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GEOLOGY OF THE FALL ZONE IN DELAWARE

BY

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CONTENTS

ILLUSTRATIONS

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ABSTRACT

The complex geologic framework of the Fall Zone in Delaware is primarily caused by diverse structural features present in the crystalline basement rocks that have exerted a considerable influence on the distribution of the overlying sediments of the Coastal Plain.

A lateral fault and three different sets of vertical faults were recognized in the crystalline basement complex. The vertical faults have broken the surface of the basement complex into horst-graben structures. Although these faults were probably formed before the deposition of the Potomac Formation (Lower Cretaceous), there are indications that they are still active.

The deposits of the Potomac Formation were brought into the area through the ancient Delaware River Valley and through the Piedmont. Fine sediments, clay and silt, are predominant. Sands are generally confined to the main distributary valleys. The areal distribution and thickness of the Potomac Formation were greatly influenced by the structures of the underlying crystalline basement complex. A considerable amount of these sediments was eroded from the area before the overlying Pleistocene deposits were laid down.

The Pleistocene Columbia Formation was also deposited by a complex distributary stream system. Most of these materials were brought into the area through the ancient Delaware River Valley, although considerable amounts were supplied directly through the adjacent Piedmont. At the close of the Pleistocene (?) extensive flooding occurred producing a set of alluvial fans at the southern margin of the Piedmont. Most of the material composing these fans seems to have been supplied by nearby sources.

The results of this study show that there are no additional major sources of ground water in the Coastal Plain sediments in the area. Because of this it is suggested that future investigations be directed toward the faults in the crystalline basement complex that may contain useful quantities of ground water. Nevertheless, it is pointed out that the mere presence of the faults does not necessarily mean that economical amounts of ground water are available.

INTRODUCTION

The area between Wilmington and Newark is among the fastest growing portions of the State. This growth necessitates the accelerated development of mineral resources, particularly water, to accommodate the needs of the thriving community. To secure such resources it is important to study the geologic framework of this area including the distribution and physical and water-bearing characteristics of the rocks present both at the surface and in the subsurface.

Therefore, the purpose of the present study is to investigate the geologic makeup of the zone between Wilmington and Newark from the standpoint of its capability to sustain the present rate of population and economic growth.

ACKNOWLEDGMENTS

Discussions of various topics related to this study held with the staff of the Delaware Geological Survey, particularly Dr. R. R. Jordan, State Geologist, and Mr. J. C. Miller, Hydrogeologist, are gratefully acknowledged. This study was partly supported by the Water Resources Center, University of Delaware, Dr. R. D. Varrin, Director.

DEFINITION OF FALL ZONE

The term Fall Zone was adopted by Davis (1904) and was applied to the sharp junction between the Appalachian Piedmont Province and the Atlantic Coastal Plain Province. This zone is marked by waterfalls and rapids on most streams crossing it. It has been suggested that this zone delimits the trace of an ancient peneplain (Sharp, 1929); a pre-Cretaceous erosional surface now covered by the Coastal Plain sediments. It was also speculated that this peneplain left traces on the Appalachians. Such speculations have been questioned by Flint (1963).

GENERAL GEOLOGY

Piedmont Province

In the study area (Figure 1) this province is composed of crystalline rocks. The oldest rocks exposed belong to the Glenarm Series (Knopf and Jonas, 1922) and they are represented by micaceous schists, gneisses, and migmatites of the Wissahickon Formation. Amphibolites and hornblende gneisses, which are in direct contact with the Wissahickon Formation, are a part of the Wilmington Complex and were studied in detail by Ward (1959). The Port Deposit Granodiorite, a quite extensive unit in nearby Maryland, occupies a small area west of Newark.

Most of the crystalline rocks of the Piedmont Province were severely metamorphosed during the Paleozoic orogenies. For this reason their age relationships are obscured. The age determinations on similar rocks in Maryland suggest a late Precambrian(?) or early Paleozic age for the Wissahickon Formation (Wetherill *et al.*, 1966).

Coastal Plain Province

The Coastal Plain sediments in the study area (Figure 1) are represented by the Early Cretaceous Potomac Formation and the Quaternary sediments of the Columbia Formation and younger, unnamed deposits.

The Potomac Formation was studied in detail by Groot (1955) who was able to subdivide it into a staurolite-zircon-tourmaline-kyanite zone and zircon-rutile zone. Only the lower, staurolite-zircon-tourmaline-kyanite zone, is present in the area of study.

Jordan (1968) showed that the lower part of the Potomac Formation is sandier than its upper part. This sandier part of the Potomac was singled out by Sundstrom et al. (1967) as the lower hydrologic zone; it is a good aquifer.

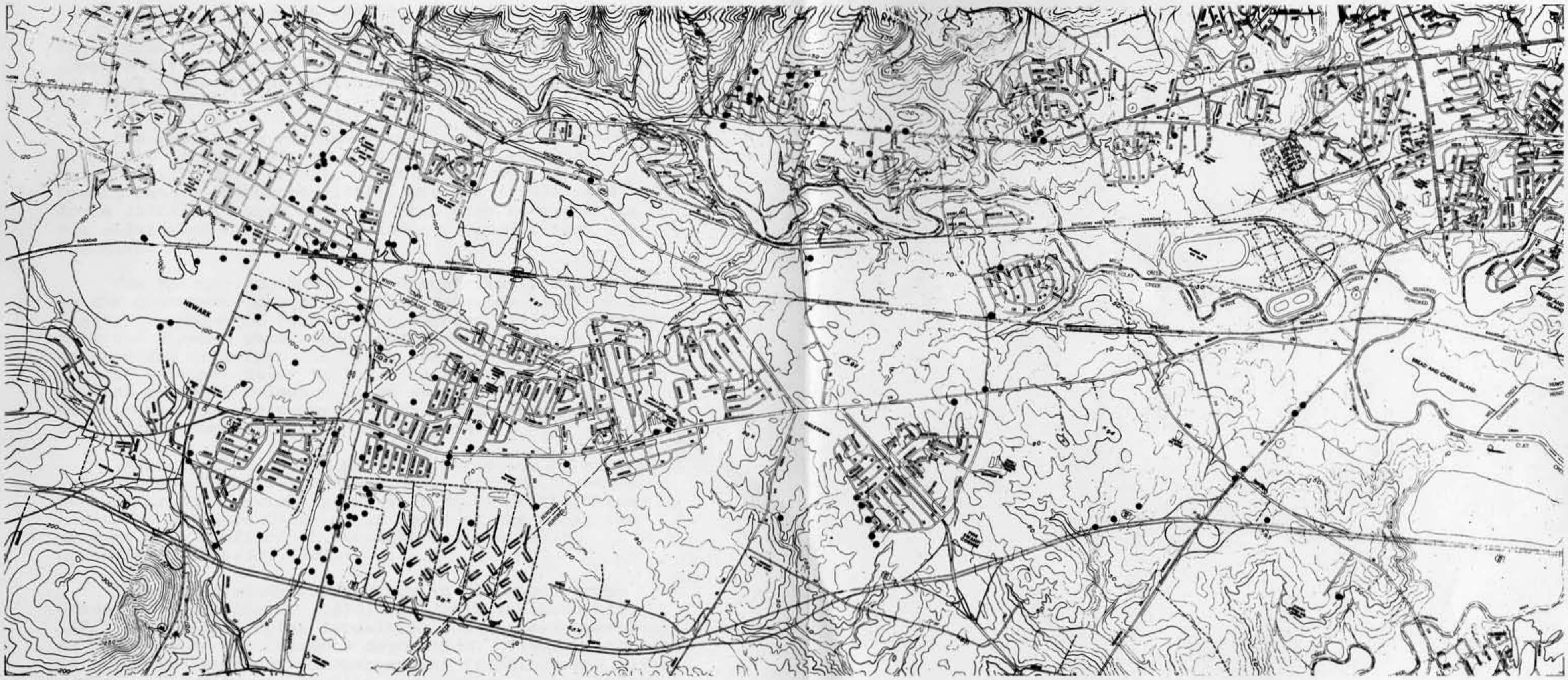

Figure 1. Area of study showing well locations.

Spoljaric (1967a) made a detailed study of these sediments in a small area west of Delaware City and concluded: "The deposition of the Potomac sediments appears to have been continuous throughout the time of their formation... The geometry of the sand bodies resembles the shoestring channel deposits formed by unidirectional currents..." Although geologists agree that the Potomac sediments were deposited by a complex stream system, their stratigraphic subdivision is still a subject of controversy (Groot, 1955; Groot and Penny, 1960).

The age of the Potomac Formation was determined primarily on the basis of paleobotanical evidences. Berry (1911), Dorf (1952), Groot and Penny (1960), Groot, Penny, and Groot (1961), Brenner (1963), and Doyle (1969) all seem to agree that this formation is not older than the Barremian and not younger than the Turonian.

The Potomac sediments are unconformably overlain by the Quaternary deposits. The statewide study of the Quaternary Columbia Formation by Jordan (1964) revealed that the streams which deposited these materials entered the area from the north, mainly through the present Delaware River Valley. In the northern and central parts of Delaware these sediments were laid down in fluvial environments. In the southern part they form a shoreline-lagoonal complex.

Investigation of the Columbia Formation in northern Delaware showed that the Pleistocene streams formed a complex braided system in the area south of the Chesapeake and Delaware Canal while north of the Canal the streams were confined to straight and meandering channels (Spoljaric, 1967b).

A detailed study carried out in the Middletown-Odessa area (Spoljaric, 1970; Spoljaric and Woodruff, 1970) disclosed complex depositional processes operating at the time of the Columbia deposition. Frequent changes in water and sediment discharges and flooding were quite common. Flooding was usually accompanied by the influx of coarse gravelly materials and changes in the position of stream channels. The streams seem to have been shallow and relatively wide, although they only rarely exceeded half a mile in width.

The age of the Columbia Formation is a subject of some contention. Basically there are two opposing views:

one (Jordan, 1964) favors, at least, Sangamon-early Wisconsin age for these sediments; the other (Spoljaric, 1970), a younger, perhaps even late Wisconsin, age. For the details of the arguments set forth by these two proponents the reader is referred to the corresponding publications. However, it should be stressed that the evidence available at present is inadequate to corroborate either view.

Younger, unnamed, Quaternary sediments unconformably overlie the Columbia Formation in the area of study. They have been discovered during the course of this study and are discussed in detail elsewhere in this report.

GEOMORPHOLOGY

Introduction

The development of land forms in the study area was mainly controlled by the underlying geologic structures and rock types. However, recent advancements in technology make it now possible for man to modify the land forms according to his needs. Although these artificial alterations of natural features of the land surface are at present relatively unimportant, they should not be ignored. Nature reacts to such alterations by attempting to reestablish the natural equilibrium which can prove to be disastrous to the people living in a particular area. History has recorded many such disasters. The most common responses of the nature are manifested as soil creep, sliding and slumping of portions of the land surface, collapse of river dams, flooding, erosion, and many others.

Piedmont Province

The area underlain by the Wissahickon Formation is characterized by relatively steep slopes and deeply incised stream valleys, gently rolling hills, and the general absence of upland plains. Main streams (White Clay, Red Clay, Mill, and Pike creeks) flow southward, roughly perpendicular to the strike of the geologic structures. Their tributary streams, however, flow either toward the southwest or northeast, following that strike. The stream valleys generally lack well-developed flood plains and there is little sediment deposited in the stream channels. This is primarily due to the relatively high stream gradients which favor degradation over aggradation.

The portion of the area of study occupied by the outcropping Wilmington Complex is not very extensive and land forms here are not significantly different from those observed in the Wissahickon Formation.

Coastal Plain Province

Geomorphologic features of the Coastal Plain are distinctly different from those in the Piedmont Province. The Coastal Plain portion of the study area is characterized by a low, flat land surface lacking distinct and diverse features observed in the Piedmont. The stream valleys are shallow and wide with well-developed flood plains. The surface elevations are low, rarely exceeding 100 feet (SLD), and many streams draining into the Delaware Bay are tidal for a considerable distance inland. A typical example of such tidal streams is the Christina River.

Because of the low gradients, and because of the tidal influence, these streams contribute little sediment to the Delaware Bay. Most of their load is deposited shortly after they enter the Coastal Plain from the Piedmont, and only very fine sediment (silt and clay) remains in suspension. Nevertheless, most of these fine sediments settle out before reaching the Bay.

Peculiar geomorphologic features of the Coastal Plain portion of the study area are Iron and Chestnut hills. These hills rise to an elevation of more than 300 feet and are composed of basic igneous rocks, predominantly gabbro. The relationship of these rocks both to the Piedmont and the Coastal Plain is unclear.

METHODS OF STUDY

The descriptive and electric logs from 140 wells were utilized in the study. Although the quality of the well logs varies somewhat, only those considered reliable were used. In addition, subsurface and surface samples were investigated and several laboratory analyses of the samples performed.

The parameters of the lithofacies maps were computed on the basis of both electric and descriptive logs. Even though the descriptive logs are not ordinarily employed in the computation of such parameters, the limited availability of electric logs made this necessary.

The density of the control points on the maps is variable and ranges from high in the Newark area to scarce in the central and eastern parts of the study area. However, because the area is so small, the bias in the distribution of the control points is not considered very significant.

INTERPRETATION OF SUBSURFACE GEOLOGY

Crystalline Basement Complex

The crystalline rocks of the Piedmont Province extend southward under the Coastal Plain and form the basement upon which the younger sedimentary rocks were deposited.

Not much is known about the composition of this basement complex. The rocks composing this complex are dense, hard, and were thought to be of little importance as a possible source of ground water; as a result they were not drilled. In addition, drilling through such rocks requires specialized equipment that is usually not readily available.

The surface of the basement complex was believed to be continuous although the existence of faults had been suspected by Groot and Rasmussen (1954). The present study has shown that this surface is indeed broken by faults into small horst-graben structures.

The main structural feature of the basement is the right-lateral fault (Figure 2) running from the northern part of Newark toward the east-northeast approximately through the central portion of the study area. Although the displacement along this fault is unknown, the configuration and smooth transition of the structural contours across the fault line suggest that the movement of several hundred yards could account for the relationships on both sides of the fault.

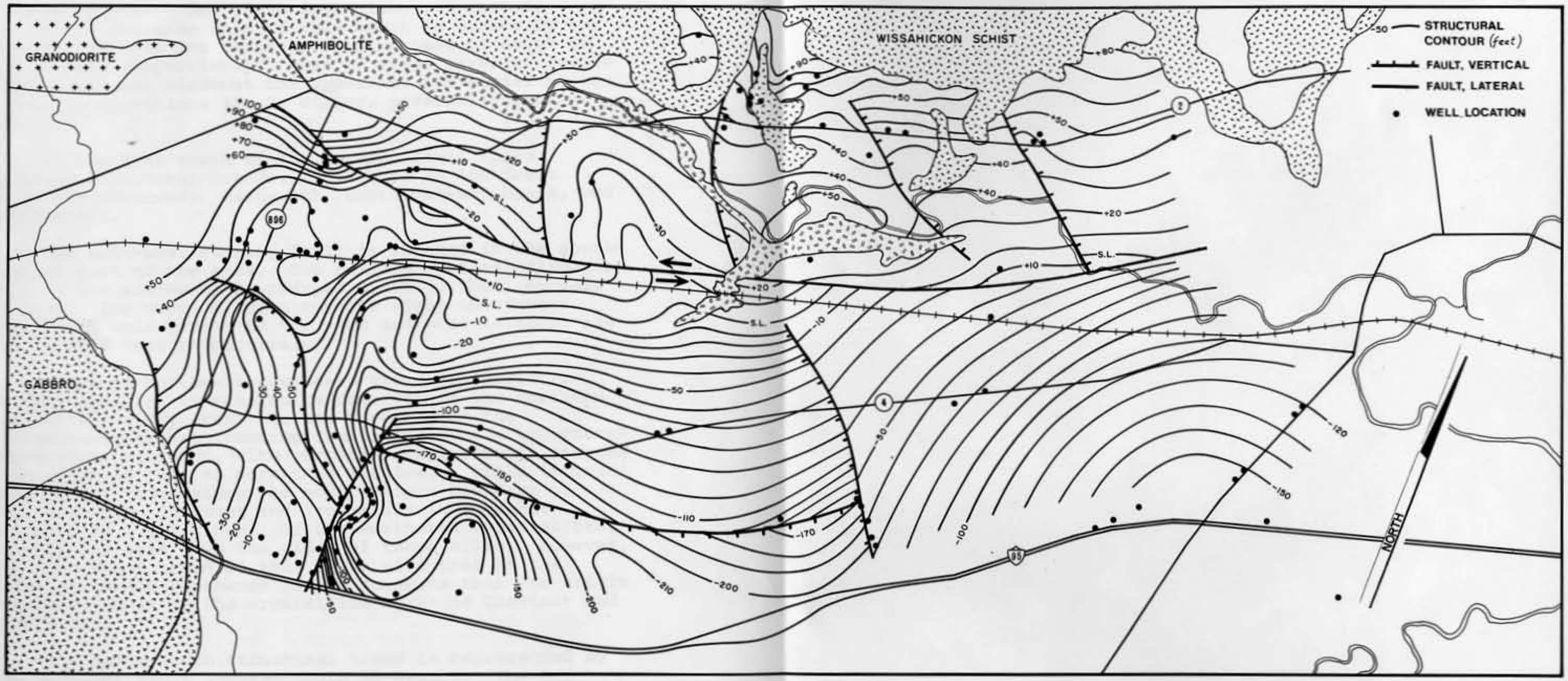

Figure 2. Surface of the crystalline basement complex (sea level datum). The location of the structural contours and fault lines are approximate. No attempt was made to adjust the structural contours to the outcrops of the crystalline rocks. The outcrop areas were delineated on the basis of the Elkton-Wilmington Folio (Bascom and Miller, 1920) and unpublished works by J. Scott (Bryn Mawr College) and T. Stafford (University of Delaware).

The area north of this lateral fault is characterized by a set of roughly parallel faults running north-northwest to south-southeast. They have produced a small horst, northeast of Newark, with a vertical displacement of about 40-50 feet along its western boundary, and 10-30 feet along its eastern boundary. The area east of this horst is broken by two step faults with the vertical displacement of about 10 and 20 feet respectively. Most of these parallel faults extend into the Piedmont and appear on the aerial photographs as lineations (J. C. Miller, personal communication).

In the area south of the lateral fault three distinct structural trends, manifested by the fault sets, are observed: east-west, northwest-southeast, and north-south.

The east-west running fault is located in the south-central part of the area. The maximum vertical displacement of its southern, downwarped block (graben) exceeds 60 feet. The vertical displacement along the faults that bound this graben to the east and west is about 130 feet and 70 feet respectively.

A set of northwest-southeast trending faults is roughly parallel to the faults observed in the northern part of the study area. In the Newark area the northwest-southeast trending faults surround a structural depression, a graben, with vertical displacements ranging from about 40 feet to more than 100 feet. The relationship of the fault along the southwestern boundary of this graben to Chestnut and Iron hills is somewhat obscured by a thick cover of the weathered material that slumped and slid down the sides of these hills. However, the consistent trend of this fault with that of the other northwest-southeast faults suggests that its origin was independent of the crystalline rocks of Chestnut and Iron hills.

The north-south structural trend is represented by the vertical fault located south of Newark. The displacement along this fault locally exceeds 100 feet. Structurally this is the most complex portion of the study area because all three structural trends intersect here. This complexity is well displayed by a perplexed configuration of the structural contours. Apparently a considerable fracturing and crushing of the crystalline rocks occurred here thus intensifying indirectly the weathering, which has resulted in more than 100 feet of weathered material.

The age of the structures in the study area is unknown. However, the fact that the faults in the basement complex controlled to a considerable extent the thickness and lithologic distribution of the overlying Potomac Formation suggests that they may have originated a relatively short time before the deposition of these sediments (see discussion on the Potomac Formation, p. 13). The mutual relationship of the fault sets shows that they did not form at the same time. It can be further concluded that in the area south of the lateral fault, the oldest structural trend is north-south. In the northern portion of the area, the vertical faulting was subsequent to the lateral movement. Although it is impossible to determine which structural set is the oldest, there is little doubt that the northwest-southeast trend is the youngest.

Are the movements along these faults still active? According to the Earthquake Information Bulletin (1971) the only earthquake to center in Delaware occurred on the 9th of October, 1871; its intensity on the Richter scale was 5 and it caused considerable damage in Wilmington. Other nearby towns also sustained some injury: New Castle and Newport in Delaware, and Oxford in Pennsylvania. In other areas the earthquake was accompanied by various noises described as rumbling and explosions. Thus it seems that the faults are indeed still active, albeit the vigor and intensity of this activity is very low. Small tremors which have been reported from time to time in recent years seem to support this.

Iron and Chestnut Hill Problem

The rocks composing these hills are mainly basic intrusives: gabbro, norite, and pyroxenite (Scott, Stafford, and Woodruff, personal communication), formed by direct crystallization from molten magma in the subsurface.

A magnetic map (Henderson et al., 1963) and a magnetic survey done recently in this area show that these igneous rocks do not extend into the subsurface basement complex (R. E. Sheridan, University of Delaware, personal communication); thus, both Iron and Chestnut hills may be considered rootless, and therefore their origin does not seem to be related to the nearby Piedmont. It is hypothesized that these rock masses were brought into the present locations by gravity gliding from the south (Sheridan, personal communication). The magnetic map (Henderson et al., 1963) suggests the existence of similar blocks in the subsurface south and southeast of Iron Hill.

If this hypothesis is correct, then the gliding must have occurred sometime between the metamorphism of the basement rocks and the deposition of the Potomac Formation in the Early Cretaceous.

Although this is an interesting and intriguing interpretation of the origin of Iron and Chestnut hills, there is no proof to substantiate it. Nevertheless, the evidence available at present warrants a serious consideration of this hypothesis.

Weathered Basement Complex

Crystalline rocks in the study area are almost everywhere overlain by their weathered products. These materials are composed of tight, varicolored clays and very clayey, poorly sorted silts and sands, and locally exceed 100 feet in thickness. Fragments and boulders of partly decomposed original rocks are frequently encountered.

The thickness of the weathered material varies from place to place and this variability if probably due to the original rock type, geochemical conditions of weathering, tectonic fracturing and crushing, and, possibly, to slumping of such materials on steep slopes, such as along the northern side of Chestnut and Iron hills, for example. For all these reasons no consistent relationship between the location of the faults and the thickness of the weathered material has been observed. The only exception to this was discussed on p. 10.

The age of the weathered material is unknown. Although no data are presently available to solve this problem, the following hypotheses are proposed: the material formed before, contemporaneously with, or after the deposition of the Coastal Plain sediments.

The first hypothesis seems most likely because a sufficient time was available (Early Paleozoic-Early Cretaceous) for the weathering of the crystalline rocks to proceed to depths sometimes exceeding 100 feet. The deposition of the fluvial Potomac sediments in Early Cretaceous time may have been accompanied, in early stages, by erosion of the underlying weathered material. However, this erosion may not have been effective because the Coastal Plain area was continuously subsiding at that time, thus promoting deposition rather than degradation. Therefore, most of the original weathered material probably would have been preserved and covered by the Potomac sediments.

The second hypothesis could have been important in the early stages of the Potomac deposition allowing direct influx of rainwater into the basement rocks through a thin veneer of the Potomac sediments thus promoting the breakdown of the unstable components in the crystalline rocks. It is, however, difficult to visualize how such a process could have produced more than 100 feet of the weathered material in a relatively short period of time.

The third hypothesis can account for a portion of the weathered material, but it seems very unlikely that the subsurface weathering could have been so effective since the commencement of the Potomac deposition to produce such a large volume of the weathered material, particularly because the crystalline rocks are quite hard, dense, and do not allow for an easy penetration of ground water. However, the subsurface weathering can be quite intensive in the presence of hydrothermal solutions, as shown by Eroshchev-Shak (1970); but there is no known evidence that such solutions were present in the study area.

So the problem of the age and origin of the weathered material in the area remains. The hypotheses set forth above, perhaps, suggest the possible avenues of future investigations.

Potomac Formation

The composition of the Potomac sediments in the study area is dominated by silts and varicolored clays. The sands are fine- to medium-grained, cross-bedded, often poorly sorted, gray to light yellow, and contain, on the average, about 5 percent clayey and silty matrix (Figure 3). They are concentrated in the southern and western parts of the area and in places reach more than 100 feet in thickness. However, in such areas the sand sequence is not continuous but, rather, it is composed of sand beds separated by thin clay layers.

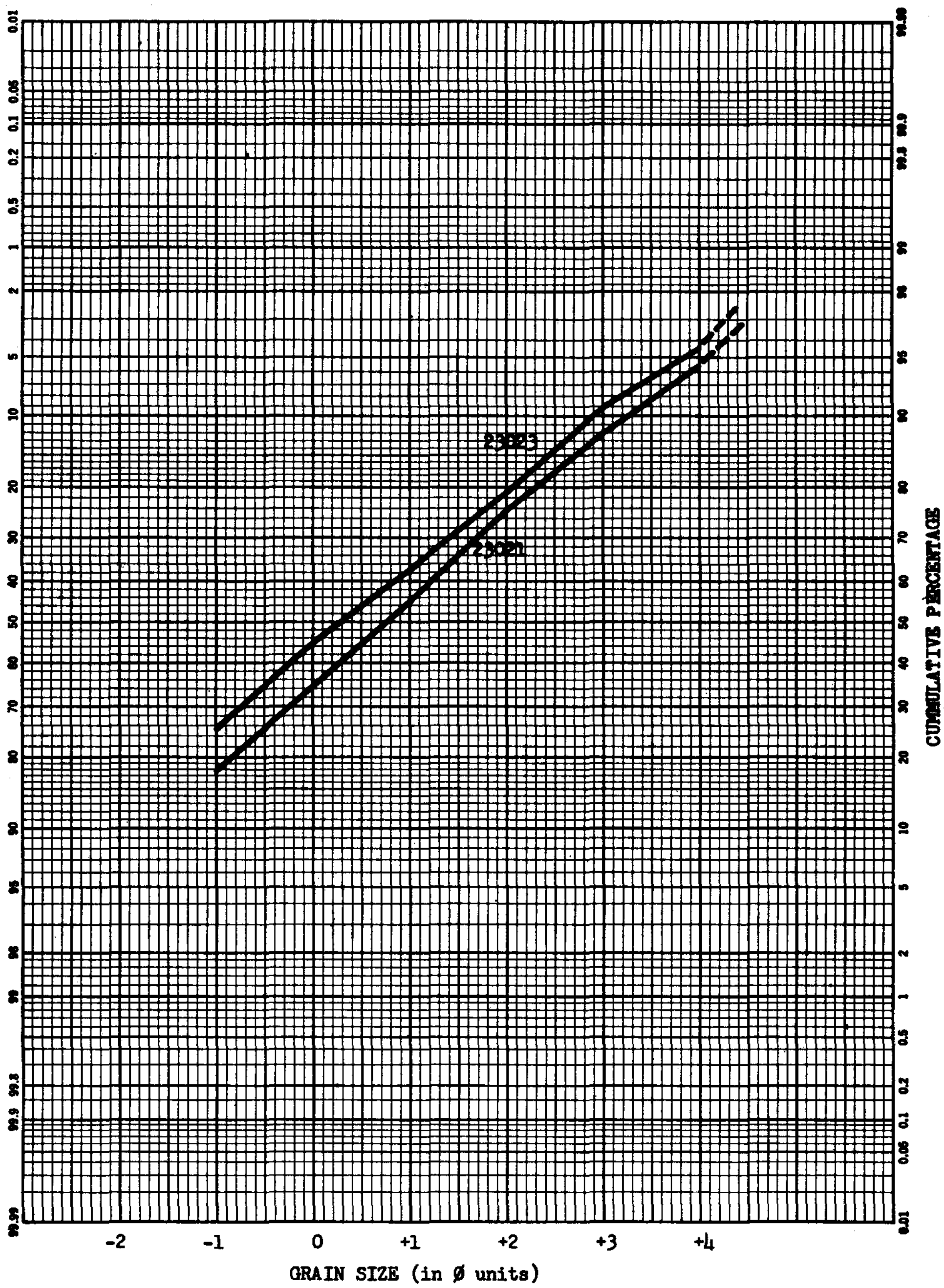

Figure 3. Cumulative curves of the Potomac Formation. Sample no. 23023 taken from the hole Db12-42 at the depth of -90 feet (SLD). Sample no. 23021 taken from the hole Db12-42 at the depth of -80 feet (SLD).

The form and areal distribution of the sand bodies (Figure 4) suggest that the streams that transported and deposited these materials entered the area from the north, northwest, and east. Main flow directions of these ancient streams were inferred on the basis of the dip of the underlying structures in the crystalline basement complex, and also from the lithofacies distributions in the Potomac sediments. The multitude of directions clearly shows that these sediments were deposited by a complex stream system.

A detailed study of the Potomac Formation at Delaware City (Spoljaric, 1967a) has revealed that the deposition of these sediments was initially strongly controlled by the configuration of the crystalline basement surface; this is also evident in the present study area. For example, the depression located in the northern portion of Newark acted as a catchment for a thick accumulation of the Potomac clays. The influence of the basement surface is also apparent in the southern part of the area along the east-west trending fault; the Potomac thickness on the downdropped side of the fault is more than 130 feet larger than on the uplifted, northern side. Similar relationships are displayed to various degrees along the other structural features in the area.

Slumping of the weathered material may have played an important role on the distribution of the Potomac sedimentary bodies in some portions of the area. Direct evidence of such slumping was observed on the northeastern sides of Iron and Chestnut hills. In addition, hole Db21-35, drilled just east of these hills, has revealed possible intermittent layering of the weathered material and the Potomac sediments that could have been produced by recurrent slumping of the weathered material into the depositional environments of the Potomac sediments. An unusually thick sequence of such material in the synclinal depression in the east-central part of Newark may have been formed by slumping from the elevated sides of the depression.

The Potomac sediments are separated from the overlying Quaternary deposits by a major erosional unconformity (Early Cretaceous-Pleistocene) in the study area. The surface of the Potomac sequence in the Coastal Plain portion of the area does not exceed 100 feet above sea level. However, in the hole Da24-3 located on Chestnut Hill at the elevation of 270 feet (SLD) the Potomac sediments were found at this same

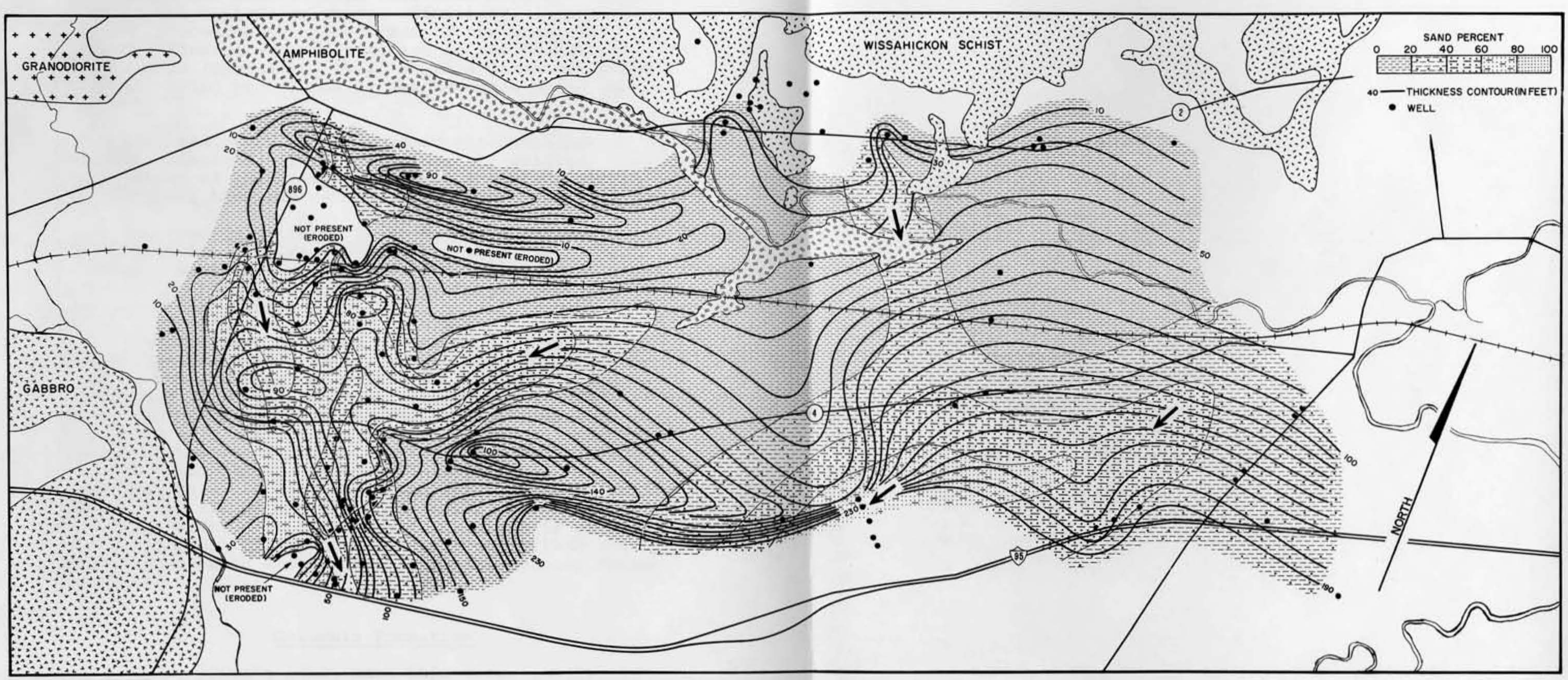

Figure 4. Lithofacies distribution of the Potomac Formation. No attempt was made to adjust the thickness contours to the outcrops of the crystalline rocks. The arrows show the inferred direction of sediment transport.

elevation; the total thickness of these sediments is 91 feet. This "anomalous" elevation is a strong indication that a considerable amount of the Potomac deposits was eroded and removed from this area before the deposition of the Quaternary units. Similarly, intensive erosion preceding the deposition of the Quaternary Columbia Formation was recognized in the Middletown-Odessa area (Spoljaric, 1971) where a large amount of the underlying greensands of the Rancocas Group was removed.

This reduction in the Potomac thickness poses several questions. First, what was the original northward extent of these sediments, and second, where is the material that was eroded and removed from this area?

Unfortunately, there is no evidence to answer the first question. It seems, however, that the Potomac Formation must have occupied at least the southernmost part of the Piedmont, but no remnants of these deposits are known from there.

There is some evidence to answer, at least partially, the second question. Recent study of the Magothy Formation in the area west of Delaware City (Spoljaric, in press) has shown that this unit is composed mainly of the reworked Potomac sediments. The Magothy sediments were deposited in a small delta at the margin of a northward transgressing sea and here they directly overlie the older Potomac units. However, this formation is rarely more than 50 or 60 feet thick and thus, probably, cannot account for all of the eroded Potomac. The location of the remaining portion of the Potomac sediments is unknown. One may speculate that it was laid down farther south in the Coastal Plain area, possibly as the younger Potomac deposits.

Columbia Formation

In the present study area this formation is composed of gravels, sands, silts, and some clays. The sands are moderately to poorly sorted, cross-bedded, yellow to brownish-yellow in color, and contain on the average about five percent clayey and silty matrix (Figure 5). Fine sediments, silts, are locally abundant and gravels are subordinate.

The Columbia sediments were deposited in stream channels, flood plains, and associated environments. A

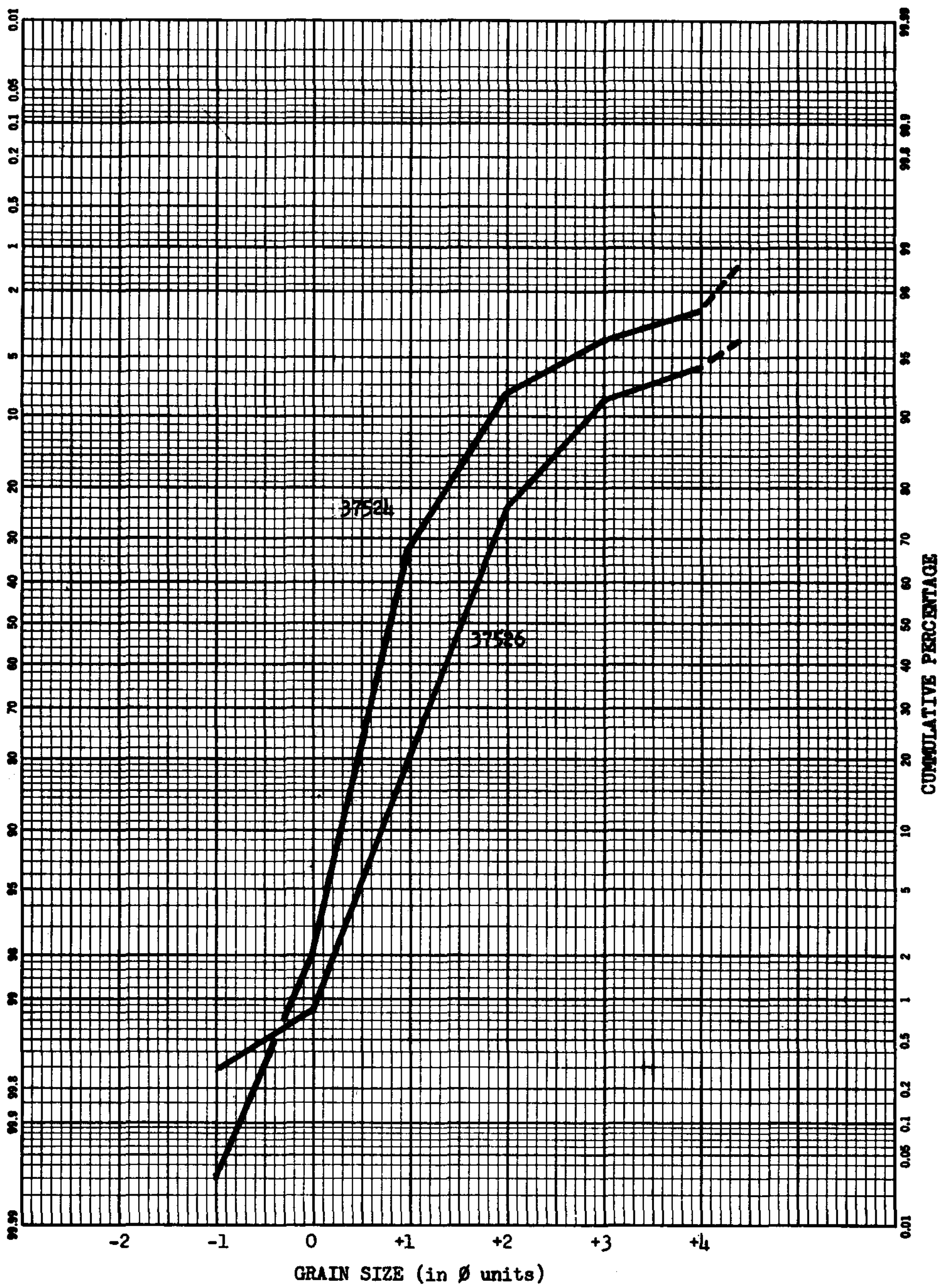

Figure 5. Cumulative curves of the Columbia Formation. Sample no. 37524 taken from the hole Db11-51 at the depth of 20-25 feet. Sample no. 37526 taken from the hole Db11-51 at the depth of 30-35 feet.

detailed study of these deposits in the Middletown-Odessa area (Spoljaric, 1970; Spoljaric and Woodruff, 1970) revealed that the ancient streams that deposited these materials were shallow, usually less than half a mile wide, and frequently shifted their courses within a braided stream system. It was suggested (Spoljaric, 1970) that the great lithologic variability of the Columbia sediments is indicative of fluctuating water and sediment discharges of the Pleistocene streams caused by short term climatic changes (seasonal, for example) and is not related to the Pleistocene glacial and interglacial phases.

In the present study area, however, the Pleistocene stream system seems to have been confined to straight valleys, as suggested by Spoljaric (1967). This is confirmed by the geometry of the sedimentary bodies; for example, the sand percent distribution shows that the sand bodies have a shoestring form characteristic of such valleys.

The lithofacies map (Figure 6) of the Quaternary deposits indicates that these ancient streams entered the area from the north and northeast. This is in general agreement with Jordan's conclusion (1964). Although there is little doubt that the main stream system was located in the ancient Delaware River Valley, a considerable amount of these materials were brought into the Coastal Plain also directly through the Piedmont. However, the evidence for this is somewhat obscured by the overlying younger Quaternary sediments.

The areal distribution of the Columbia lithologies seems to have been controlled by the topography and composition of the underlying Potomac surface. The valleys in this surface were developed in the areas composed of fine Potomac deposits, such as clays and silts. For this reason these areas were the location of main Pleistocene stream system and the transport routes of the overlying Columbia sands. Thus, the Columbia sands are usually directly underlain by the Potomac fine sediments, although there are a few exceptions to this, for example, the Newark area and the southeastern portion of the study area.

A similar relationship has been also observed between the Pleistocene surface and the locations of the recent streams elsewhere in New Castle County (Spoljaric, 1967).

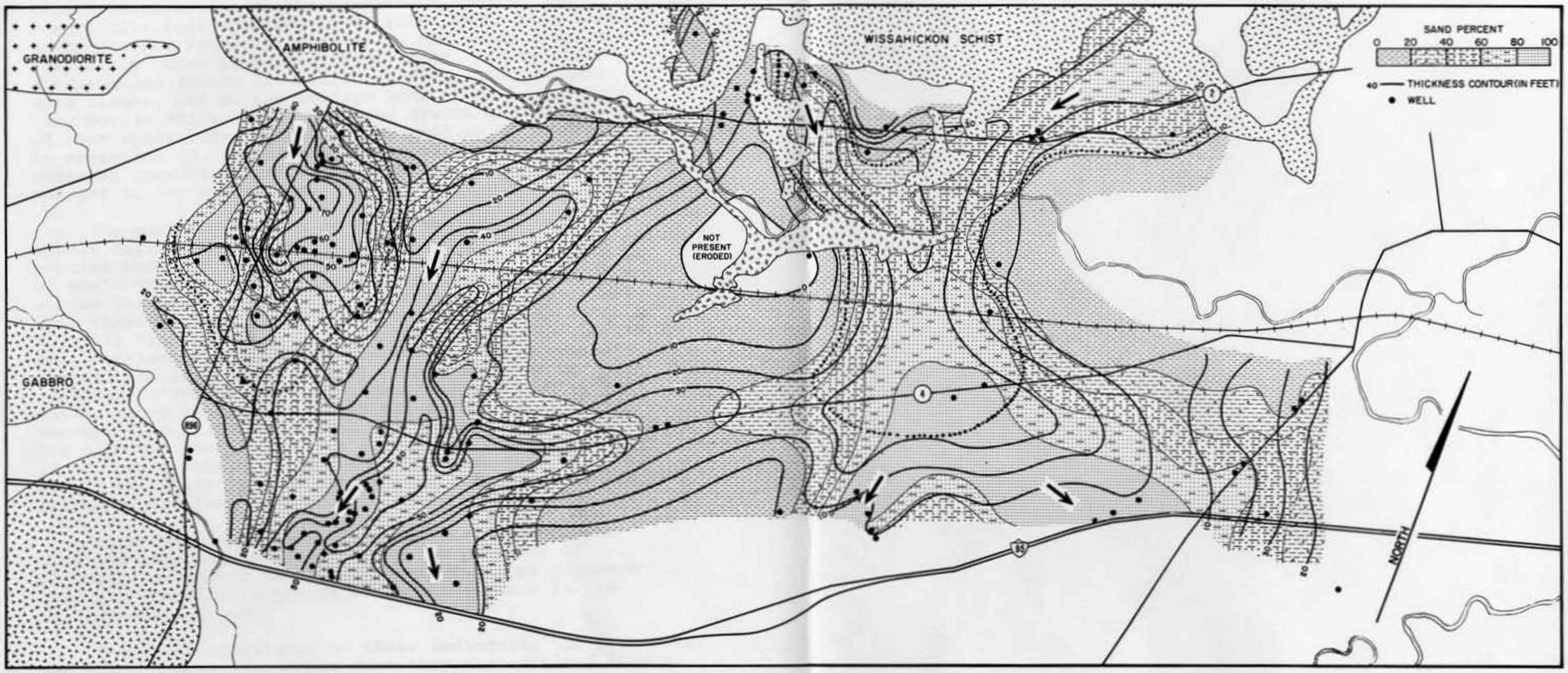

Figure 6. Lithofacies distribution of the Quaternary deposits. No attempt was made to adjust the thickness contours to the outcrops of the crystalline rocks. Thick dotted lines delimit the approximate southward extent of the alluvial fans. The inferred sediment transport is shown by arrows.

Younger Quaternary Sediments

Recent construction work at the University of Delaware and nearby areas has revealed the existence of the Quaternary deposits younger than the Columbia Formation. Reinspection of the subsurface samples and descriptive logs obtained by drilling shows that these sediments are indeed widespread in the study area; they are mostly brown to yellow-brown sands, poorly sorted, cross-bedded (Plate 1), coarse to fine, contain large mica flakes, and on the average have about two percent clay matrix (Figure 7). The sand grains are angular and of poor sphericity. The heavy mineral suite is dominated by magnetite (P. B. Leavens, University of Delaware, personal communication) which comprises more than 45 percent of the assemblage.

The southward extent of these sediments is tentatively delineated on the lithofacies map (Figure 6); the precise boundary is unknown. The geometry and the form of the sedimentary bodies, and their relationship to the stream valleys of the Piedmont are strong indications that these sediments were deposited as alluvial fans. Alluvial fans generally form in the areas where heavily sediment-loaded streams emerge from mountains onto a lowland and are accompanied by a marked change in gradient. "The building of fans takes place largely during flood times, when great volumes of water with accompanying alluvium debouch onto them. During much of the time the stream channels across the fans are dry, or, if permanent streams occupy the channels, much of their waters is likely to sink into coarse alluvium near the apices of the fans" (Thornbury, 1969, p. 173).

Although streams heavily sediment-loaded do not exist in the Piedmont at present, the presence of alluvial fans along the Fall Zone in the area suggests that such conditions prevailed in the streams in the not too distant past.

The fresh appearance of these sediments, their texture, and their composition imply that they were derived from a nearby source in the Piedmont. However, the occurrence of relatively large amounts of magnetite in these deposits does not support this conclusion, because only traces of this mineral are present in the metamorphic rocks of the Piedmont. There are several possible explanations offered here to define this inconsistency.

Large concentration of this mineral may have been the result of the drop of stream gradients upon entering

Plate 1. A well-developed cross-bedding in alluvial fan sediments (Smith Hall, University of Delaware).

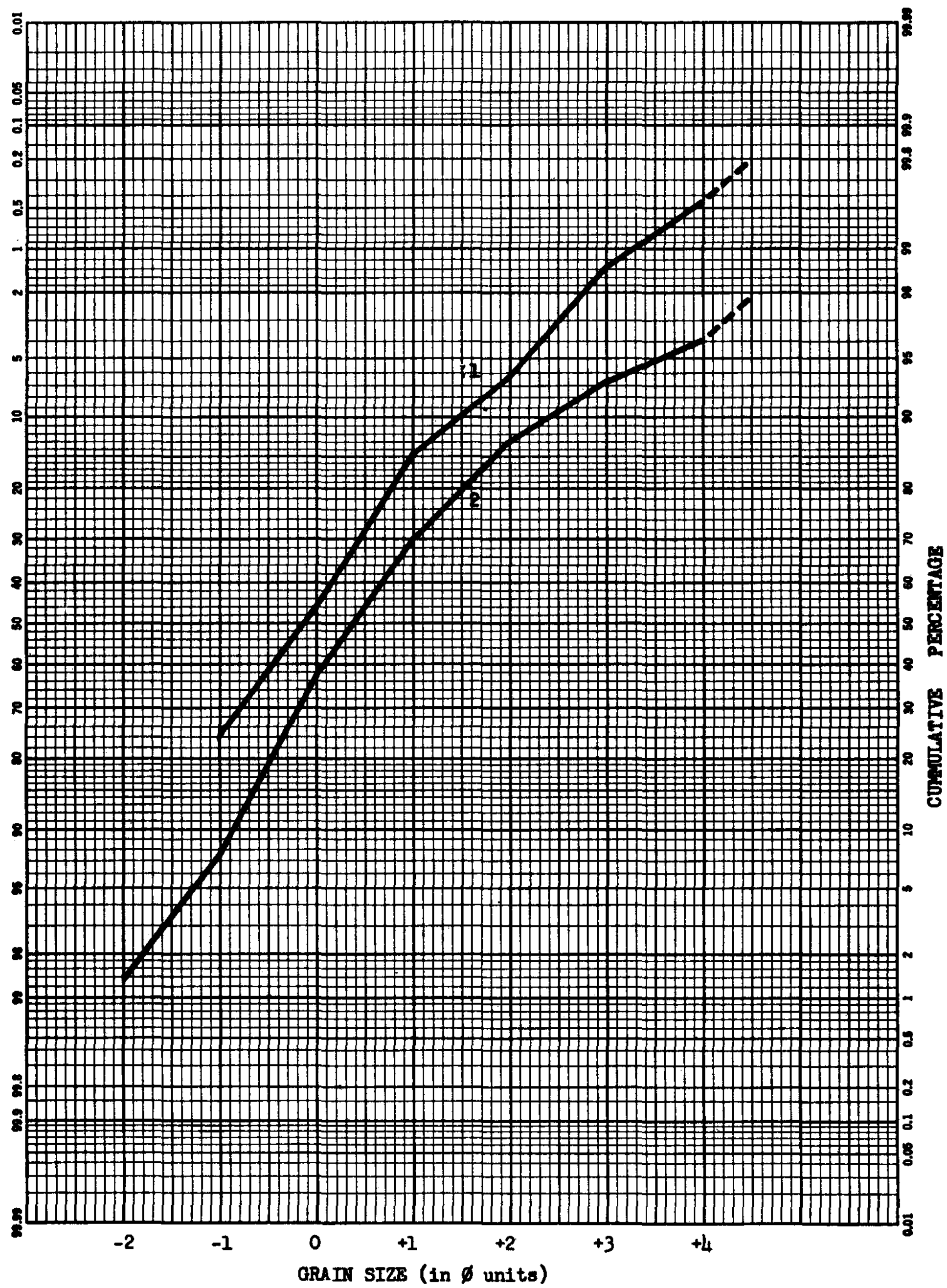

Figure 7. Cumulative curves of the alluvial fan sediments. Sample no. 1 taken at the foundation of Smith Hall, University of Delaware. Sample no. 2 collected at Polly Drummond Hill Road, about 1/2 mile south of the contact between the Piedmont rocks and the sediments of the Coastal Plain.

the Coastal Plain; magnetite is dense and it could have been deposited with the coarse sediments. Although this is a possibility, it is somewhat contradicted by the results of a study carried out on the Columbia Formation (Spoljaric, 1970). These results show that the heavy minerals found in the Columbia Formation were transported with fine suspended sediments, and not with the coarse materials. The fact that there is hardly any silt and clay in the alluvial fan deposits indicates that the suspended load went completely through the system and was deposited elsewhere.

The second possibility is that the magnetite was associated with serpentine bodies, only remnants of which are still present in the Piedmont. Magnetite is a common alteration product of minerals containing ferrous oxide, as veins in serpentine, that have resulted from the alteration of chrysolite.

The spreading of these sediments southward, away from the Piedmont, and the locations of the apices of the fans suggest that their origin is related to the present stream valleys of the Piedmont. This, in addition to the fact that they unconformably overlie the Columbia Formation in the study area (Plate 2), shows clearly that they are here post-Columbia in age. However, the deposition of the alluvial fans may have occurred during the last extensive Pleistocene flooding when a large volume of the sediments was brought into this area by the Piedmont streams. This flooding may have had a regional significance; an episode of flooding of a similar magnitude was detected farther south, in the vicinity of Middletown and Odessa (Spoljaric, 1970; Spoljaric and Woodruff, 1970). If the flooding in both areas was indeed the result of the same event, then the alluvial fan sediments, in the present study area, and the Columbia flood deposits in the Middletown-Odessa area, were laid down contemporaneously.

CONCLUSIONS

Geologic History

The origin and composition of the crystalline basement complex is very poorly known. This complex probably formed during the late Precambrian - early Paleozoic and the original rocks were later, during the Paleozoic, severely metamorphosed. The metamorphism did not only

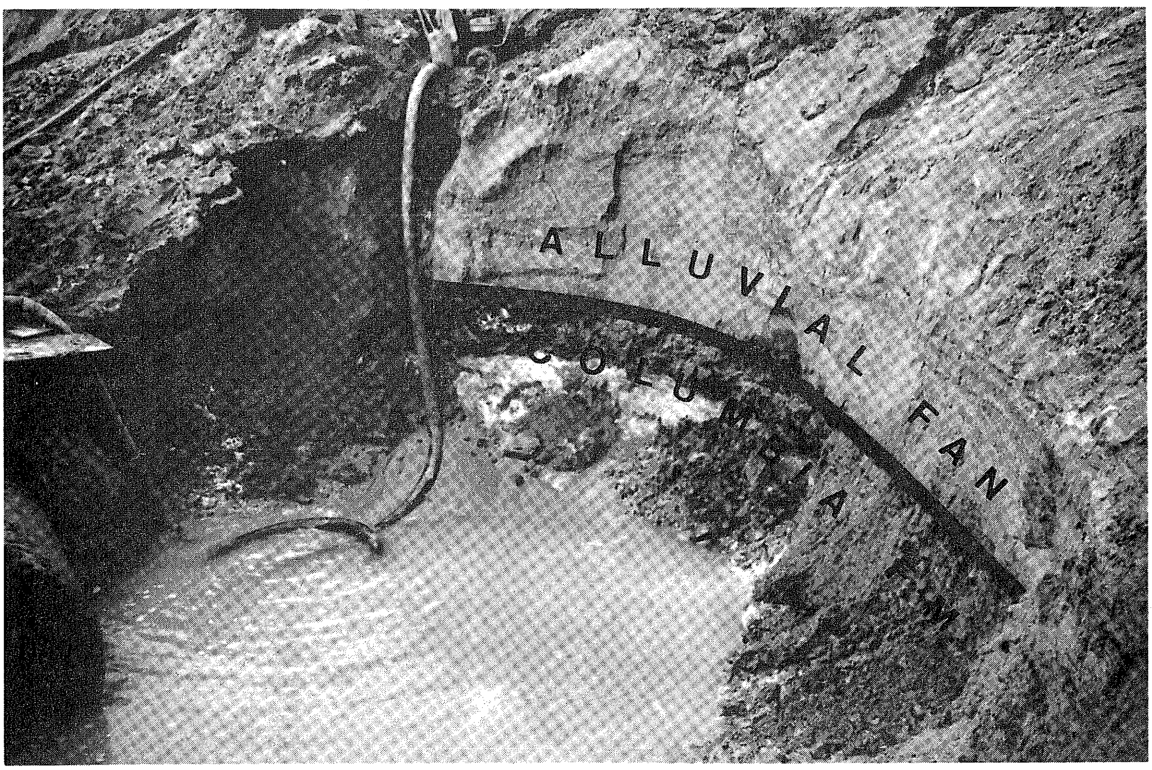

Plate 2. Erosional unconformity between the alluvial fan deposits and the Columbia Formation. About 1/2 mile north of the intersection between Harmony Road and Chestnut Hill Road.

involve the recrystallization of the minerals composing these rocks but was also accompanied by intensive folding and faulting thus greatly obliterating the mutual relationships among the rock units of this complex.

The events that occurred between the main phases of metamorphism and the commencement of the Potomac deposition in the Early Cretaceous are an enigma. Iron and Chestnut hills must have been formed sometime in that period. Three phases of faulting must have also occurred during that time. In the Early Cretaceous a complex stream system developed in the area. The locations of the streams seem to have been strongly controlled by the topography of the underlying crystalline basement surface. The sediments deposited during the Early Cretaceous reached considerable thicknesses leaving Iron and Chestnut hills as small protrusions in the Potomac surface. The deposition of the Potomac Formation appears to have been continuous suggesting that the area was persistently subsiding.

The events that took place between the end of the Potomac deposition and the beginning of the Pleistocene sedimentation (Columbia Formation) are another puzzle. It seems, however, that the subsidence of the area ended and erosion of the Potomac sediments from this area started. A portion of the materials removed from here was deposited farther south, in a small delta at the margin of the northward transgressing sea, forming the Magothy Formation. What happened to the remainder of the eroded Potomac is unknown. The degradation must have reached its maximum in Pleistocene time when the deposition of the Columbia Formation started.

During the Pleistocene, another complex stream system developed. The main streams seem to have entered the area from the direction of the Delaware River Valley, although a considerable quantity of the Columbia deposits was also brought through the Piedmont. Close to the end of the Pleistocene sedimentation a surge of heavily sediment-loaded flood waters entered the area of study through the Piedmont and produced a set of alluvial fans at the south margin of the Piedmont.

Although the description of the geologic history of the study area presented here is very sketchy, it, nevertheless, shows that the area has gone through a sequence of intricate geologic processes. The complex geologic framework is primarily caused by diverse structural features present in the crystalline basement rocks that have exerted a considerable influence on the distribution of the overlying, younger, sediments.

Applied Geology

The main sources of ground water in the study area are the sands of the Potomac Formation and Quaternary deposits. To be economically suitable as an aquifer, sands must have good permeability and porosity, and a sufficient saturated thickness. The sands of both the Potomac and the Quaternary generally have these qualities, but only in certain parts of the study area. Unfortunately, most such areas are already utilized as water wellfields; for example, the City of Newark fields. Although the sand units are also present in other parts of the study area, their saturated thicknesses are usually too small for the development of economical supplies of ground water.

A recent study carried out by the Delaware Geological Survey (1972) in a small portion of the Piedmont has revealed that ground water in considerable quantities may be present along faults and fractures in the crystalline rocks. However, it should be pointed out that quantities of water in such rocks are unpredictable and the mere presence of faults and fractures does not necessarily mean that a sufficient amount of ground water is available.

Other mineral resources, such as sand, gravel, and crushed rock, used in construction, are available in the study area but are not exploited here.

Future Prospects

Based on the estimated population increase projections for the study area, the demand for ground water will reach the available supply in about fifteen years. As the present study showed, there are no hidden sources present in the Potomac and Quaternary sediments in the area.

Future investigations for ground water may be directed toward the crystalline rocks both in the Piedmont and in the Coastal Plain basement complex in the subsurface. Before any drilling into the faults in the crystalline basement complex is attempted, it is necessary to determine accurate locations and inclinations of the fault planes. For this reason the area would have to be geophysically surveyed, preferably by seismic methods. The weathered material, which covers the crystalline basement rocks almost everywhere in the area, could pose some serious problems to a possible exploitation of ground water from the faults. This material is usually impermeable, due to its clayey composition, and may impede the recharge of ground water from the Coastal Plain sediments above into the fractured zones of the crystalline basement complex below.

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