator of weathering in this assemblage. No pronounced trend toward the more stable species in the heavy- or light-mineral fractions in sand was observed.

Thus, in this general region, the weathering mineral assemblages are considered normal relative to the age of the deposit on which they were formed.



FIGURE 36.—Transmission electron microscope micrograph of the clay fraction in sand of the "Van Sciver Lake beds" in Pennsylvania (locality no. TW 15A). Vermiculite, chlorite, and illite are difficult to resolve in electron micrographs because of their intricate admixture and their lack of truly characteristic morphology. In addition to platiness, some vermiculite may still show hexagonal edges; chlorite is platy and irregular in outline; extremely fine and platy particles are interpreted as illite. The presence of all three minerals in varying amounts is confirmed by X-ray identification. Magnification $\times 15,000$.

CONCLUSIONS

The purpose of this study was to determine whether the depth and intensity of subaerial oxidation in well-drained sand could be used to estimate the age of the surficial beds in the Middle Atlantic States. In all, 12 sites were sampled, and the sand and clay mineralogy of the surficial units present at each locality was studied in the laboratory.

We interpret the results of this study to suggest that there are three general categories of mineral alteration in the surficial beds of the Middle Atlantic States: (1) those deposits that have a normal weathering profile relative to their age, (2) those deposits that have an abnormally immature profile relative to their age, and (3) those deposits that have an abnormally mature profile relative to their age.

Deposits that have normal mineral alteration relative to their age contain the following mineral assemblages:

late Quaternary: (60,000–80,000 years)	Worton Point beds “Van Sciver Lake beds” Ironshire Formation
Clay-sized material	chlorite + illite → vermiculite feldspar → illite-smectite → kaolinite → (halloysite) ferromagnesian minerals → lepidocrocite → goethite
Sand-sized material	immature heavy-mineral suite → no pronounced change immature (feldspathic) light-mineral suite → some weathering of feldspar grains, particularly plagioclase, in near-surface beds

In this assemblage, the most pronounced effect of subaerial oxidation in the clay-sized material is the development of vermiculite and hydrated iron oxides (some lepidocrocite but mostly goethite), especially in the beds nearest the surface. Kaolinite is present but appears less stable than vermiculite or goethite in this uppermost zone. An objection to using vermiculite as an in-place weathering indicator is the possibility that this mineral has been inherited from the Piedmont crystalline rocks (for example, in the Worton Point beds and the “Van Sciver Lake beds”).

Of the sand-sized material, feldspar (plagioclase particularly) shows the most obvious weathering effects. Concentrations of this mineral typically are reduced in the beds nearest the surface in most units of late Quaternary age. The heavy minerals show far fewer weathering effects than the light minerals do. In general, in the profiles, the heavy minerals show little variation in type or concentration. In Jackson's (1965) model, these sediments have been subjected to mild desilication under low weathering intensity.

middle(?) Pleistocene (about 200,000 years or perhaps older)	“Jerseyan drift,” Bernardsville site
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The clay mineral transformation in this unit is as follows:

illite → vermiculite
feldspar → illite-smectite → kaolinite → halloysite
ferromagnesian minerals → goethite

In the sand-sized minerals, the percentages of feldspar do not decrease throughout the profile, but the feldspar grains in the shallower beds are much more weathered

than those at the base of the section. The heavy minerals show few effects of subaerial oxidation throughout the profile studied. In addition to the formation of vermiculite in the near surface, halloysite appears to have formed from kaolinite in the clay mineral fraction. Halloysite in these glacial sediments may have been derived from the source rocks, but the weathered nature of the feldspathic crystalline gravel (weathering presumably occurred postdepositionally) suggests that the halloysite is also an in-place weathering product. If this is true, then the weathering in these beds is more advanced than that in the upper Pleistocene deposits. The transformation of kaolinite to halloysite suggests such a possibility.

In Jackson's (1965) model, the weathering in the middle Pleistocene beds would represent intermediate desilication under intermediate weathering intensity.

late Tertiary:	Beaverdam Sand (late Pliocene?) Pensauken Formation (late Miocene) Bridgeton Formation (late Miocene)
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The following clay-mineral assemblages occur in these beds:

illite → vermiculite
feldspar → illite-smectite(?) → kaolinite → endellite
gibbsite
ferromagnesian minerals → lepidocrocite → goethite → hematite

The following sand-mineral assemblages occur in these beds:

immature heavy-mineral assemblages → more mature assemblages (higher concentrations of ZTR)
immature light-mineral assemblages (two feldspars) → more mature (feldspar mainly K-feldspar; percentage reduced near surface)

Beds of this age probably span an interval of between 2 and 8 million years. The near-surface beds in the oldest upper Tertiary deposits (Bridgeton Formation) essentially are characterized by the vermiculite-gibbsite-hematite assemblage; gibbsite and hematite are present in much smaller amounts in the younger Pensauken and Beaverdam. Halloysite (+endellite locally) in these upper Tertiary beds is well developed at depths greater than those in the middle Pleistocene(?) beds. A pre-Quaternary age for such mature clay mineral assemblages in Coastal Plain sediments elsewhere was observed in deposits in the Southeastern United States (Clarke, 1971).

The heavy and light minerals show considerable variation from zones of less intense weathering to those of more intense weathering. Plagioclase, hornblende, and hypersthene are selectively depleted upward through the section. In Jackson's (1965) model, these sediments would have been subjected to intensive desilication under high weathering intensity.

On the basis of the examples cited above, it would seem that the maturation of mineral alteration suites can be used as a guide to the age of what were originally fairly fresh sediments.

In the younger units (60,000 to 80,000 years old), the typical weathering mineral assemblage is characterized in the uppermost weathering profile by vermiculite and small amounts of gibbsite. Kaolinite tends to increase from the base of the profile to the middle and then to decrease upward. Illite decreases from the base to the top. No illite-smectite was found in the samples tested, so the effect that subaerial alteration had on this mineral during this time frame is conjectural. Most likely, illite-smectite follows the same pattern as illite. In general, the sand minerals show little change as the result of intrastratal solution except for a weathering rind on the feldspar grains.

The middle Pleistocene beds are characterized by the breakdown of feldspar, which produces large quantities of halloysite, kaolinite, and locally(?) moderate amounts of gibbsite. Vermiculite is again abundant in the upper zone of oxidation. Illite again decreases from the base to the top. The increase in gibbsite concentration and the abundance of halloysite are the significant differences between the 80,000- and the 200,000-year-old beds.

In the pre-Quaternary units, the trends established in the middle Pleistocene are accentuated. Gibbsite increases in both concentration and the depth at which it is found. Halloysite is formed to greater depths in these units than it is in the Quaternary beds. Vermiculite is still very common in the uppermost beds. The iron phases goethite and, to a lesser degree, hematite are more abundant and better crystallized in beds of this age.

Overall, therefore, the transformation from silicates to oxides seems to follow a systematic age trend. Specifically, the concentration and depth distribution of gibbsite appear to be good indicators of the relative age of a formation, particularly where the age spread between formations is long. Time, therefore, is an important element in the generation of mature weathering mineral assemblages.

The Coastal Plain deposits that have abnormally immature assemblages for their age all occur west of Chesapeake Bay: the Potomac Formation at the Hayfield site, the Yorktown Formation at the Bowling

Green site, and the Calvert and Aquia Formations at the Round Bay site.

The clay mineral assemblage in these units suggests the following reactions:

illite → vermiculite
feldspar → illite-smectite → kaolinite
ferromagnesian minerals → lepidocrocite → goethite

The sand minerals apparently are affected in the following manner:

mature heavy minerals → mature heavy minerals
immature light minerals (two feldspars) →
immature light minerals (two feldspars slightly
more weathered at the surface)

The clay mineral assemblages in all of these units are poorly crystalline. Vermiculite, which is so abundant in all the samples of late Pleistocene age taken nearest the surface, is less common in all of these deposits west of Chesapeake Bay. Other common alteration minerals such as goethite and kaolinite are also present in small amounts in these beds.

The heavy and light sand minerals show little alteration in a vertical section in these beds. The lack of thick alteration zones on these older beds (Pliocene to Lower Cretaceous), which lie at the surface at relatively high topographic elevations, suggests that the beds have been stripped in relatively recent time. Certainly, the deposits at the Hayfield site, where they are overlain by the "upland gravels" (Pliocene?), point to such an interpretation. If these beds were stripped after deposition of the "upland gravels," their "normal" alteration profile as outlined earlier points to a late Pliocene or perhaps an early Quaternary tectonic uplift and an associated period of stripping of the uppermost mantle of weathered beds.

It is apparent, therefore, that an understanding of local tectonics (and perhaps associated eustatic changes) is very important if the mineral alteration-age technique is applied areally. Additionally, this mineral alteration-age technique could be used as a tool in regional tectonic studies. From the data already presented, it would appear that uplift in the area of immature mineral alteration west of Chesapeake Bay has been greater than that in the areas of mature mineral alteration to the east or northeast in the Delmarva Peninsula and New Jersey.

The Coastal Plain deposits that have abnormally mature alteration zones for their age are best exemplified by the Parsonsburg Sand (Pittsville sample, late Wisconsinan Age, about 26,000 to 30,000 years B.P.)

(Sirkin and others, 1977). Deposits of this type form a thin but widespread veneer over much of the central Delmarva Peninsula. The clay mineral assemblage in these beds suggests the following relationships:

mica → vermiculite
 vermiculite → more ordered vermiculite
 feldspar → illite-smectite(?) → kaolinite → halloysite → gibbsite
 halloysite → gibbsite (less ordered) → gibbsite (more ordered)
 ferromagnesian minerals → goethite

The sand minerals indicate the following relationship:

relatively immature heavy-mineral assemblage → no significant change
 relatively immature light-mineral assemblage (feldspar) → no significant change

The presence of gibbsite + kaolinite + halloysite + goethite, a mature mineral assemblage for upper Wisconsinan deposits, seems anomalous if such minerals indicate that a given deposit is old (pre-Quaternary). As we have noted, however, some of the more diagnostic weathering minerals can be inherited from older units. For example, reworked gibbsite in the base of the Ironshire Formation (Ber. 2 sample) or vermiculite in the Worton Point beds and "the Van Sciver Lake beds" was apparently derived from saprolites formed on Piedmont-type rocks. The eolian origin of part of the Parsonsburg Sand, therefore, would require that the weathered minerals be introduced into this unit by the wind. Apparently, the source beds, on the basis of regional geology, have been the Beaverdam Sand, which the Parsonsburg Sand overlies. Upper weathered beds in this upper(?) Pliocene unit contain significant concentrations of gibbsite, halloysite, and goethite (Harr. 5 sample) and thus provide a nearby supply of these minerals to be eroded and transported by wind action.

In conclusion, we feel that the depth and intensity of subaerial oxidation have much promise as tools in determining the relative age of otherwise unfossiliferous, unconsolidated sediments in the Coastal Plain. It is important to note, however, that, if this technique is to be applied regionally, the depositional and tectonic history of deposits should be understood before the laboratory results are interpreted.

APPENDIX

Anna 1, Hayfield site. Annandale 7.5-minute quadrangle, Virginia, lat 38°45'15" N., long 77°08'35" W. Pit adjacent to Telegraph Road (State Route 611) at

Hayfield, Va. Surface elevation about 66 m (220 ft) above sea level.

Bowling Green 1. Bowling Green 7.5-minute quadrangle, Virginia, lat 38°05'00" N., long 77°20'00" W. Roadcut on eastern side of country road, 1,500 m north of Bowling Green, Va. Surface elevation about 60 m (200 ft) above sea level.

R.B. 51. Round Bay 7.5-minute quadrangle, Maryland, lat 39°02'00" N., long 76°32'00" W. Bluff on eastern side of Severn River just south of Arnold Point, 1,350 m southwest of Maryland State Highway 2. Surface elevation 30 m (100 ft) above sea level.

Bet. 3. Betterton 7.5-minute quadrangle, Maryland, lat 39°22'32" N., long 76°05'00" W. Bluff along southern side of Sassafras River, 1,000 m west of Betterton, Md. Surface elevation of bluff about 27 m (90 ft) above sea level.

Harr. 5. Harrington 7.5-minute quadrangle, Delaware, lat 38°45'00" N., long 75°31'15" W. Pit on northern side of Murderkill River, 7,500 m northwest of Houston, Del. Surface elevation of pit about 12 m (40 ft) above sea level.

Wh. 1A. Whaleyville 7.5-minute quadrangle, Maryland-Delaware, lat 38°23'15" N., long 75°16'05" W. Auger hole is at crossroads called Longridge, 2,000 m east of Whaleyville, Md. Auger hole spudded in at about 11 m (36 ft) above sea level.

Ber. 2. Berlin 7.5-minute quadrangle, Maryland, lat 38°19'10" N., long 75°12'00" W. Pit near Germantown, Md., 1,500 m east of U.S. 113. Surface elevation of pit about 11 m (35 ft) above sea level.

Hanesville 1. Hanesville 7.5-minute quadrangle, Maryland, lat 39°19'00" N., long 76°11'00" W. Bluff at Worton Point on eastern side of Chesapeake Bay, 3,600 m northwest of Newtown, Md. Surface elevation about 12 m (39 ft) above sea level.

Pitt. 8. Pittsville 7.5-minute quadrangle, Maryland-Delaware, lat 38°25'10" N., long 75°27'45" W. Shallow pit along western side of country road, 5,100 m northwest of Pittsville, Md. Surface elevation of pit 15 m (75 ft) above sea level.

Newtonsville 1. Newtonsville 7.5-minute quadrangle, New Jersey, lat 39°37'18" N., long 74°49'10" W. Gravel pit between 11th and 12th Streets in Hammonton, N.J. Surface elevation about 33 m (110 ft) above sea level.

Bern. 1. Bernardsville 7.5-minute quadrangle, New Jersey, lat 40°33'45" N., long 74°33'15" W. Roadcut on northwestern side of Interstate Highway 287 between Basking Ridge and Bernardsville, N.J. Surface elevation of cut about 128 m (420 ft) above sea level.

TW 15A. Trenton West 7.5-minute quadrangle, Pennsylvania-New Jersey, lat 40°10'00" N., long

74°48'10" W. Gravel pit on eastern side of Van Sciver Lake adjacent to Ford Mill Road, 400 m northwest of Turkey Hill. Surface elevation 6 m (20 ft) above sea level.

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