STATE OF DELAWARE

DELAWARE GEOLOGICAL SURVEY

REPORT OF INVESTIGATIONS NO. 12

QUANTITATIVE LITHOFACIES ANALYSIS OF POTOMAC FORMATION, DELAWARE

By

Nenad Spoljaric

Newark, Delaware

October, 1967

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NENAD SPOLJARIC

Geologist, Delaware Geological Survey

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ABSTRACT

The quantitative lithofacies analysis of the Potomac Formation in a small area west of Delaware City revealed that the deposition of these sediments was continuous throughout the time of their formation.

The uppermost part of the Potomac sequence appears to have been removed, probably by erosion, prior to the deposition of the younger Upper Cretaceous marine sediments. The sand bodies contained in Potomac deposits have a shoestring channel form and were most probably deposited by unidirectional currents. The direction of the flows, however, cannot be determined on the basis of the available subsurface data.

INTRODUCTION

Rapid economic and population expansion of the State of Delaware necessitates the accelerated development of mineral and water resources. Such a development can be accomplished only through a thorough understanding of the properties and origin of the rock units which contain these resources.

The sediments of the Potomac Formation are a very important source of ground water in the State. Recent hydrologic and geologic investigations of these deposits have revealed their complex lithofacies interrelationships and have encountered great difficulties in correlating individual lithic units. Therefore, the present study was undertaken with the purpose of determining, primarily, the lithologic variability of these sediments, their genesis, environments of deposition and the geometry of sand bodies contained in these deposits.

ACKNOWLEDGMENTS

The author wishes to thank Dr. J. J. Groot, State Geologist for his suggestions and criticism of the original manuscript.

PREVIOUS INVESTIGATIONS

The Potomac sediments have attracted a considerable interest of geologists who have worked in this area.

McGee (1886) introduced the name Potomac Formation for these deposits in the District of Columbia, Virginia, and parts of Maryland. Later (1888) he applied the same name to the corresponding sediments in Delaware. Clark and Bibbins (1897), who worked in Maryland, divided the Potomac into the Patuxent, Arundel, Patapsco and Raritan Formations. Bascom and Miller (1920) traced the same formations into Delaware but were able to recognize only the Patuxent, Patapsco, and Raritan. They pointed out, however, that in Delaware these cannot be always separated with ease. Groot (1955) also stressed the difficulty of dividing the Potomac sediments into smaller units in Delaware.

LITHOLOGIC DESCRIPTION

In Delaware, the Potomac Formation is composed of variegated silts and clays with interbedded sands of varying textures. Its stratigraphic subdivision has been attempted many times during the past but with no apparent success. The formation as a whole is of Early and partly Late Cretaceous age (Berry (in Clark et al. 1911, 1916); Dorf, 1952; Groot and Penny, 1960; Groot, Penny, and Groot, 1961). Groot (1955) who studied the petrology and provenance of these sediments was able to recognize two major divisions based on the heavy mineral composition only; a lower Patuxent zone characterized by a staurolite-tourmaline-kyanite suite and an upper Patapsco-Raritan zone characterized by high percentages of zircon and rutile with various amounts of tourmaline and alterite.

The Patuxent zone is composed primarily of fine to coarse sand with some silt and clay. The composition and sedimentary parameters indicate "...that the Patuxent sediments are nonmarine and that their environment of deposition must be considered partially continental and partially estuarine." (Groot, 1955, p. 101).

The composition of the Patapsco-Raritan zone is even more heterogeneous than that of the underlying Patuxent zone. Here, the sediments range from clays to medium sands usually containing considerable amounts of silt and varicolored clays. Their environment of deposition was "...a low lying swampy coastal plain in which fluviatile, bimodal sediments were deposited, some in brackish, swampy lagoons and estuaries, and some in stream channels and flood plains." (Groot, 1955, p. 103).

The Potomac sediments in Delaware were derived, essentially, from the same source area; the Piedmont Province and the adjacent folded Appalachian Mountain system (Groot, 1955).

In general, sediments deposited in a continental environment are rarely preserved in it over long periods of time. However, the fact that the great volume of the Potomac sediments is preserved and that they attain great thickness (the thickness at Salisbury, Maryland, for instance, is more than 3,700 feet) suggests that either their deposition was relatively rapid and the deposits were buried before they could have been removed by various transporting agents into the sea, and/or the preservation was the result of the tectonic subsidence of the area. The Potomac sediments form a piedmont accumulation which is, lithologically, similar to the marine deposits near the mobile rim of a geosyncline.

QUANTITATIVE LITHOFACIES ANALYSIS: GENERAL CONSIDERATION

Lithofacies analysis as applied to the Potomac Formation in this study, is a quantitative approach to litho-stratigraphic mapping. In combination with statistical methods, which provide the basis for the correlation between various geophysical logs and well samples, it is particularly useful in the study of subsurface problems. The number of variables which can be simultaneously shown on a quantitative map is limited but such maps are important because they show the rate of change as it occurs regardless of the variable being analyzed. In addition, such maps indicate how areal variations in the characteristics of the sediments are distributed within a genetically related sedimentary sequence. The changing patterns of sedimentation within such sequences reflect differences not only in the regional framework, but in the local environment as well (Bishop, 1960).

The interpretation of quantitative maps is a very complex problem and each situation should be, preferably, interpreted individually. Therefore, recognizing the importance of different factors being mapped is, to some degree, subjective. Also, quantitative maps are only as reliable as the correlation of the mapped unit itself.

A number of very specific problems is usually encountered when dealing with fluviatile sediments such as the deposits of the Potomac Formation. This is primarily due to the rapid and sudden lithofacies changes which occur laterally and vertically and to the complex and unpredictable geometry of fluviatile sedimentary bodies.

One of the most obvious characteristics of fluviatile sediments is the deposition of a coarse fraction into channels and a fine fraction on banks and in flood plains. The general tendency is for the coarse sediments to be concentrated in the channels; nevertheless, the proportion of "true" channel deposits to the overbank and flood plain sediments may range from only a small portion to almost the entire formation.

The quantitative analysis is a rather new approach to stratigraphic problems and in a relatively short period of time a number of very sophisticated methods have been developed (see Forgotson, 1954 and 1960; Krumbein, 1954; Pelto, 1954 and others). However, the most advanced method does not always appear to be the most suitable one. A number of methods have been tested in the present study with an attempt to choose the most appropriate one. The method selected seems to render the results with the least complexity.

METHOD OF PRESENT STUDY

The area of the present study is located west of Delaware City (Figure 1). It occupies about 26 square miles and its greater part is the property of the Tidewater Oil Company. A number of wells drilled in this area reached the crystalline basement complex and most of them were electrically and gamma-ray logged.

Data for the quantitative analysis were derived from the electric logs of 25 wells in the following manner: the "shale base line" and the "sand line" were traced along extreme positive and negative edges of the SP curves, respectively. It was assumed that all the beds where the SP peaks reached the sand line were virtually free of clay matrix. Such peaks, therefore, represent the static SP (SSP). All other peaks which do not reach the sand line have smaller SP values (pseudostatic SP or PSP) and contain various amounts of clay depending on the height of their peaks. A line representing 25 per cent value of SSP has been drawn between the shale base and sand lines closer to the first one. Areas under the SP curve on the negative side of this line were considered to be sands while areas on the positive side, clays. The thickness of sand and clay beds have been measured and used in calculating sand isolith and sand percentage values.

The method of the present study was designed so that special attention could be paid to the study of the deposition and geometry of sedimentary bodies. The difficulty,

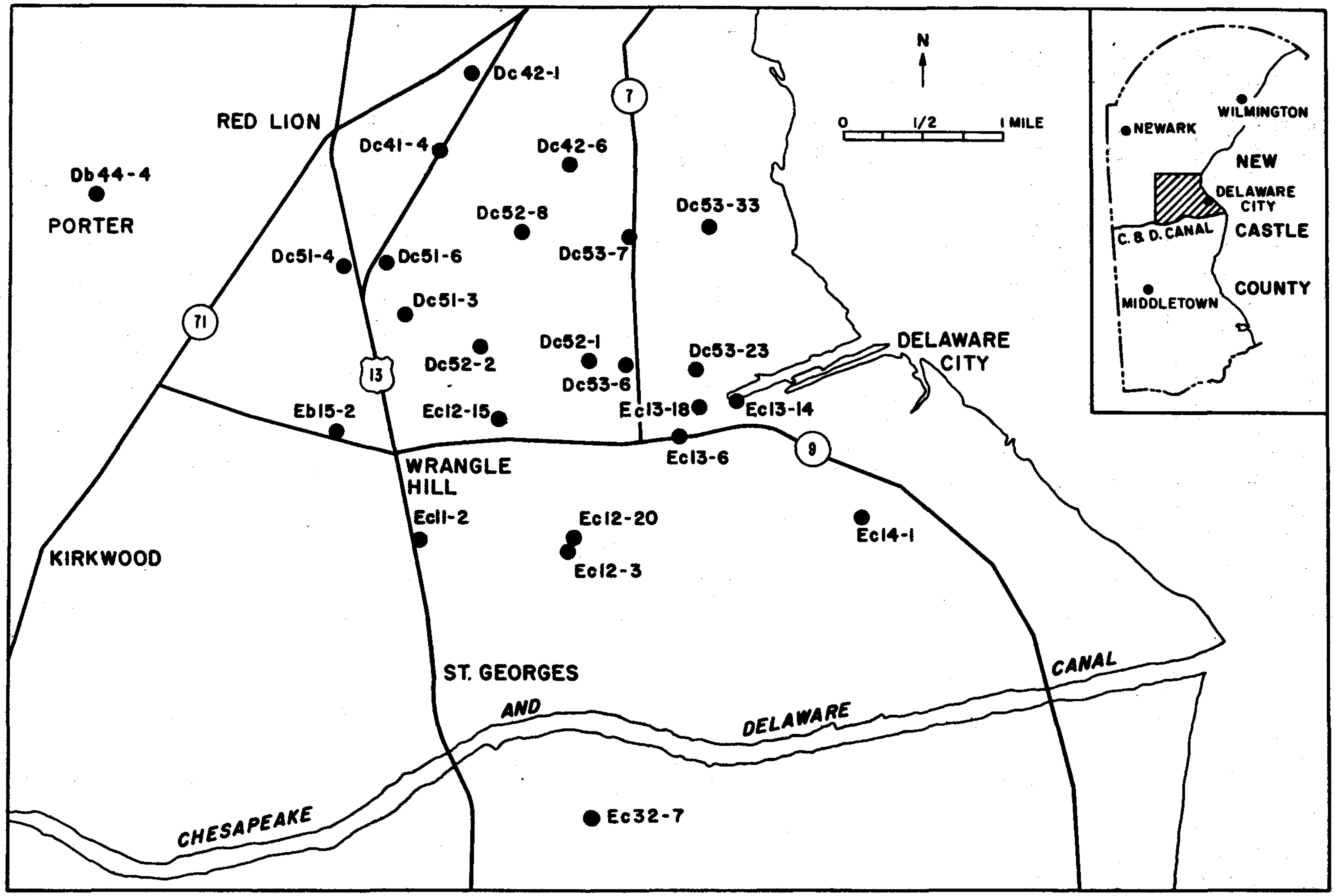

Figure 1. Area of investigation showing well locations. The well numbering system is that used by the Delaware Geological Survey.

particularly in recognizing the geometry of the fluviatile sedimentary bodies in the subsurface is primarily due to the limitations exerted by drilling. This is especially true when working with sections several hundred feet thick. To minimize such problems the whole Potomac section has been cut arbitrarily into seven 130 feet thick layers parallel to the average dip of the strata which is toward the southeast (about 20 feet per mile). Most of the layers, however, are partly less than 130 feet thick because of the influence of the uneven upper surface of Potomac and topography of the crystalline basement. The layers have been studied individually and sand percentage and sand isolith (thickness) maps constructed. The well data were statistically treated to determine the effect of erosion, if any, particularly on the surface of the formation which is an unconformity.

Such a method is direct but there is a limitation which has to be taken into account in the interpretation of results. Each of the mapped units (layers) is considered to be a time-stratigraphic succession for the following reason: the area of the study, presented in three dimensions, contains an infinitesimal portion of the total volume of the Potomac sediments in the Coastal Plain region. Therefore, layers cut parallel to the average dip of the strata will very closely approach true time-stratigraphic zones. In fact, the angle between the layers and the time-zones is probably so small that it can be neglected. Any expansion of the area, however, increases this angle and the technique becomes invalid.

RESULTS AND INTERPRETATIONS

Since each layer is considered to be a time-stratigraphic unit, the depositional processes as interpreted from the constructed maps represent general time-equivalent events. The layers have been studied separately and a composite interpretation of the whole Potomac sequence is also presented.

Quantitative Interpretation of Layers

Layer no. 1 (Figure 2) is the deepest and oldest unit studied, resting on the crystalline basement complex. The Potomac sediments are concentrated in a basement valley which extends in a southerly direction. The close relationship between the sand isolith contours and the basement topography observed is to be expected. The general parallelism between the sand percentages and the sand isolith contour lines is pronounced suggesting continuous deposition throughout the time of formation of this layer.

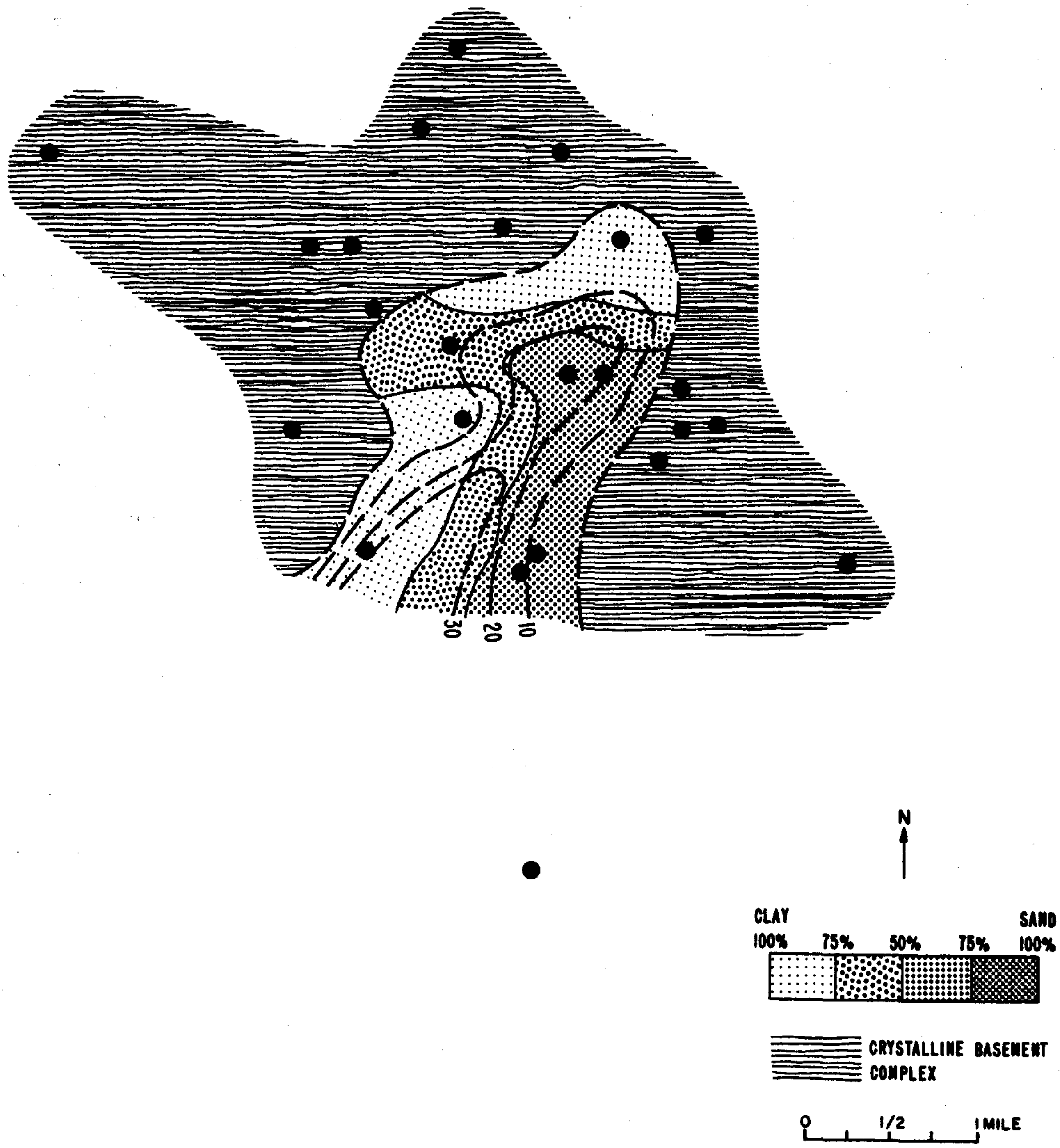

Figure 2. Layer no. 1. Concentration of Potomac sediments in a basement valley is apparent. Sand isolith contours are in feet.

Layer no. 2 (Figure 3). The areal distribution and the geometry of the sand body in this layer strongly suggests the continuation of the depositional trend from the layer no. 1. The crystalline rocks appear in the northern and south-eastern parts of the area indicating topographic heights in the basement complex. The relationship between the sand percentages and the sand isolith contours suggests depositional continuity with the highest concentration of the coarse fraction having an east-west trend.

Layer no. 3 (Figure 4). The general trend of the deposition initiated in the layer no. 1 and continued into the layer no. 2 is preserved here as well. However, there are some significant differences. The high sand concentration in the central part of the area observed in the layers no. 1 and 2 is here replaced by clay. The sand concentration is, however, preserved in the northern and southern parts of the study area as is the case in layer no. 2. The connection between the northern and southern sandy portions is established along the eastern margin of the area. The east-west depositional trend remains the most significant one while the north-south trend of the sand body is shifted toward the east. The basement complex is present only in the northernmost portion of the area indicating the most-elevated part of the crystalline basement.

Layer no. 4 (Figure 5). The topographically high basement complex which extends from layer no. 3 into the northernmost portion of this layer as well is here covered by the Potomac sediments. The deposition appears to have been progressing along the general northeast-southwest direction. The central part of the area which is characteristically clayey in layer no. 3 becomes again sandy. The sand body has a typical shoestring form and is bounded in the northwest and southeast by clays.

Layer no. 5 (Figure 6). The general sand distribution pattern is similar to that of layer no. 4. The trend of the sand body, however, shows a clockwise rotational shift.

Layer no. 6 (Figure 7). The western and southwestern parts of this layer are characterized by a thickness deficiency. In these parts of the area the uppermost layer (no. 7) is entirely missing and the sediments of layer no. 6 are directly overlain by younger Upper Cretaceous deposits. Consequently, there is little or no parallelism between the sand isolith contours and the sand percentage distribution and, therefore, it is not possible to determine whether the deposition from layer no. 5 continued without interruptions into layer no. 6.

Figure 3. Layer no. 2. Topographic highs in the basement complex are observed in the northern and southeastern parts of the area. Geometry of the sand body suggests the continuation of the depositional trend from layer no. 1. Sand isolith contours are in feet.

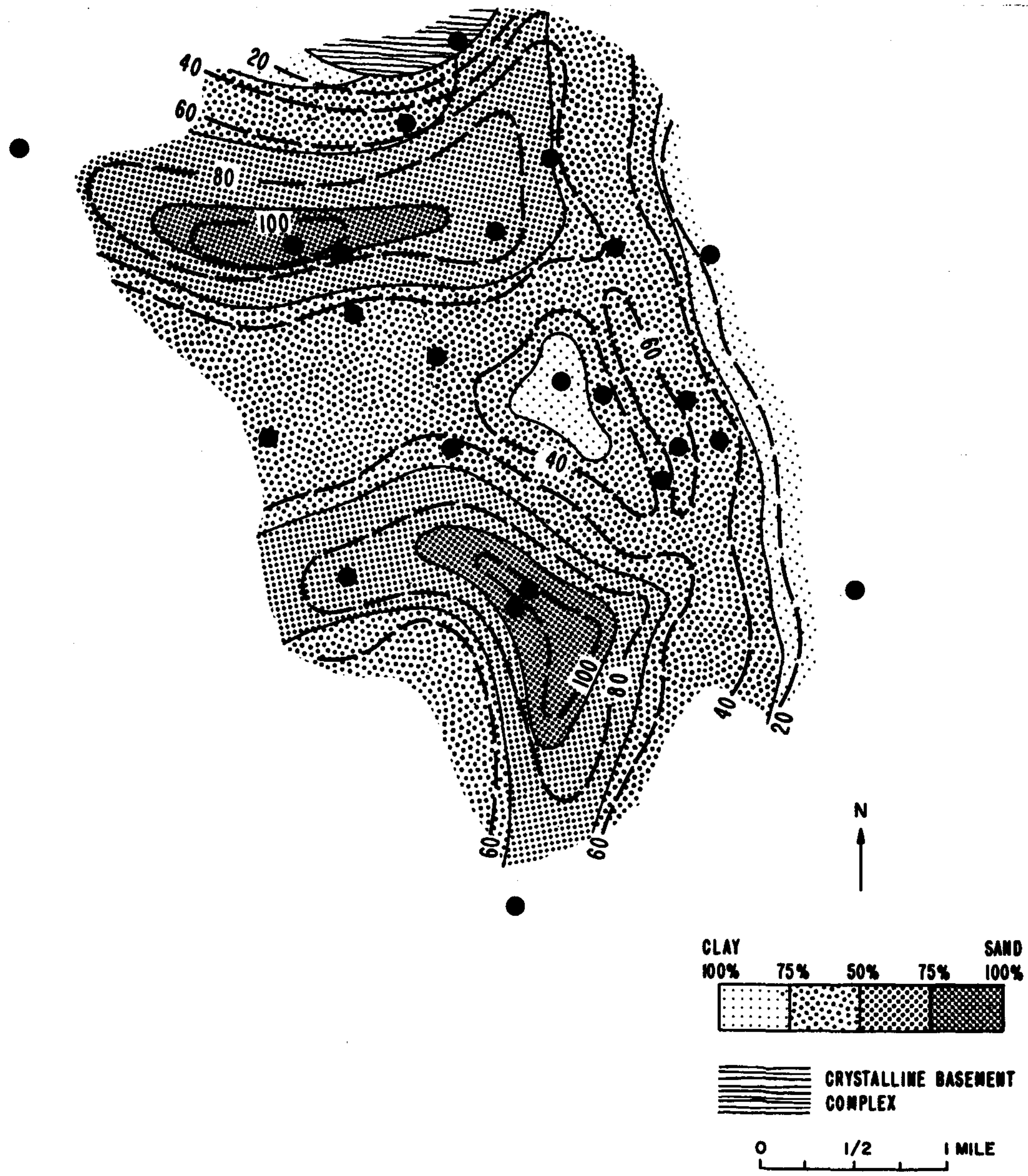

Figure 4. Layer no. 3. Presence of crystalline rocks in the northernmost part of the area indicates the most elevated part of the basement complex. The east-west depositional trend of Potomac sediments appears to be the most significant one while the north-south trend is shifted toward the east. Sand isolith contours are in feet.

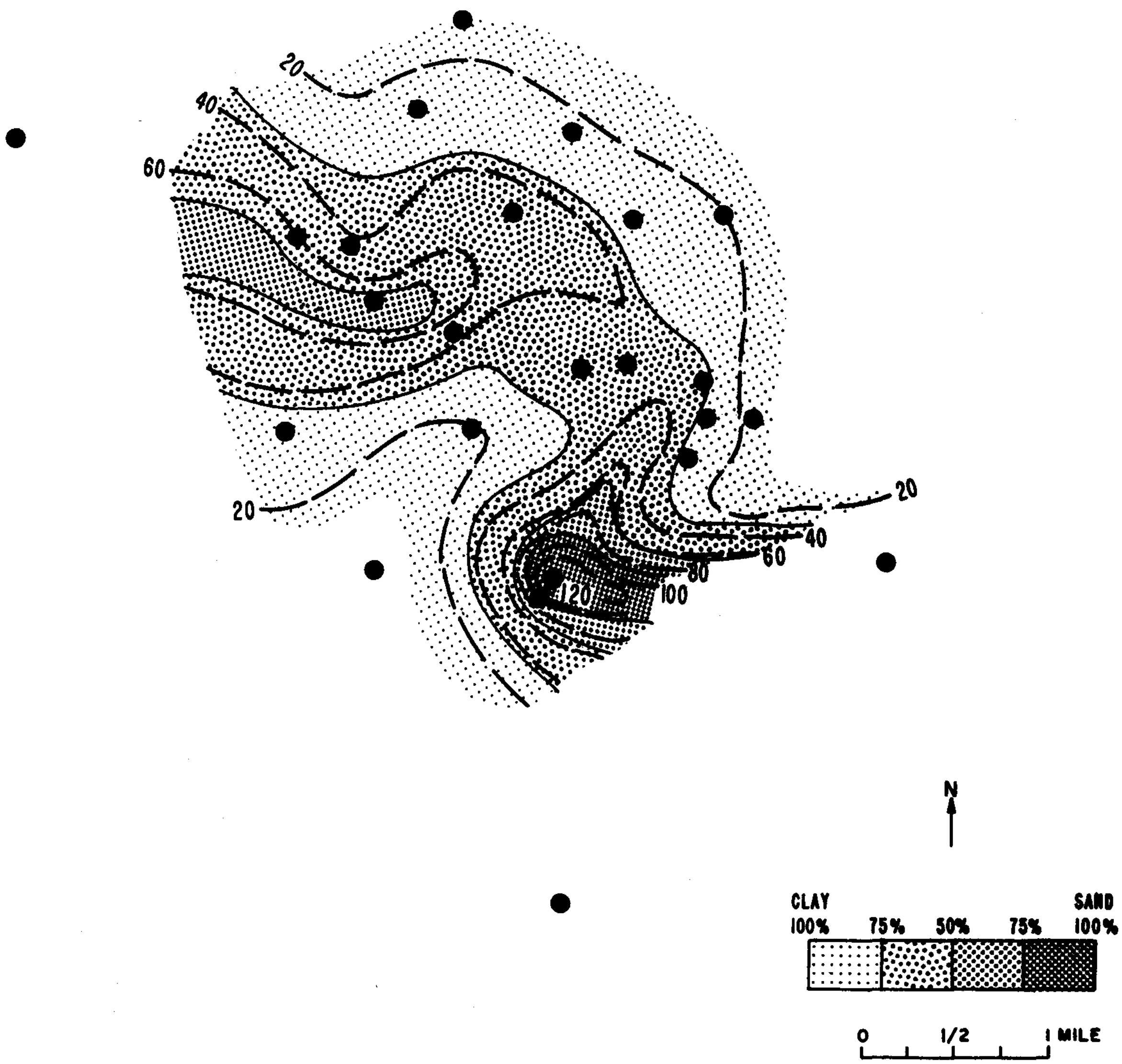

Figure 5. Layer no. 4. Sand body has a typical shoestring form. Sand isolith contour lines are in feet.

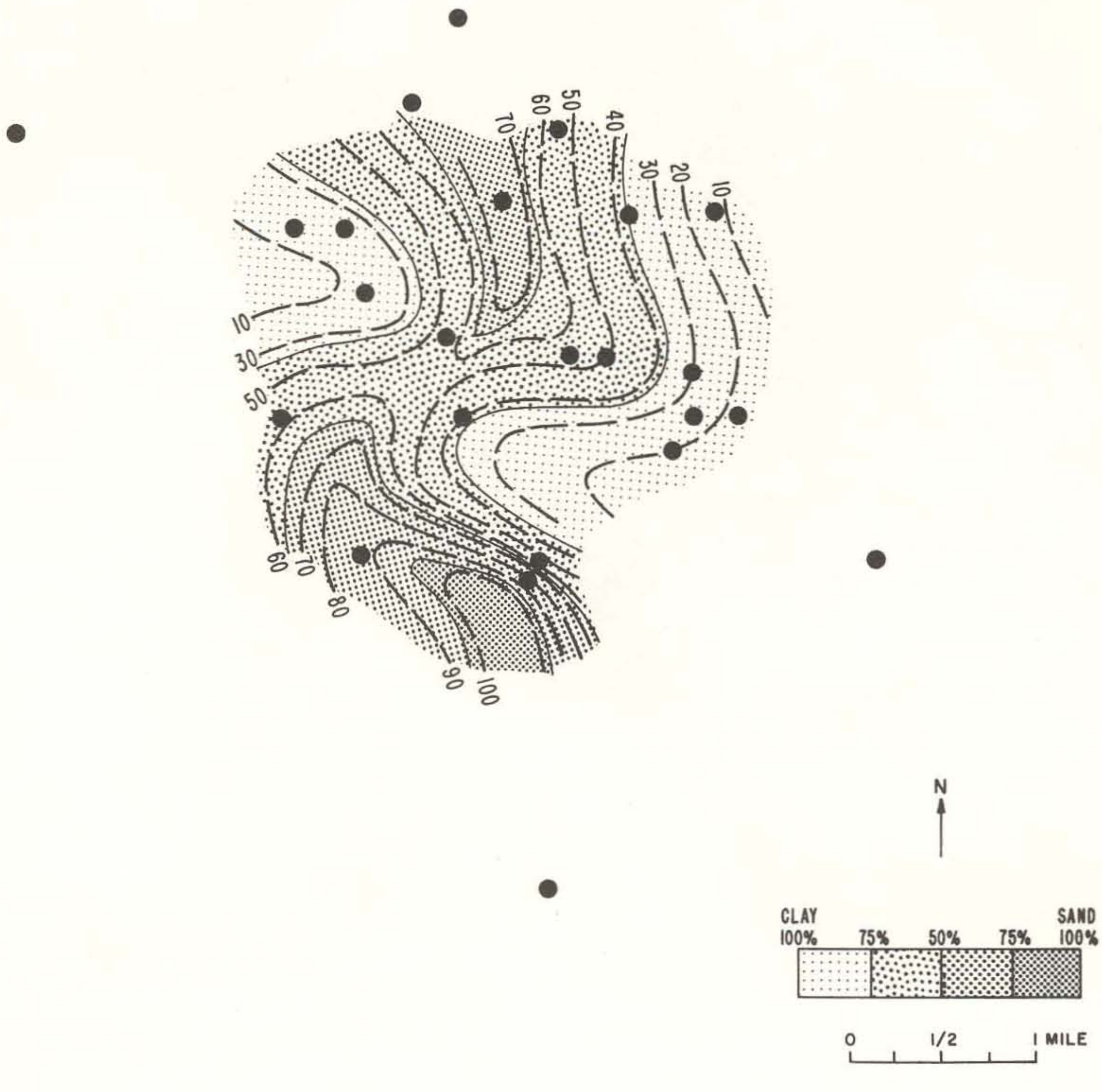

Figure 6. Layer no. 5. Sand distribution pattern is similar to that in layer no. 4; however, the trend of the sand body shows a rotational shift. Sand isolith contours are in feet.

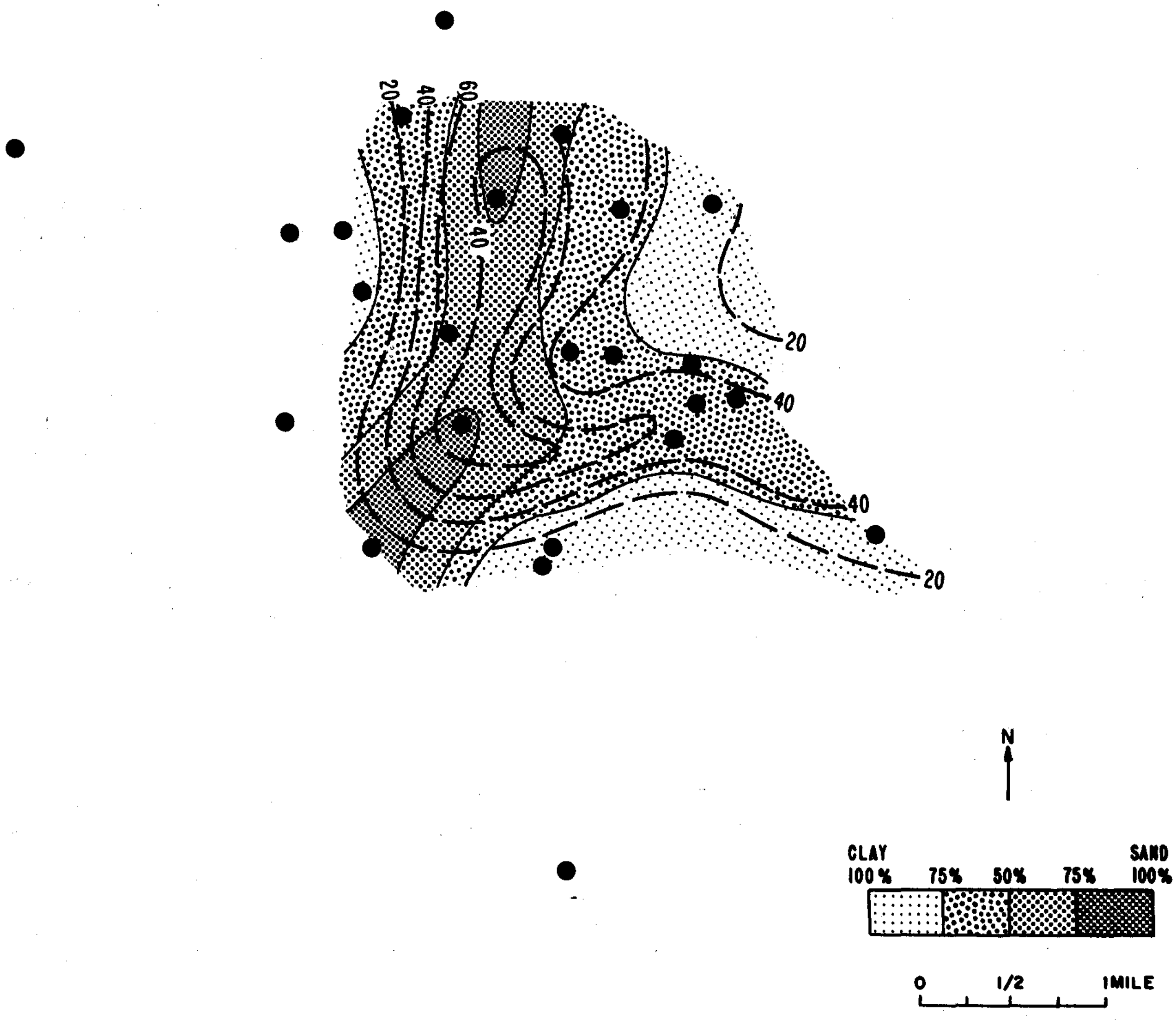

Figure 7. Layer no. 6. Western and southwestern parts of this layer are characterized by a thickness deficiency. In these parts the uppermost layer (no. 7) is entirely missing. Sand isolith contours are in feet.

Layer no. 7 (Figure 8) is the uppermost layer of the Potomac sequence. The sediments are present only in the eastern and southeastern parts of the study area. The sand distribution appears to have a pronounced trend; however, the uneven thickness of the layer and its deficiency in the thickness do not permit any conclusive interpretation.

Geometry of Sand Bodies

The term "geometry" as used throughout this study refers to more than merely three-dimensional form. It may be considered as being applied to two extreme size arrangements: 1) the primary sedimentary unit (layer), and 2) the composite unit made up of all layers and referred to as the Potomac Formation. In dealing with these two, the discussion includes shape (form), trend, and internal characteristics of sand bodies. If the origin of a sand body can be determined reasonably well, the interpretation becomes considerably simplified because sand bodies originating under various sets of environmental conditions have quite different and distinct geometric forms.

The examination of the sand geometry in each of seven layers of the Potomac sequence indicates two important things: 1) the sand distributions of all seven layers seem to be genetically related and, 2) the trend of the sand bodies suggests the deposition by unidirectional currents.

The genetic relationship is recognized by comparing all seven layers in a chronological order, i.e. from the lowermost one (layer no. 1) to the uppermost one (layer no. 7). There is a general tendency for the sand bodies to continue into the adjacent layer with only transitional modifications suggesting the depositional continuity.

The unidirectional nature of the depositional agents is suggested by the geometry of the sand bodies and the sand distribution patterns. The currents which deposited these sediments, however, varied somewhat in the direction of flow, which is reflected in the lateral shifts of the sand bodies, and particularly in the competency, which is evidenced by the variable sand percentage distributions in different layers.

In pure geometric terms, the sand bodies may be described as shoestring sands; however, in genetic terminology, they appear to be channel deposits. Nevertheless, the application of the term "channel" can be misleading since the maps do not give the vertical position of the sand bodies within the layers.

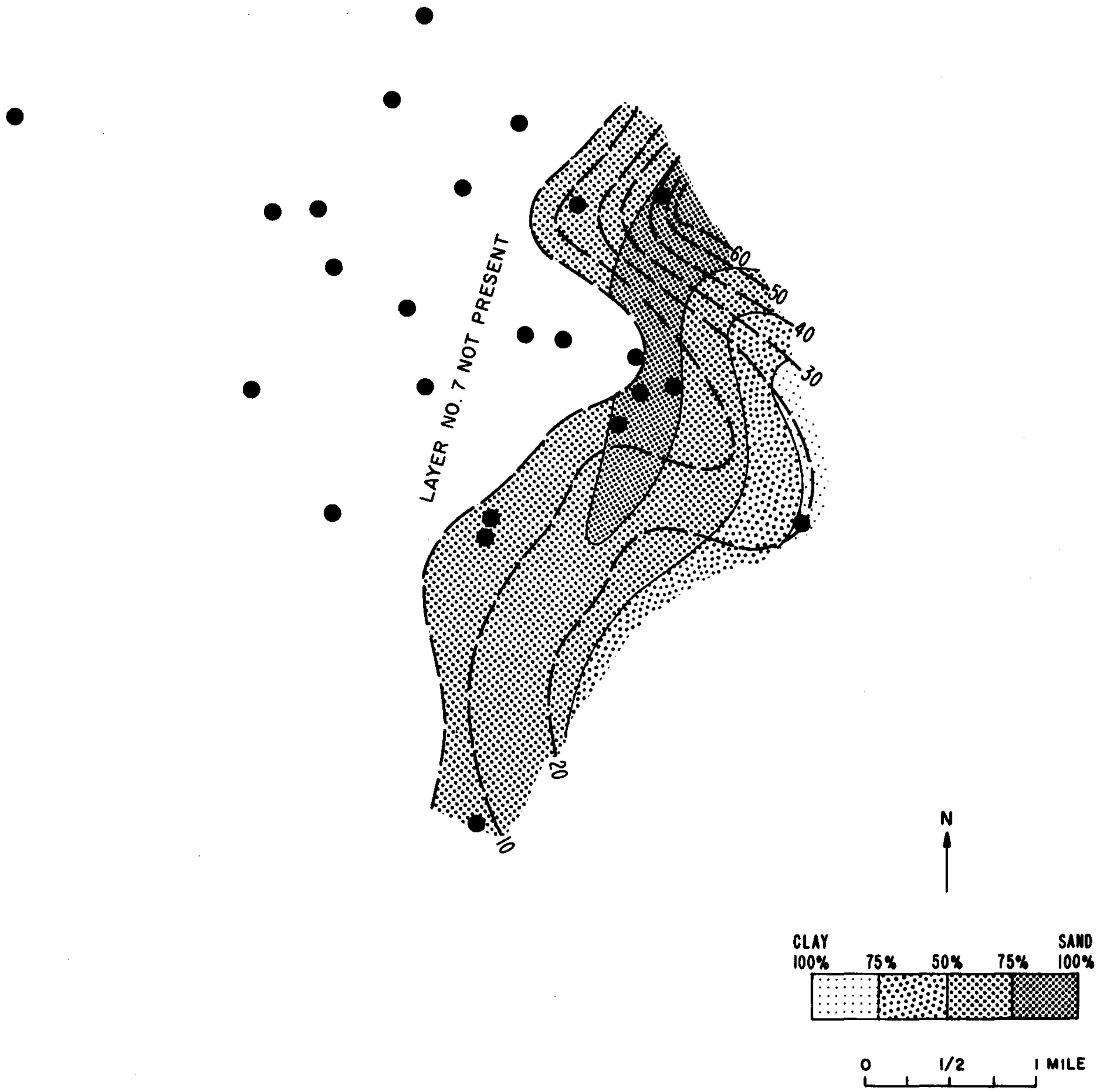

Figure 8. Layer no. 7. The area where the sediments of the layer no. 7 are not present is indicated. Sand isolith contours are in feet.

Thickness Deficiency

Theoretically, the relationship between the thickness of a clastic sedimentary sequence and its base elevation may be represented on a linear graph by a straight line. The application of this theoretical assumption to the Potomac sediments is represented in Figure 9. Plus-minus 50 feet is allowed for the measuring error which is considered quite reasonable since the total thickness of the sequence does not exceed 700 feet i.e. more than 14 per cent is allowed to be in error. Most of the points on the graph fall within the zone of the measuring error and very closely follow the theoretical line. However, 6 points are located in the area of the graph designated as thickness deficiency zone. Inasmuch as the discussion of the individual layers suggests rather continuous deposition throughout the Potomac section, with the exception of the uppermost two layers where this is undeterminable, the thickness deficiency may be explained by the removal of the uppermost part of the succession prior to the deposition of the younger Upper Cretaceous marine sediments. To verify this suggestion the isopach map of the Potomac Formation has been constructed (Figure 10). In the area designated as being thickness deficient the isopach map indicates an anomalous pattern with locally closely-spaced contour lines. These features of the isopach map may be indicative of the removal of a part of the sedimentary sequence (Bishop, 1960).

On the basis of the above discussion, it is suggested that erosion is the most probable cause responsible for the deficiency in thickness of the Potomac sediments in that part of the study area (Figure 11).

Composite Interpretation

The interpretation of the individual layers indicates two important things which appear to be common to almost all layers: (1) the deposition seems to have been continuous throughout the Potomac sequence, and (2) the geometry of the sand bodies suggests morphologic continuity with only some transitional modifications. This aspect of continuity is the most important conclusion reached by the study. However, it must be pointed out that a more detailed investigation could reveal some brief interruptions in deposition which probably would not alter the fundamental conclusions reached by this study.

The deposition of the Potomac sediments appears to have been continuous. Sediments deposited in a continental environment, such as these deposits, are only rarely

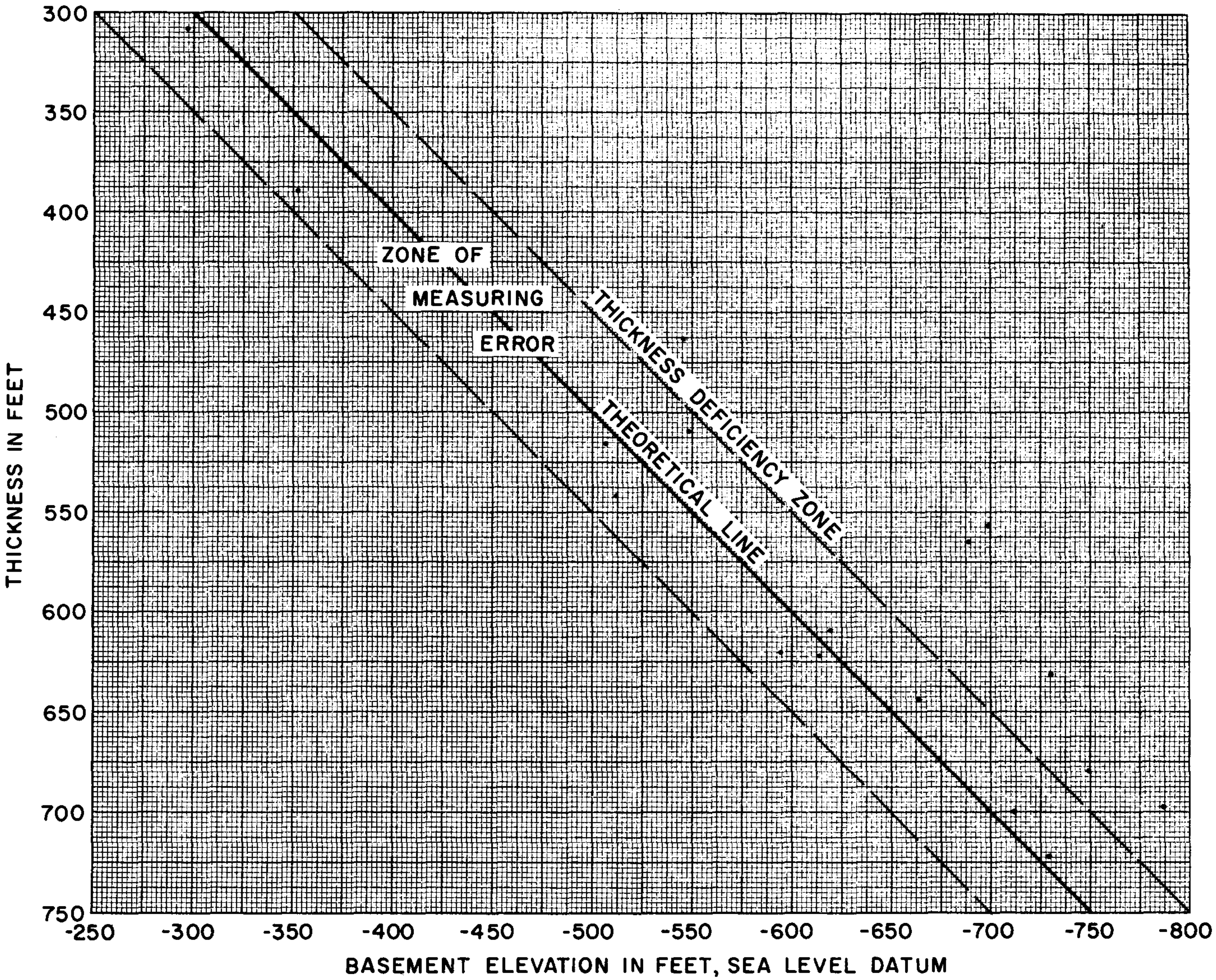

Figure 9. Graph showing the theoretical relationship between the thickness of the Potomac sequence and its base elevation. It is assumed that the zone of the measuring error suffices not only for the inaccuracies resulted from the measuring but also for the change of the average dip caused by the epeirogenic subsidence of the area as well as the distortions produced by the compaction of the sediments.

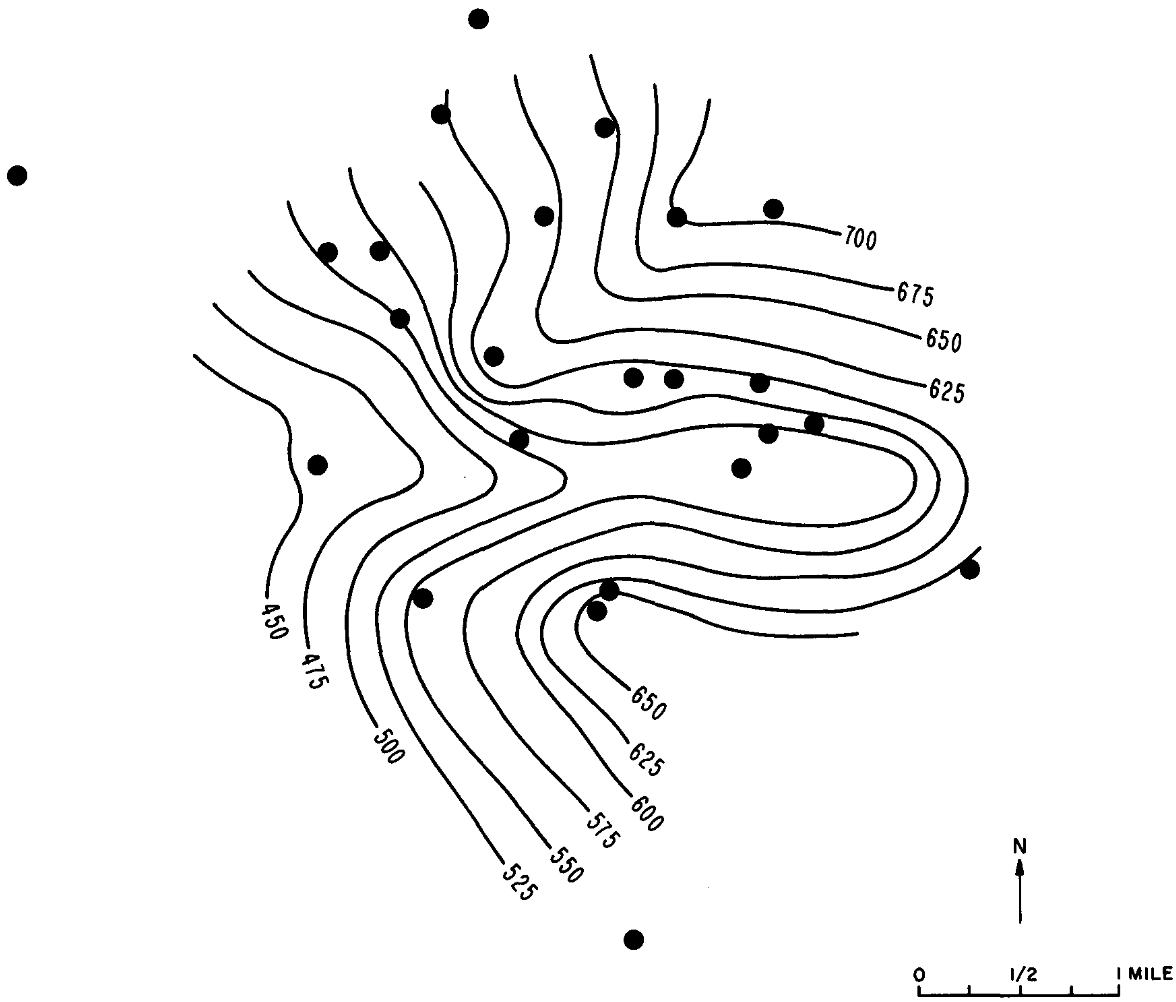

Figure 10. Isopach map of the Potomac Formation. Note anomalous pattern and significant change of the spacing between the contour lines. Thickness is in feet.

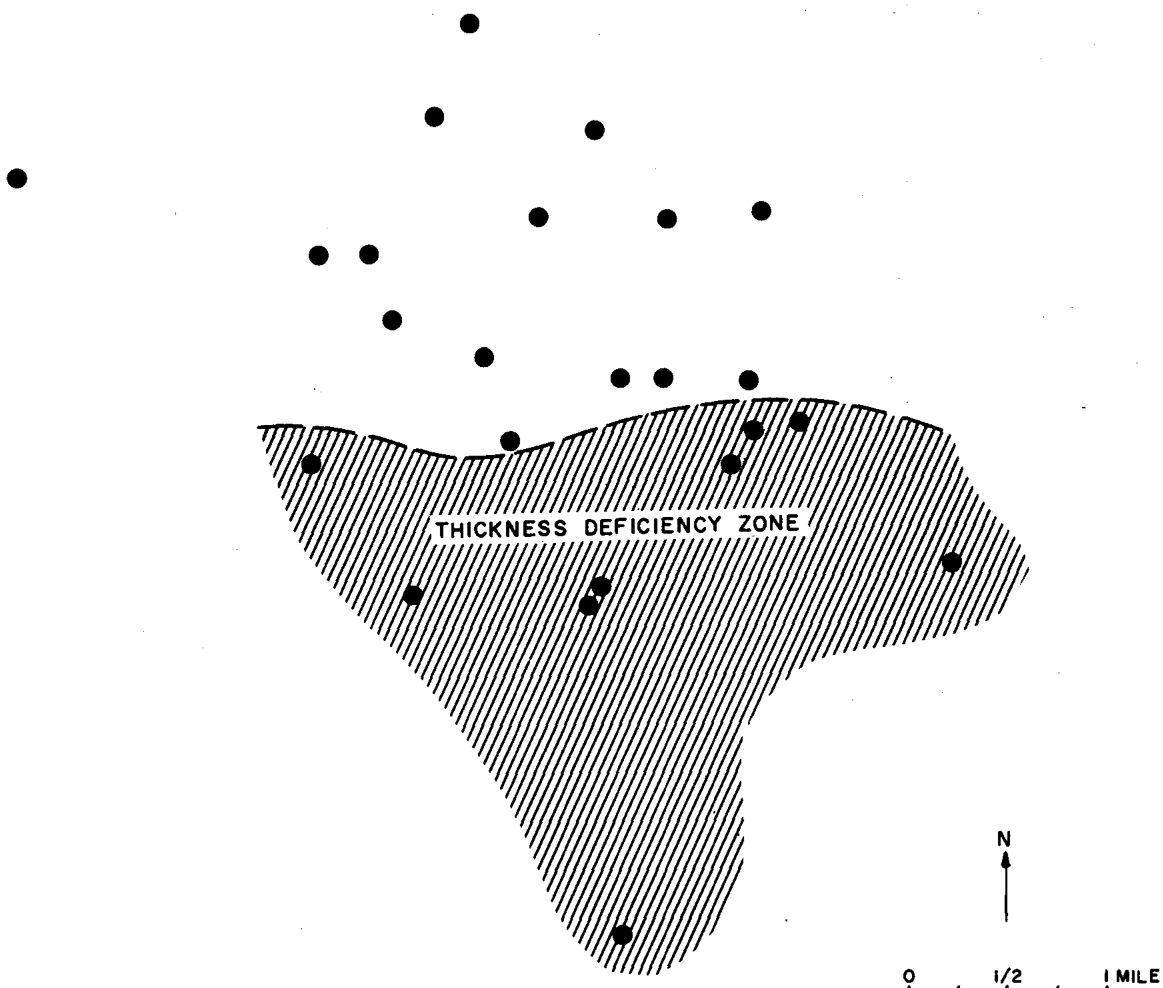

Figure 11. Area of Potomac thickness deficiency apparently due to erosion prior to the deposition of the younger Upper Cretaceous marine sediments.

preserved since they are most likely to be removed by various erosional processes. If they are preserved, the rate of deposition and tectonic subsidence are the most likely factors responsible for it.

Unidirectional currents are suggested as the transporting agents of the Potomac deposits. However, it is not possible to detect the direction of their flow owing to the nature of the available subsurface data.

The interpretation of environments of deposition from the electric logs as applied to this study is shown in Figure 12. It reveals three closely related environments in which the deposition of the Potomac sediments in this area took place: channel, bank, and flood plain. Channel deposits are recognized on the electric logs by their general tendency to decrease in grain size upward in the section. In the case of steady flow deposition, however, the grain size distribution may be uniform throughout the interval. The over-bank deposits usually bear the "imprints" of small flow fluctuations and are composed of thin layers of coarse and fine sediments. A channel sequence may have similar characteristics; however, the individual beds are usually much thicker. Flood plain deposits, which are here considered to be the outward extension of the bank deposits, are, generally, composed of fine sediments laid down under tranquil flow conditions.

The flow fluctuations of the Potomac streams seem to have been relatively frequent as evidenced by the electric logs. The direction of the flow was also variable and this has been discussed elsewhere in this study. The mapping of the environmental features has not been attempted because of the inability of the applied method to give the vertical position of sand bodies within the layers and extreme difficulty in lateral correlation of individual beds from the electric logs.

The persistence of the depositional trends, pointed out previously, is a remarkable characteristic which very consistently correlates with the depositional continuity. The initial trend, however, was strongly influenced by the basement topography. The structural map of the surface of the crystalline basement complex is shown in Figure 13, and reveals two distinct valleys extending, generally, west-east; they are separated by a narrow ridge which widens in its eastern part. The central part of the "northern valley" is a flat area and it makes a distinct change in topography between the two extreme parts of the valley. The "southern valley", however, deepens uniformly toward the east. Figure 13 represents actually the distorted replica of the

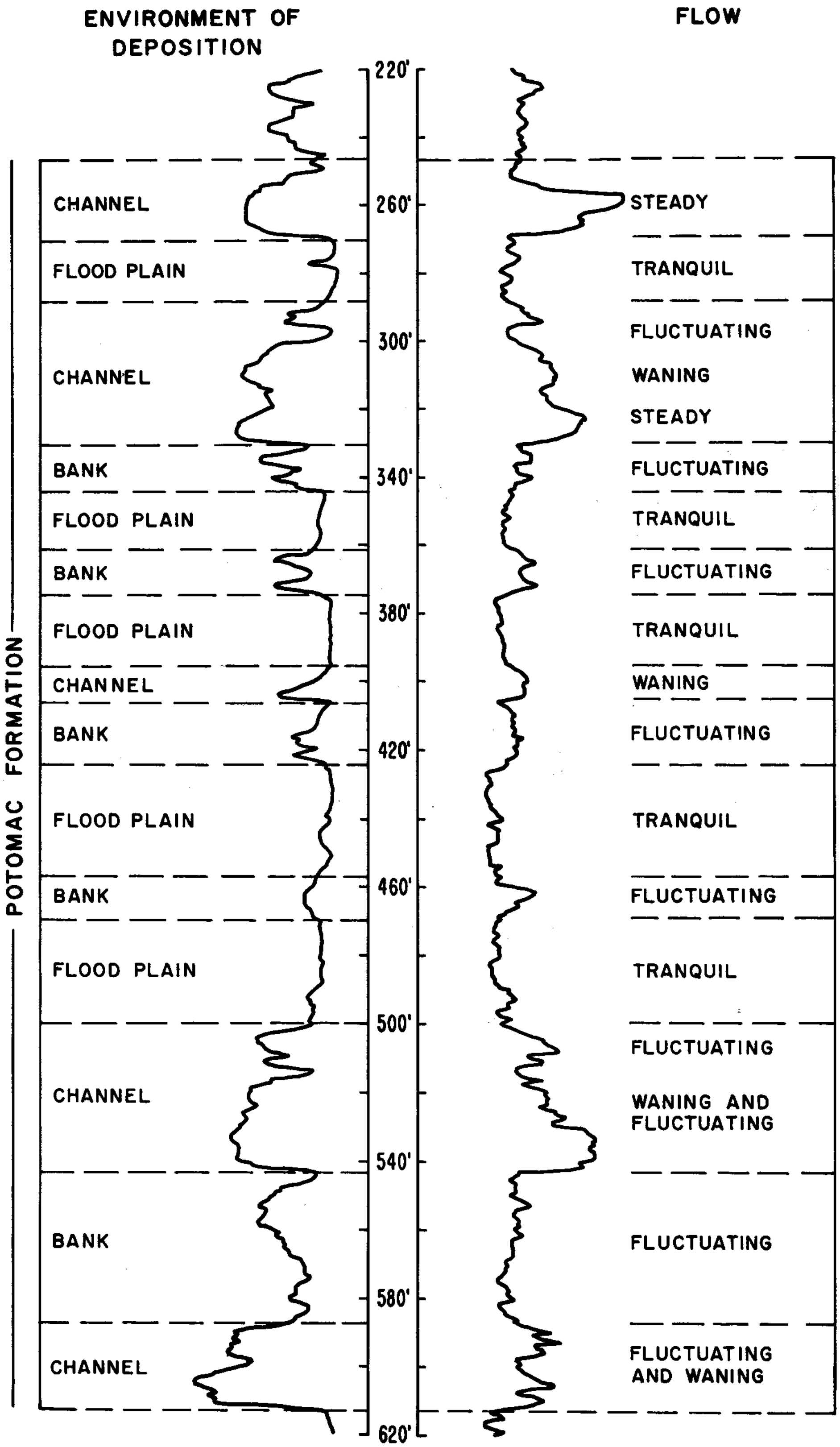

Figure 12. Interpretation of depositional environments and general flow characteristics of well Dc52-1. Lateral correlation of the individual environments has not been attempted because of the complex lateral lithofacies changes and the large spacing between individual wells.

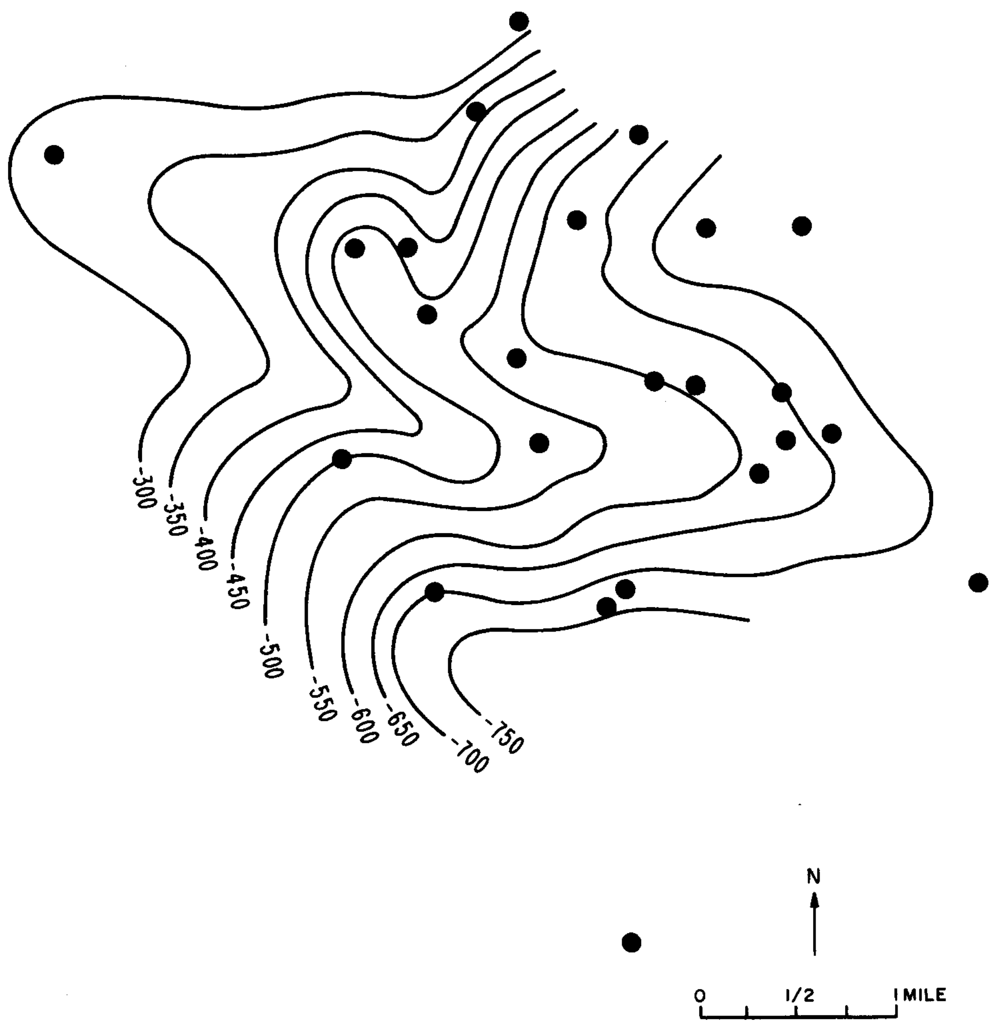

Figure 13. Structural map of the surface of the crystalline basement complex. The "northern" and "southern" valleys and the narrow ridge which separates these two are apparent. Contours represent the depth to the basement complex in feet measured from sea level datum.

original configuration of the basement topography since the whole Coastal Plain region has experienced epeirogenic downwarping, and it is, therefore, necessary to level off the structural map to obtain the original configuration. Such a process reveals the change in the direction of the trend of the topographic features. The general trend is now north-south as indicated in Figure 2. The influence of this initial trend may be followed into the layers no. 2 and 3 (Figures 3 and 4) which suggests that the depositional trend of the Potomac sediments, at least in the lower part of the succession, has been governed by the configuration of the crystalline basement complex.

CONCLUSIONS

(1) The deposition of the Potomac sediments appears to have been continuous throughout the time of their formation. Interruptions, if they indeed existed, were probably short so that they did not alter the apparent depositional continuity.

(2) The depositional trend is remarkably consistent through the Potomac section and is characterized by only transitional modifications.

(3) The geometry of the sand bodies resembles the shoestring channel deposits formed by unidirectional currents. The direction of the flow, however, cannot be determined on the basis of the available data.

(4) The initial deposition of the Potomac sediments was governed by the basement topography. The influence is apparent in the lower three layers of the section.

(5) The uppermost part of the Potomac sequence seems to have been removed by erosion. The most conclusive evidence for this is the observed thickness deficiency and the anomalous pattern of the isopach map of the whole Potomac sequence.

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