The Stratigraphy Of The Trimmers Rock Formation In Northeastern Pennsylvania.

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THE STRATIGRAPHY OF THE TRIMMERS ROCK FORMATION IN NORTHEASTERN PENNSYLVANIA

by

Lane Donald Schultz

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J. Donald Ryan

Paul B. Myers Jr.

Accepted June 21, 1974

Special committee directing the doctoral work of Mr. Lane Donald Schultz

J. Donald Ryan
Co-chairman

Paul B. Myers Jr.
Co-chairman

Bobb Carson

James M. Parks

William D. Lee

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PLATE

ABSTRACT

The Trimmers Rock Formation is a marine turbidite facies of Upper Devonian age. In northeastern Pennsylvania the unit consists of shale, siltstone, and minor fossiliferous lenses with a virtual absence of sandstone. Along the Lehigh River, a thin, calcareous shale layer, the Tully Limestone equivalent, immediately underlies the turbidite sequence. To the east this relationship is not obvious but probably present. The top of the unit lies immediately below the base of the first thick sandstone bed of the Towamensing Member of the Catskill Formation.

Turbidite structures found within the rocks include graded and finely laminated siltstones, disturbed laminae, and non-laminated intervals of mixed silt and clay or clay-sized sediments. "Ball and pillow" structures apparently are related to the thixotropic failure of lutite sediments overlain by silt rapidly deposited during a turbidity event.

Sediments were dispersed through several complex delta loci. Both turbidite and nonturbidite deposition took place upon the paleoslope. Sediments deposited between loci were transported by shoreline-parallel currents.

The Trimmers Rock Formation is interpreted as the prodelta facies of the northwestward and westward prograding Catskill Delta. The ancestral coastal fringe was situated southeast of the study area.

The prodelta facies thickens to the northeast from approximately 1000 feet in Schuylkill and Carbon Counties to a maximum thickness of approximately 1400 feet in Pike County. Widening of the coastal shelf during deposition is postulated to have occurred in the Pike County area.

Initially, sediments involved in deltaic sedimentation were derived from the granitic and metamorphic highlands of the Piedmont. However, as the shoreline prograded westward and northwestward, source materials were available from an uplifted source area which migrated contemporaneously with seaward construction of the Catskill clastic wedge. A process of cannibalization evidently was established wherein delta sediments were recycled and the existing prodelta facies no longer reflects mineralogically the crystalline detritus originally eroded from the Piedmont.

INTRODUCTION

The Upper Devonian Trimmers Rock Formation in northeastern Pennsylvania is transitional between the deep off-shore marine sediments of the Middle Devonian Mahantango Formation and the shallow near-shore marine sediments of the Upper Devonian Towamensing Member of the Catskill Formation. It was the purpose of this investigation to study the stratigraphy of the Trimmers Rock in order to determine its depositional environment and the relationship of that environment to those of the overlying and underlying rock units.

The paleoenvironment of the Trimmers Rock Formation is interpreted as the prodelta facies of a northwesterly prograding clastic wedge. Although the shales and siltstones comprising this transitional interval presumably have undergone turbidity transport and deposition, they are atypical of many turbidites elsewhere in the world owing to a conspicuous lack of abundant sand.

The rocks of the Middle and Upper Devonian series in Pennsylvania and New York have been examined in considerable detail over the course of the past 130 years. The earliest investigations summarily described the stratigraphy of the units largely on the basis of their faunal content in New York (Hall, 1839, 1840; Vanuxem, 1839, 1840, 1842; Emmons, 1846). Lithologic descriptions were published by Rogers

(1858) in his differentiation of the Devonian in the Formal Report of the First Pennsylvania Geologic Survey.

After the turn of the century, a complex pattern of Devonian deltaic sedimentation was postulated by Barrell (1913, 1914a, 1914b). Chadwick (1933, 1944) further refined the facies concept and applicability of this concept to the understanding of the spatial relationships of Devonian rock units in New York. Similarly, Cooper (1941) conducted extensive field studies in New York, applying the facies concept to the Devonian of that state. In Pennsylvania, Willard made many significant contributions toward understanding Middle and Upper Devonian stratigraphy. His Catskill Delta model (1939), indicating a general westward regression of the Upper Devonian shoreline within Pennsylvania, has proved to be especially valuable.

Continual refinements of earlier stratigraphic work as well as modifications to this model of deltaic sedimentation were contributed by many, including Colton and deWitt (1958), deWitt and Colton (1959), and Sutton and others (1962). In 1963 a "Symposium on Middle and Upper Devonian Stratigraphy of Pennsylvania and Adjacent States" was held in Stroudsburg, Pennsylvania. The proceedings of this meeting have been recorded in a volume edited by Shepps (1963).

During the last decade considerable effort has been concentrated on reconstruction of the depositional environments of the Catskill Delta sediments. The Devonian correlation chart and geologic map prepared by the New York State Geological Survey (Rikhard, 1964, and Broughton, J.G. and others, 1962) have been of considerable importance in facies reconstructions in New York. Sutton and others (1970) have discussed the environmental history of the marine shelf of the Catskill Delta in New York during Upper Devonian time. Mazzullo (1973a, 1973b) carried out similar studies on the Middle Devonian marine rocks of the Hamilton Group in New York and argued that existing evidence of Middle Devonian terrestrial deposition suggests that deltaic conditions actually were initiated in the Middle Devonian. Glaeser (1973) has contributed largely to the further differentiation of the Catskill rocks particularly in central and eastern Pennsylvania. Basic field mapping by Sevon, Epstein, and Berg (1973) in the northeastern sector of the state has been successful in demonstrating the mappability of Glaeser's Catskill units. A new interpretation of the Upper Devonian stratigraphic column in Pennsylvania as reported by Walker and Harms (1971) and Walker (1971, 1972) has resulted in the proposed revision of Willard's Catskill Delta model, arguing that the depositional model is like that of a westward prograding muddy shoreline marked by episodic regressive and transgressive sequences.

The marine facies of the Catskill deltaic complex have received far less attention throughout the evolutionary development of contemporary models than the younger continental facies. Willard (1935) recognized the distinctiveness of this marine facies (which includes the Trimmers Rock) in central Pennsylvania and assigned it as a member of the Fort Littleton Formation. Frakes (1967) attempted a regional stratigraphic correlation of the Trimmers Rock and offered an interpretation of its depositional environment generalized for the whole of Pennsylvania. Walker (1971) investigated the Upper Devonian of central Pennsylvania. He correctly noted that to the east of his study area significant stratigraphic changes can be recognized which indicate changes in the depositional processes for both the marine and continental facies.

METHODS OF STUDY

Detailed information was obtained from measured sections at seven localities in Pike, Monroe, Carbon, and Schuylkill Counties in northeastern Pennsylvania (Appendix). Exposures at other localities in these counties were also studied. Particular attention was addressed to the relative stratigraphic position of disrupted intervals characterized by the conspicuous presence of ball and pillow structures.

Representative, oriented samples were collected so that other depositional structures also could be studied. Many of the specimens collected were slabbed and polished so that the details of the structures could be better observed. Sedimentary structures were also studied in thin section.

In characterizing the textural elements of the siltstones, a microscopic examination was made of 16 thin sections representative of the coarsest siltstone beds observed within the indicated sections. Several complete traverses were made across each thin section and the percentages of each component--sand, silt, and clay matrix--were calculated from 300 point counts on each slide. The results of these studies are shown on Figure 16 and the data is included within the Appendix.

Mineralogical determinations were conducted both by microscopic examination and by X-ray. Silt-size framework constituents were identified on the basis of 400 point counts. The results of these studies are also included within the appendix. Only tentative conclusions regarding the matrix material could be reached by using optical methods. Therefore, samples of siltstone and shale were pulverized and wet sieved thereby isolating the silt and clay fraction. The less-than-five micron fraction subsequently was separated through settling in distilled water using a settling time calculated according to Stokes Law. The suspended fraction obtained was concentrated by centrifuging and decanting. Pipetting was used to transfer the final suspension to a petrographic glass slide. The glass slide was dried for 24 hours and then glycolated according to the method of Brunton (1955). The sample was X-rayed on a standard Norelco wide-angle X-ray diffractometer with a gas proportional counter using nickel filtered copper K_{α} radiation at 40 KV. and 20 MA. The scanning speed was one degree-two θ per minute and the chart speed was ½-inch per minute; this provided a one degree-two θ per ½-inch printout. The divergent, scattering, and receiving silts were one degree, one degree, and 0.006 inch, respectively. The rate meter was set at four, one, four for the scale factor, multiplier, and time constant, respectively. The mineral identifications obtained from these X-ray analyses can only be considered qualitative.

LOCATION AND REGIONAL GEOLOGY

Within northeastern Pennsylvania the Trimmers Rock Formation forms a continuous belt traversing the four-county study area, Schuylkill, Carbon, Monroe, and Pike Counties, generally following a northeasterly trend (Figure 1). The northern limit of study is at the west bank of the Delaware River near the village of Millrift, Pennsylvania. The southwestern limit of study is a nearly complete section measured along the east side of Pennsylvania Route 433 north of New Ringgold.

In Schuylkill and Carbon Counties and part of Monroe County, the unit lies in the Appalachian Mountain Section of the Valley and Ridge Physiographic Province. This section is characterized by a structural terrain which changes from west to east (Sevon, Epstein, and Berg, 1973). In the west folds are nearly symmetric, although in places they are steepened or overturned on the north-dipping limb with wavelengths greater than one mile and amplitudes of 3,500 feet or more. The fold axis of the Lehighton Anticline passes through the town of Lehighton with a southwesterly bearing and plunge (See Plate 1). Parallel to this axis and to the south, an elongated structural trough is formed by the doubly plunging fold axis of the Weir Mountain Syncline (See Plate 1). The Trimmers Rock Formation is exposed on the

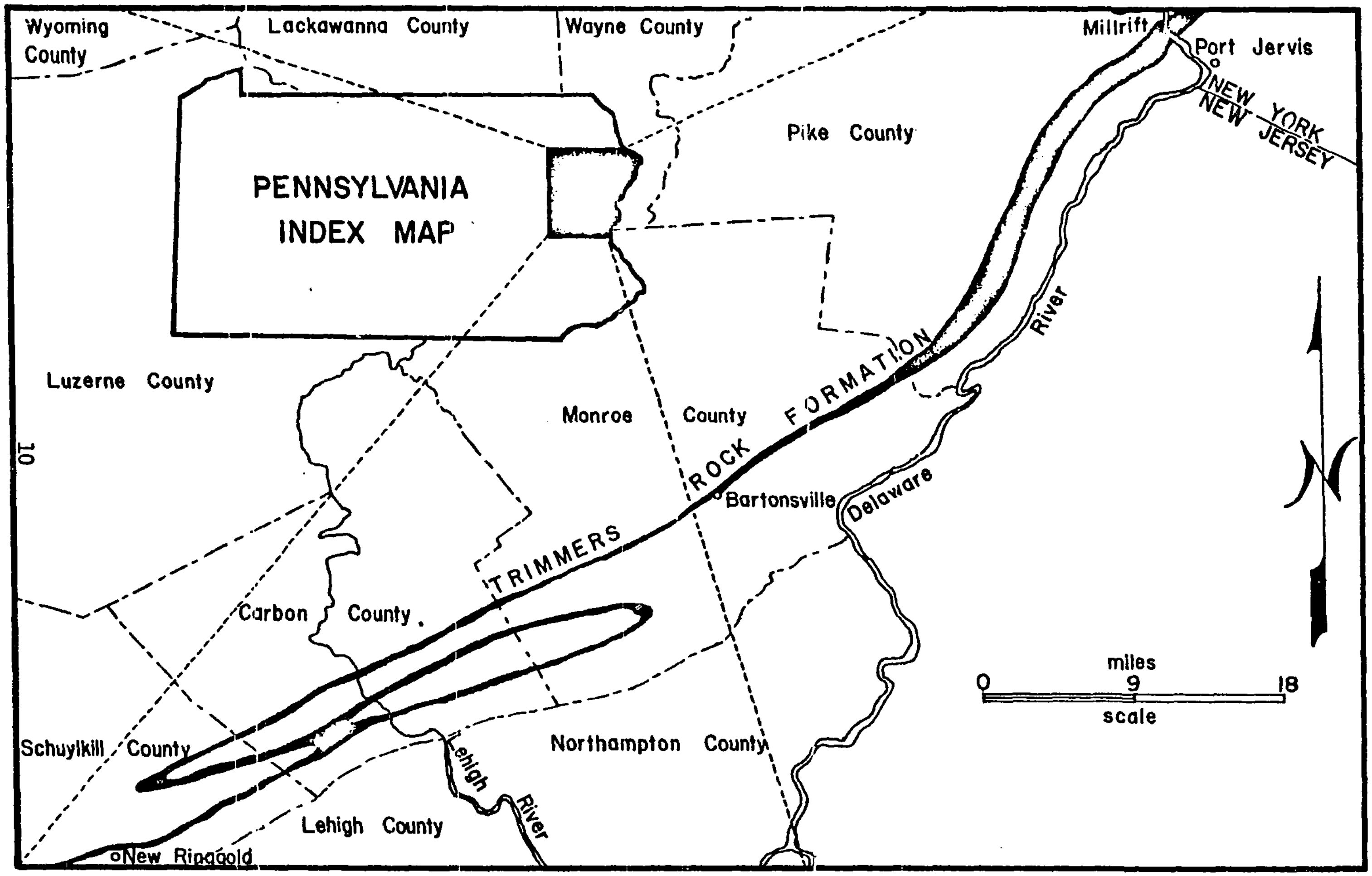


Figure 1. Index map of the Trimmers Rock Formation in northeastern Pennsylvania.

eroded limbs of these major folds. To the east in central Monroe County, the magnitude of these folds decreases and the previously cited major folds die out. The Trimmers Rock Formation is exposed sporadically to the northeast along the gently northwesterly dipping limb of the projection of the Lehighton Anticline.

Near where the Trimmers Rock Formation traverses the boundary of Monroe and Pike Counties in the vicinity of Analomink (See Plate 1), the unit forms a southeasterly sloping escarpment of the Glaciated Low Plateau Section of the Appalachian Plateau Physiographic Province. In Pike County there is approximately 100 feet of relief associated with this slope. Parallel to this ridge and to the southeast are the scenic, nearly vertical cliffs of the Mahantango Formation which mark the western boundary of the Appalachian Structural Front.

According to the interpretations of Epstein and Epstein (1967), the Middle and Upper Devonian rocks fall within their "Lithotectonic unit 4." They describe the style of folding within this unit as nearly symmetric, concentric, and predominantly flexural slip. In addition to the Lehighton Anticline and Weir Mountain Syncline, other smaller folds of very low amplitude and long wavelength have been mapped by the writer west of the Structural Front in Pike County.

Presumably, a zone of décollement exists within the Marcellus Formation, the older subdivision of Willard's

(1939) Hamilton Group, as evidenced by flow cleavage which, along with major folding, becomes progressively more intense to the southwest. This cleavage is present but less well developed in the Mahantango escarpment facing the west bank of the Delaware River in Pike County and dies out within the formation to the northwest. In central and western Pennsylvania, upward-shearing décollement zones frequently cause the repetition of stratigraphic sequences (Gwinn, 1964). This phenomenon has neither been reported by others nor observed by the writer in the study area. Most probably the deformation of the Appalachian Mountain Section in northeastern Pennsylvania is of Late Paleozoic Age.

At least two periods of Pleistocene glaciation have left a veneer of glacial drift over most of the study area. Southeast-facing slopes are sometimes covered with a thick deposit of either till or colluvium; west-facing slopes which are subparallel to bedding surfaces are usually covered with thinner deposits of till or colluvium. In some cases the northwest-facing slopes are bare; consequently, isolated bedrock exposures are rare. Additionally, severe freeze and thaw conditions, characteristic of periglacial times, have caused considerable disintegration of the occasional bedrock exposures. Commonly, the weathered surface of an exposure is remarkably dissimilar in appearance to a fresh surface of the same rock. Where closely spaced joint sets and fracture cleavage have increased the depth of penetration of weathering, representative fresh samples were extremely difficult to obtain. In fact, the combined effects of glacial drift deposition, colluviation, and periglacial weathering in most instances preclude the physical tracing of distinctive beds or stratigraphic sequences for distances exceeding a few hundred feet.

STRATIGRAPHY

General

Logs of seven measured sections in the form of stratigraphic columns are listed in the appendix. Where indicated, both published and unpublished data were evaluated and integrated along with that which was collected independently by the writer. Nearly complete sections of the Trimmers Rock Formation are found along the Lehigh River and north of New Ringgold. Further to the northeast, continuous exposure from top to base is lacking, although the approximate stratigraphic position can be calculated from isolated outcrops.

Historical Background

Figure 2 summarizes the historical development of stratigraphic nomenclature pertinent to and including the units differentiated within the scope of this investigation.

The first systematic subdivision of Paleozoic rocks in Pennsylvania was attempted by H.D. Rogers in the mid 1800's. In the Second Annual Report of the First Geological Survey of Pennsylvania (Rogers, 1838), Rogers assigned Roman numerals to identify the major rock formations of the state. His Unit VIII included nearly everything overlying what is now known as the Oriskany Formation but underlying what is

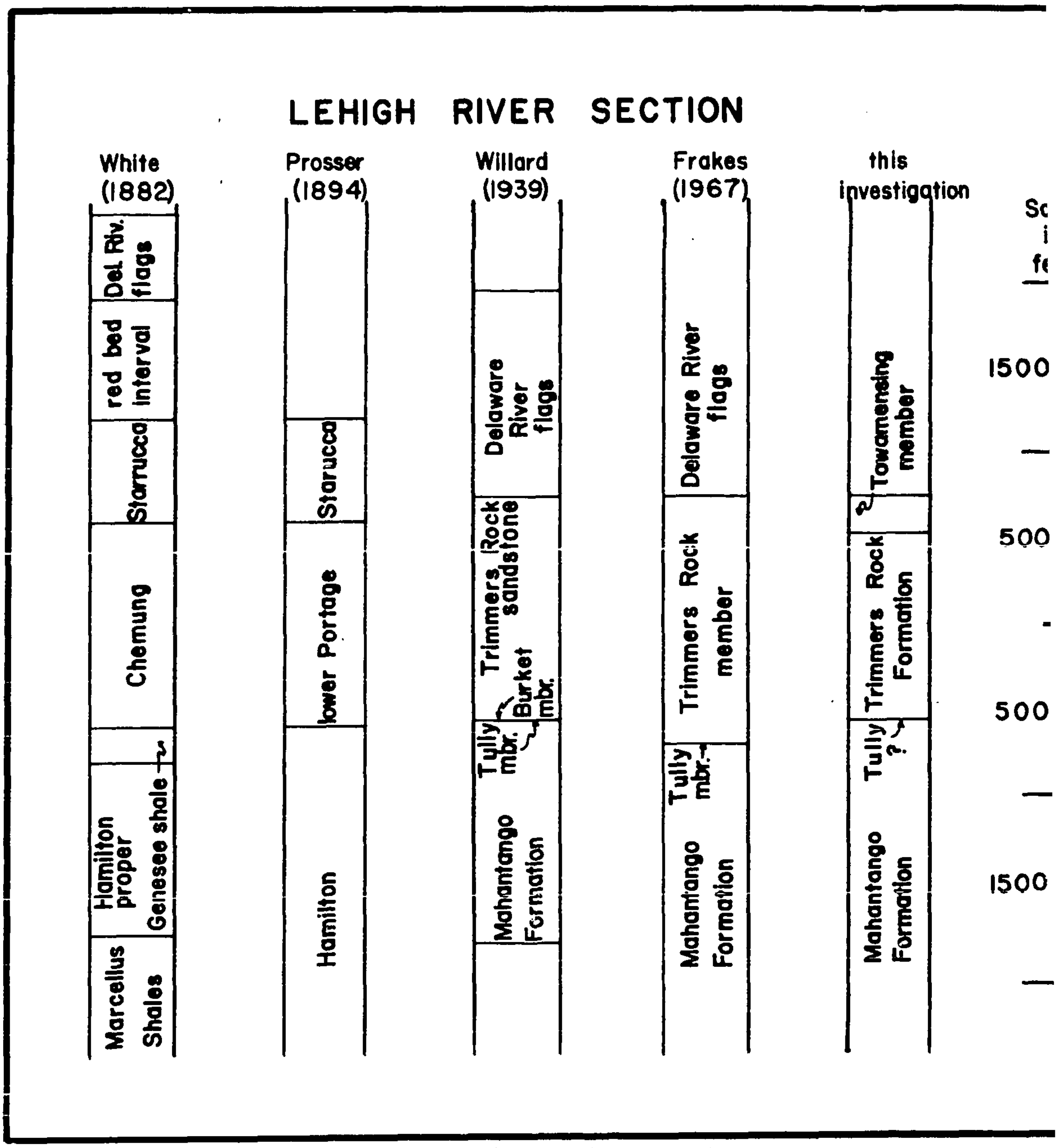
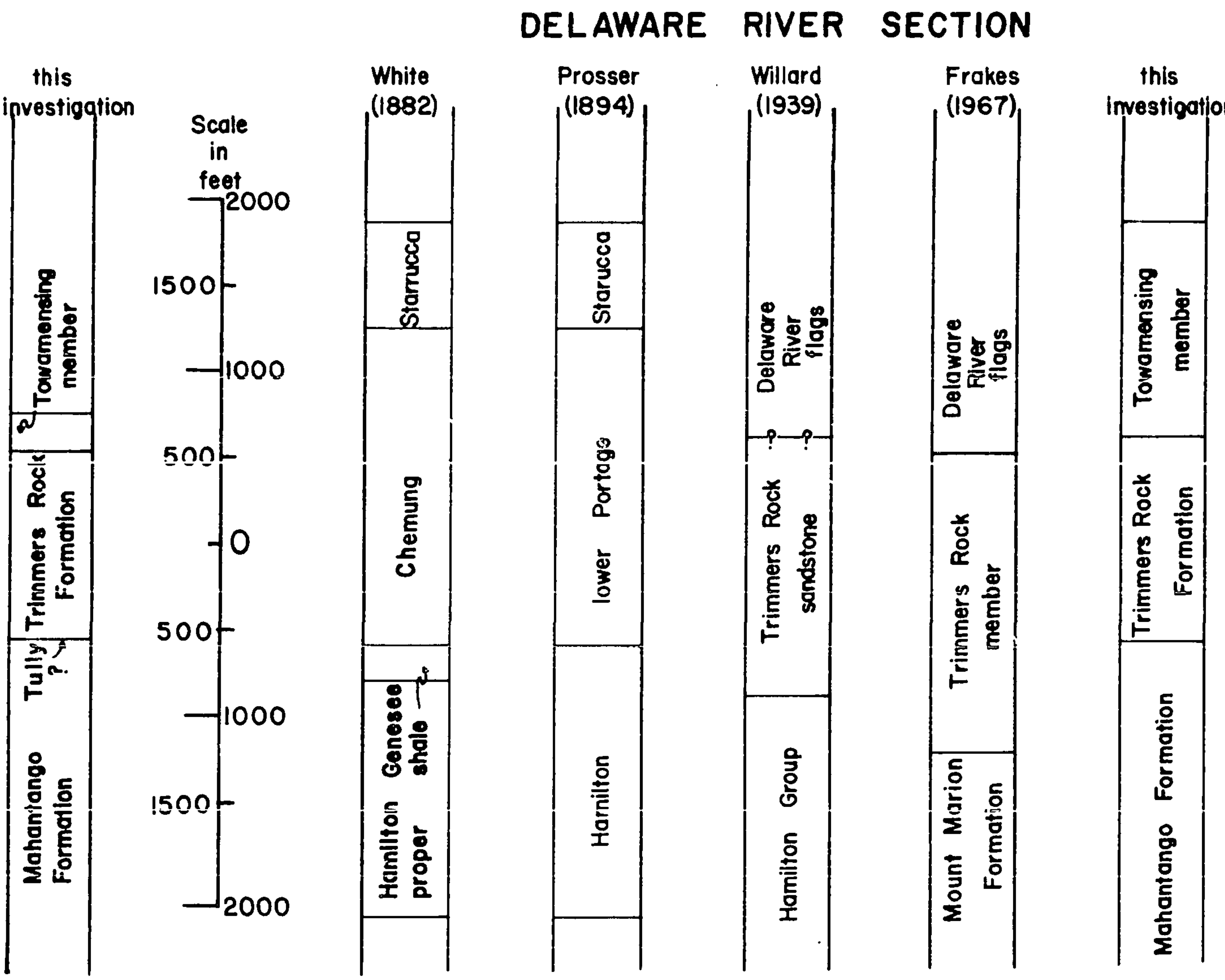


Figure 2. Summary of part of the Middle and Upper Devonian stratigraphic nomenclature in northeastern Pennsylvania.


DELAWARE RIVER SECTION
this investigation
Scale in feet
2000
1500
1000
500
0
500
1000
1500
2000
White (1882)
Prosser (1894)
Willard (1939)
Frakes (1967)
this investigation
Towamensing member
Trimmers Rock Formation
Tully
Mahantango Formation
Starucca
Chemung
Genesee shale
Hamilton proper
Starucca
lower Portage
Hamilton
Delaware River flags
Trimmers Rock sandstone
Hamilton Group
Delaware River flags
Trimmers Rock member
Mount Marion Formation
Towamensing member
Trimmers Rock Formation
Mahantango Formation

per
tern

now thought to be the continental facies of the Catskill Formation. Rogers assigned a thickness of 5000 feet to the strata within this unit which corresponds reasonably well with today's reported thicknesses of this section of the Devonian. It is not possible to determine how much of this interval is represented by the Trimmers Rock, although his accompanying stratigraphic column shows about half of the section to consist of olive-colored slate and gray argillaceous sandstone. This is roughly comparable to the combined thicknesses of the Mahantango and Trimmers Rock Formations.

The Second Pennsylvania Geological Survey under the next State Geologist, J.P. Lesley, published a geologic map of each county in the state and applied formational names (obtained largely from New York) to units designated previously by Roman numerals. The principal investigator in northeast Pennsylvania was I.C. White, an extraordinary geologist, whose published work (1882) is the most complete reconnaissance study of the geology in this sector of the state. White defined the "Catskill Series" as those rocks underlying the Pocono Series and overlying the Chemung Series. These Catskill rocks included a basal, non-red, predominantly sandstone unit which he termed Starrucca Sandstone. Lesley (1885, 1892) was critical of White's stratigraphy and insisted on moving the base of the Catskill upward, excluding the Starrucca and therein conforming with the Catskill stratigraphy of central and southcentral Pennsylvania.

Much of the disagreement between Lesley and White and among other earlier authors dealing with the Upper Devonian resulted from their failure to recognize the westward progradation of the Catskill shoreline. The unit in question, the Starrucca (shale) sandstone, consisted of nearly 600 feet of dominantly grayish-green sandstone as measured by White on the Pennsylvania side of the Delaware River north of Millrift. The underlying unit was mapped as the Chemung Series and its outcrop belt coincides approximately with what recently has been mapped by the writer and others as the Trimmers Rock Formation. It was Lesley's contention that the Starrucca should be included within the Chemung Series. White conceded with reluctance.

The Chemung Series reported by White decreased in thickness from 1850 feet along the Delaware River to 1200 feet along the Lehigh River. It seems probable that strata of the underlying unit, correlative with today's Mahantango Formation, were included in the measured Delaware River section since no datum plane exists at the base of the Chemung. As defined by White, the underlying Hamilton Series comprised three units: the Genesee Shale, the Tully Limestone, and the Hamilton Sandstones or Hamilton Proper from youngest to oldest, respectively. It is highly probable that

White incorrectly correlated as Tully equivalents beds of fossiliferous biostromes which are actually stratigraphically lower within the Mahantango Formation.

Prosser (1894) re-examined the Upper Devonian in eastern Pennsylvania and concurred with White's earlier subdivision of the lower Catskill Series which included the Starrucca sandstone. He further noted that the Chemung fauna, particularly Spirifer disjunctus, appeared to be lacking from that which White had mapped as Chemung Series. Prosser concluded that White had incorrectly identified Spirifer measastrilatis as Sprifer disjunctus. Therefore, owing to the dissimilarities between the observed fauna in this interval and typical Chemung, he renamed it Portage and reported a regional thickness of 1150 feet in northeastern Pennsylvania.

The work of the Third Pennsylvania Geological Survey and contemporaneous independent investigations added little to the knowledge of the overall Devonian stratigraphy. Actually, it was not until the decade of the 1930's that a resurgence of activity in the realm of non-economic geology was initiated under the auspices of the Fourth Pennsylvania Geological Survey. The prime investigator of the Middle and Upper Devonian during this era was Bradford Willard.

Willard, whose studies were largely biostratigraphic, initially (1932) restricted the interval lying between the

Hamilton and Catskill Groups to the Ithaca Formation of the Portage Group. In 1935 Willard placed the base of the Upper Devonian at the top of the Mahantango Formation. The type section for the Mahantango Formation lies in central Pennsylvania. Further subdivision of this unit is strictly on the basis of fauna as described by Willard. He also subdivided the Catskill Facies Group (see especially, 1939). He defined the base of the Catskill strata as the first appearance of red beds and named these lowermost red beds the Analomink red shale. To the east in Pike County, rocks of this first red-bed Catskill unit, the overlying Delaware River Flags and underlying Trimmers Rock were presumed to be of Portage age. Consequently, White's Starrucca sandstone had again lost its identity.

Willard (1939) described the Trimmers Rock as a sandstone unit and designated it as a member of the Fort Littleton Formation. His type locality for the Trimmers Rock is a prominent hill bearing the same name and lying 1½ miles east of Newport, Perry County, along the west bank of the Juniata River. Despite the acknowledged absence of other Upper Devonian marine units in northeastern Pennsylvania, Willard maintained his member classification for the Trimmers Rock. At the Lehigh River Willard reported the existence of a probable Tully limestone horizon and Burket shale, the latter a member of his basal Upper Devonian Rush Formation.

After Willard's classic work (1939), study of Upper Devonian marine stratigraphy remained somewhat dormant for several years. McIver (1961) reported on a basin analysis study of these marine units and emphasized their turbidite character. Later, Frakes (1962a, 1962b) emphasized their turbidite character. The stratigraphic problem related to the upper contact of the Trimmers Rock nevertheless remained unsolved; the base of the Catskill remained at the lowest occurrence of red beds. In a later investigation, Frakes (1967) did not accept the Trimmers Rock as a valid formational unit despite its widespread occurrence throughout Pennsylvania. However, an editor's note in Frakes' report emphasized that the Pennsylvania Geological Survey did recognize the formational status of the Trimmers Rock.

Unfortunately, later investigators did not all accept the Trimmers Rock as a valid formation, and new stratigraphic terms were introduced for the sequence. Fletcher and Woodrow (1970) introduced several new terms for the section in eastern Pike County. These new formational units included from oldest to youngest the Sparrow Bush, Sloat Brook, and Millrift. It was their contention that the Sparrow Bush, 35-40 feet of fossiliferous, calcareous, fine-grained sandstones and siltstones, was correlative with the Tully Limestone on the basis of lithology, stratigraphy, and paleontology. The criteria for subdividing the latter two units appear to have been based upon the increasing presence of fine-grained sandstones. Their reluctance to accept the name Trimmers Rock was defended on the basis that the rocks in Pike County exhibited a much wider range of grain size than the Trimmers Rock of central Pennsylvania. This triformational interval is approximately 900 feet thick. It overlies the Mahantango Formation and underlies the non-marine sandstones of the Delaware River Formation as defined by Fletcher and Woodrow (1970).

To the south in northern Monroe County and nearly contemporaneous with the above, Alvord and Drake (1971) mapped an interval of marine siltstones and shales which they called the Trimmers Rock Sandstone. This interval occupies a stratigraphic thickness of 1700 feet with gradational upper and lower contacts. The underlying unit was mapped as the Mahantango Formation while the overlying unit, the Delaware River Flags, was presumed to be the basal member of the Catskill Formation correlative with the Towamensing Member, a new stratigraphic name employed by the Pennsylvania Geological Survey (Epstein, Sevon, and Glaeser, 1974).

Recent field investigations have contributed considerably to present knowledge concerning Upper Devonian stratigraphy in northeastern Pennsylvania. Excellent bedrock exposures along the Lehigh River have permitted subdivision of the Catskill Formation (Epstein, Sevon, and Glaeser, 1974). These investigators place the base of the

Catskill Formation at the position where massive quartzitic siltstones of the Trimmers Rock Formation change to flaggy, medium-grained sandstones of the Towamensing Member, a non-red Catskill member. This definition of the top of the Trimmers Rock Formation has been utilized in mapping to the northeast in Monroe and Pike Counties (Sevon, Epstein, and Berg, 1973; Berg, Schultz, and Sevon, in progress) (See Plate 1). This mapping shows that the Towamensing Member is correlative with the Starrucca of White (1882) in Pike County. To the southwest at the Lehigh River section, Walker (1972) has accepted the applicability of this recently defined Catskill base.

Age

An Upper Devonian age can be established for the Trimmers Rock Formation on the basis of stratigraphic position and fauna. The Middle-Upper Devonian boundary is marked by the Tully Limestone (Willard, 1939). Although the Tully's lithic distinctiveness is lost in northeastern Pennsylvania, Fletcher and Woodrow (1970) believed that they had located its stratigraphic equivalent in the Sparrow Bush Formation, a highly fossiliferous, sandy siltstone on the order of 40 feet thick. However, in Pike County, gamma-ray neutron log interpretations suggest that the Tully Limestone is absent and its stratigraphic position is occupied by dark shales (Wagner, 1963).

North of Bowmanstown (See Plate 1), Willard (1939) reports ±20 feet of calcareous shale, or argillaceous limestone in which faunal elements of Tully occur. He reported *Hypothyridina* and abundant corals including *Lopholasma* (*Metriophyllum*). Such a calcareous zone does exist in which unmistakable Mahantango and Trimmers Rock units are found in conformable contact below and above, respectively. Nowhere else in the study area has this relationship been observed. Willard, however, does report faunal elements of both Tully and Ithaca (Portage) lying within the lower Trimmers Rock along Brodheads Creek in Monroe County. The assemblage noted there consists of *Leiorhynchus mesacostale*, *Hypothyridina venustula*, and *Echinocoelia ambocoelioides*. The presence of such an assemblage in Trimmers Rock beds could suggest a younger age for the more easterly exposures of the Trimmers Rock Formation.

To the extreme northeast Fletcher and Woodrow (1970) believe that their Sparrow Bush Formation is the Tully equivalent on the basis of lithology, stratigraphic position, and paleontology. The fauna largely consists of *Leiorhynchus mesacostale* (most abundant), *Mucrospirifer mucronatus*, and crinoid columnals. The New York State Geologic Map (Fisher and others, 1970) places the Middle-Upper Devonian time boundary in the southeastern part of the state between the base of the younger Genesee Group and the top of the older

Hamilton Group. This contact traverses southwesterly, passing just to the south of Sparrow Bush, New York, where it crosses the Delaware River into Pennsylvania.

The question of a northeasterly extension of the Tully horizon and the existence of its lateral equivalent, the Sparrow Bush Formation, in extreme northeastern Pike County may be somewhat academic since the assemblages noted in the Mahantango and Trimmers Rock are unique (Willard, 1939). During mapping in eastern Pike County, the writer was able to distinguish between the two units although never encountering a horizon similar to the Tully or Sparrow Bush reported elsewhere. Therefore, on the basis of stratigraphic position and faunal assemblages, the Middle-Upper Devonian boundary is accepted as previously established at the Mahantango-Trimmers Rock transition.

The top of the Trimmers Rock lies well within the Upper Devonian.

Contacts

Both the upper and lower contacts of the Trimmers Rock are gradational. As such, the top and basal contacts are rarely observed in bedrock exposures. Further, it is difficult to recognize useful marker horizons for purposes of correlation.

In most instances definition of the Towamensing-Trimmers Rock contact must rely upon the gradual change from abundant, medium and coarse-grained siltstone interbedded with rare, very fine-grained, thin sandstone beds to abundant, fine and medium-grained sandstone interbedded with thin siltstone and shale beds. Rarely, the top of the Trimmers Rock Formation is clearly defined as the base of a massive sandstone bed which marks the base of a thick sandstone sequence. These relationships can be demonstrated in the four westernmost measured sections (Appendix). A gradation in color takes place in this transition from the dark and medium-gray hues (N3-N5) characteristic of the Trimmers Rock Formation to medium-gray and light olive gray-grayish olive hues (N5-10Y 4/1) of the overlying Towamensing rocks.

Crescentic burrow structures (Figures 3, 4, 5, and 6), presumably the result of burrowing pelecypods, are present within the Towamensing Member. Molds of the burrowing pelecypods occur at one key outcrop just above the top of the Trimmers Rock. Neither the burrows nor their associated pelecypods are known to occur in the Trimmers Rock Formation and their presence may be used for stratigraphic unit definition where exposure is incomplete. The burrow structures are roughly normal to bedding, being as long as 1.3 meters with a diameter between 3 to 5 cm. In other areas, particularly in Pike County, talus blocks of sandstone containing the burrow structures are found at the base of the topographic rise associated with the Trimmers Rock.

Figure 3. Pelecypod burrowing structures in the Hawks Nest section, along New York Route 97, about 4 miles northwest of Port Jervis, New York.

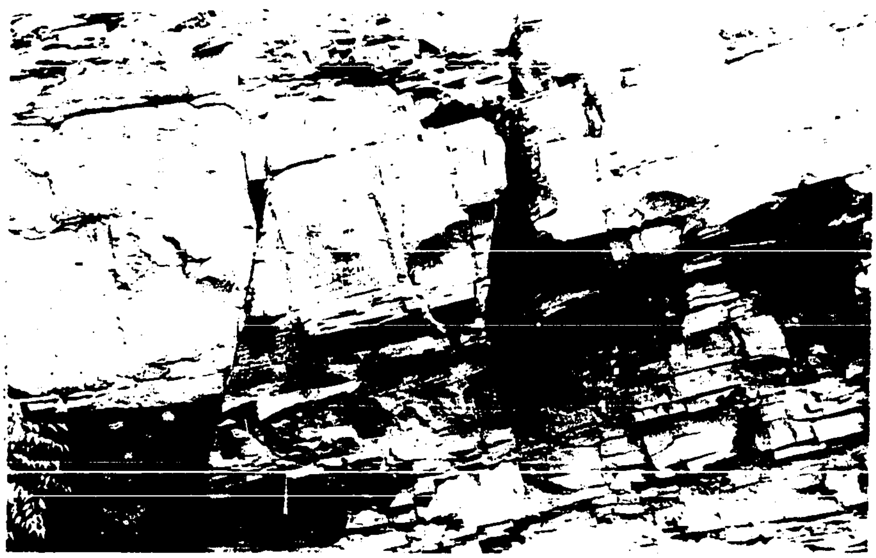


Figure 4. Pelecypod burrowing structures at Hawks Nest section, along New York Route 97, about 4 miles northwest of Port Jervis, New York. Note curvature of structure near base.

Figure 5. Pelecypod burrowing structures in northeastern Monroe County, about 4 miles north of Marshalls Creek, Pennsylvania, along Pennsylvania Route 402.

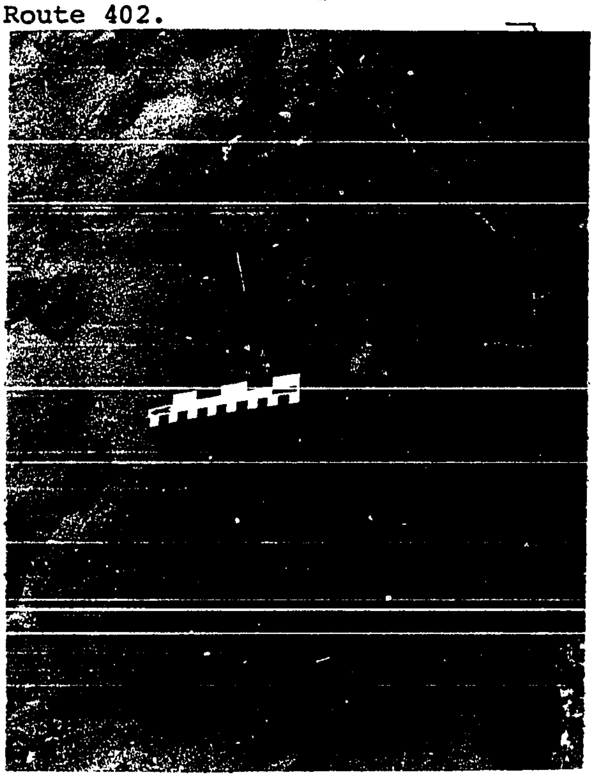


Figure 6. Top view of pelecypod burrow structures as seen on bedding surface just east of Harrity, Pennsylvania, along Pennsylvania Route 209.

The Mahantango-Trimmers Rock contact is not separated by a Tully limestone horizon in Monroe and Pike Counties as discussed previously. In general the upper several hundred feet of the Mahantango Formation is finer grained than the Trimmers Rock and is dominated by shale although containing intervals of coarser-grained beds. Color differentiation between weathered rocks of the two units may be difficult, but on unweathered surfaces Mahantango rocks usually are not lighter than medium-dark gray (N4) in comparison to the many medium-gray (N5) beds of the Trimmers Rock Formation. Bedding laminae are normally more difficult to discern in the Mahantango, whereas bedding in the Trimmers Rock is easily recognized. The more resistant rocks of the Trimmers Rock Formation form a prominent southeasterly facing ridge. The Mahantango contact is found near or at the base of this ridge slope. Regrettably, this relationship is rarely exposed as a result of the accumulation of colluvium at the base of this slope. The contact is exposed in the Lehigh and Millrift sections (Appendix).

LITHOLOGY

The Trimmers Rock is composed of siltstone-shale turbidites and is somewhat unique in that there is an exceptional lack of sandstone beds. A few thin sandstone beds occur in the upper half of the formation, but they represent an insignificant percentage of the total stratigraphic interval. In general, there is an upward coarsening of the unit in its upper half as the siltstone beds, although remaining interbedded with shale, become thicker. In contrast, the overlying Catskill Formation is dominated by thick and thin, red, gray, and green sandstone beds. The transition between these two very different lithologies is found within the basal Catskill member, the Towamensing. Although of marine origin and lacking red beds, the Towamensing Member contains numerous thinly bedded, fine-grained sandstones (Figure 7) and, in places, thickly bedded, fine-grained sandstone.

Measured Sections

New Ringgold

At this locality the Trimmers Rock is dominated by evenly laminated siltstones, shales, and turbidites. Many of the siltstone beds undergo upward fining. Fossiliferous lenses occur sporadically throughout nearly the entire

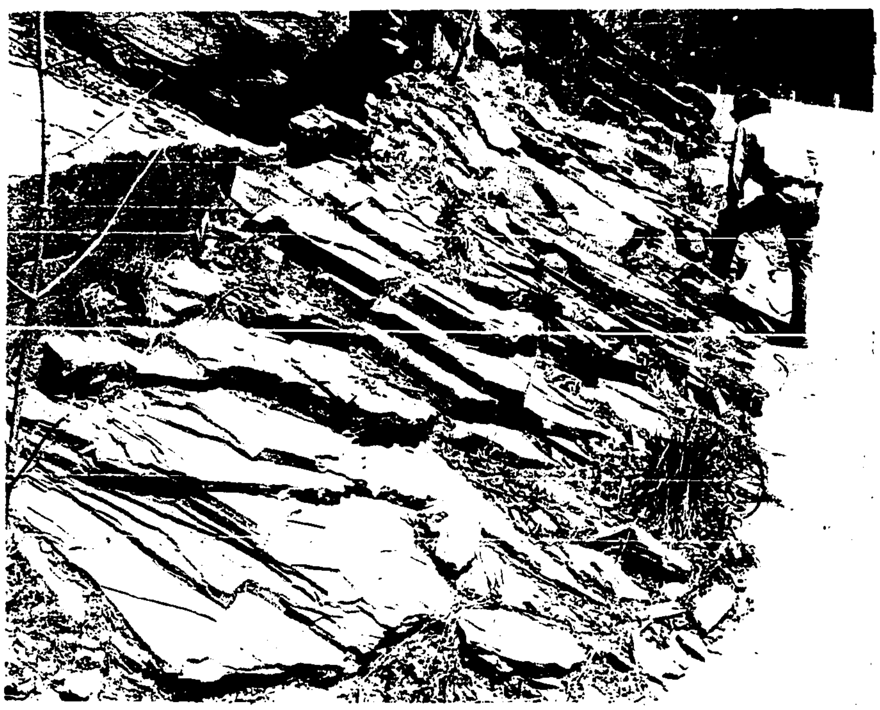


Figure 7. Fine-grained, flaggy sandstone beds just east of Harrity, Pennsylvania, along Pennsylvania Route 209.

section but are conspicuously scarce within the upper 200 feet. This upper 200 feet in places is covered, severely weathered, and in general poorly exposed. Several layers containing a peculiar type of load cast hereafter referred to as "ball and pillow" structures are found in a 30-foot section underlying the upper 200 feet of poorly exposed Trimmers Rock. Plant and other fossil-shell fragments are found scattered throughout the entire section.

The nearly 200 feet of Towamensing at New Ringgold are characterized by abundant sandstone, although the lower half contains many interbedded siltstones and shales. The base of the unit is defined by the first massive sandstones. The upper third of the section consists of fine to coarse-grained, thin to thickly bedded sandstones. A few of the sandstone beds contain thin zones of white quartz pebbles. One interval of sands 20 feet thick is marked by successive cross-bed sets, each with quartz pebbles at the base and overlies seven feet of shale. Shale clasts and abraded brachiopod valves are scattered throughout the base. No red beds are found within this unit which is dominated by gray and light-olive hues (See Section 1, Appendix).

<u>Lehigh River</u>

The Lehigh River Section consists of nearly continuous exposure through approximately 1000 feet of siltstones and shales of the Trimmers Rock Formation (See Section 3, Appendix). Although of comparable thickness to the New Ringgold Section there are many more fossiliferous lenses and ball and pillow structure intervals, particularly in the upper half of this section. In general the siltstone beds are thicker in the upper half than in the lower half. Many of the siltstone beds lie on irregular and scoured surfaces. Abundant plant debris is scattered throughout the section. The lower 200 feet are very poorly exposed but consist of thinly bedded shale interbedded with thin, fine-grained siltstone. Upward fining siltstone beds are a common feature within this section. The base of the formation lies at the top of the Tully Limestone equivalent which is both argillaceous and calcareous. This outcrop is located to the south of the measured section.

Approximately 200 feet of gray and green sandstone, siltstone, and shale overlie the Trimmers Rock. The base of this unit, the Towamensing Member of the Catskill Formation, is defined by a ball and pillow structure interval in which the balls consist of fine-grained sand rather than silt. Interbedded sandstone, siltstone, and shale characterize the lower two-thirds. The upper one-third contains thicker sandstone beds, some of which have medium-scale cross-bed sets. The top of the Towamensing lies at the base of a thick interval of red beds which define the next Catskill unit, the Walcksville Member.

Wild Creek Reservoir

Approximately 600 feet of Trimmers Rock siltstones and shales are exposed here (See Section 3, Appendix). There are a few thin, fine-grained sandstone beds in the upper half of the exposed section. However, except for the upper 50 feet of the unit, ball and pillow structure intervals are rare. Similarly, fossiliferous lenses and upward-fining intervals are far less frequent than in either the Lehigh River or New Ringgold Sections. The top of the Trimmers Rock is defined at the base of the first massive sandstone bed. The base is not exposed in the measured section.

Both the top and base of the Towamensing are found within this section which is estimated to be about 400 feet thick. However, much of the section is concealed. Several thick,upward-fining intervals lie in the upper 120 feet. Siltstones interbedded with thin and thick sandstone beds characterize the lower 100 feet. There are several ball and pillow structures in these sandstone beds, one of which defines the Towamensing base. The top is sharp and clearly defined by red siltstones of the Walcksville Member.

Effort

Strata of the Trimmers Rock include approximately 500 feet of siltstone, shale, and a few thin, fine-grained sandstone beds (See Section 4, Appendix). The occasional ball and pillow structure intervals are usually thin but far more frequent than fossiliferous lenses. Upward-fining siltstone beds are largely restricted to the lower 100 feet of measured section. Several of the upward-fining cycles contain appreciable sand at their bases. The top of the Trimmers Rock is placed where siltstone is interbedded with abundant and thin sandstone beds. The base of the Trimmers Rock is not exposed in the measured section.

Bartonsville

Although a relatively short section, the unweathered and recently exposed rocks at the Bartonsville Section contain abundant graded siltstone beds, fossiliferous lenses, and thick and thin ball and pillow structure intervals (See Section 5, Appendix). Shale is notably absent except at the tops of repetitious cycles of graded bedding. Spheroidal weathering in siltstone found near the top of the measured rocks can be directly related to weathering along intersecting curved and linear joint sets. These structures are readily distinguished from balls and pillows which are surrounded by shale. Neither the top nor the base of the Trimmers Rock is exposed.

Bushkill

The Bushkill Section is both poorly exposed and discontinuous (See Section 6, Appendix). Numerous, but thin, ball and pillow structure intervals are found in the upper 150 feet. Below this and within the next 200 feet successive cycles of graded beds occur in which siltstone grades upward into shale. The top of the Trimmers Rock is not exposed but the base is placed at the top of a thick interval of very dark-gray Mahantango shales.

Millrift

Nearly 700 feet of section are found along the west bank of the Delaware River south of Millrift, Pennsylvania (See Section 7, Appendix). Although several hundred feet of section are concealed, most of the exposed rocks are fresh and highly indurated. The top of the unit is not exposed in this section. Thick ball and pillow structure intervals are conspicuous. The thickest interval, approximately 25 feet, is found near the base of the Trimmers Rock. Ball and pillow structure sections thin laterally within the exposed cliffs bordering the Delaware River. There are many upward-fining siltstone beds throughout the entire measured section; the siltstones usually grade upward to shale. A few fossiliferous lenses are found at the base of graded siltstone.

Siltstone

Siltstone beds are fairly well preserved in outcrop, showing less of the effects of weathering than shale.

Normally, shale-siltstone contacts are planar and sharp (Figure 8). Some siltstones grade upward into shale. Silt-size gradation is a common feature of siltstone beds. Individual bedding thicknesses vary between less than an inch to as much as one foot with the latter being exceptional.

Texture and Composition

Framework

The framework consists mostly of disrupted grains (Figure 9), that is, grains not in contact but surrounded by matrix materials. In rocks with a large percentage of framework grains, there is a tendency for individual grains to become nearly tangential yet still maintain an overall disrupted fabric. On the basis of 400 point counts of framework components, a typical sandstone bed contains from 90 to 95 percent quartz. Rock fragments, largely shale clasts, will comprise as much as 6 percent of the grains in a graded siltstone bed. Neither plagioclase nor potash feldspar exceeds 2 percent of the total grains (See page 130, Appendix).

The predominant mineralogical component is quartz. The quartz occurs as subangular to subrounded grains with the smaller silt sizes generally exhibiting greater angularity. Quartz occurs as individual grains, polygranular

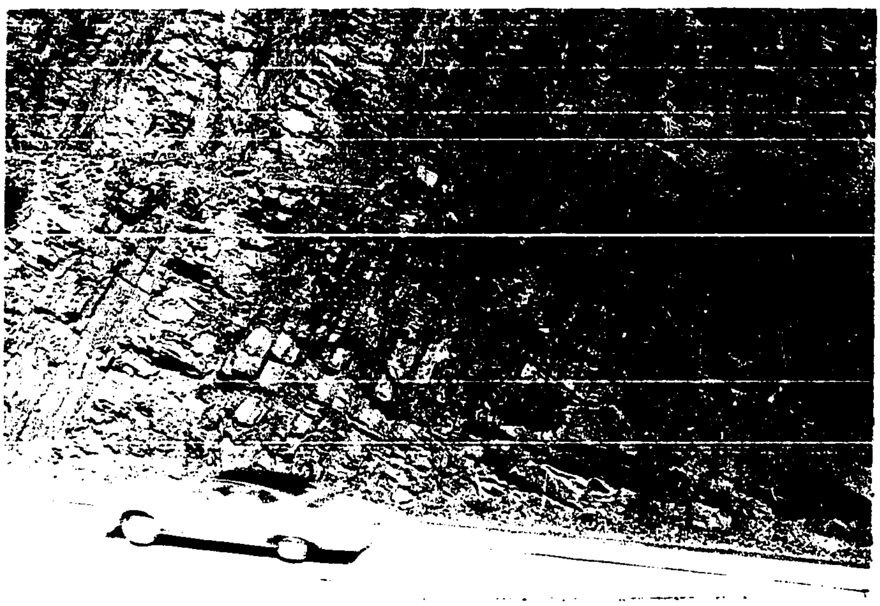


Figure 8. Interbedded shale and siltstone in Trimmers Rock Formation, north of Bowmanstown, Pennsylvania (See Section 2, Appendix, for exact location).

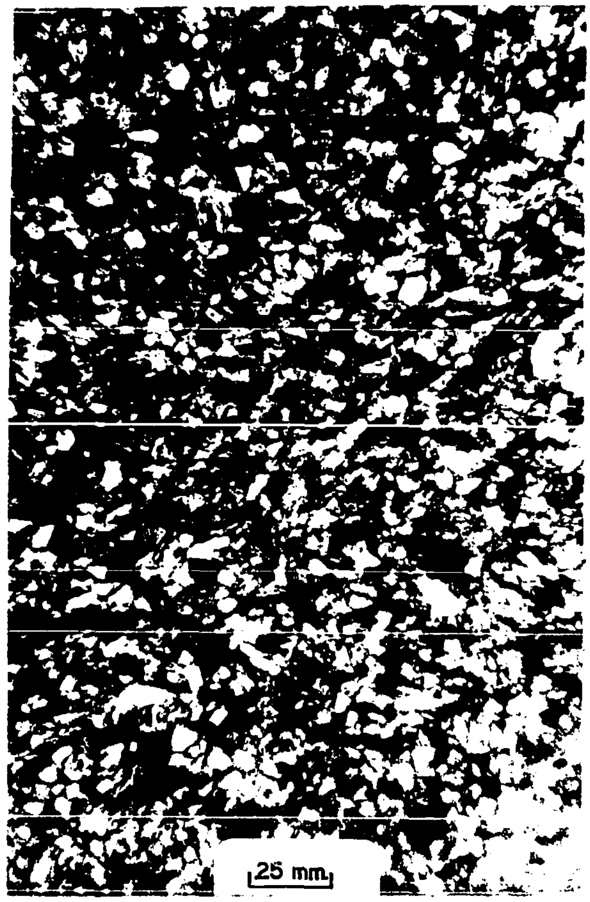


Figure 9. Photomicrograph with crossed nicols showing disruptive framework grains in a typical siltstone bed of the Trimmers Rock Formation, near Bartonsville, Pennsylvania (Section 5, Appendix).

mosaics, chert rock fragments, and microcrystalline quartz. Chert grains have a definite outline and can be distinguished from the microcrystalline quartz on that basis. Individual quartz grains containing inclusions of rutile are found in siltstone beds at the Millrift section. Other rare quartz inclusions include apatite and zircon. Highly strained polygranular mosaics, presumably metaquartzite grains, are common in silt beds from the Bartonsville and Lehigh River sections and are less commonly found in siltstone beds further to the northeast in Pike County (Figure 10).

Although the siltstones of the Trimmers Rock are predominantly quartzose other framework components include rock fragments and feldspar. Rock fragments are irregularly shaped shale clasts (Figures 11 and 12). Their lengths may exceed one inch but volumetrically they are of only minor significance. Shale clasts usually are found near the basal contact of a silt bed where in contact with shale. Twinned plagioclase grains occur as fractured laths and may be partially or wholly sericitized. Potash feldspar grains nearly always demonstrate the greatest rounding, as expected, due to their limited ability to resist abrasion during transport.

Accessory minerals include rare occurrences of rutile, zircon, apatite, tourmaline and garnet. Opaque minerals,

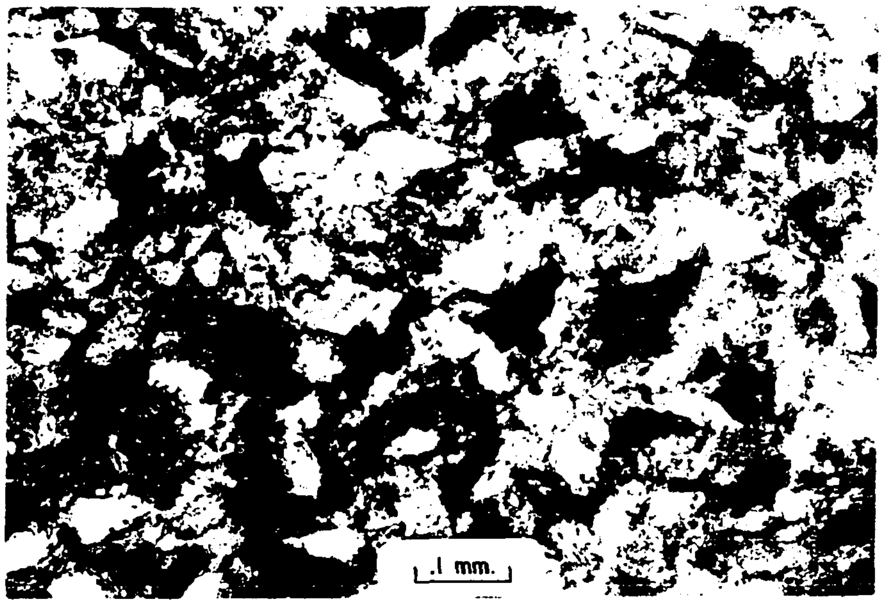


Figure 10. Photomicrograph with crossed nicols showing undulose extinction of strained quartz grains comprising framework constituents in a typical siltstone from the Trimmers Rock Formation north of Bowmanstown (Section 2, Appendix).

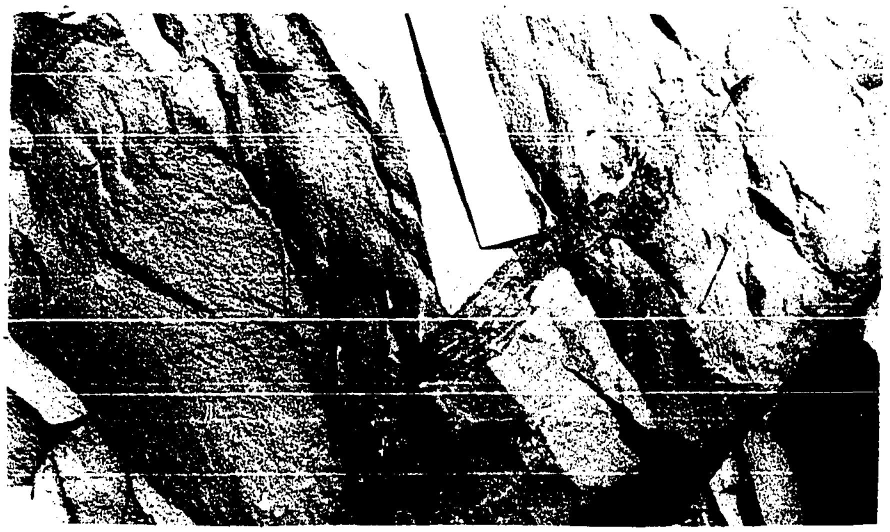


Figure 11. Large shale clast isolated in siltstone bed north of Bowmanstown, Pennsylvania (Section 2, Appendix).

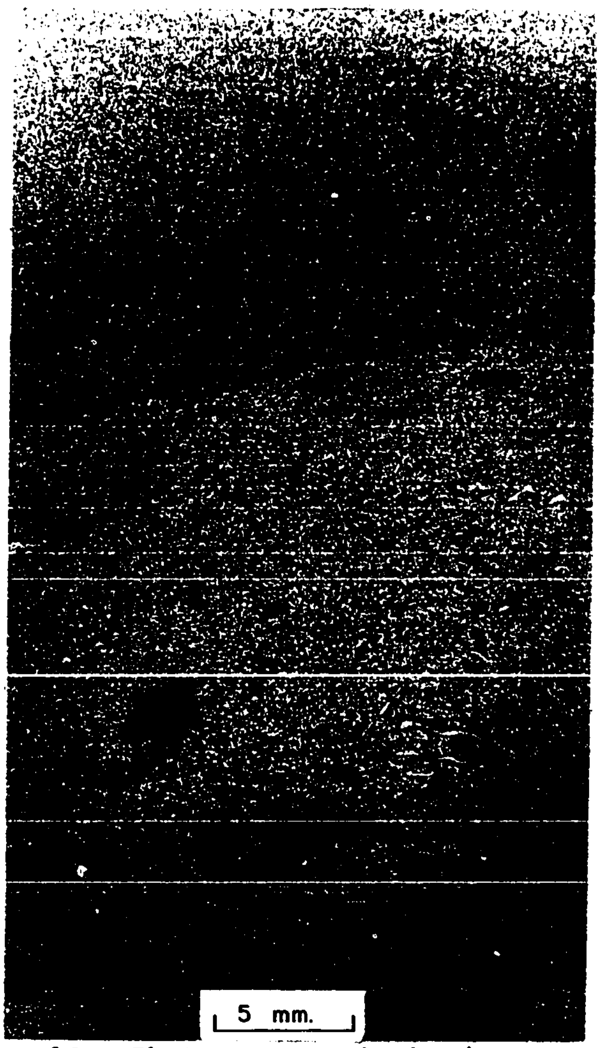


Figure 12. Photomacrograph showing several shale chips in siltstone bed north of Bowmanstown, Pennsylvania (Section 2, Appendix).

while rare overall, may occur as discernable although laterally discontinuous laminae of small silt-sized hematite and authigenic pyrite grains (Figure 13). Hematite stains are also observed on potash feldspar grains and quartz. Individual cubic forms of pyrite can be observed with the aid of a hand lens in fresh exposures. Only very minor traces of detrital muscovite and chlorite were detected.

Matrix

The matrix, dominantly clay, of the siltstones ranges between 69 and 46 percent and consists largely of kaolinite, sericite, and chlorite. Minor amounts of microcrystalline quartz are also present. The matrix is largely detrital but includes products of the diagenetic alteration to sericite of the framework feldspar grains. In beds where the matrix exceeds 50 percent, there has been a modest development of a microfoliation parallel to bedding. This development is enhanced in beds in which the framework grains are aligned parallel or subparallel to the bedding foliation (Figure 14). Trails of small burrowing organisms which parallel and traverse coarse-grained silt have been subsequently infilled with fine silt-clay material (Figure 15).

Microcrystalline accumulations of calcite are observed as aggregates whose diameters range from clay size to as much as 0.5 millimeter. However, these occurrences

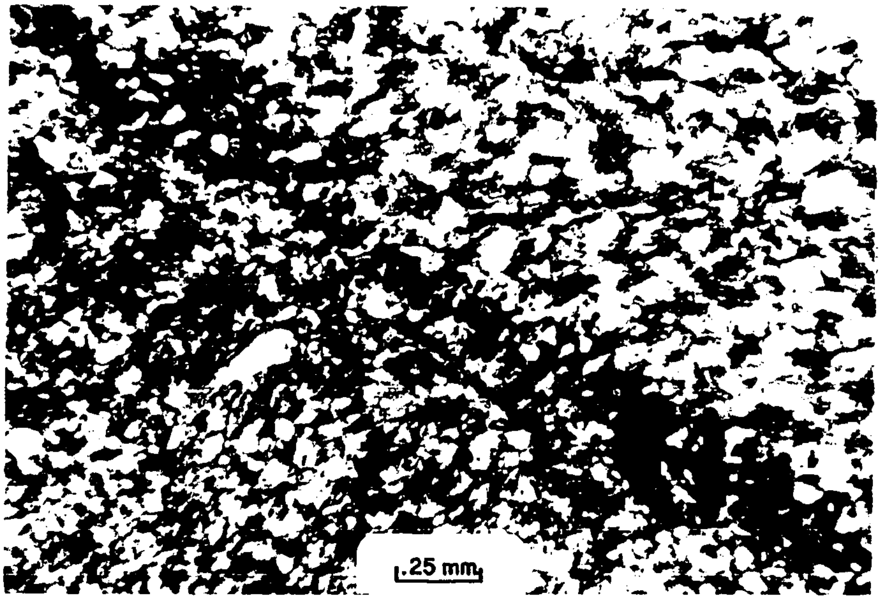


Figure 13. Photomicrograph showing authigenic pyrite laminae in a siltstone bed of the Trimmers Rock Formation, north of Bowmanstown, Pennsylvania (Section 2, Appendix).

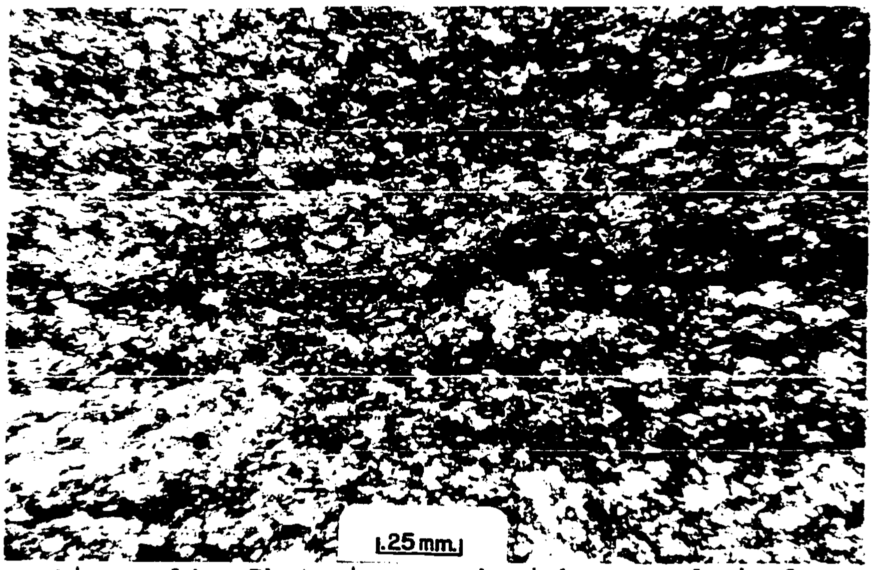


Figure 14. Photomicrograph with crossed nicols of foliation development within siltstone of the Trimmers Rock Formation, north of Bowmanstown, Pennsylvania (Section 3, Appendix).

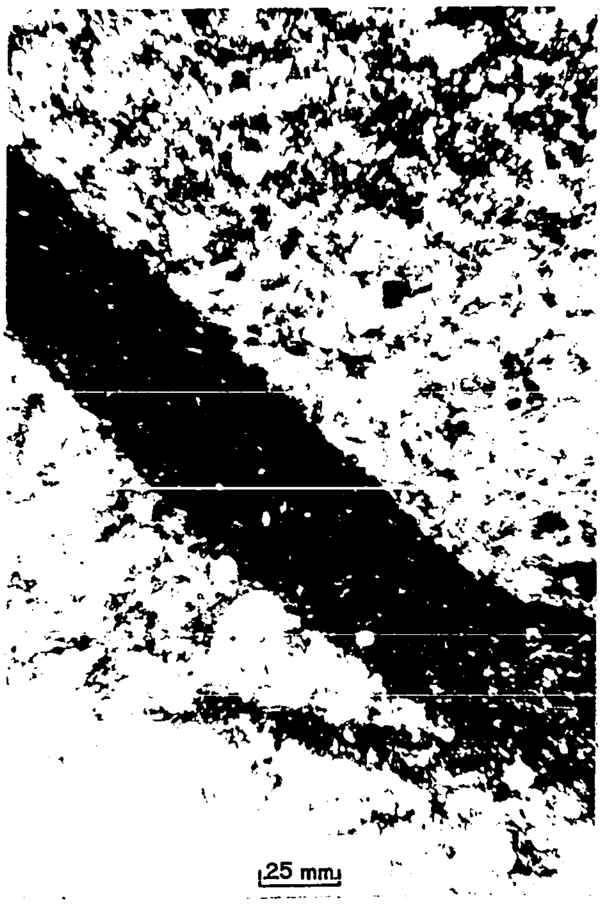


Figure 15. Photomicrograph, plane-polarized light, showing trail of small burrowing organism filled with very fine-grained sediment in siltstone of the Trimmers Rock Formation near Bartonsville, Pennsylvania (Section 5, Appendix). Trail is diagonal to bedding.

generally are limited to the fossiliferous lenses. Overall the carbonate contained within the matrix does not exceed one percent.

Classification

Quartz usually comprises at least 90 percent of the framework grains. The matrix in all cases comprises 46 to 69 percent of the siltstones (See Figure 16 and page 129, Appendix). Thus, the siltstones belong to the wacke clan (Krynine, 1948) or, more specifically, following the definition of Pettijohn and others (1972, p. 198-203), they are wacke siltstones. The lack of an appreciable amount of feldspar or rock fragments in the framework grains precludes further subdivision of this rock according to Pettijohn's scheme.

Frakes (1967) noted that near the top of the Trimmers Rock Formation, the quantity of quartz decreases and is offset by a corresponding increase in feldspar and rock fragment grains. The writer found that the mineralogical changes suggested by Frakes do not occur within the Trimmers Rock, but in the overlying Catskill rocks, a change previously noted by Glaeser (1973). Within the siltstone the writer detected neither lateral nor vertical variation in mineralogy. This is not contradictory to the work of Frakes since in northeastern Pennsylvania Frakes included at least part of the overlying Towamensing in his Trimmers Rock (Plate 17).

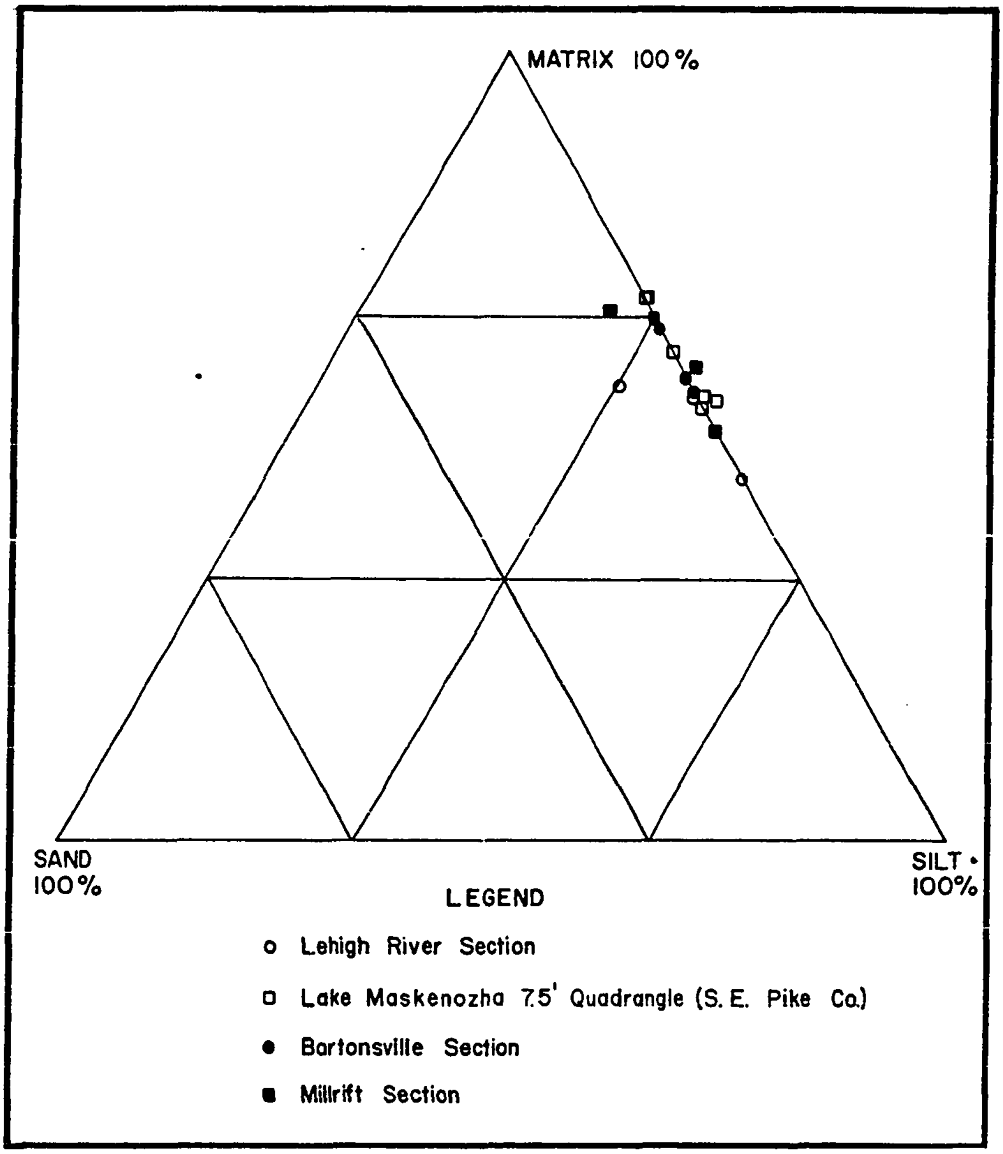


Figure 16. Ternary diagram of sand-silt-matrix in siltstones.

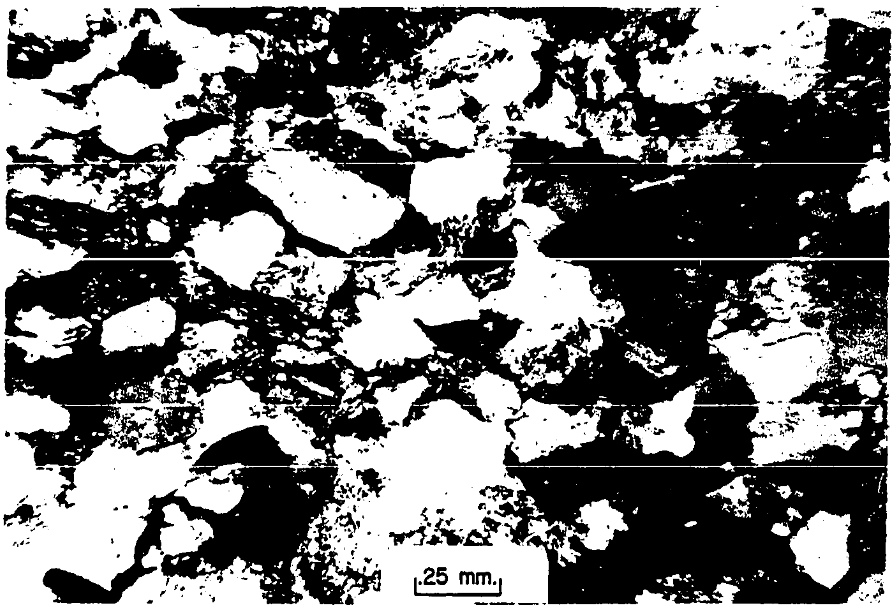


Figure 17. Photomicrograph, plane polarized light, of Towamensing Member, Catskill Formation, from Lake Maskenozha 7.5-minute quadrangle, southeastern Pike County, Pennsylvania.

Shale

The distinction between shale and siltstone becomes somewhat arbitrary when the matrix percentage exceeds two-thirds of the total rock. Blatt, Middleton, and Murray (1972, p. 374-375) suggest that when the silt component exceeds two-thirds, rocks are correctly classified as siltstones if nonfissile and silt-shale if fissile. Other fine-grained sedimentary rocks retain the suffix "shale" if fissile. These criteria are of some assistance where microscopic examination has been undertaken, but they are of limited value with respect to hand-specimen study. In this investigation nonfissile rocks which contain abundant silt visible with a hand lens are considered siltstone. Shale refers to fissile, fine-grained sedimentary rocks in which silt cannot be resolved with a hand lens.

Shale occurs as interbeds, usually one foot or less in thickness, between siltstone (Figure 18). In the lower one-third of the formation, thicker shale intervals are abundant; some are several tens of feet thick, being interrupted by an occasional siltstone bed (Figure 19). Near the contact with the Mahantango Formation, shales dominate over coarser-grained rocks. Shale also occurs at the top of graded intervals. Upward gradational changes from siltstone to shale may extend through stratigraphic intervals ranging in thickness from one foot to several feet.

Figure 18. Interbedded siltstone and shale. Shale is shown by dark, thin bands between thicker siltstone beds. Interval lies within Lehigh River Section (Section 2, Appendix) in lower third of Trimmers Rock Formation.

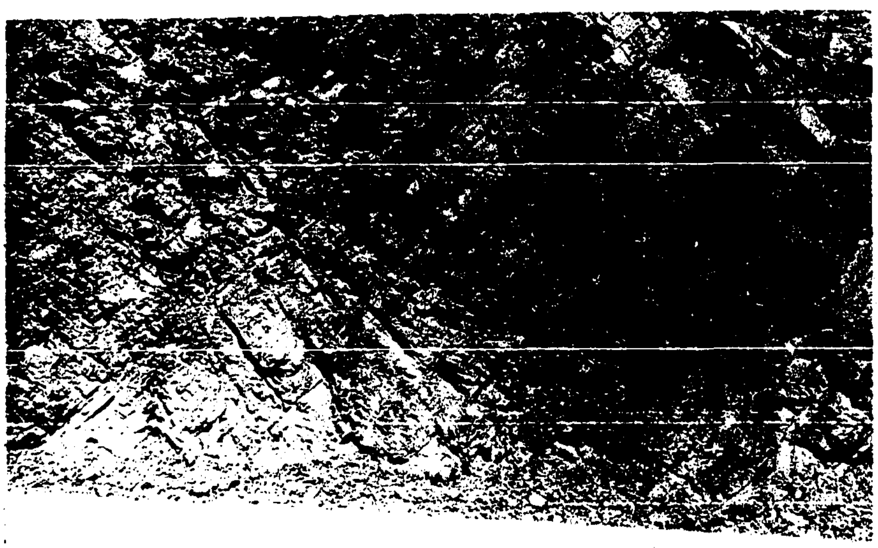


Figure 19. Thick section of foliated shales left of center. Note accumulation of disintegrated rock at base of exposure. Outcrop is part of Lehigh River Section (Section 2, Appendix).

The fissile shales in which a foliation parallel to bedding exists are quite common throughout the formation. They occur as bed sets bounded by the coarser siltstone. Bedding-plane cleavage traces are closely spaced, being less than a millimeter apart. With increasing quantities of silt-sized grains, this incipient cleavage development is hindered.

On the basis of qualitative X-ray analyses the shale is comprised of kaolinite, sericite, and chlorite. The few silt grains dispersed throughout the clay media are predominantly quartz. There is no evidence to suggest that lateral or vertical mineralogical changes occur within individual shale beds or all shales of the Trimmers Rock Formation in northeastern Pennsylvania.

Color

The color designations and code numbers herein employed follow the Rock-Color Chart prepared by the Rock Color Committee of the Geological Society of America (1963).

Most of the rocks in the Trimmers Rock Formation range from medium gray to dark gray (N5-N3). These comprise over 90 percent of the measured sections. Some of the shales and mudstones are olive gray to olive blackish gray (5Y 4/1). Several of the graded intervals were found to be moderate olive gray (5Y 4/2). The disturbed siltstone and undisturbed siltstone intervals generally can be assigned values of gray but rarely were assigned olive hues (5Y).

Color changes throughout the unit are subtle and never abrupt. The colors of rocks in the underlying Mahantango Formation are within lower values of gray and olive gray on the Color Chart. Rock colors in the overlying Towamensing Member show an appreciable increase of olive hues, especially those at the Lehigh River and Wild Creek Reservoir sections. These color variations are useful in identifying the stratigraphic units.

Primary Structures

Primary structures in the siltstones and shales of the Trimmers Rock include graded bedding, plane parallel bedding and laminae, fossiliferous lenses, ball and pillow structures, ripples, and disturbed micro-laminations. Such structures in siltstone-shale sequences generally are considered to indicate deposition by turbidity currents (Middleton and Hampton, 1973; and others). In many cases, several of these structures appear to occur in a definite sequence which is cyclically repeated.

Fossiliferous Lenses

Generally distinctive fossiliferous lenses are found at the base of many graded intervals as shown by the seven measured sections in the Appendix. In most cases they occur within turbidite intervals and less frequently at the base of an upward-fining cycle. Such lenses usually do not exceed six inches in thickness but usually extend laterally for several tens of feet (Figure 20). They thin very gradually laterally to thin laminae. Where limited exposure exists, the locally uniform thickness of these zones creates a false impression which conceals their lenticularity. It is not uncommon for these lenses to occur intermittently in stratigraphic succession at the base of several siltstone beds contained within a cyclic graded interval as shown in the Lehigh River Section (Section 2, Appendix). One individual lens is shown on Figure 21 from the same section.

These lenticular zones are easily recognized in exposed outcrop as iron oxide commonly stains their weathered surfaces. On weathered surfaces these lenses are characterized by abundant voids where the carbonate fossil debris has been dissolved out and the casts of fragmental fossils remain. In places where bedrock is extremely fresh and unweathered, these zones are more difficult to recognize.

<u>Texture and Composition</u>

The lenses consist of a varied assortment of fossil-shell fragments, shale clasts, and quartz grains set in a matrix of clay-sized sericite and chlorite (Figures 22, 23, 24, and 25). Fossil-shell fragments and shale clasts range

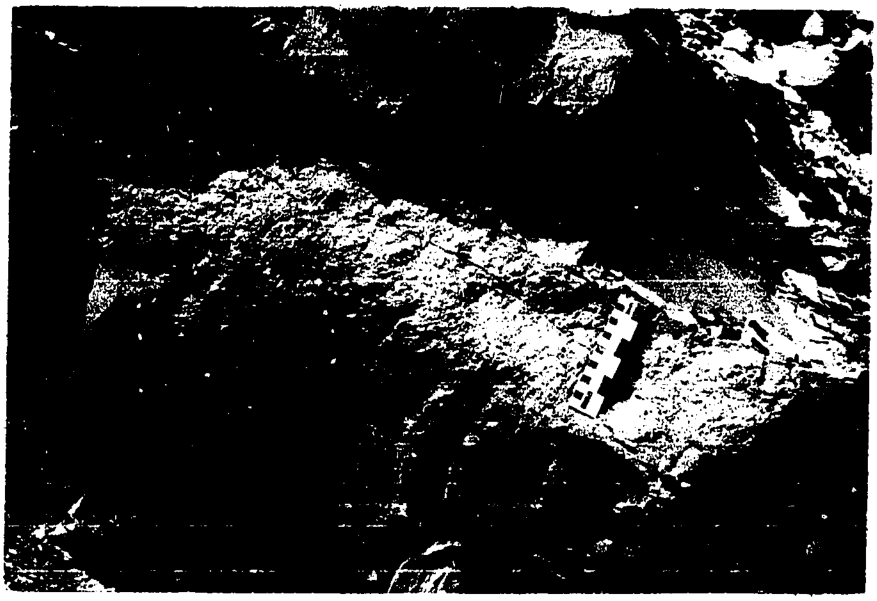


Figure 20. Fossiliferous lens located along Bartonsville Section (Section 5, Appendix).

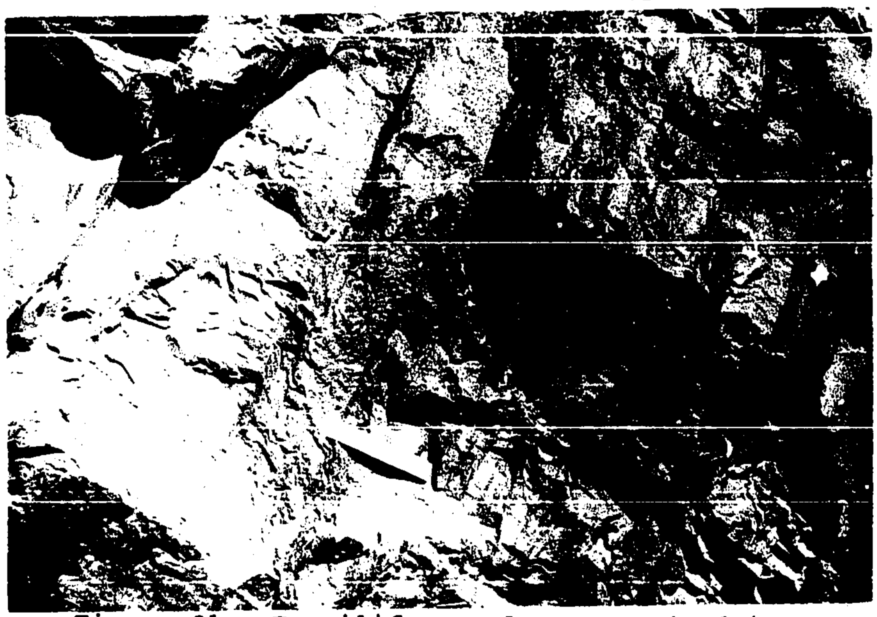


Figure 21. Fossiliferous lens contained in cyclical graded interval found near middle of Trimmers Rock Formation in Lehigh River Section (Section 2, Appendix).

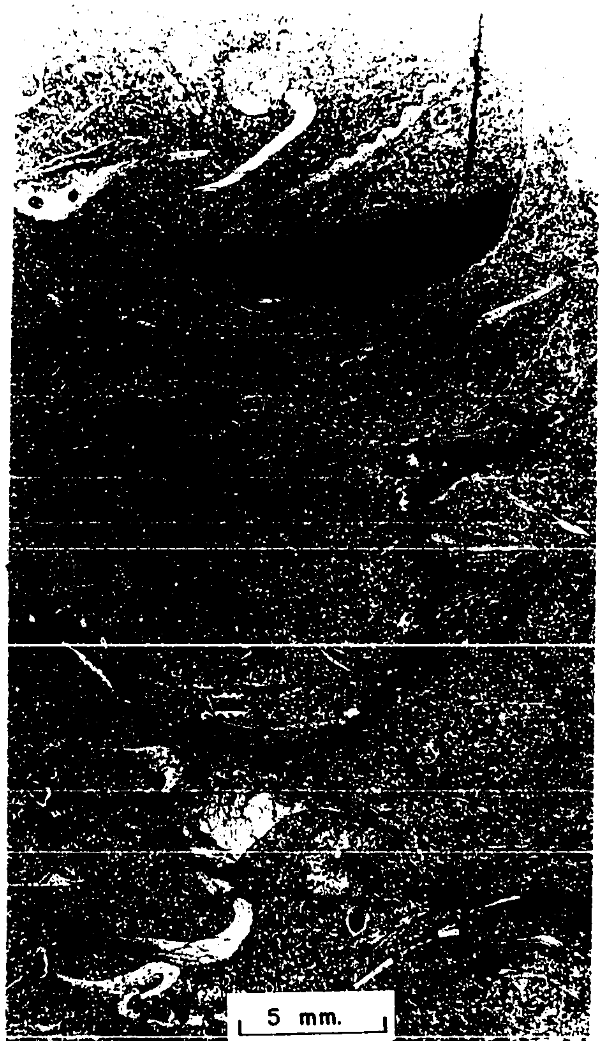


Figure 22. Photomacrograph of fossiliferous lens in Trimmers Rock Formation near Bartonsville, Pennsylvania (Section 5, Appendix). Note graded sediments in concave up pelecypod valve. Top of bed is toward top of page.

Figure 23. Photomicrograph with crossed nicols showing rare sectional view of gastropod contained within fossiliferous lens in Trimmers Rock Formation near Bartonsville, Pennsylvania (Section 5, Appendix).

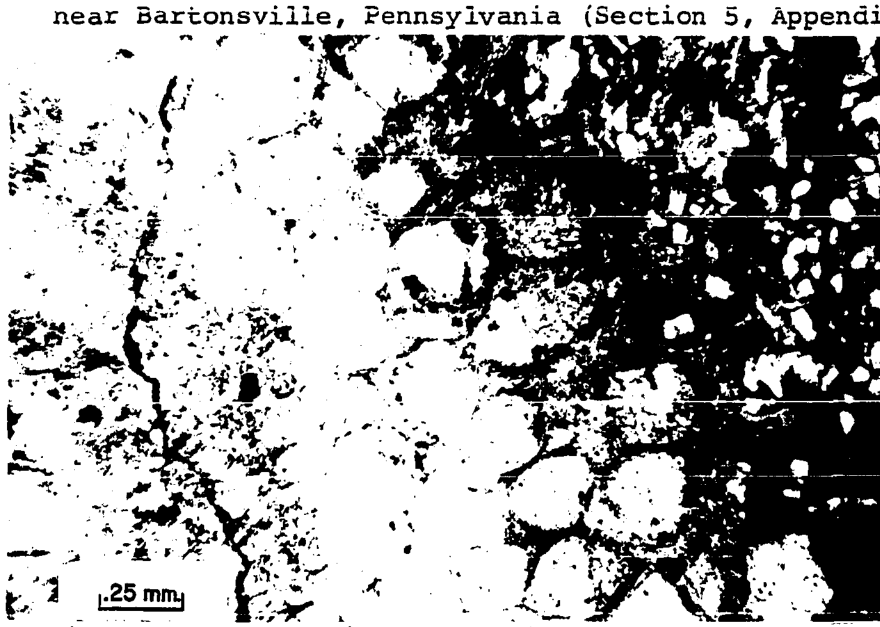


Figure 24. Photomicrograph with crossed nicols of *Favosites* in fossiliferous lens of Trimmers Rock Formation near Bartonsville, Pennsylvania (Section 5, Appendix).

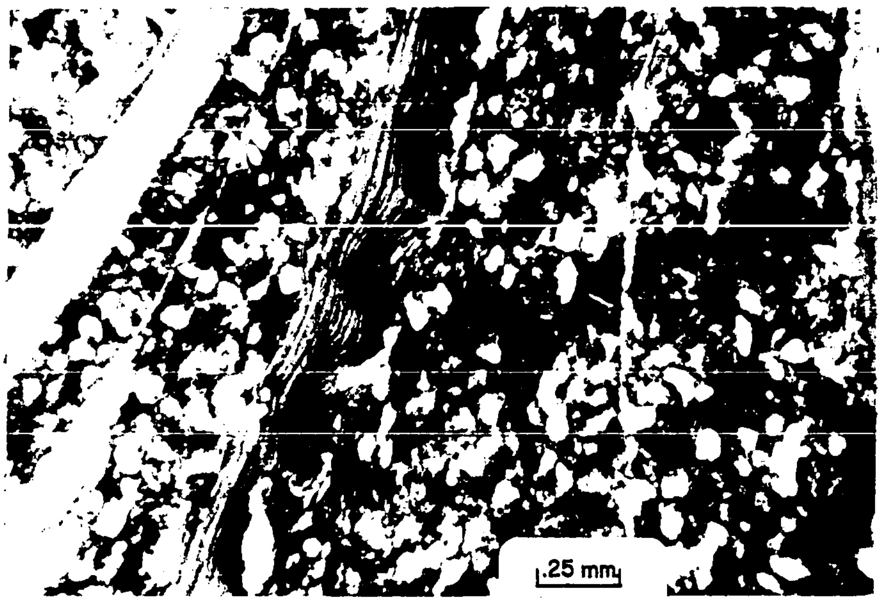


Figure 25. Photomicrograph with crossed nicols showing typically abundant brachiopod fragments in fossiliferous lens of the Trimmers Rock Formation near Bartonsville, Pennsylvania (Section 5, Appendix).

in size from fine silt size up to fragments one millimeter and longer. The fossils greatly exceed the shale clasts in abundance. As in the siltstone beds, the shale clasts are usually angular with very jagged edges. Most quartz grains are silt sized, subangular or subrounded, and occur either as aggregates of several grains or as individual grains.

The framework is open and disrupted and the assembly of shell fragments, clasts, and grains normally fines upward. The uppermost contacts of the lenses are sharp, and overlying silty sediments are completely void of any fossil or shale clast material (Figure 26). Similarly, lower contacts are sharp and generally planar. In places thin laminae stained with iron oxide mark the contact between the fossiliferous lenses and overlying silt. Whole valves, although rare, are not preferentially oriented. Bedding laminae within shale clasts are randomly disposed with respect to bedding of the lenses.

The fossil shells include primarily brachiopod and pelecypod valves, most of which are fragmental. Valves which are concave up are filled with fine-grained sericite, chlorite, and silt-sized sediment which may be graded. Crinoid columnals are abundant in lenses in the Lehigh River and Wild Creek Reservoir sections. Further to the northeast they are far less abundant.

Other identifiable fauna include fragmental remains of gastropods, trilobites, and coral. Most of the fossil

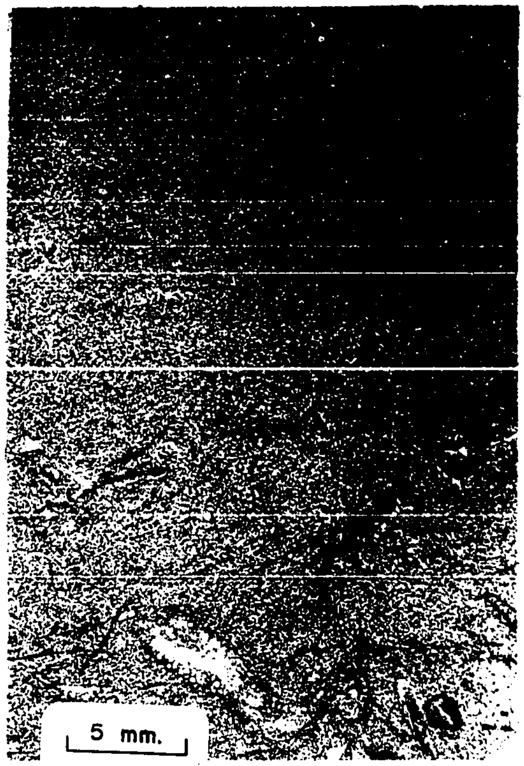


Figure 26. Photomacrograph showing upper contact between fossiliferous lens (lower half of photograph) and overlying siltstone bed in Trimmers Rock Formation near Bartonsville, Pennsylvania (Section 5, Appendix).

detritus consists of calcium carbonate. In cases where calcite has been dissolved, silica filled the voids so that a complete replica of the fossil remains.

Matrix

The matrix of the fossiliferous lenses is mainly sericite and chlorite. The matrix increases from base to top proportionately with a decrease in fossil-shell fragments, shale clasts, and quartz silt. There is no incipient cleavage development within these zones.

Origin

The detrital fossil-shell fragments, shale clasts, and silt grains are presumed to have been transported to their depositional sites as traction load during the initial phase of a turbidity event. This conclusion is suggested by the occurrence of this zone near or at the base of turbidite siltstone beds which grade upward into shale.

Fossil lenses or lens layers commonly are interbedded with graded siltstones which do not contain fossil fragments. Some of these layers contain shale clasts, some do not. Such layers are also products of turbidity events. The absence of fragmental shell material may indicate the unavailability of this material at the time of the turbidity event.

Turbidites

An idealized sequence of structures in a single turbidite unit was proposed by Bouma (1962) and subsequently modified by Walker (1965) and Walton (1967), all of whom related the changes to changes in flow regime. The fivefold subdivision of an idealized "Bouma Sequence" is shown in Figure 27. A considerable quantity of sand comprises the bulk of the sediments found within the lowermost three units, A through C. The upper two units, D and E, are argillites. Variation in primary structures within these units is as shown in Figure 27.

Nowhere within the several thousands of feet of measured section of Trimmers Rock nor in isolated outcrops have all of these sections been observed consecutively. Many variations of the sequence have been recognized, however. These include massive, graded intervals (usually cyclic), finely planar laminated intervals, disrupted and contorted intervals, as well as very fine-grained shale intervals which correspond to the A, B and D, C, and E units, respectively. However, their order takes on virtually any vertical array including cyclic A intervals, AB, AC, ABC, BC, CB, or each independently.

Walker (1970) concluded after having recorded and analyzed over 16,000 turbidite measurements that less than 0.5 percent will fit the normal Bouma sequence, assuming

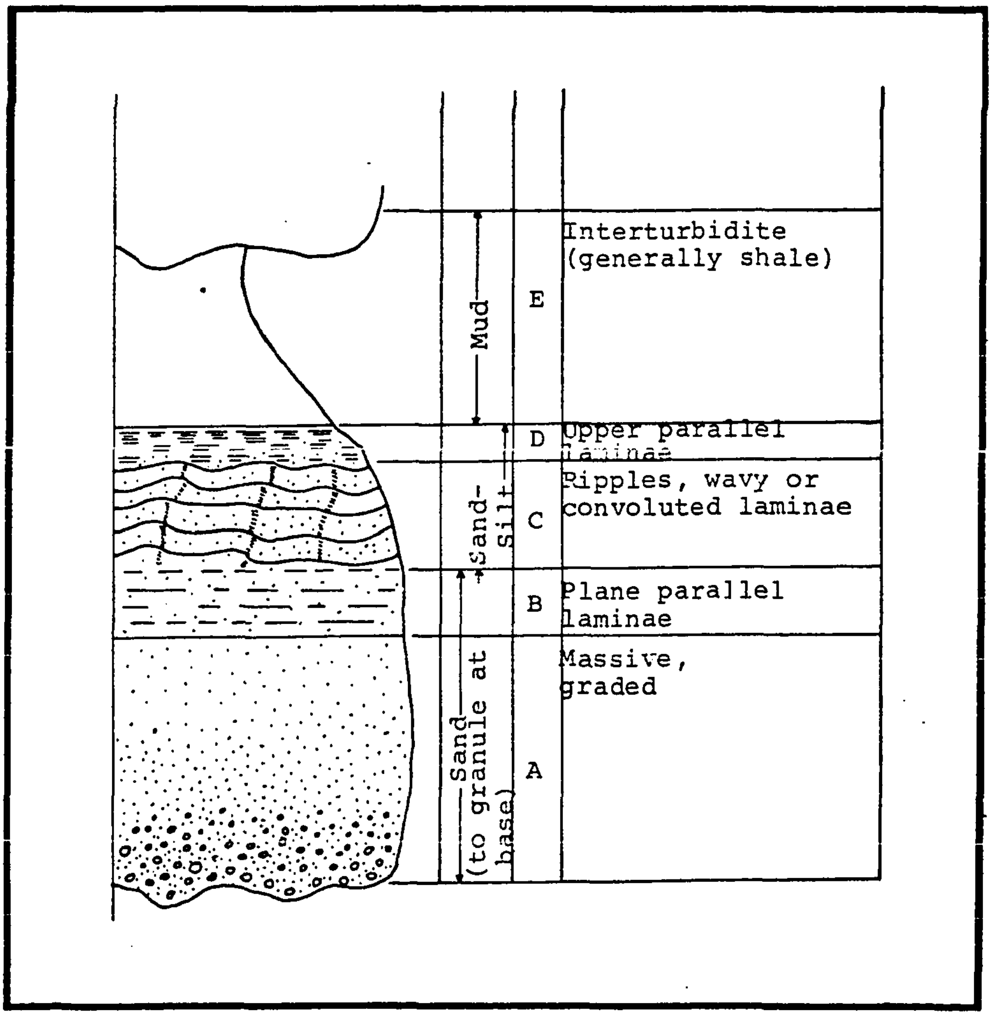


Figure 27. Idealized sketch of structures in a typical "Bouma Sequence" (from Blatt, Middleton, and Murray, 1972, p. 123).

minor reversals. Further, units D and E, which he considers to be virtually indistinguishable particularly in older rocks, represent the finer sediments attributable to both turbidity and palagic (nonturbidite) deposition. Bouma (1962) also notes that tectonism or weathering may render the laminae completely invisible within unit D. Certainly, these very fine-grained sediments were deposited within a low-energy environment. A notable difference between all the turbidite models reviewed by Walker in his 1970 paper and the turbidites of the Trimmers Rock Formation in northeastern Pennsylvania is the conspicuous lack of sand-sized sediments.

The Bouma sequence has not been reproduced experimentally and the exact mechanism responsible is not clearly understood. However, Bouma and others believe that a single sequence (or cycle) is representative of one turbidity event initially characterized by extremely rapid deposition of short duration. If a turbidity event is followed by a long period of quiescence, it is not unreasonable to assume that the deposition of very fine-grained, pelagic-like sediments would occur during this time. A large number of graded intervals suggests a relatively high frequency of turbidity events. In all measured sections of the Trimmers Rock, graded beds, individually averaging about 0.5 feet thick, occur repeatedly (Figure 28). Many siltstone beds appear

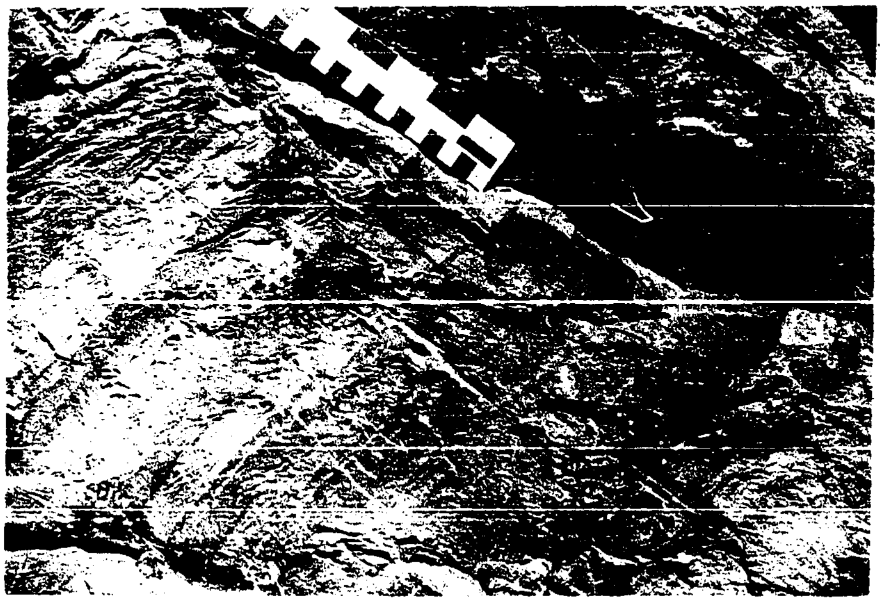


Figure 28. Cycles of graded intervals in the Lehigh River Section (Section 2, Appendix).

to be homogeneous in hand specimen but are found through microscopic examination to fine upward. It is not uncommon to find a fossiliferous lens at the base of a graded interval. This suggests a relatively high-energy condition at the beginning stages of a turbidity flow.

The B and D or DE units may occur independently of the graded unit although commonly these are found near the top of a fining-upward cycle. The change from massively graded to closely spaced laminae is transitional and signifies (1) a decrease in energy regime, (2) a decrease in detrital sediment supply, and (3) a state of fairly constant conditions. Laminae may be separated by several millimeters of coarser-grained, silt-sized sediments or may be as closely spaced as 0.5 millime or less (Figure 29). On other than very clean hand-specimen surfaces, the laminae are rarely observed but are easily seen on slabbed sections or in thin sections (Figure 30).

While many of the laminated rocks undoubtedly owe their origin to the waning flow regime of a turbidity current, it also seems possible that such laminated units can document fluctuations in amount and size distribution of the suspended sediment load available for deposition. Some very small-scale grading may continue to take place even though laminations predominate. This could reflect a variance in the conditions controlling rates of erosion within the

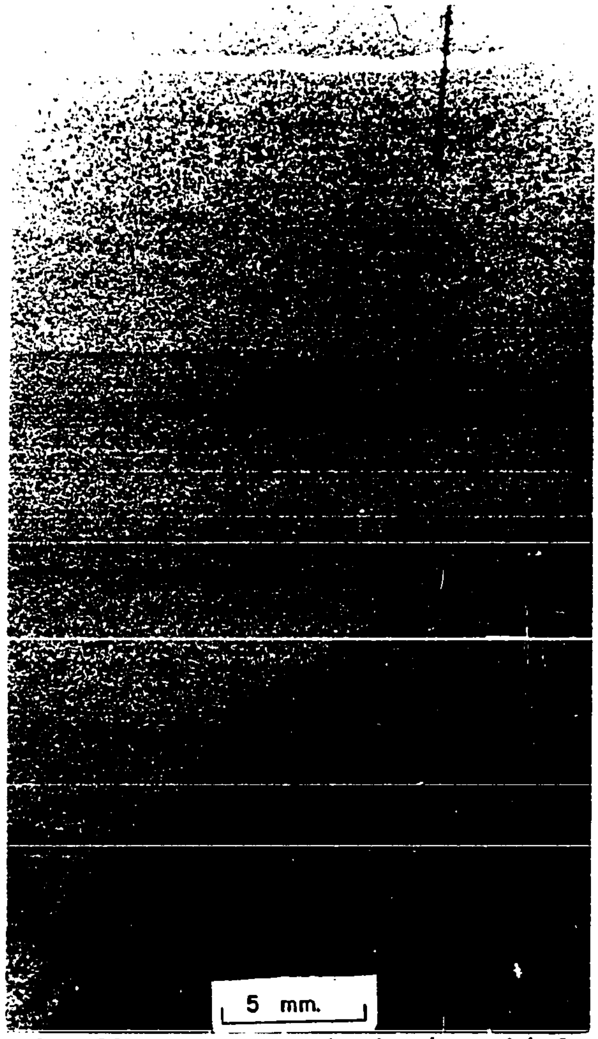


Figure 29. Photomacrograph showing thinly laminated siltstone of the Trimmers Rock Formation near Bartonsville, Pennsylvania (Section 5, Appendix).

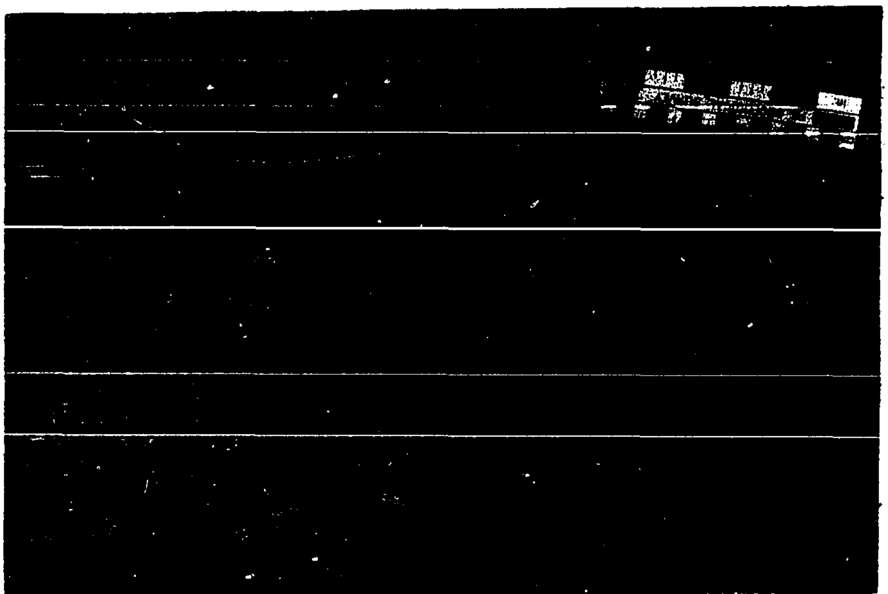


Figure 30. Faintly visible laminae in Trimmers Rock siltstone bed, north of Bowmanstown, Pennsylvania (Section 2, Appendix).

source area or variations in the competence and capacity of the seaward transport media. Inasmuch as the laminated units in themselves do not reflect the mode of deposition, it is necessary to infer the prevailing conditions as interpreted from the underlying unit.

Unit C is the unit containing small-scale cross bedding in Bouma's idealized portrayal (1962). Laminated fore-set beds inclined at angles less than 20 degrees to overlying horizontal laminae are fairly common but not easily observed except on slabs or in thin sections (Figure 31). In most cases the inclined laminae are slightly concave upward. Thinly laminated fore-set beds in some specimens lie on scoured surfaces whose angle of inclination can exceed 40 degrees (Figure 32). Fore-set beds measured vertically are six inches thick or less. Convoluted rippled sections, which according to Bouma are present in many turbidite sequences, do not occur in the Trimmers Rock.

As pointed out by Blatt, Middleton, and Murray (1972, p. 168), "Direct observation of the formation of modern turbidity current deposits is very difficult, if not impossible, so that many details of interpretation, and even the turbidity current hypothesis itself, remain controversial." The hypothesis, however, does account satisfactorily for graded graywacke sandstones and siltstones, the Bouma sequence in such sandstones and siltstones,

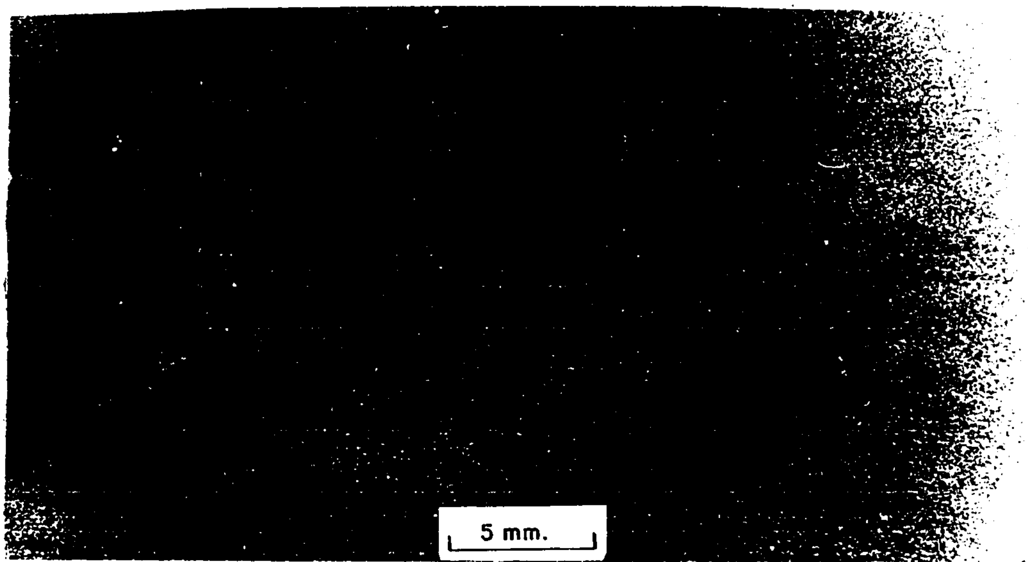


Figure 31. Photomacrograph of small-scale cross bedding in Trimmers Rock siltstone north of Bowmanstown, Pennsylvania (Section 2, Appendix).

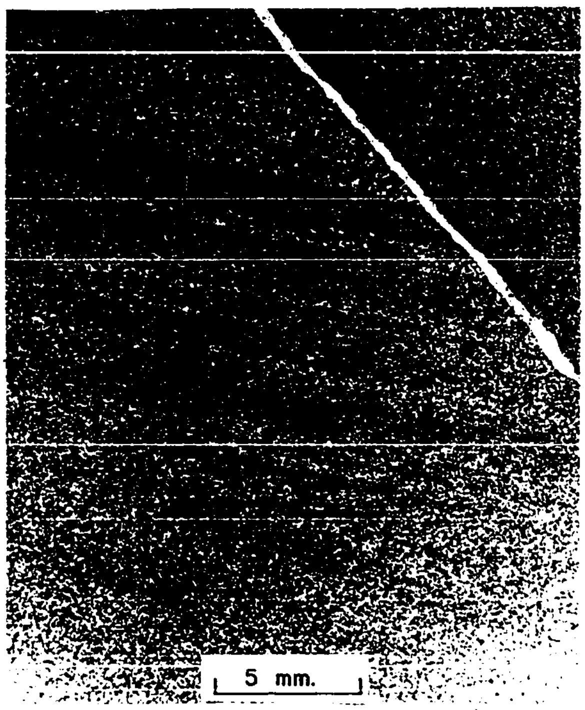


Figure 32. Photomacrograph showing scoured surface in Trimmers Rock siltstone near Bartonsville, Pennsylvania (Section 5, Appendix).

and certain associated structures including those of the type described in this report for the Trimmers Rock.

Modern graded sediments thought to be produced by turbidity currents occur in modern deep-sea deposits (Bouma and Hollister, 1973), in lakes such as Lake Geneva and Lake Mead (Blatt, Middleton, and Murray, 1973, p. 167-168), and in the pro-delta facies of some modern deltas such as the Niger delta (Allen, 1964) and the Mississippi delta (Gould, 1970). For reasons to be discussed later, the most satisfactory explanation for the Trimmers Rock deposits is that they represent the prodelta facies of a delta complex.

Structures indicative of channelized turbidity flow are wholly lacking from the exposed rocks. Rather, flows radiating outward and downward from a locus situated farther landward seems highly feasible. The effects of each turbidity event were apparently controlled by the quantity and character of the detrital sediments made available periodically at a dispersal apex. Flows which scour the depositional surface are characterized by higher energy levels than those from which graded beds have been deposited conformably upon the finer-grained, thinly bedded sediments.

Disturbed Zones

"Ball and pillow" structures as described by Pettijohn and others (1972, p. 124) are found at various stratigraphic intervals of variable thickness throughout the Trimmers Rock Formation (Figures 33 and 34). The balls and pillows are small, nodule-like bodies of siltstone completely surrounded by shale which have the appearance of having been either wrapped around or squeezed around the nodule. The terms "ball" and "pillow" simply describe the variety of geometric shapes of these structures as observed in outcrop. Assemblages of ball and pillow structures occur in intervals less than one-foot thick to more than 25-feet thick. Generally, the thicker the interval, the larger the structures and the greater the sense of internal disturbance and disorientation. Intervals containing these structures overlie shale interbedded with minor very fine-grained siltstone; usually they are capped by a thin bed of shale. Individual balls have an ellipsoidal shape, not unlike pillows, and vary greatly in size. They may be slightly concave up or down (Figure 35). In other instances their tops are planar. Their long axes range between less than one foot to more than seven feet in length. A section oriented perpendicular to and bisecting this axis usually is circular. The diameter of this section rarely exceeds one-half the length of the long dimension of the ball.

The balls are extremely dense and compositionally identical to typical siltstones of the Trimmers Rock. Rare, unaltered, authigenic, pyritic cubes nearly one millimeter

Figure 33. Ball and pillow structures south of Childs Park, Pikes County, Pennsylvania.

Figure 34. Massive ball and pillow structures located near Analomink, Pennsylvania.

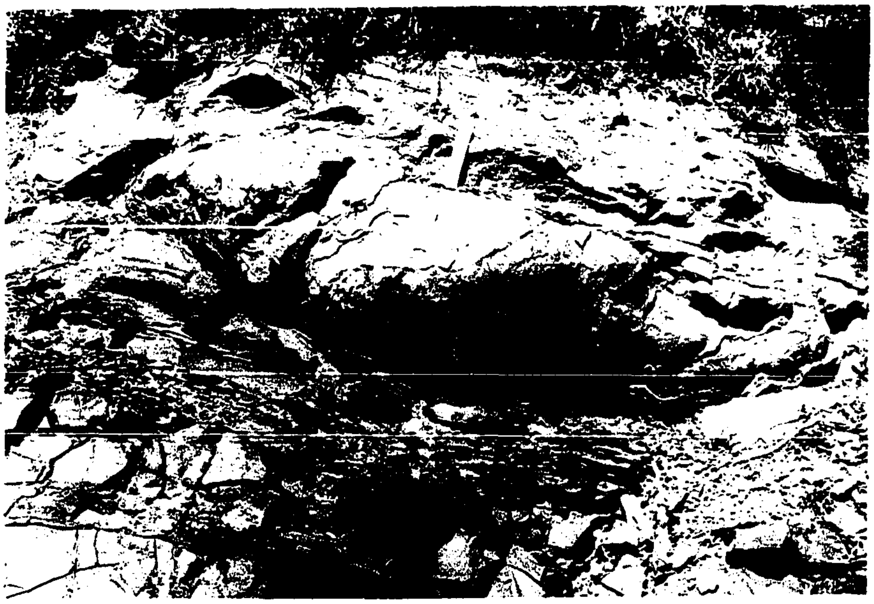


Figure 35. Resistant ball structure completely surrounded by shale, located along Pennsylvania Route 402, north of Marshalls Creek, Pennsylvania.

large are present. Oxidation of the iron on recently exposed surfaces imparts a slightly reddish-brown hue. This weathering enhances the outcrop appearance of individual structures.

Frakes (1967) set forth a lengthy explanation justifying his interpretation of lateral movement or landslide movement of these structures which he interpreted to be load cast zones. Basically, he summarized the evidence based on the following observed features: (1) presence of overturned bolsters (ball and pillow structures in this investigation), (2) presence of subangular blocks, (3) marked erosion of the substratum, (4) bolsters or blocks of two or more distinct rock types in disordered arrangement, (5) great variation in size of bolsters, (6) tightly packed bolsters in contact but not pressed into one another, and (7) drag marks on the substratum of the bolsters. Most of the referenced locales are situated in central Pennsylvania. Walker (1971), who studied the prograding Catskill shoreline in the same region, never saw all seven features at one location. Similarly, even within the thicker ball-and-pillow structured intervals of northeastern Pennsylvania, all of the fore-mentioned features occur, but independently of each other. The strongest argument marshalled by Frakes to substantiate his landslide movement is the presence of drag marks observed at the base of such sections. However, these could well be indicative of scour prior to the loading of silt.

The origin of ball and pillow structures and mechanisms of emplacement have been studied both in situ and under laboratory-simulated experiments. Moore (1961), Dott (1963), Conybeare and Crook (1968), Pettijohn and others (1972, p. 370-373), and Blatt, Middleton, and Murray (1972, p. 159-164) have dealt with the whole realm of soft-sediment deformations. These workers are in agreement that most importantly and a prerequisite is the presence of a thixotropic material such as water-saturated clay preceeding the deposition of a denser sediment such as sand or silt. The specific weight per unit volume of the overlying material must exceed that of the underlying material, thereby establishing a situation of instability. Specific weight differences may result from any number of factors including (1) original porosity differences, (2) degree of water saturation, and (3) the presence of montmorillonitic clays with their capacity to take on water within an expendable lattice (Conybeare and Crook, 1968).

Pseudo-nodules, somewhat similar to ball and pillow structures were produced artificially by Kuenen (1958). A layer of sand, locally thickened, was placed over a thixotropic clay layer. Shock was applied, the clay liquefied, and the sand foundered in the liquefied clay, producing nodule-like sand bodies. The various geometric shapes of these modelled forms are identical to those observed in the Trimmers Rock Formation.

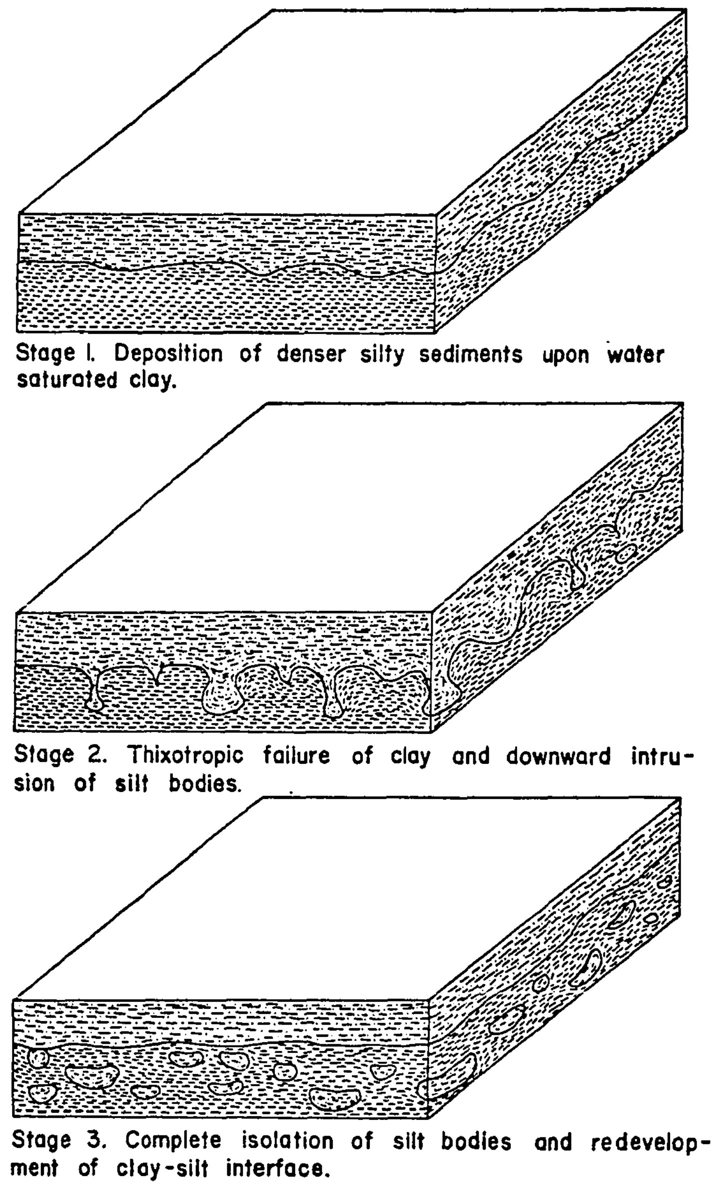
In the case of the Trimmers Rock Formation the evidence strongly suggests that these structures were largely a function of the hydroplastic behavior of the sediments involved. That is, that failure of the underlying clay sediments permitted the intrusion of overlying silt bodies. Initially, sedimentation rates of the overlying silt sediment are presumed to have been rapid, occurring prior to compaction and dewatering of the clay substratum.

Where accumulations of silt were typically thin and interlayered with clay, clastic dikes intruded the underlying shale nearly normal to their interface. These structures were noted in interlayered siltstone and shale or silty shale intervals along the Delaware River. At this locality the individual beds are two-to-three inches thick; the dikes are on the order of one inch thick.

Limited lateral displacement within the disturbed zones while the intermixed materials were still thixotropic is considered possible, if not probable. The presence of deformed laminae within the structure could argue for partial failure within the silt as well. The actual downward intrusion of silt into a clay matrix is somewhat more difficult to explain. These structures sometimes are incorrectly referred to as casts which implies an infilling of a pre-existing mold or void. Figure 36 is an idealized model portraying the development of these structures.

The mechanism triggering initial failure could be tectonism. It is not unreasonable to assume as did Walker (1971) that these structures are a "reflection" of Acadian tectonism more active to the east.

A reasonable interpretation can be advanced to account for the development of ball and pillow structures by relating experimental observations of the hydroplastic materials to the conditions presumed operative in the turbidite-dominated environment of the Trimmers Rock Formation. An appreciable thickness of dominantly clay-rich sediments deposited during the waning stage of a single turbidity event or during a period of prolonged quiescence must initially be available. Subsequently, a new turbidity event deposits thick accumulations of medium to coarse-grained silt. The rapidity of silt deposition will determine whether or not the buried clay will behave thixotropically. Downward intrusion of silt bodies will only occur in cases where the underlying clay has not undergone considerable dewatering owing to slow silt deposition; otherwise, a significant specific weight differential will not have been attained. This unique set of conditions presumably was established on several occasions at restricted locales. Lateral thinning



(after experimentally formed pseudo-nodules by Kuenen, 1958)

Figure 36. Schematic portrayal of ball and pillow structure development.

of individual zones precludes the correlation of individual ball and pillow intervals.

Ripple Marks

Ripple marks occur on a few bedding surfaces in siltstone or in silty shales. Their forms normally are gradational variants between those having rectilinear crests and those with sinuous crests. Ripple crests generally have wavelengths ranging between three to six inches and amplitudes of about 0.5 inch.

Possible small-scale interference ripples are found at one location in Pike County (Figure 37). On the same bedding surface of an adjacent outcrop a circular section of a ball structure is observed (Figure 38), suggesting that lateral thinning of this ball and pillow horizon has taken place.

Owing to the rarity of ripple marks and sole markings, both indicators of paleocurrent direction, it was not possible to prepare a current vector model for the Trimmers Rock. In the central and southcentral portions of the state, McIver (1961) and Frakes (1967) were able to conduct such studies and to postulate a general northerly to westerly flow pattern. These analyses were based on abundant flute casts, groove casts, and prod casts in addition to ripple marks. In eastern Pennsylvania Frakes was forced to rely largely on ripple-mark orientations. In deeper marine

Figure 37. Interference ripples on bedding surface found at 41°9'42"n/74°56'3"W in Pike County, Pennsylvania.

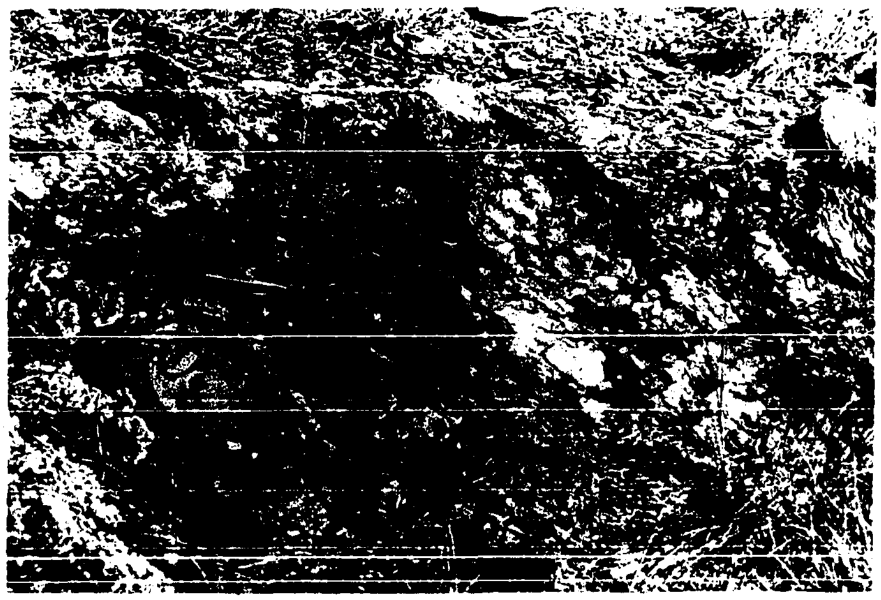


Figure 38. Outcrop surface showing section through ball structure below head of geologic pick. Location as above in Figure 37.

environments, the reliability of ripples as dominant current direction indicators remains a topic of debate. Heezen and others (1966) concluded that ripple crests paralleling the dip of the Atlantic Continental Rise are formed by contour currents flowing parallel to the strike of the Rise. Walker (1971) accepted the results of McIver (1961) and Frakes (1967) for his study in the Upper Susquehanna River Valley. There has been no evidence collected during the course of this investigation to permit any postulation regarding the general direction of clastic deposition.

Intra-formational Correlation

Frakes (1967) extended ten intraformational lithologic units from northern Maryland through Pennsylvania to southwestern New York. Strong objections to this have been raised by Walker (1971) based on his more geographically restricted study.

In the present study, the distances between measured sections along the outcrop belt range from 8 to 25 miles. These stations are, in fact, more closely spaced than those of Frakes and others. The top and bottom of the formation are seldom exposed and the surficial trace of these contacts is an interpretation based on the field mapping of many workers as indicated on Plate 1. The delineation of contacts is often difficult due to the lack of exposures and the mixing of parent float with Pleistocene morainal material. Accordingly, mapped contacts are commonly approximate, if not inferred. Although generally uncomplicated by structural deformation, total stratigraphic thicknesses are approximate where only scant bedrock exposures exist. Marker beds or distinctive bed sets are wholly missing. For these reasons, severe reservations are harbored by this writer regarding any attempt at intra-formational correlations within the Trimmers Rock Formation.

Vertical and lateral variations within the formation indicate a complex pattern of deposition. Figure 39 shows thickness variation of the measured sections of the Trimmers Rock Formation supplemented between sections by data acquired from bedrock exposures and maps.

In the broadest scope, these Upper Devonian marine rocks are transitional. The older Mahantango Formation is largely a mudstone and shale unit with minor siltstone, and the younger Towamensing Member of the Catskill Formation is a sandstone and siltstone unit with minor shale. Occupying the transition are the siltstones and shales with very minor sandstones of the Trimmers Rock Formation.

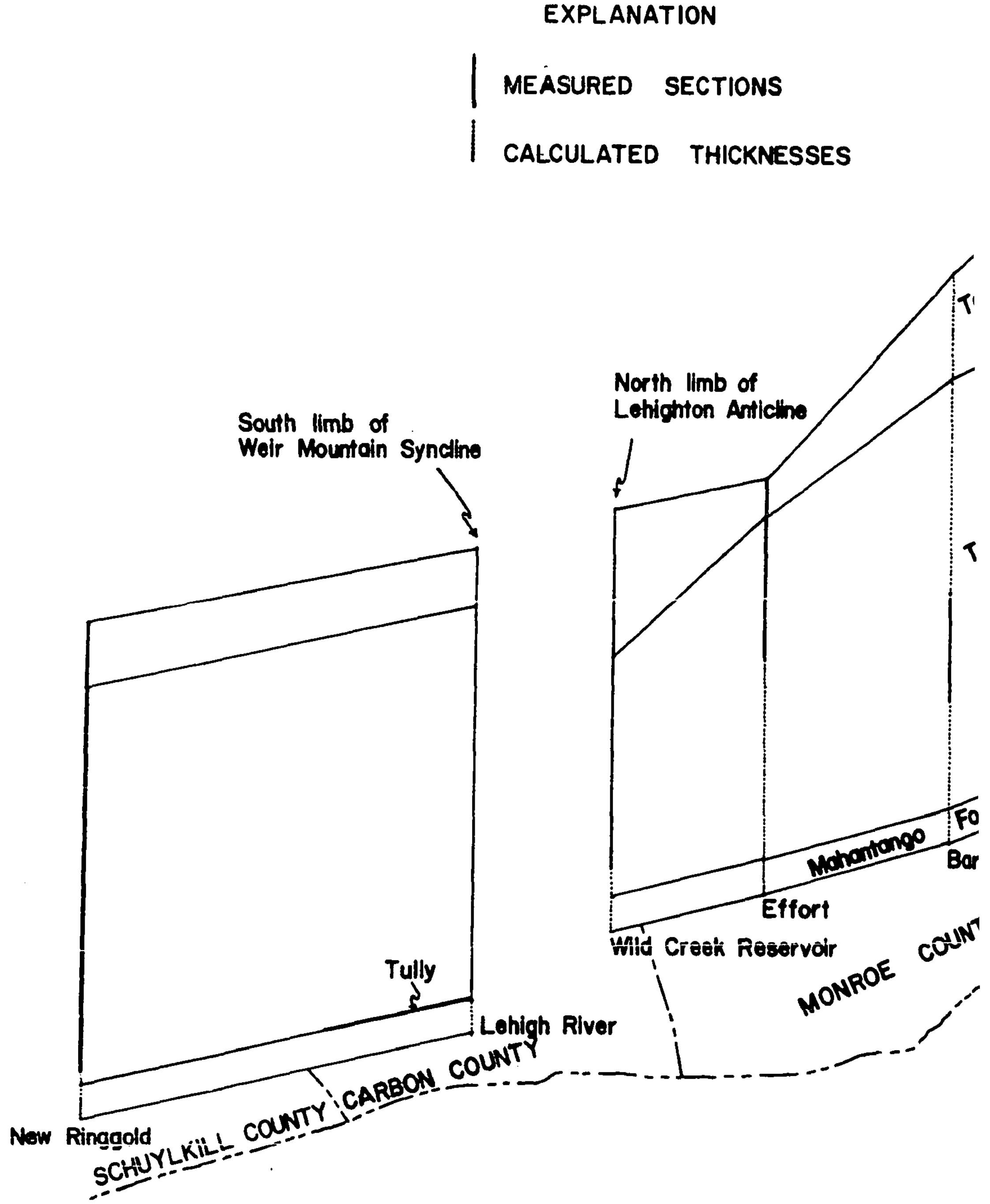
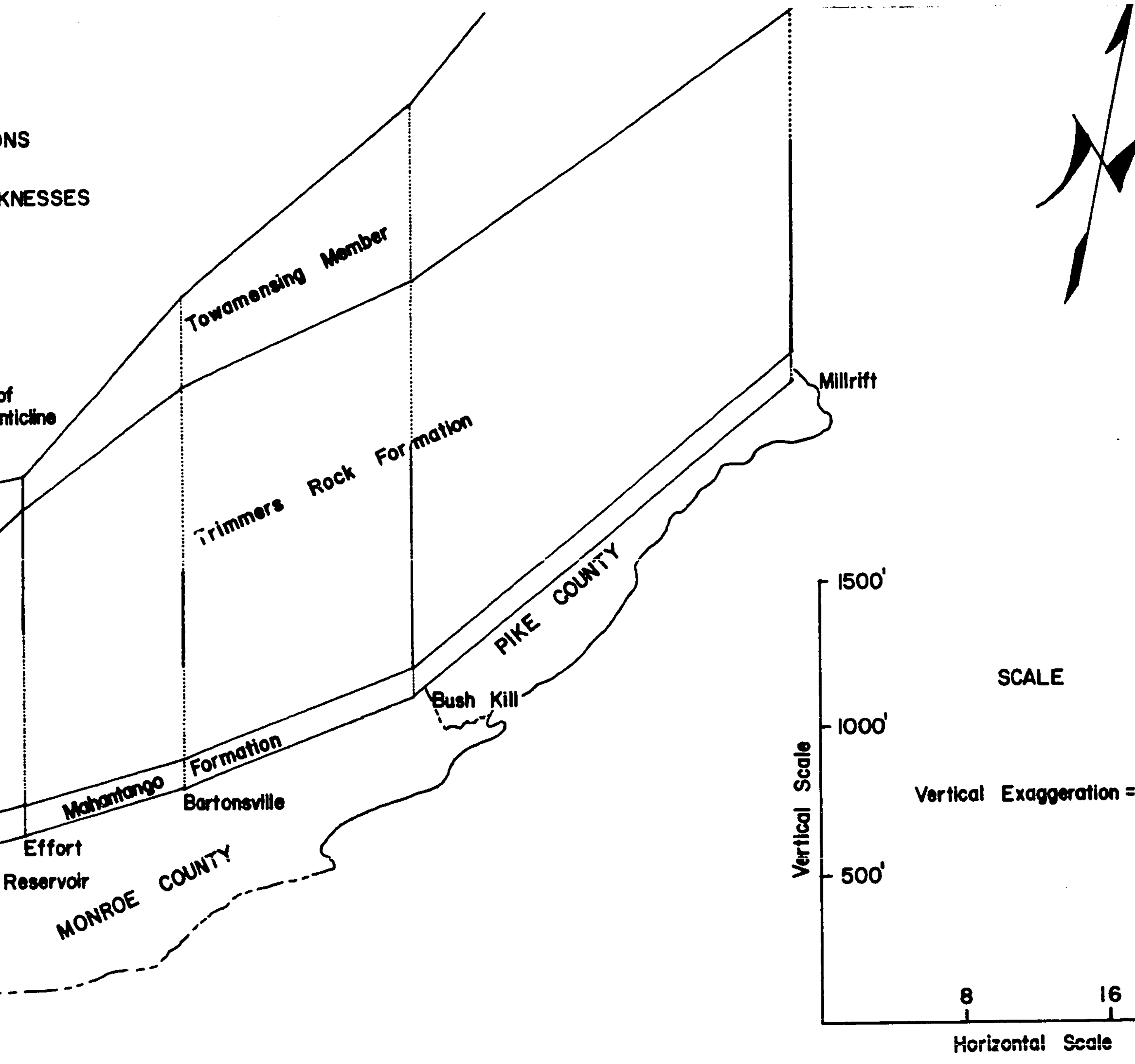


Figure 39. Section thickness correlations of the Trimmers Rock Formation in northeastern Pennsylvania.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Vertical Scale
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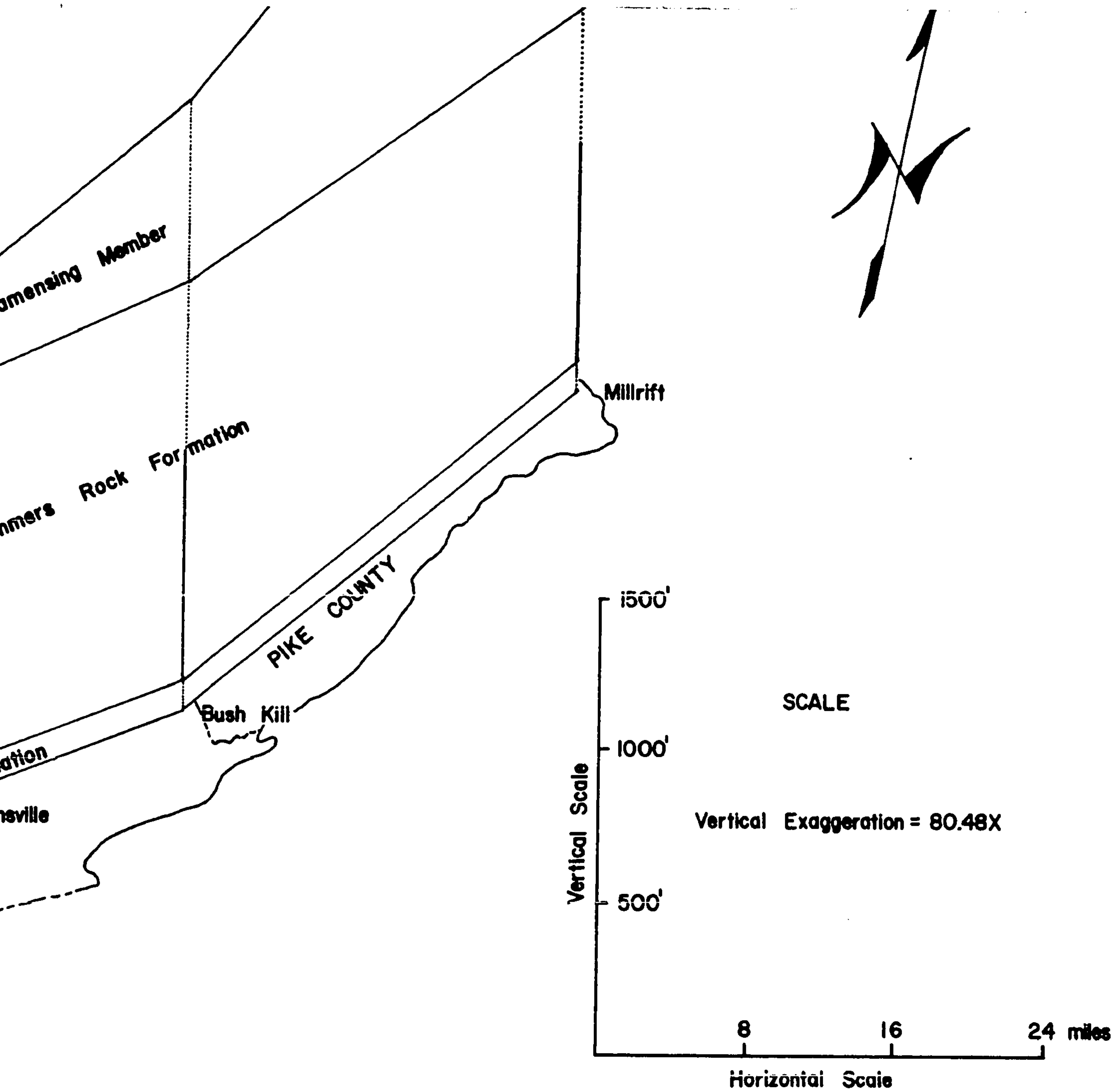

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SEDIMENT DISPERSAL

General

The classical works of Chadwick (1924, 1933) Cooper (1930, 1933), and more recently of Sutton and others (1970) in New York have conclusively documented the westward progradation of the Upper Devonian shoreline. Willard (1939) was able to detect a similar pattern in Pennsylvania. In essence, they demonstrated the upward vertical succession in time of the marine facies as the Catskill shoreline prograded westward. While continental facies were being deposited to the east and southeast, their time equivalents the west and northwest were marine facies. This vertical and lateral facies change is evident in the distribution of sediment size also. Upward coarsing occurs as a consequence of the migration of continental facies over marine environments. Finer marine sediments were transported northwestward while rudite deposition occurred subaerially.

Friedman and Johnson (1966) proposed that the Upper Devonian clastic wedge is the type example of a "Tectonic Delta Complex" owing to the close proximity of the source terrain, a contiguius and active mountain front. Uplift in the source area accompanied by probable basin subsidence is presumed to have been initiated during the early Middle Devonian and greatly accelerated by the Upper Devonian time.

Mencher (1939) advocated a Taconic source area at least for the bulk of the clastic sediments observed in New York State.

Walker (1971) was less enthusiastic with the tectonic concept as advanced by the Friedman and Johnson model (1966). However, he readily acknowledged the southeasterly source of derived sediments. Certainly the source area must have been extensive, owing to the tremendous thickness of the Devonian clastics in central and eastern Pennsylvania. Glaeser (1973) has measured 8,000 feet of Catskill stratigraphy including a basal marine interval at the Lehigh River Section. Central Pennsylvania is generally regarded as having received the thickest Appalachian geosynclinal accumulation of marine and continental clastic sedimentation during the Upper Devonian (Colton, 1970; Oliver and others, 1971). Lateral thinning of this wedge takes place to the extent that the entire Upper Devonian is represented by about 35 feet of Chattanooga Shale in Tennessee. There is no appreciable Upper Devonian clastic sedimentation in the Northern Maritime Appalachian Provinces, and Boucot (1968) and Belt (1968) noted that the manner of deposition as well as their paleoenvironments are quite unlike those observed in the Central Appalachians during the same time interval. In fact, this province was characterized by active tectonism rather than sedimentation. The inference of an ancient southeasterly situated source area, whether contiguous or not to the marine basin, remains suspect unless the vertical relationships of the deltaic facies are considered in light of their subaerial distribution.

The problem of paleocurrent direction has been considered by several authors taking into account several related concepts: (1) the postulated existance of a southeasterly located source area, (2) the vertical and westward migration of the entire Catskill clastic wedge, and (3) Acadian tectonism active to the east during Early and Middle Devonian time. However, as will be shown, the paleocurrent directional features preserved in the coarser-grained facies of the deltaic complex stand as unequivocal evidence of westward and northwestward transport. McIver (1970) noted a gradual change from dispersal to the northwest to dispersal to the west during the deposition of succeedingly younger material in the Portage Group of southwestern and central Pennsylvania. Burtner (1963) recorded over 2000 cross-bed readings in the Catskill sandstones of southeastern New York and northeastern Pennsylvania. His dispersal pattern reveals a westerly bearing. Despite the younger age of these rocks, there is little reason to be suspicious of a salient difference between the current vector of these rocks and that of the marine facies of the entire westward prograding deltaic complex. In fact, McCave (1968) indicated that a similar pattern in southwestern New York has been recorded in the Portland Point member of Middle Devonian age.

The parallel to subparallel inferred contacts bounding the outcrop belt of the Trimmers Rock Formation are gently convex to the northwest except where stream channel erosion has incised a V-shaped pattern. There are no major lobate, cuspate, apical, or other irregular boundaries. Between New Ringgold and Millrift the thickness of the Trimmers Rock increases from approximately 1000 feet to nearly 1200 feet. However, substantial thickening of this formation occurs in southeastern Pike County and northeastern Pike County.

It is the writer's thesis that the Trimmers Rock Formation is the prodelta facies of a northwesterly advancing deltaic shoreline. Sediment was dispersed from several small delta loci. The actual transport and deposition of material within this environment was accomplished by turbidity currents flowing down the prodelta slope and by shoreline-parallel currents flowing along the prodelta slope. These processes resulted in a fairly uniform rate of sediment accumulation along most parts of the prodelta slope although varying stratigraphic thicknesses occur throughout the belt of outcrop in northeastern Pennsylvania.

Primary structures characteristic of modern prodelta environments include graded bedding, plane-parallel bedding and laminae, fossiliferous lenses and disturbed laminations (Gould, 1970; Allen, 1964; Coleman and Gagliano, 1965).

The sediments of these facies are almost wholly silt and clay with only minor sand (Gould, 1970; Allen, 1964). All these structures are found within the siltstones and shales of the Trimmers Rock.

Allen (1964) and Coleman and Gagliano (1965) have noted the presence of biotic debris concentrations in the prodelta facies of many modern deltas. Allen, in his study of the Niger River, reported the occurrence of "shell pockets." Fossiliferous lenses in the Trimmers Rock Formation may be an ancient equivalent. Coleman and Gagliano (1965) noted the presence of plant and shell debris throughout the same environment in the modern Mississippi River delta complex. Scattered plant and shell debris is also common in the Trimmers Rock. Gould (1970) concluded that less than two percent of the total volume of prodelta sediments of the Mississippi River delta contain clastic detritus coarser than silt size. This scarcity of sand is not at all inconsistent with many other modern coastal deltas (Selley, 1970). Throughout northeastern Pennsylvania the Trimmers Rock contains only a few thin, fine-grained sandstone beds.

The exact mechanism wherein a turbidity current is activated upon the ancient prodelta slope cannot be resolved satisfactorily according to modern interpretations. One mechanism evoked for the initiation of turbidity events is subaqueous slumping near the summit of the prodelta slope

(Morgan, 1970; Hampton, 1972; Klein and others, 1972). Oversteepening near the summit of the prodelta slope, followed by slope failure in some modern deltas, has resulted in the downslope displacement of considerable quantities of pre-lithified but coherent slabs of sediment. For example, seismic profiling indicates that large-scale, recent slump features have been active at the mouth of the Mississippi trough (Walker and Massingill, 1970). Nowhere within either the Trimmers Rock Formation or Towamensing Member are large authochthanous blocks or slices observed. Neither is there any evidence of growth faults such as that observed on the Mississippi delta front. In short, the stratigraphic record does not support the contention that instability at the top of the prodelta slope, prodelta front transition, provided the necessary impetus for generating a turbidity event. In all liklihood, turbidity flows were initiated high on the prodelta slope in response to gravitation.

In progressing upward from the Trimmers Rock prodelta facies onto the delta front, a transitory facies, the Towamensing, is next encountered. In comparison to the Trimmers Rock significant variations in stratigraphic thickness in the overlying marine Catskill interval are known by the writer to occur throughout northeastern Pennsylvania. In the northeast, particularly in Pike County, the marine

Catskill is exceptionally thick. Fletcher and Woodrow (1970) reported a thickness of approximately 1250 feet along the east bank of the Delaware River at Hawks Nest, New York. Substantial thinning apparently takes place to the south-west. The writer calculated a stratigraphic thickness of approximately 900 feet during mapping in the southeastern Pike County corner in the Lake Maskenozha 7.5-minute quadrangle. At the sites of the Lehigh River and New Ringgold Sections, the Towamensing is nearly 200 feet thick. T. M. Berg, of the Pennsylvania Geological Survey (written communication, 1973), has suggested that within southwestern Monroe County the unit may be less than 100 feet thick or, in the vicinity of the town of Effort, intertonguing with the next youngest unit, the Walcksville Member. These relationships are considered of critical importance in establishing the coastline geometry of the Upper Devonian marine basin during the deposition of the sediments comprising the outcrop belt.

Although the Towamensing is characterized as a marine sandstone unit, there actually is a gradual increase of sand over silt and clay stratigraphically, particularly at the New Ringgold and Lehigh River Secions, suggesting that sand simply was not available for offshore transport into the deeper water prodelta facies. Presumably, the thicker accumulations of sand observed at these two sections to the southwest and in Pike County to the northeast occurred in a shallower-water near-shore environment.

Loci of Sediment Dispersal

Deposition of the prodelta facies (Trimmers Rock) of the Catskill Delta was apparently controlled by several relatively small delta systems. The interdeltaic coastline, although not directly receiving the bulk of the sediments, nevertheless underwent substantial growth. These interpretations are based on the presence or absence of primary structures and thickness variations of the Trimmers Rock in northeastern Pennsylvania. It is most probable that the delta systems did not maintain a static position relative to each other but actually migrated laterally along the coastline. Based on the stratigraphic record maintained within the outcrop belt of the Trimmers Rock Formation between New Ringgold and Millrift, several different examples of loci can be advanced as specific types operative during the deposition of these rocks.

New Ringgold Loci

Sediment dispersal was presumably accomplished at New Ringgold by several small distributary channels flowing to the northwest on a narrow coastal shelf. The cross-bed sets observed in the upper half of the Towamensing are interpreted as channel-fill deposits. The lateral extent of these subaqueous channels is unknown although similar structures are not observed in the Trimmers Rock-Towamensing transition. Sediment coarser than silt normally was unavailable for downslope transport. However, the source of transported fragmental fossil debris can be traced to the delta front-prodelta transition, a subenvironment impoverished with respect to sand. Eventually their concentration as thin, lenticular pockets in the prodelta facies is effected by turbidity events.

Lehigh River Loci

The Lehigh River Section is considered to be the locale of a separate and major delta loci. In no other measured section are scoured and irregular bases of siltstone so frequent. There are similarly far more fossiliferous lenses in this section than any other. The abundance of these features suggests considerable turbidite deposition, although the pattern of sedimentation is comparable to that observed further west. A general upward coarsening of sediments is encountered throughout the Towamensing with abundant cross-bed sets interpreted as channel-fill deposits in the upper 20 feet. Here too, the Towamensing Member seems to represent deposition upon a narrow coastal shelf. In the Mississippi delta complex the delta front sands which overlie clayey silt deposits contain laminated sands and silts, laminae of wood fragments, thin cross-bedded layers, and disturbed zones (Gould, 1970). All of these features are found in the ancient equivalent, the Towamensing at New Ringgold and along the Lehigh River.

The occurrence of burrow structures and abundant molds of the pelecypod Archanodon sp. in a key sandstone outcrop of the Towamensing Member near Harrity, Pennsylvania (Figure 40), in southern Carbon County suggests that parts of the delta-front environment may be situated in shallow marine waters. Associated sedimentary structures include normal bedding, medium-scale cross-bedding, ripple marks, and some parting lineations (Berg, 1972). Weir (1969) has postulated that "Archanodontacea are a cryptogenic group of very large Anodonta-like freshwater shells of the Upper Paleozoic, such as those known from the Upper Devonian (Up. Old Red Ss.) of Ireland." However, no similar Archanodon sp. molds or burrowings have been identified in the delta-plain or other subaerial facies of the Catskill delta complex.

Between the Lehigh River and Bartonsville Secions, the thickness of the Trimmers Rock Formation is maintained. However, thinning of the Towamensing Member, particularly at the Effort Section, is indicative of a narrowing of the coastal shelf and reduction in the seaward transport of terrestrially derived materials. Scouring and irregular

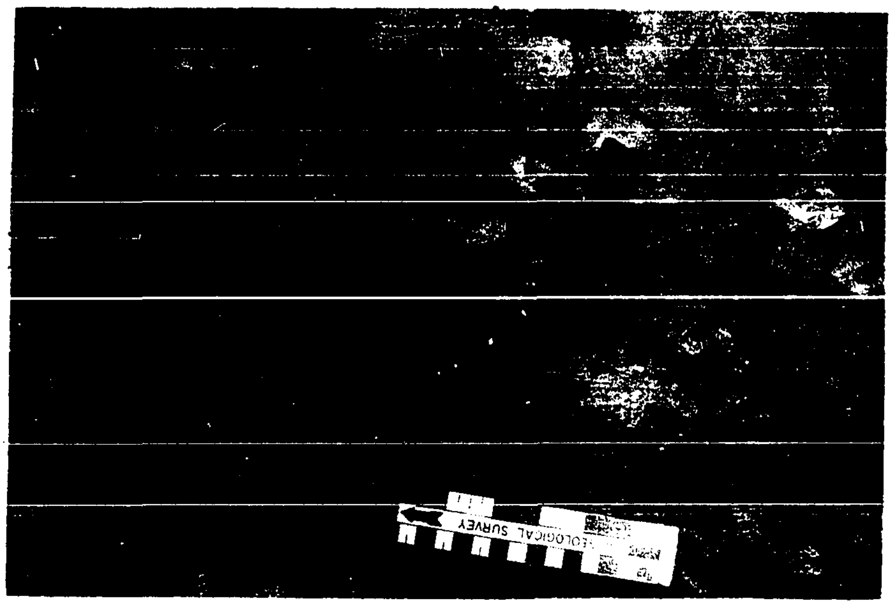


Figure 40. Casts of the pelecypod Archanodon sp. located near Harrity, Pennsylvania.

siltstone beds are rare at a nearly complete section of the Trimmers Rock at Wild Creek Reservoir as well as at the Effort and Bartonsville Sections. Deposition of silt and clay on the prodelta slope must be largely attributed to shoreline-parallel currents. Along these lines of evidence, it is presumed that the mid-Monroe County area occupied an inter-deltaic positicn between the southwesterly Lehigh River and northeasterly Maskenozha Loci.

Maskenozha Loci

Thickening of the prodelta facies occurs near the Pike County border (See Figure 39). The Trimmers Rock is approximately 1400 feet thick at that locale. Alvord and Drake (1971) estimated the Trimmers Rock to be approximately 1700 feet thick in their work in the vicinity of the Pike-Monroe County boundary. However, this writer believes that 300 feet ot this thickness should be assigned to the overlying Towamensing Member because of the occurrence of massive sandstone beds, and in one sandstone bed abundant and well-preserved burrowings of Archanodon sp. occur.

The increasing thicknesses of both the prodelta and delta-front facies at the northeastern boundary of Monroe County indicates changing basinal conditions along the Upper Devonian coastal fringe and possibly the general position of of another loci. This is also reflected by local conglomeratic facies several thousand feet stratigraphically higher in the Catskill Formation (W. D. Sevon, Pennsylvania Geological Survey, personal communication, 1974). Either the basin of sediment deposition was deeper here than it was to the southwest in Carbon and Schuylkill Counties, or it was one which received prodelta sedimentation over a longer period of time.

Other Loci

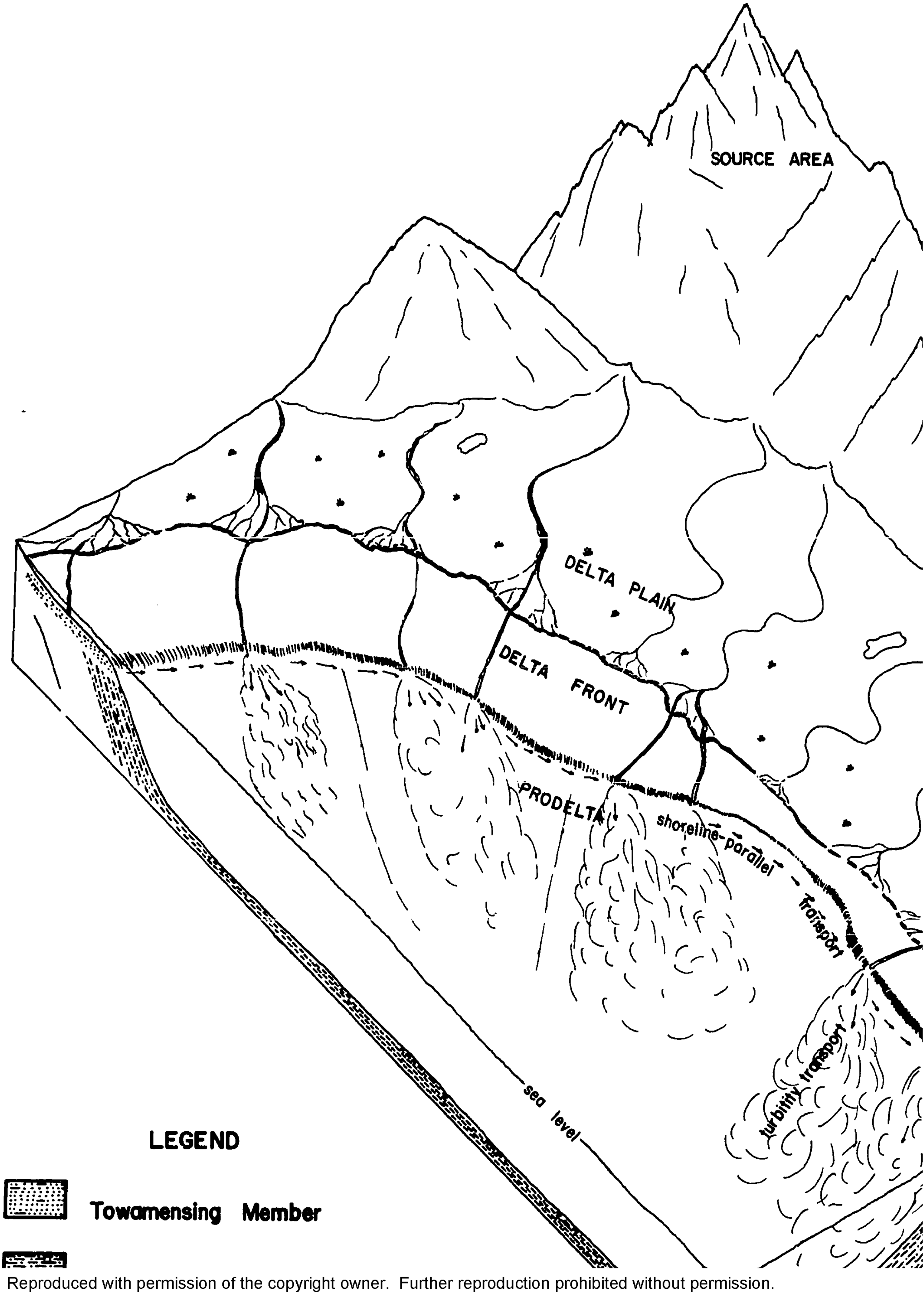
No further thickening of the Trimmers Rock Formation occurs in Pike County. The unit reaches its greatest calculated thickness, approximately 1400 feet, in the Lake Maskenozha 7.5-minute quadrangle. From this general vicinity to the Millrift Section the unit gradually thins to about 1200 feet. The Towamensing Member increases from 600 feet in northeastern Monroe County to approximately 1000 feet within the Lake Maskenozha 7.5-minute quadrangle. This thickness similarly is maintained along the outcrop belt to the Millrift Section.

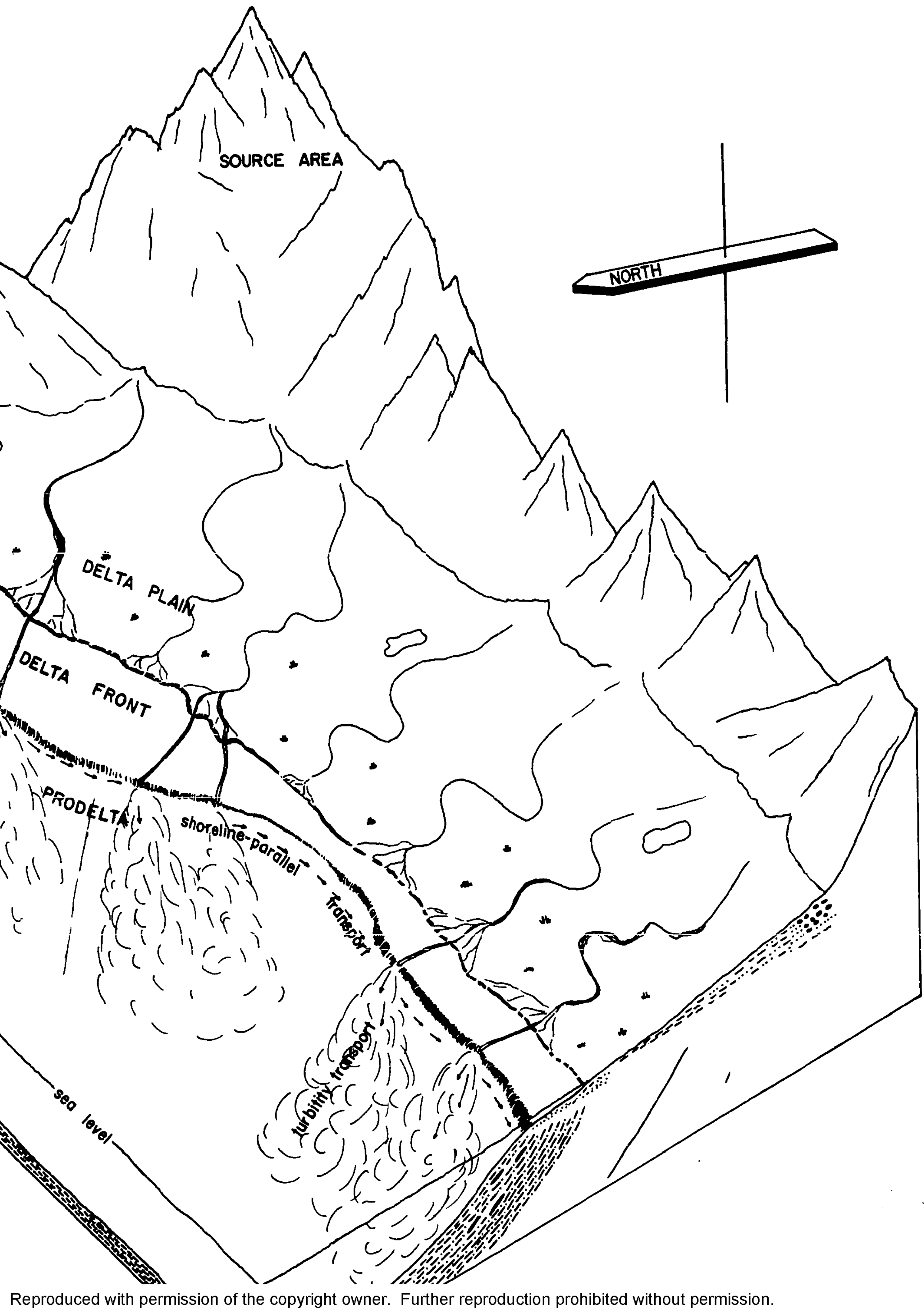
The coastal shelf must have continued to broaden from what is now eastern Monroe County into northeastern Pike County where it reached a maximum width. Alternatively, if the delta-front sands were not deposited upon a wider depositional surface, then substantial subsidence or longer shelf sedimentation as to the southwest at the Maskenozha

Loci may account for this accumulation of marine sands. In either case, the mode of sediment transport and deposition are considered similar to those further to the southwest. Lithologic variations and primary structural features are identical and stratigraphically equivalent along the entire outcrop belt in Pike County. Burrows of Archanodon sp. are found in bedrock, detached blocks, and in boulder colluvium deposits of Towamensing sandstone. Several spectacular beds of these clam burrows occur in the continuous exposures along New York Route 97 in the vicinity of Hawks Nest, New York. Medium-scale cross-bed sets and troughs are found throughout the county in isolated exposures of these marine sandstones above the Trimmers Rock Formation. Abundant silt and clay were transported seaward atop the delta front and subsequently by unchannelized turbidity currents into the prodelta slope. Shoreline-parallel currents along the prodelta slope also were active.

Much of Pike County received its sediment from the northeast. Paleocurrent delta collected by Burtner (1963) from the Catskill rocks in this general vicinity show a southwesterly trend. The apparent lack of evidence, either stratigraphic or depositional, suggests that no dispersal loci were located in northeastern Pike County. This area may have been situated on the fringe of another ancient and major loci situated just to the east of what is now known as the Catskill Mountains of New York.

A schematic diagram reconstructing the Upper Devonian shoreline at the time of Trimmers Rock deposition is shown in Figure 41. The model suggests the introduction of detrital sediments into the prodelta environment at the mouths of subaqueous delta-front facies channels. These sediments were transported both down the paleoslope and along the transition between the prodelta and delta-front environments.


SOURCE AREA
DELTA PLAIN
DELTA FRONT
PRODELTA
shoreline-parallel transport
turbidity transport
sea level
LEGEND
Towamensing Member


SOURCE AREA
NORTH
DELTA PLAIN
DELTA FRONT
PRODELTA
shoreline-parallel transport
turbidity transport
sea level

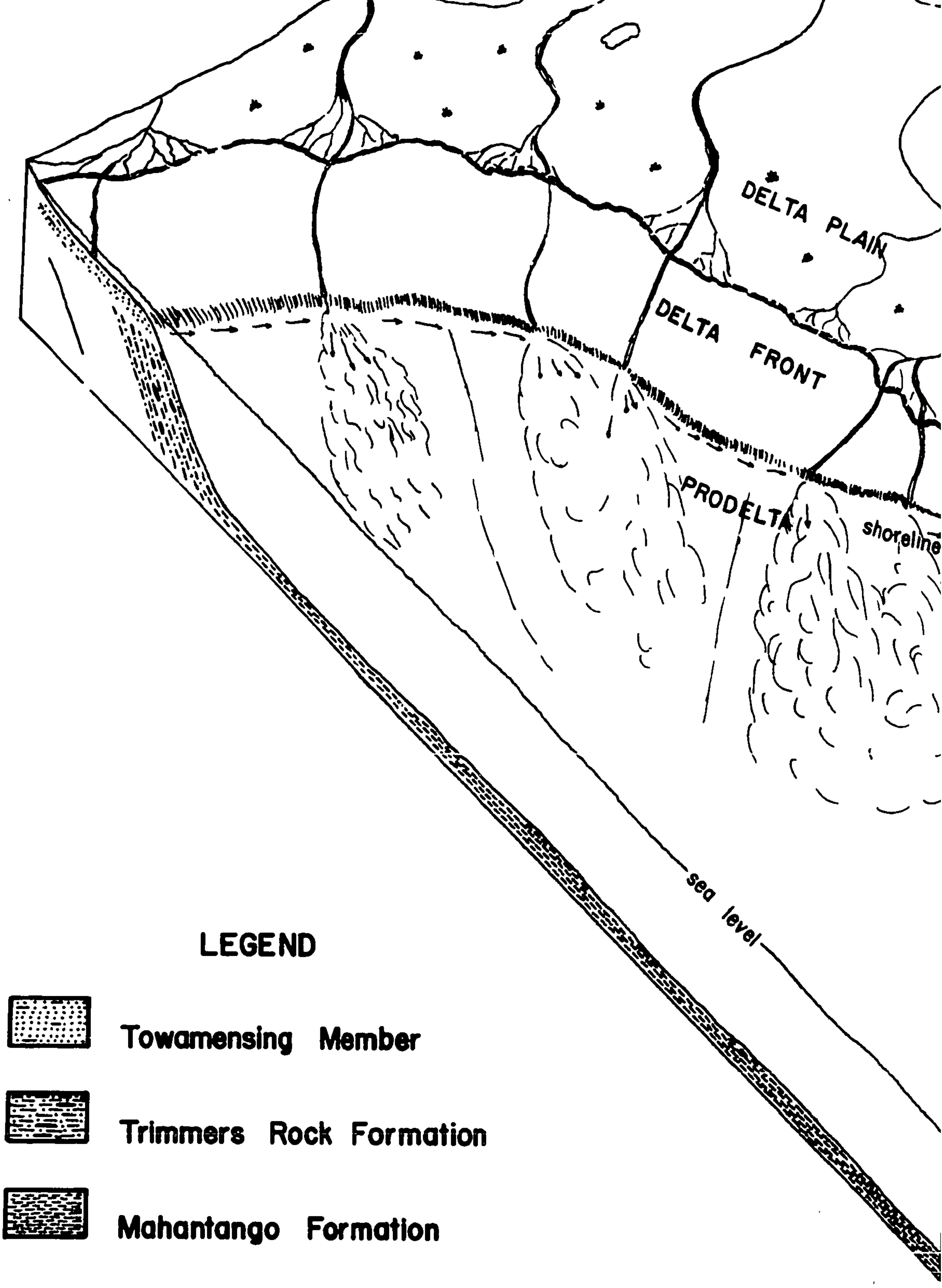
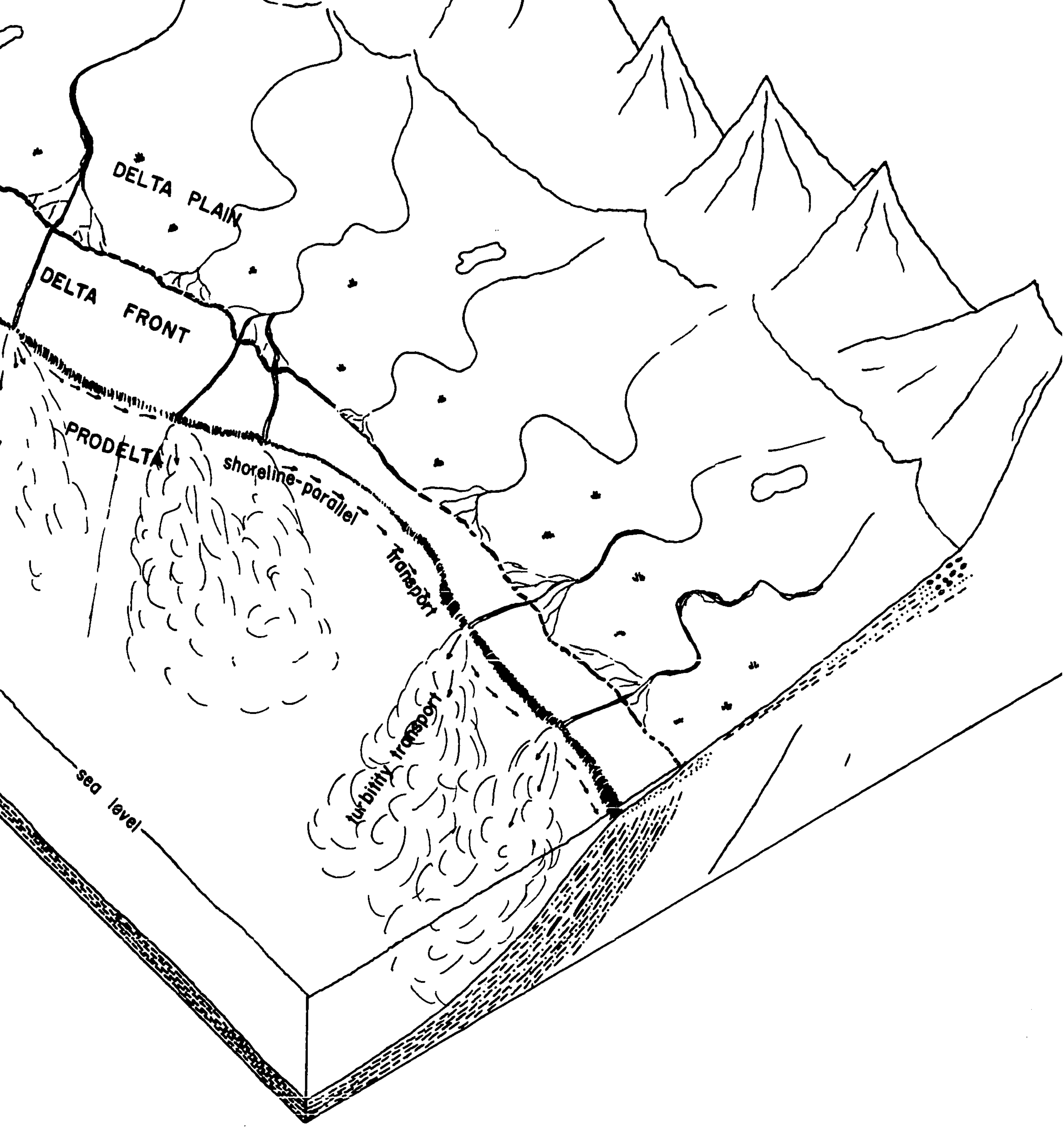


Figure 41. Diagrammatic paleoenvironmental reconstruction.



al reconstruction.

SOURCE AREA

Early investigations, beginning with Barrell (1913) postulated the existance of an island-arc complex lying generally eastward of the present Atlantic coastline. It was from this source that all Catskill delta clastics were derived. Frakes (1967) specifically proposed a source for the Trimmers Rock in the southern portion of the Great Valley, the northwestern Piedmont, and perhaps at the site of the present Coastal Plain. More recently, Walker (1971) suggested a highlands source, the "Acadian Mountains," lying several tens of miles to the southeast of the Trimmers Rock outcrop belt. These workers and others noted in the Central Appalachians that the Catskill strata thicken markedly southeasterly and easterly to the limit of eroded outcrop. Paleocurrent analyses made by several authors all indicate that the mean bearing of sediment transport was from southeast to northwest (Pettijohn, 1962; Hunter, 1960; McIver, 1970; Burtner, 1963; Meckel, 1964, 1967). Thus, all authors seem to agree at least that the source area of the sediments comprising the Upper Devonian delta complex was to the southeast.

It is dangerous to assign provenance on the basis of the mineral content of siltstones. However, if one considers the mineralogy of both the Trimmers Rock siltstones and the sandstones and conglomerates of the Catskill and Pocono Formations (Glaeser, 1973; and Sevon, 1969), it is clear that crystalline rocks must have been exposed in the source area beyond the fall line. It has been shown earlier in this report that the Trimmers Rock contains a substantial proportion of plagioclase and potash feldspars. This is also true of the sandstones in the Catskill Formation--in fact, the proportion of feldspar increases slightly in the Catskill sandstones (Glaeser, 1973).

The nearest source of crystalline rocks is the Reading Hills and these may very well have contributed. The Reading Hills are nappe structures (Drake, 1970) which are postulated to have developed high on the Appalachian Geanticline by the upthrusting of allochthanous basement Precambrian rocks into a sedimentary cover involving post-Precambrian rocks as young as those in the Martinsburg flysch deposition. The erosional remnant observed today in the Great Valley and Reading Prong Provinces of eastern Pennsylvania and New Jersey Highlands of New Jersey is the result of erosion down to the inverted limb of these nappes. Post-tectonic (?) faulting and folding have reversed the stratigraphy so that now Precambrian rocks occupy the troughs of synforms while younger rocks lie in the cores of antiforms. If Drake's model is a reasonable approximation of the tectonic history describing the complex structure of the Precambrian and

Lower Paleozoic rocks, then a volumetrically significant source has been eroded from the right-side-up limbs of these crystalline rock-cored nappes.

There is little doubt that considerable erosion took place during the Silurian, denuding much of this limb. Therefore, a bathometric chart of the Upper Devonian sea would have revealed the existence of several submerged submarine hills, consisting of basal Cambrian orthoquartzites and Precambrian granitic gneisses. Although initially overlain by a thin, clastic veneer, as the constructional shoreline migrated northwestward, subsequent uplift and erosion would have exposed the crystalline rocks, enabling them to contribute simultaneously with the cannibalized delta clastics. This process of cannibalization involved both the uplift and erosion of a source area which migrated simultaneously to the northwest behind the regressive Upper Devonian shoreline. Although deltaic source material initially may have been derived from lower Cambrian and Precambrian rocks, eventually uplifted Catskill deltaic sediments were eroded and transported to the northwest through dispersal loci into the Appalachian Basin.

The Green Pond Syncline may represent a modern remnant of these relationships. A trough of Silurian and Devonian clastics, 58 miles long and 4 miles to less than a mile wide in northeastern New Jersey and New York, lie unconformably on Precambrian and Lower Paleozoic rocks (Lewis and Kümmel, 1910-1912; Broughton and others, 1962).(See Figure 42). Within this 6000 feet of strata, at least one unconformity is present; rocks of Onondaga age lie on Upper Silurian rocks (Lewis and Kümmel, 1940). The Devonian units of particular interest include the Skunnemunk Conglomerate, Bellvale Sandstone and Pequanac Shale. These three units are grossly correlative lithologically with the continental Catskill facies, the Towamensing Member and Trimmers Rock Formation, and Mahantango Formation, respectively. This isolated outlier, located more than 25 miles from the edge of the Upper Devonian outcrop belt, reenforces the contention of a northwestward-prograding Catskill delta through this region. All these relationships support the supposition that the crystalline granitic rocks together with cannabalized delta sediments both furnished source sediments at least during one static phase of the delta growth.

The most abundant framework mineral of the Trimmers Rock Formation is quartz. Many of the grains are characterized by strongly undulose extinction. Aaron (1969) reported that almost without exception detrital quartz grains of the Hardyston Formation show strongly undulose extinction. Trace amounts of zircon, tourmaline and rutile are also reported and similarly occur as very minor accessory constituents of the prodelta rocks. Aaron concluded on the basis of

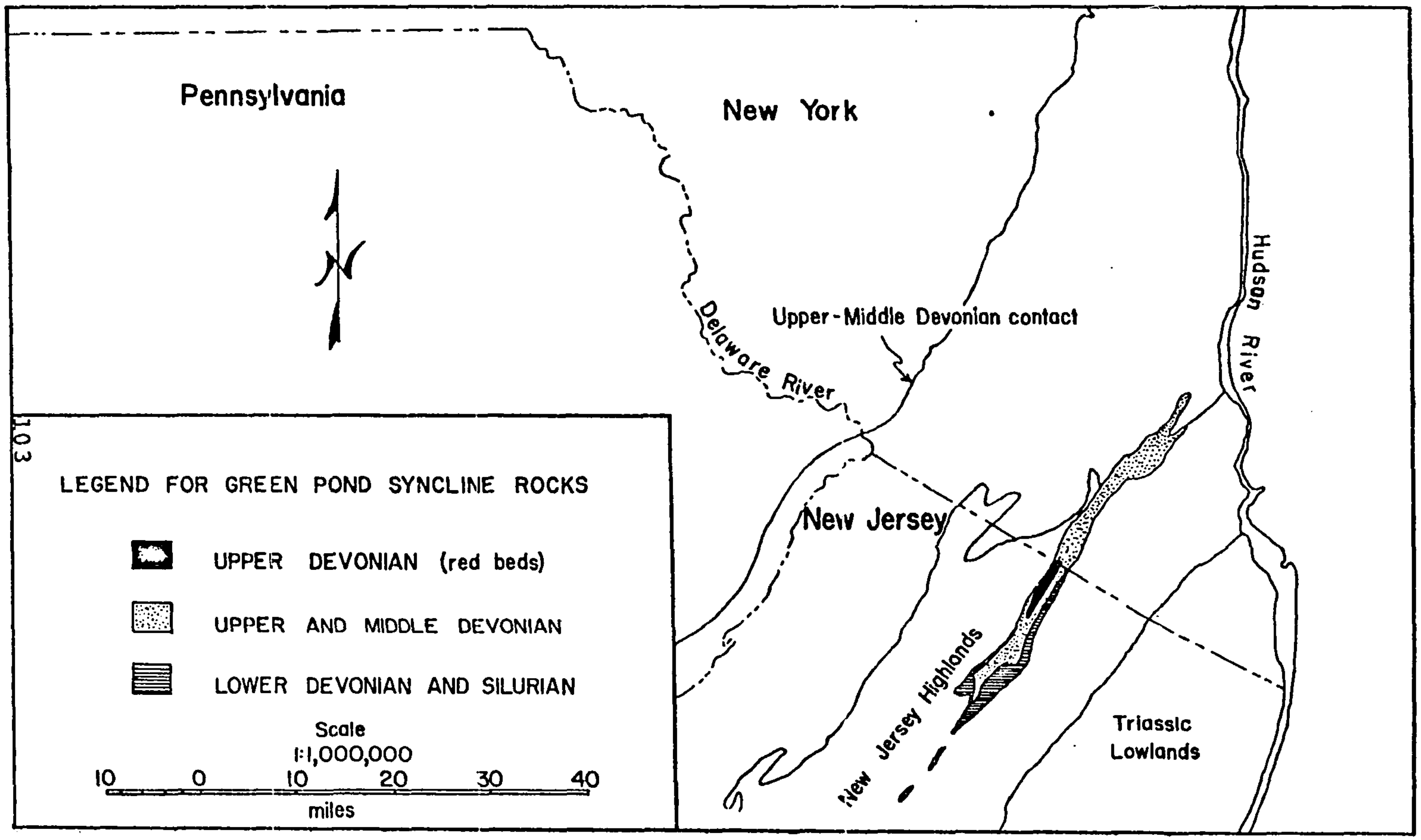


Figure 42. Green Pond Syncline location map.

the complete mineralogical assemblage that there was but a single source for the Hardyston, that being the rocks of the Reading Prong. Much of the quartz in the Trimmers Rock Formation likewise could have been derived from the crystalline rocks of the Reading Hills as well as the associated Hardyston quartzite.

Generating the necessary tectonic front required to elevate the source terrain situated to the rear of the prograding Upper Devonian shoreline merits speculation in light of plate-tectonic theory. Bird and Dewey (1970) have suggested that Appalachian stratigraphic-tectonic zones and deformation are related to a sequence of expansion and contraction of a Proto-Atlantic ocean situated between two mobile lithospheric plates. One such period of progressive contraction was initiated during the Middle Ordovician and culminated in the actual collision between the two opposing continental margins during late Devonian time. The effects of this collision were propagated westward and northwestward. The prograding Catskill Delta is one obvious manifestation of the Bird and Dewey model.

CONCLUSION

It has been shown that the Trimmers Rock Formation in northeastern Pennsylvania is an ancient equivalent of modern prodelta environments. Several of the salient similarities between the two include: (1) an abundance of silt and clay and a corresponding scarcity of sand; (2) an upward gradation into a facies characterized by an abundance in sand and depletion in silt and clay; (3) identical primary structures such as parallel laminae, disturbed laminae, upward-fining cycles, cross-bedding, fossiliferous lenses, and ripples; and (4) deposition by both turbidity flow and shoreline-parallel currents.

Stratigraphic thickness variations and associated depositional structures along the outcrop belt between New Ringgold and Millrift, Pennsylvania, suggest the existance of several dispersal loci through which deltaic sedimentation was controlled during the Upper Devonian. Three major loci were situated in the vicinity of the New Ringgold, Lehigh River, and Bushkill Sections. One inter-deltaic regime was located in western Monroe County. Northeastern Pike County probably comprised the southwestern flank of one very large loci which controlled the thick deltaic wedge now known as the Catskill Mountains of New York.

On the basis of mineralogy alone, very little can be concluded regarding the source area of the Trimmers Rock.

Paleocurrent studies of other central Appalachian clastics indicate a northwesterly bearing. The writer did not encounter any evidence suggesting a reversal in trend of transport pattern during Upper Devonian time in northeastern Pennsylvania. Logically, the source of all Upper Devonian Catskill clastics was situated to the southeast and may have included the crystalline rocks of the Reading Prong. As the Upper Devonian shoreline prograded northwestward an uplifted source prograded similarly. Evidently, a process of cannibalization was established wherein uplifted deltaic sediments were re-eroded and re-deposited.

REFERENCES

Aaron, J. M., 1969, Petrology and origin of the Hardyston Quartzite (Lower Cambrian) in eastern Pennsylvania and western New Jersey: in Subitzky, S., ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: New Brunswick, New Jersey, Rutgers University Press, p. 21-34.

Allen, J. R., 1964, Sedimentation in the modern Niger River: in van Straaten, L. M. J. V., ed., Deltaic and shallow marine deposits, v. 1 of Sedimentation: New York, Elsevier Publ. Co., p. 26-34.

Alvord, D. C., and Drake, A. A., Jr., 1971, The Bushkill quadrangle, Pennsylvania-New Jersey: U.S. Geol. Survey, Map GQ-908.

Barrell, J., 1913, The Upper Devonian delta of the Appalachian geosyncline, Part I: Am. Jour. Sci., v. 186, p. 429-472.

_____, 1914a, The Upper Devonian delta of the Appalachian geosyncline, Part II: Am. Jour. Sci., v. 187, p.87-109.

_____, 1914b, The Upper Devonian delta of the Appalachian geosyncline, Part III: Am. Jour. Sci., v. 187, p. 225-253.

Belt, E. S., 1968, Post-Acadian rifts and related facies, Eastern Canada: in Zen, E-An, White, W. S., Hadley, J. B., Jr., and Thompson, J.B., Jr., eds., Studies of Appalachian geology: northern and maritime: New York, Interscience Pubs., p. 95-113.

Berg, T. M., 1972, Clam Burrows in the Upper Devonian or: "Quo Vadis Archanodon?": Pennsylvania Geol. Survey, Pennsylvania Geology, v. 3/6, p. 6-8.

Berg, T. M., Schultz, L. D., and Sevon, W. D., (in progress), The bedrock and surficial geology of Pike County, Pennsylvania: Pennsylvania Geol. Survey, 4th ser.

Bird, J. M., and Dewey, J. F., 1970, Lithosphere plate: continental margin tectonics and the evoluction of the Appalachian orogen: Geol. Soc. America Bull., v. 81, p. 1031-1060.

Blatt, H., Middleton, G., and Murray, R., 1972, Origin of sedimentary rocks: Englewood, N.J., Prentice-Hall, Inc., 634 p.

Boucot, A. J., 1968, Silurian and Devonian of the northern Appalachians, in Zen, E-An, White, W. S., Hadley, J.B., and Thompson, J. B., Jr., eds.: Studies of Appalachian geology: northern and maritime: New York, Interscience Pubs., p. 83-94.

Bouma, A. H., 1962, Sedimentology of some flysch deposits: New York, Elsevier Publ. Co., 168 p.

Bouma, A. H., and Hollister, C. D., 1973, Deep ocean basin sedimentation: in Middleton, G. V., and Bouma, A. H., co-chairmen, Turbidites and deep-water sedimentation lecture notes for SEPM Pacific Section meeting, Anaheim, p. 79-118.

Broughton, J. G., and others, 1962, Geologic map of New York, 1961: New York State Mus. and Sci. Service, Geol. Survey, Map and Chart Ser. No. 5, 5 map sheets, scale 1:250,000, and text.

Brunton, G., 1955, Vapor pressure glycolation of oriented clay minerals: Am. Mineralogist, v. 40, p. 124-126.

Burtner, R. L., 1963, Sediment dispersal patterns within the Catskill facies of southeastern New York and northeastern Pennsylvania: in Schepps, V. C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geol. Survey, 4th ser., General Geol. Rpt. 62, p. 7-23.

Chadwick, G. H., 1924, The stratigraphy of the Chemung group in western New York: New York State Mus. Bull. 251, p. 149-157.

______, 1933, Great Catskill delta: and revision of Late Devonian succession (Upper Devonian revision in New York and Pennsylvania): Pan-Am. Geologist, v. 60, p. 91-107, 189-204, 275-286, 348-360. (Chadwick distributed a list of important changes necessitated by editorial revision).

______, 1944, Silurian and Devonian geology, with a chapter on glacial geology, Part 2 of Geolgoy of the Catskill and Kaaterskill quadrangles: N. Y. State Mus., Bull. 336, 251 p.

Coleman, J. M., and Gagliano, S. M., 1965, Sedimentary Structures: Mississippi deltaic plains: in Middleton, G. V., ed., Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Sp. Pub. 12, p. 133-158.

Conybeare, C. E. B. and Crook, K. A. W., 1968, Manual of sedimentary structures: Department of National Development, Bureau of Mineral Resources, Geology, and Geophysics of Australia, Bull. No. 102, p. 35-41.

Cooper, G. A., 1930, Stratigraphy of the Hamilton group of New York: Am. Jour. Sci., 5th ser., v. 19, p. 116-134, 214-236.

_____, 1933, Stratigraphy of the Hamilton group of eastern New York: Am. Jour. Sci., 5 ser., v. 26, p. 537-551; v. 27, p. 1-12.

_____, 1941, Facies relations of the Middle Devonian (Hamilton group) along the Catskill front (abst.): Geol. Soc. America Bull., v. 52, p. 1893.

Colton, G. W., 1970, The Appalachian basin--its depositional sequences and their geologic relationships; in Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and Weaver, K. N., eds., Studies of Appalachian geology: central and southern: New York, Interscience Pubs., p. 5-48.

Colton, G. W., and deWitt, W., Jr., 1958, Stratigraphy of the Sonyea formation of late Devonian age in western and west-central New York: U.S. Geol. Survey Oil and Gas Inv. Chart OC 54.

deWitt, W., Jr., and Colton, G. W., 1959, Revised correlations of lower Upper Devonian rocks in western and central New York: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 2810-2828.

Dott, R. H., Jr., 1963, Dynamics of subaqueous gravity depositional processes: Am. Assoc. Petroleum Geologists Bull., v. 47, p. 104-128.

Drake, A. A., Jr., 1970, Structural geology of the Reading Prong: in Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., Weaver, K. N., eds., Studies of Appalachian geology: central and southern: New York, Interscience Pubs., p. 271-291.

Emmons, E., 1842, Geology of New York, Part II (second geological district): New York, D. Appelton & Co. and Wiley & Putnam, 434 p.

Epstein, J. B., and Epstein, A. G., 1967, Geology in the region of the Delaware to Lehigh Water Gaps: Pennsylvania Geol. Survey, Guidebook for the 32nd annual field conference of Pennsylvania geologists, 89 p.

Epstein, J. B., Sevon, W. D., and Glaeser, J. D., 1974, Geology and mineral resources of the Lehighton and Palmerton quadrangles, Carbon County, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Atlas 195 cd.

Fisher, D. W., Isachsen, Y. W., and Rickard, L. V., 1970, Geology map of New York: New York State Mus. and Sci. Service Map and Chart Series No. 15, Lower Hudson Sheet, scale 1:250,000.

Fletcher, F. W., and Woodrow, D. L., 1970, Geology and economic resources of the Pennsylvania portion of the Milford and Port Jervis 15-minute quadrangles: Pennsylvania Geol. Survey, 4th ser., Atlas 223, 64 p.

Frakes, L. A., 1962a, Graded bedding in fine-grained sedimentary rocks (abst.): Geol. Soc. America, Spec. Paper 67, p. 155.

_____, 1962b, Characteristics of graded bedding in the Fort Littleton formation: Pa. Acad. Sci. Proc., v. 36, p. 208-212.

_____, 1967, Stratigraphy of the Devonian Trimmers Rock in eastern Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Rept. G-51.

Friedman, G. M., and Johnson, K. G., 1966, The Devonian Catskill deltaic complex of New York, type example of a "Tectonic Delta Complex": in Shirley, M. L., ed., Deltas: Houston Geol. Survey, p. 171-188.

Glaeser, J. D., 1973, Description and evolution of the Catskill stratigraphic framework in northeastern Pennsylvania and a preliminary interpretation of its sedimentologic implications: Pennsylvania Geol. Survey, open-file report, 24 p.

Gould, H. R., 1970, The Mississippi delta complex: in Morgan, J., ed., Deltaic sedimentation, modern and ancient: Soc. Econ. Paleontologists and Mineralogists Sp. Pub. 15, p. 3-30.

Gwinn, V. E., 1964, Thin-skinned tectonics in the Plateau and northwestern Valley and Ridge provinces of the central Appalachians: Geol. Soc. America Bull., v. 75, p. 863-900.

Hall, J., 1839, Third annual report of the fourth geological district: New York State Geol. Survey, 3rd Ann. Rept., p. 287-339.

_____, 1840, Fourth annual report of the fourth geological district: New York State Geol. Survey, 4th Ann. Rept., p. 389-456.

Hall, B. A., and Stanley, D. J., 1973, Levee-bounded submarine base-of-slope channels in the lower Devonian Seboomook formation, northern Maine: Geol. Soc. America Bull., v. 84, p. 2101-2110.

Hampton, M. A., 1972, The role of subaqueous debris flow in generating turbidity current: Jour. Sed. Petrology, v. 42, p. 775-793.

Heezen, B. C., Hollister, C. D., and Ruddiman, W. F., 1966, Shaping of the Continental Rise by deep geostrophic contour currents: Science, v. 152, p. 502-508.

Hunter, R. E., 1960, Iron sedimentation in the Clinton group of the central Appalachian basin: Ph.D. Thesis: Johns Hopkins University, 242 p.

Klein, G. deV., deMelo, V., and Favera, J. D. D., 1972, Subaqueous gravity process on the front of Cretaceous deltas, Recôncavo basin, Brazil: Geol. Soc. America Bull., v. 83, p. 1469-1492.

Krynine, P. D., 1948, The megascopic study and field classification of sedimentary rocks: Jour. Geology, v. 56, p. 130-165.

Kuenen, Ph. H., 1958, Experiments in geology: Geol. Soc. Glasgow Trans., v. 23, p. 1-28.

Lesley, J. P., 1885, A geological hand atlas of the sixty-seven counties of Pennsylvania: Pennsylvania 2nd Geol. Survey, Report of Progress X, 112. p. with maps.

_____, 1892-95, A summary description of the geology of Pennsylvania: Pennsylvania 2nd Geol. Survey, final report, 4 vols.

Lewis, J. V., and Kümmel, H. B., 1910-12, Geologic map of New Jersey: New Jersey Geol. Survey; revised 1931 by H. B. Kümmel; 1950 revision by M. E. Johnson, pub., as New Jersey Dept. Conserv. and Econ. Devel., Atlas Sheet 40.

__________, 1940, The geology of New Jersey: New Jersey Dept. Conser. and Devel., Geol. Ser. Bull. 50, 203 p.

Mazzullo, S. J., 1973a, Sedimentary structures and trace fossils as criteria for distinguishing peritidal deposits: Hamilton group (Middle Devonian), southeastern New York: Jour. Sed. Petrology, v. 43, p. 569-572.

_____, 1973b, Deltaic Environments, Hamilton group: Jour. Sed. Petrology, v. 43, p. 1061-1071.

McCave, I. N., 1968, Shallow and marginal marine sediments associated with the Catskill complex in the Middle Devonian of New York: Geol. Soc. America Sp. Paper 106, p. 75-107.

McIver, N. L., 1961, Upper Devonian marine sedimentation in the central Appalachians: Ph.D. Thesis, The Johns Hopkins University, 347 p.

_____, 1970, Appalachian turbidites: in Fisher, G. W., Pettijohn, F. J., Reed, J. C., and Weaver, K. N., eds., Studies of Appalachian geology: central and southern: New York, Interscience Pubs., p. 69-81.

Meckel, L. D., 1964, Pottsville sedimentology central Appalachians: Ph.D. Thesis: The Johns Hopkins University, 411 p.

_____, 1967, Origin of Pottsville conglomerates (Pennsylvanian) in the central Appalachians: Geo. Soc. America Bull., v. 78, p. 223-258.

Mencher, Ely, 1939, Catskill facies of New York State: Geol. Soc. America Bull., v. 50, p. 1761-1793.

Middleton, G. V., and Hampton, M. A., 1973, Sediment gravity flow: mechanics of flow and deposition: in Middleton, G. V., and Bouma, A. H., co-chairmen, Turbidites and deep-water sedimentation, lecture notes for SEPM Pacific Section meeting, Anaheim, p. 10-13.

Moore, D. G., 1961, Submarine slumps: Jour. Sed. Petrology, v. 31, p. 343-357.

Morgan, J. P., 1970, Depositional processes and products in the deltaic environment: in Morgan, J. P., ed., Deltaic sedimentation, modern and ancient: Soc. Econ. Paleontologists and Mineralogists Sp. Pub. 15, p. 31-47.

Oliver, W. A., Jr., deWitt, W., Jr., Dennison, J. M., Hoskins, D. M., and Huddle, J. W., 1971, Isopach and lithofacies maps of the Devonian in the Appalachian basin: Pennsylvania Geol. Survey, Progress Rept. 182, Sheet 6.

Pettijohn, F. J., 1962, Paleocurrents and paleogeography; American Assoc. Petroleum Geologists Bull., v. 46, p. 1468-1493.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1972, Sand and sandstone: New York, Springer-Verlag, 618 p.

Prosser, C. S., 1894, The Devonian system of eastern Pennsylvania and New York: U.S. Geol. Survey Bull. 120, 81 p.

Rickard, L. V., 1964, Correlation of the Devonian in New York state: New York State Mus. and Sci. Survey Map and Chart Ser., No. 4, with text.

Rogers, H. D., 1838, Second annual report on the geological exploration of the State of Pennsylvania: Pennsylvania Geol. Survey, 93 p.

_____, 1858, The geology of Pennsylvania, a government survey: Philadelphia, 2 v., 586 and 1046 p.

Selley, R. C., 1970, Ancient sedimentary environments: Ithaca, New York; Cornell University Press, p. 74-109.

Sevon, W. D., 1969, The Pocono formation in northeastern Pennsylvania: Pennsylvania Geol. Survey, Guidebook for the 34th annual field conference of Pennsylvania geologists, 129 p.

Sevon, W. D., Epstein, J. B., and Berg, T. M., 1973, Preliminary bedrock geologic map of Monroe County, Pennsylvania: Pennsylvania Geol. Survey, open-file report, scale 1:48,000, with text.

Shepps, V. C., ed., 1963, Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geol. Survey, 4th ser., Bull. G-39, 301 p.

Stanley, D. J., 1969, Sedimentation in slope and base-of-slope environment, Lecture 8, The new concepts of continental margin sedimentation: A. G. I., p. DJS-8-1 to DJS-8-25.

Sutton, R. G., Humes, E. C., Jr., Nugent, R. C., and Woodrow, D. L., 1962, New stratigraphic nomenclature for Upper Devonian of south-central New York: Am. Assoc. Petroleum Geologists Bull., v. 46, p. 390-393.

Sutton, R. G., Bowen, Z. P., and McAlester, A. L., 1970, Marine shelf environments of the Upper Devonian Sonyea group of New York: Geol. Soc. America Bull., v. 81, p. 2975-2992.

Vanuxen, L., 1839, Third annual report of the geological survey of the third district: New York State Geol. Survey, 3rd Ann. Rept., p. 241-285.

_____, 1840, Fourth annual report of the third geological district: New York State Geol. Survey, 4th Ann. Rept., p. 355-383.

_____, 1842, Geology of New York, Part III (third geological district): New York, D. Appelton & Co. and Wiley & Putnam, 306 p.

Wagner, W. R., 1963, Correlation of Susquehanna group in northeastern Pennsylvania: in Shepps, V. C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geol. Survey, 4th ser., General Geology Rept. G-39, p. 63-77.

Walker, J. R., and Massingill, J. V., 1970, Slump features on the Mississippi fan, northeastern Gulf of Mexico: Geol. Soc. America Bull., v. 81, p. 3101-3108.

Walker, R. G., 1965, The origin and significance of the internal structures in turbidites: Proc. Yorkshire Geol. Soc., v. 33, p. 1-29.

_____, 1970, Review of the geometry and facies organization of turbidites and turbidite-bearing basins: Geol. Soc. Canada, Sp. Paper No. 7, p. 219-251.

_____, 1971, Non-deltaic depositional environments in the Catskill clastic wedge (Upper Devonian) of central Pennsylvania: Geol. Soc. America Bull., v. 82, p. 1305-1326.

_____, 1972, Upper Devonian marine-nonmarine transition, southern Pennsylvania: Pennsylvania Geol. Survey, 4th ser., General Geology Rept. 62, 25 p.

Walker, R. G., and Harms, J. C., 1971, The "Catskill Delta": A prograding muddy shoreline in central Pennsylvania: Jour. Geol., v. 79, p. 381-399.

Walton, E. K., 1967, The sequence of internal structures in turbidites: Scottish Jour. Geol., v. 3, p. 306-317.

Weir, J. T., 1969, Superfamily ARCHANODONTACEA, new superfamily: in Moore, R. C., ed., Treatise on vertebrate paleontology: Geol. Soc. America and University of Kansas, Part N, v. 1 (of 3), p. 402-404.

White, I. C., 1882, The geology of Pike and Monroe Counties: Pennsylvania 2nd Geol. Survey, Rept. G-6, 407 p.

Willard, B., 1932, Devonian faunas in Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. G-4, 43 p.

_____, 1935, Portage group in Pennsylvania: Geol. Soc. America Bull., v. 46, p. 1195-1218.

_____, 1939, Middle and Upper Devonian, in the Devonian of Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. G-19, 481 p.

APPENDIX

LOCATIONS OF MEASURED SECTIONS

Section 1: New Ringgold Section

Nearly complete sections of the Trimmers Rock Formation and Towamensing Member are located along a continuous exposure situated on the east side of Pennsylvania Route 443. The section begins along the highway about 150 feet north of the last house encountered when travelling north from New Ringgold, Pennsylvania.

Section 2: Lehigh River Section

Nearly a complete section of the Trimmers Rock is exposed along the east side of Pennsylvania Route 248 north of Bowmanstown, Pennsylvania. The Trimmers Rock-Towamensing contact is located at the Lehighton-Jim Thorpe mileage marker. The Tully Limestone equivalent-Trimmers Rock contact can be found south of a parking area located on the east side of an access lane extending north from Bowmanstown onto Route 248.

Section 3: Wild Creek Reservoir Section

The Trimmers Rock Section occurs along the west side of the Wild Creek Reservoir spillway in Carbon County, Pennsylvania. The Towamensing occurs in part at the top of the Trimmers Rock and in part below full storage water level along the shore line north of the spillway. The base of the Trimmers Rock Section is found at the southernmost outcrop above the west wall of the spillway.

Section 4: Effort Section

The Effort Section consists of both Trimmers Rock and Towamensing and is found along Pennsylvania Route 115. The section begins in the Trimmers Rock on the east side of the highway at the north end of the village of Effort, Pennsylvania, but south of the junction with Monroe County Route 1013. The section then moves to the west side of the state highway beyond this junction. The Trimmers Rock-Towamensing contact is not well defined within the section.

Section 5: Bartonsville Section

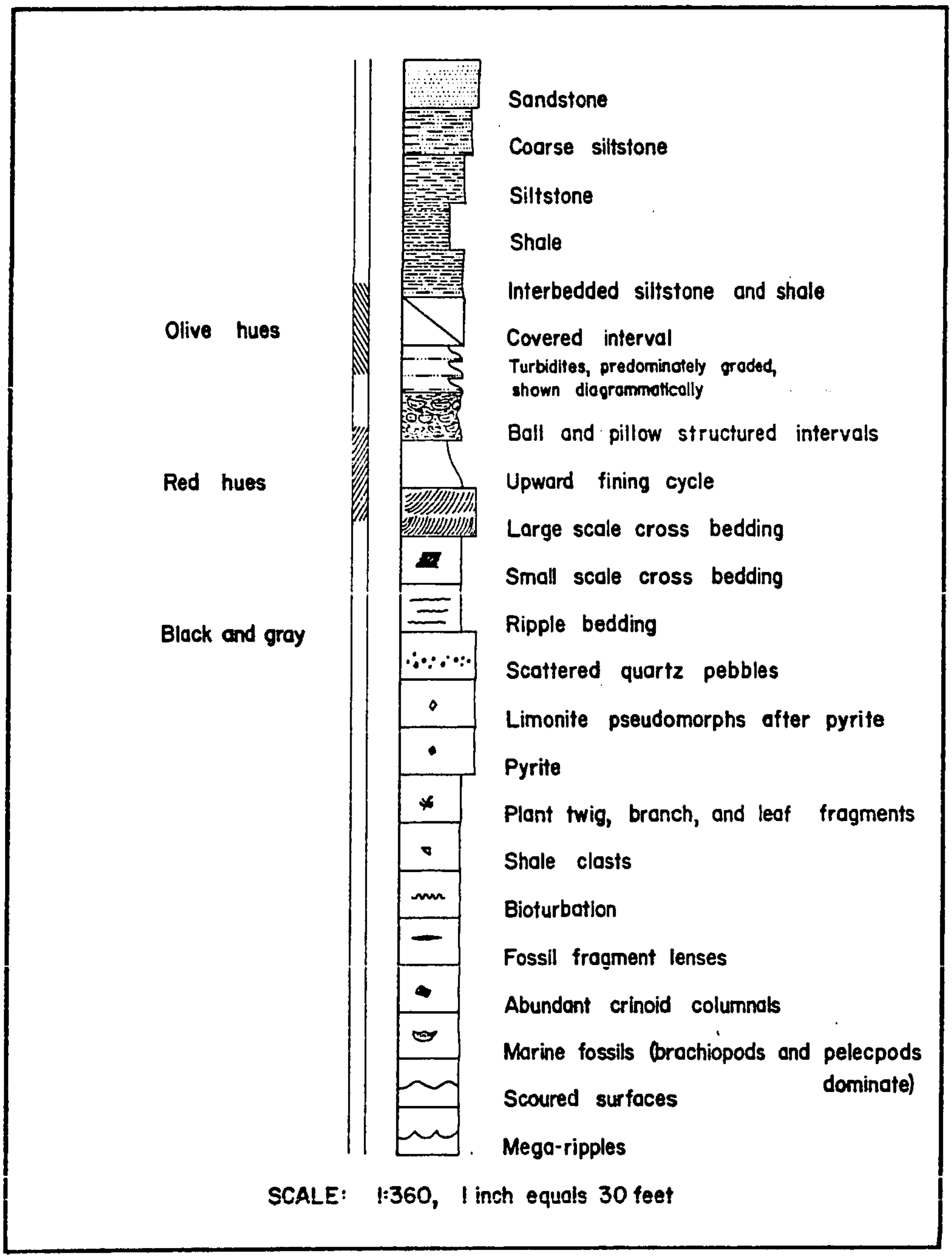
Several hundred feet of Trimmers Rock are located on the west side of U.S. Interstate 80 about ½ mile north of the interchange connecting this four-lane highway with Pennsylvania Route 33.

Section 6: Bushkill Section

Discontinuous exposures of the Trimmers Rock are located along the north side of Bushkill Creek in northeastern Monroe County, Pennsylvania, between 41°06'12"N/75°04'24"W and 41°05'56"N/75°04'04"W which is the base. Access to this section can be gained by proceeding north on Pennsylvania Route 402 from Marshalls Creek, Pennsylvania. Immediately after crossing the Bushkill Creek, turn right onto the Ressaca Falls Boy Scout Camp road. Proceed east on this one-lane road for 0.8 mile. On the left side of the road there are several permanent buildings with ample parking space. Walk on a southeasterly bearing for approximately 1500 feet to the Bushkill Creek. Trimmers Rock outcrops are exposed on the south and southwesterly facing bluffs along the stream. At the base of the Trimmers Rock where dark-gray Mahantango shale is exposed, it will be necessary to cross the stream as Mahantango exposures lie along the south bank.

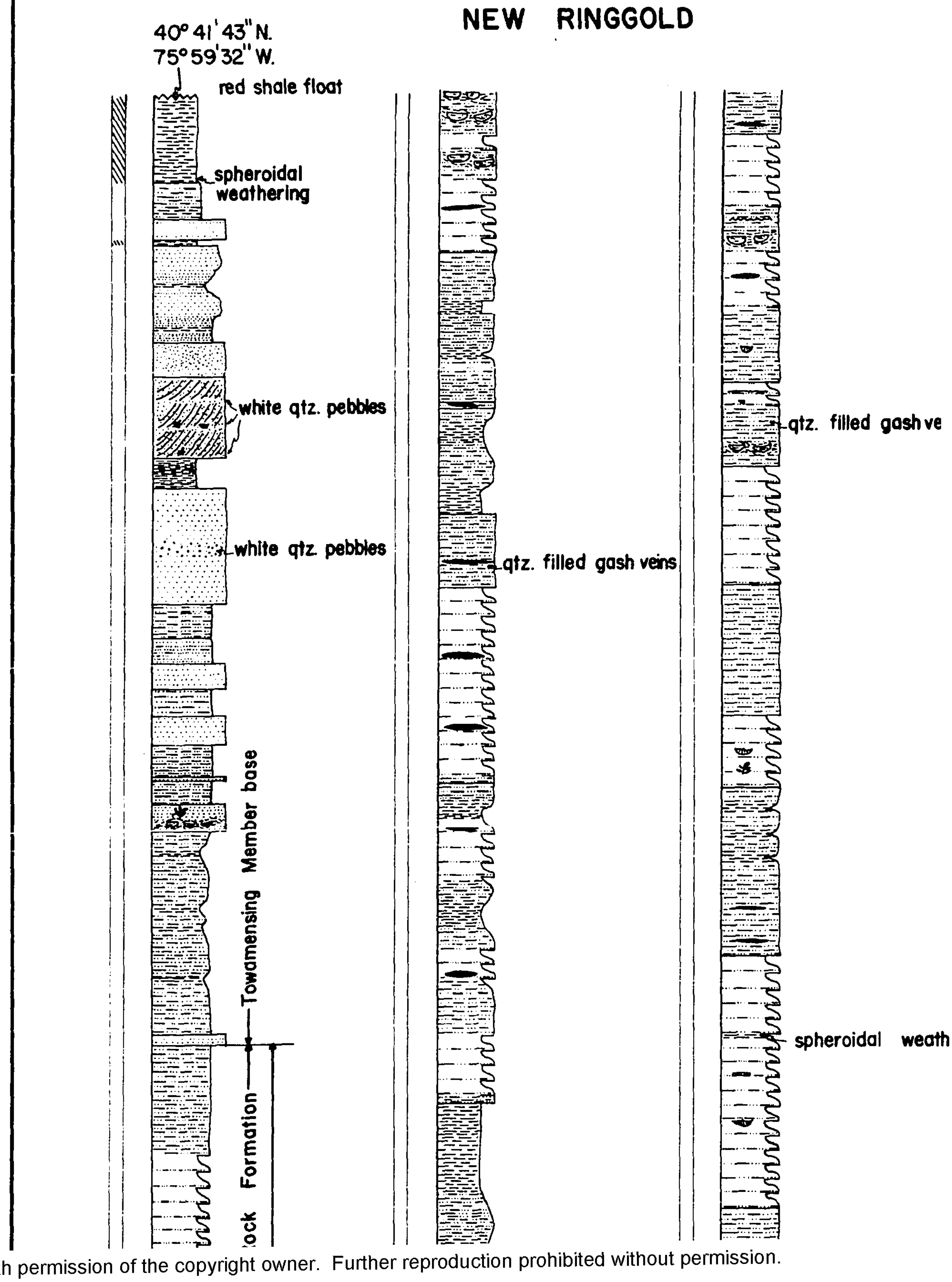
Section 7: Millrift

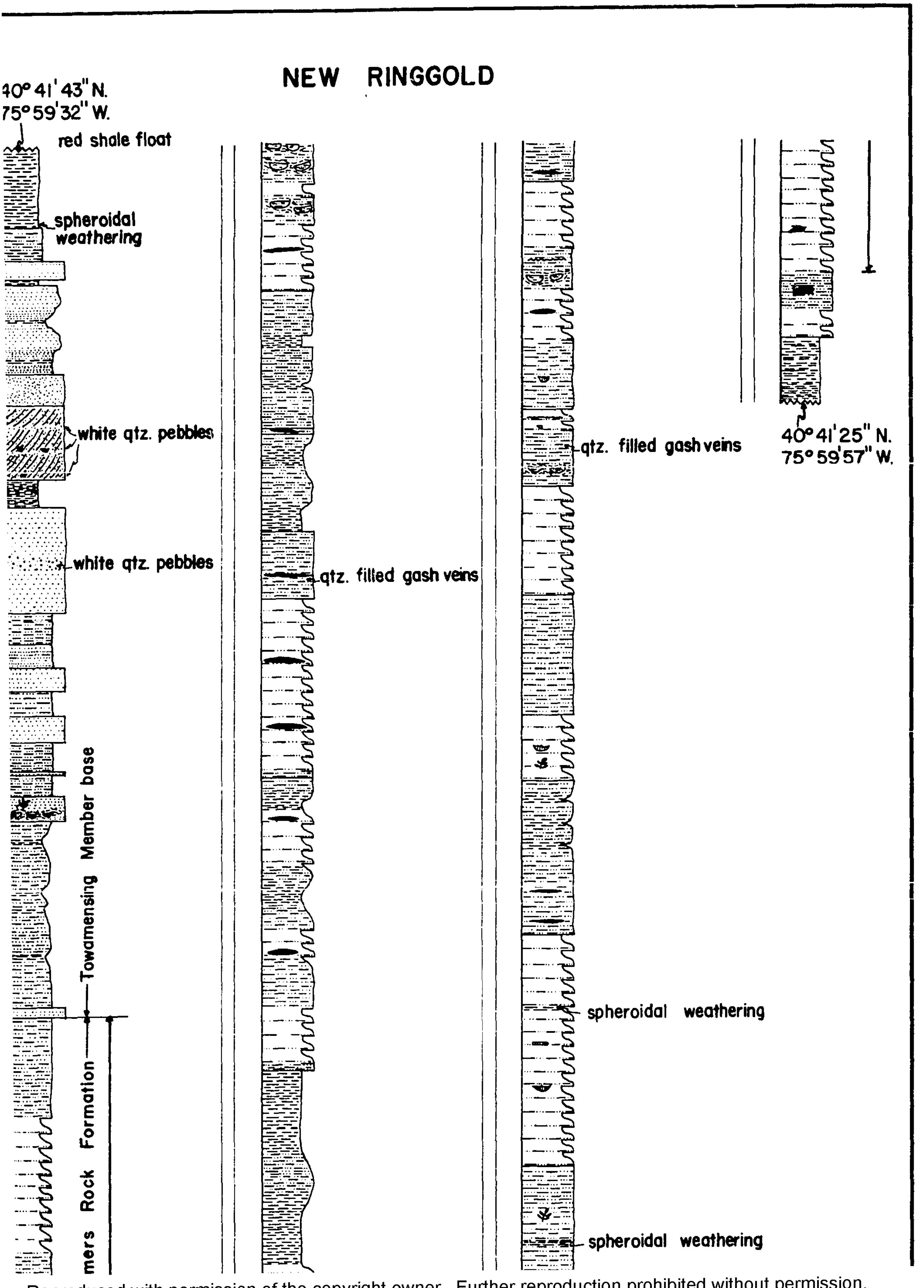
The Millrift section is found primarily along the southwest bank of the Delaware River in northeastern Pike County. Access to this section can be gained by proceeding northwest from Matamoras, Pennsylvania, on a two-lane paved highway leading to the village of Millrift, Pennsylvania. The top of the measured section occurs along a railroad cut approximately 700 feet south of the Millrift Post Office. From here to the Delaware River, exposures occur mostly on the south side of the railroad tracks. From the location where the Erie Railroad bridge crosses the Delaware River to the base of the measured unit, the Trimmers Rock is located along the Pennsylvania side of the Delaware River. Access to these outcrops can only be gained by canoeing south along the river's edge. The Trimmers Rock-Mahantango contact is located approximately 3300 feet south of the railroad bridge and 600 feet north of a waterfall which spills into the river on the Pennsylvania side of the river. Both distances are measured along the river bank.

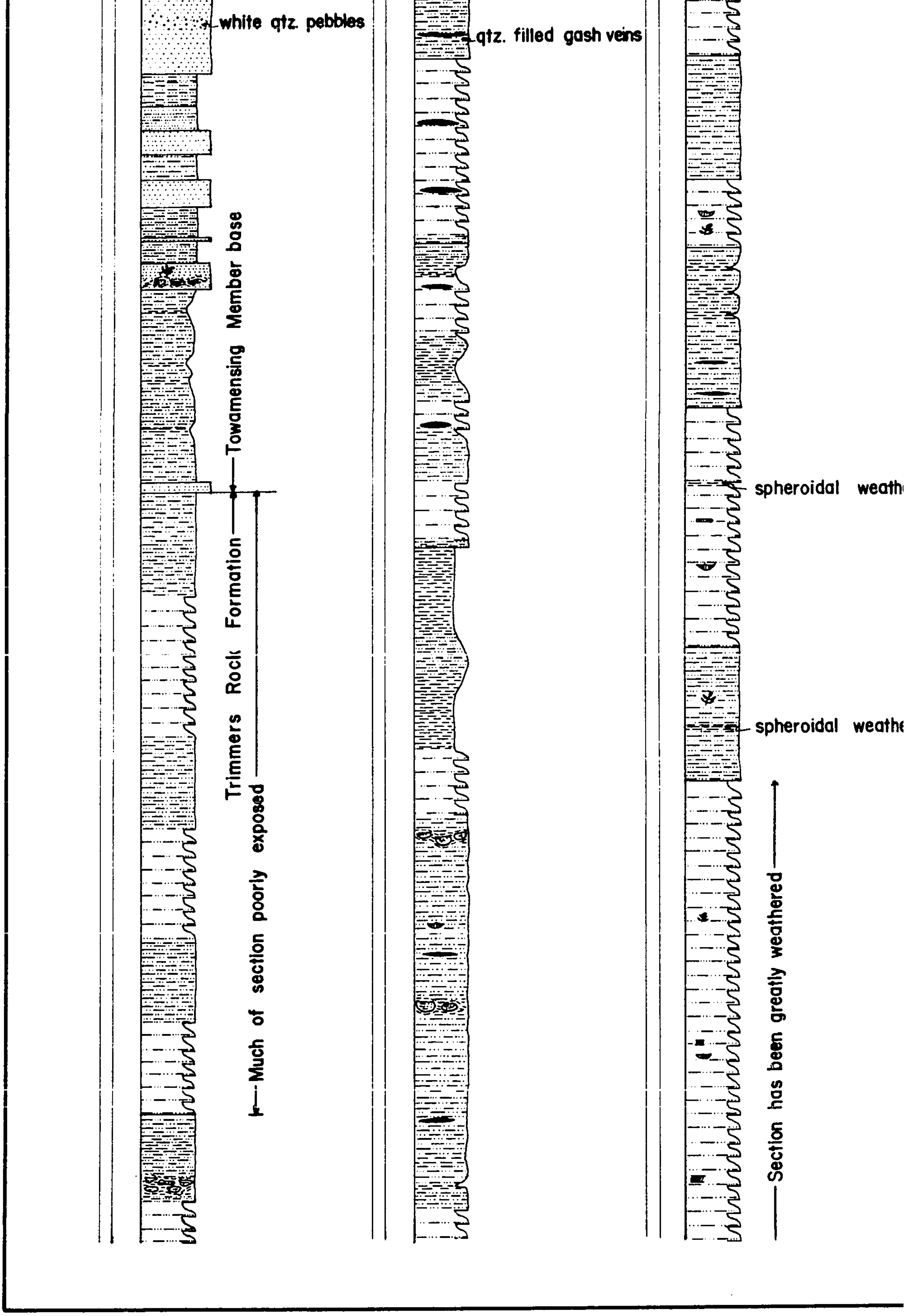


Explanation for measured sections

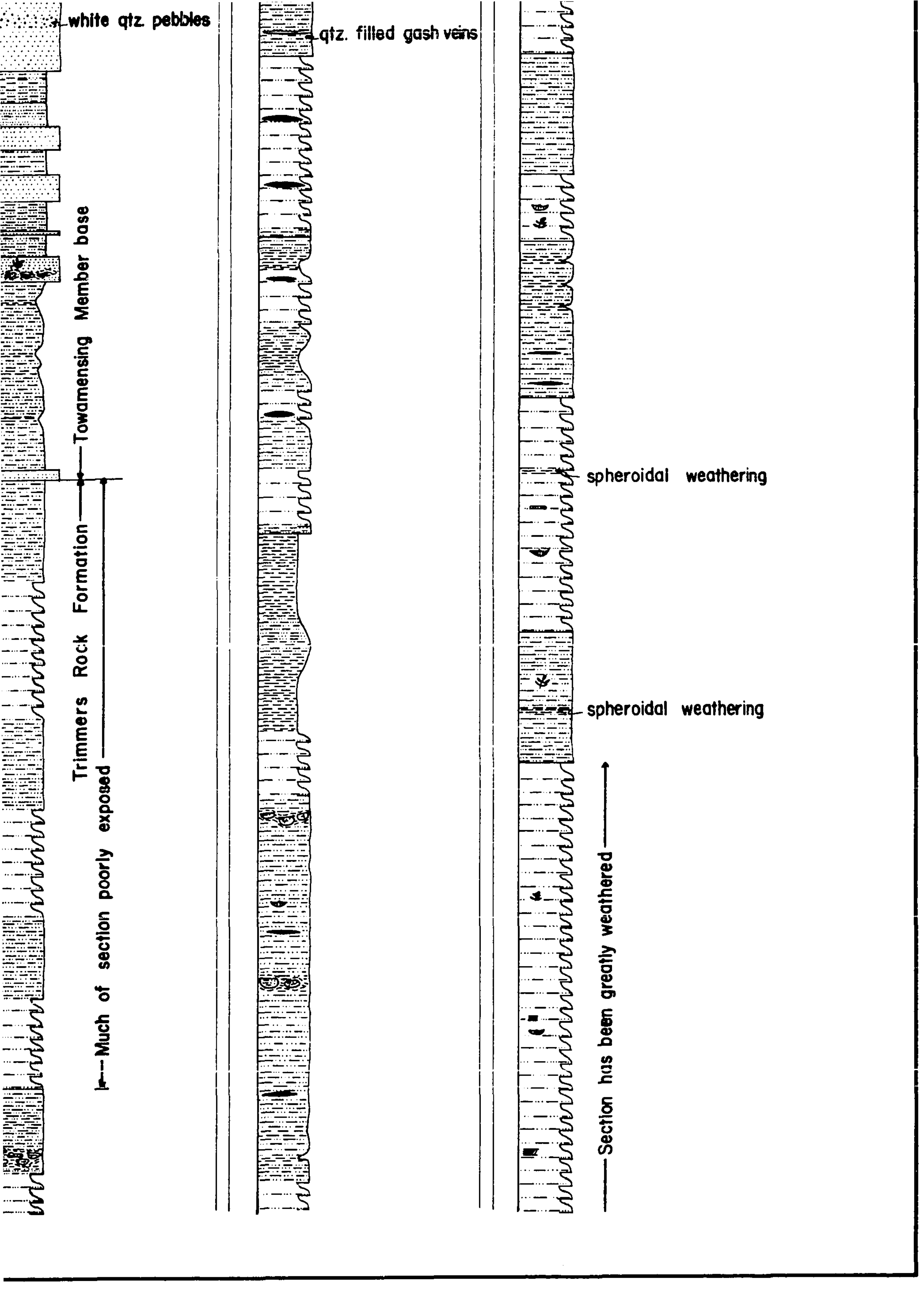
NEW RINGGOLD



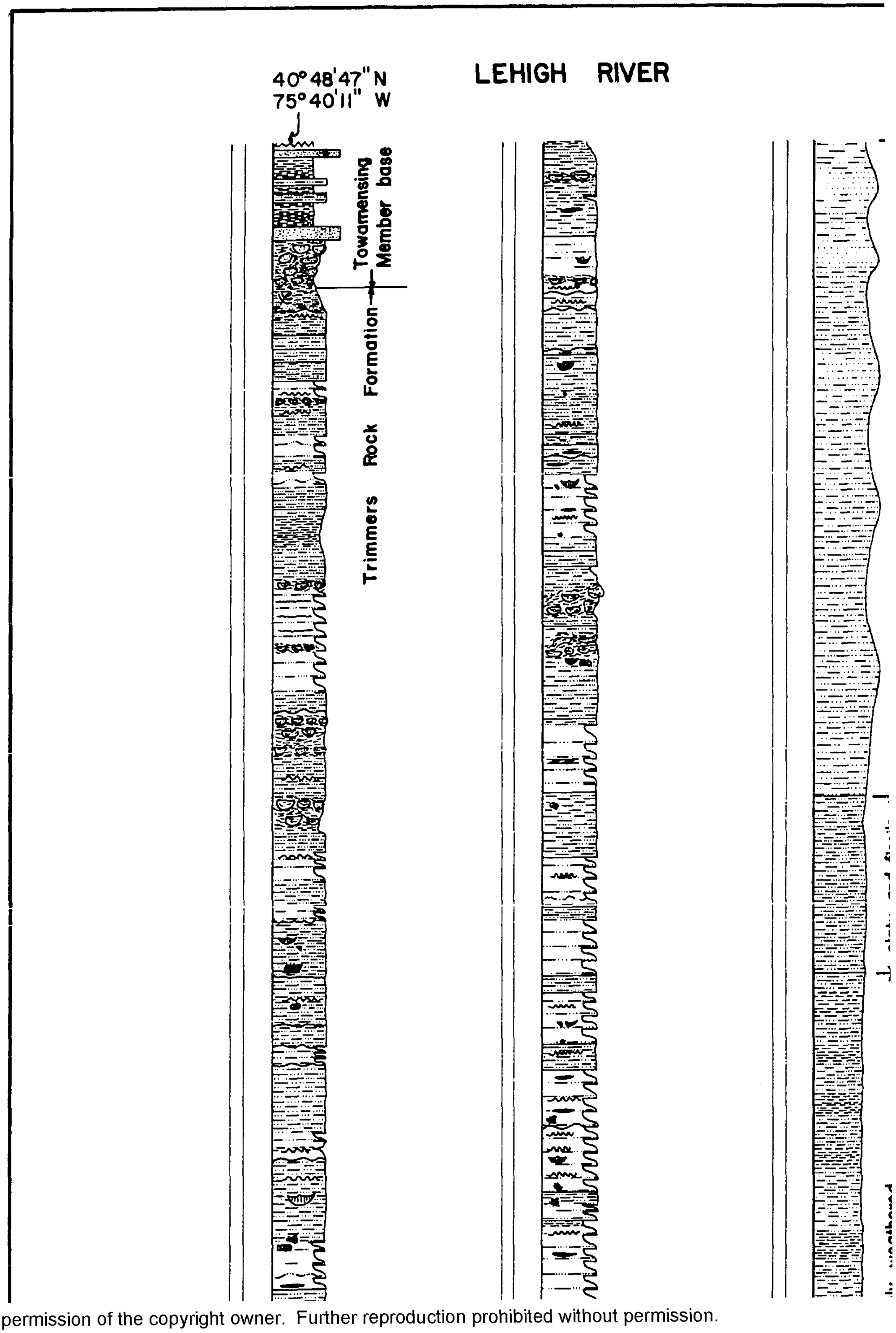

NEW RINGGOLD
40° 41' 43" N.
75° 59' 32" W.
red shale float
spheroidal weathering
white qtz. pebbles
white qtz. pebbles
Towamensing Member base
mers Rock Formation
qtz. filled gash veins
qtz. filled gash veins
spheroidal weathering
spheroidal weathering
40° 41' 25" N.
75° 59' 57" W.

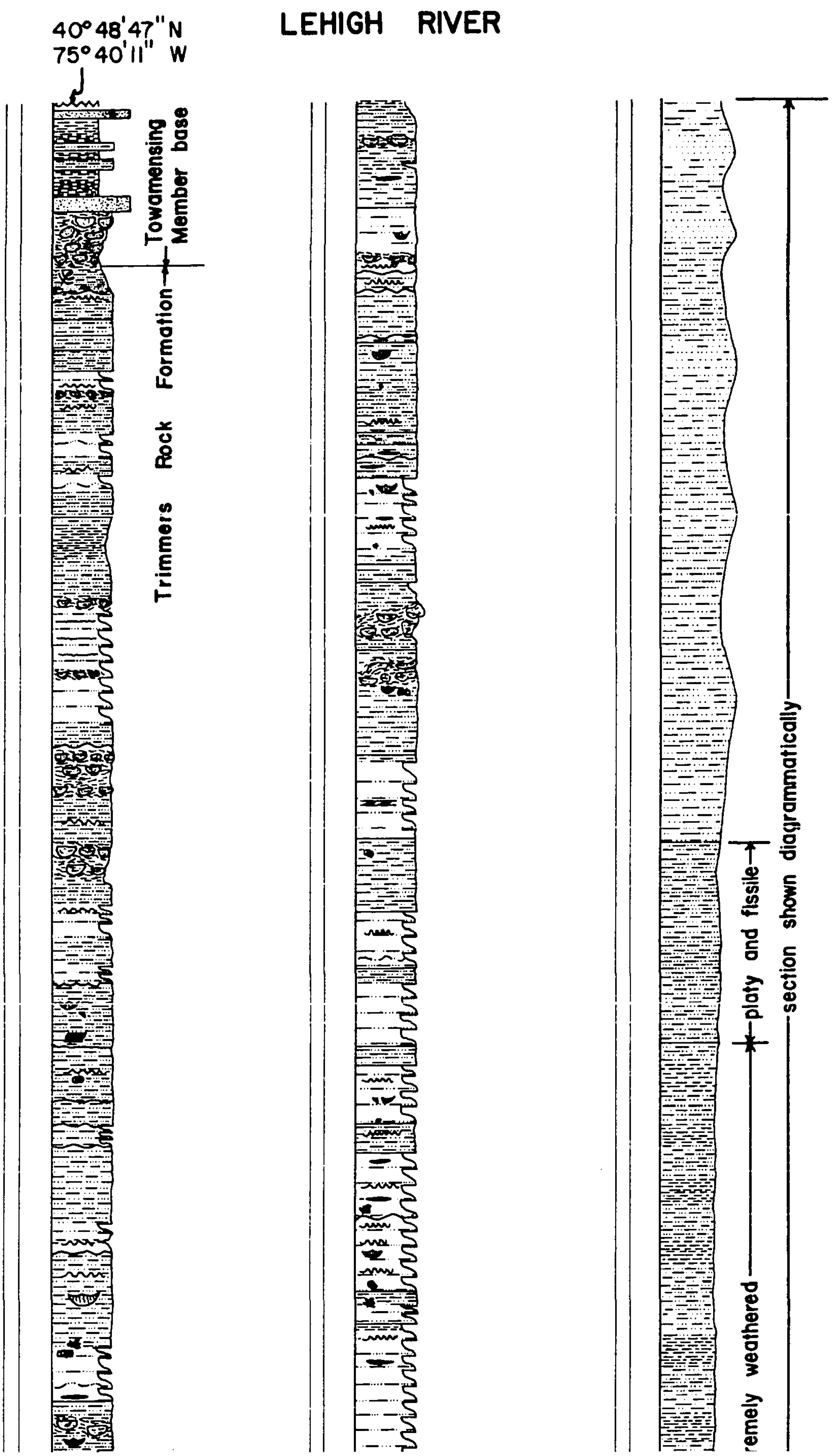

white qtz. pebbles
qtz. filled gash veins
Towamensing Member base
Trimmers Rock Formation
Much of section poorly exposed
spheroidal weath
spheroidal weathe
Section has been greatly weathered

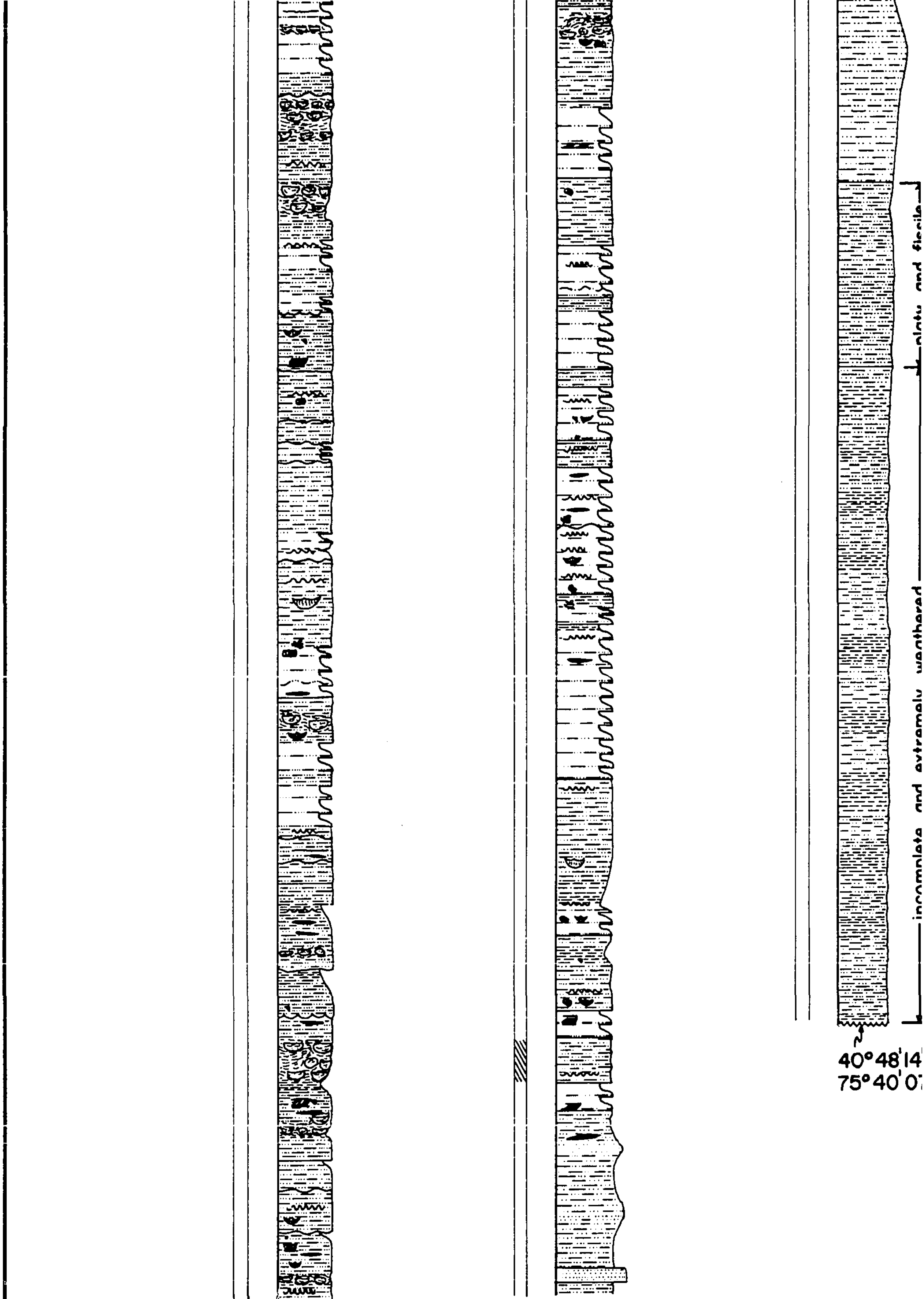
Section 1.


white qtz. pebbles
qtz. filled gash veins
Towamensing Member base
Trimmers Rock Formation
Much of section poorly exposed
spheroidal weathering
spheroidal weathering
Section has been greatly weathered

Section 1.

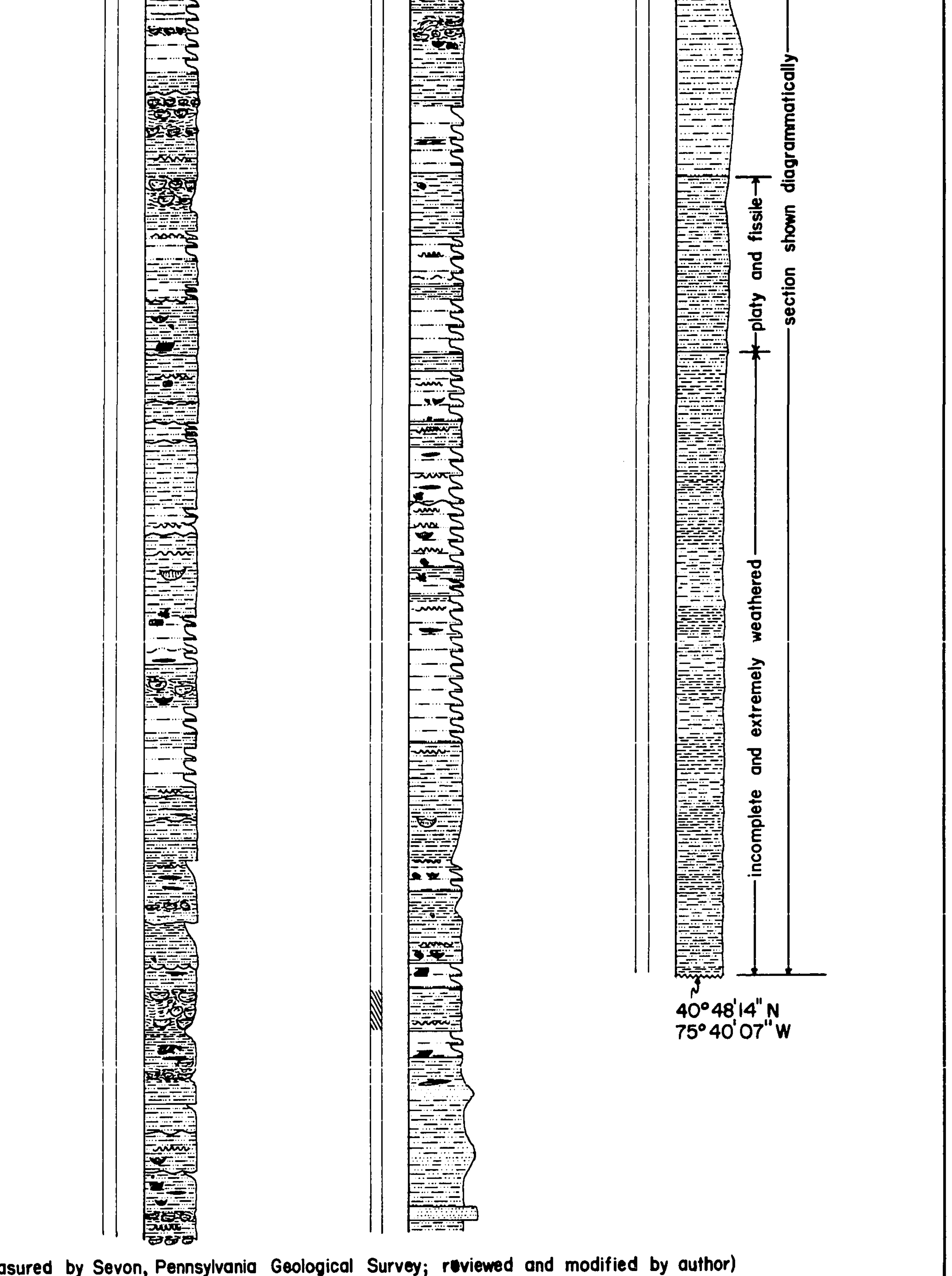

LEHIGH RIVER
40°48'47"N
75°40'11" W
Towamensing Member base
Trimmers Rock Formation


LEHIGH RIVER
40°48'47"N
75°40'11" W
Towamensing Member base
Trimmers Rock Formation
platy and fissile
section shown diagrammatically
remely weathered



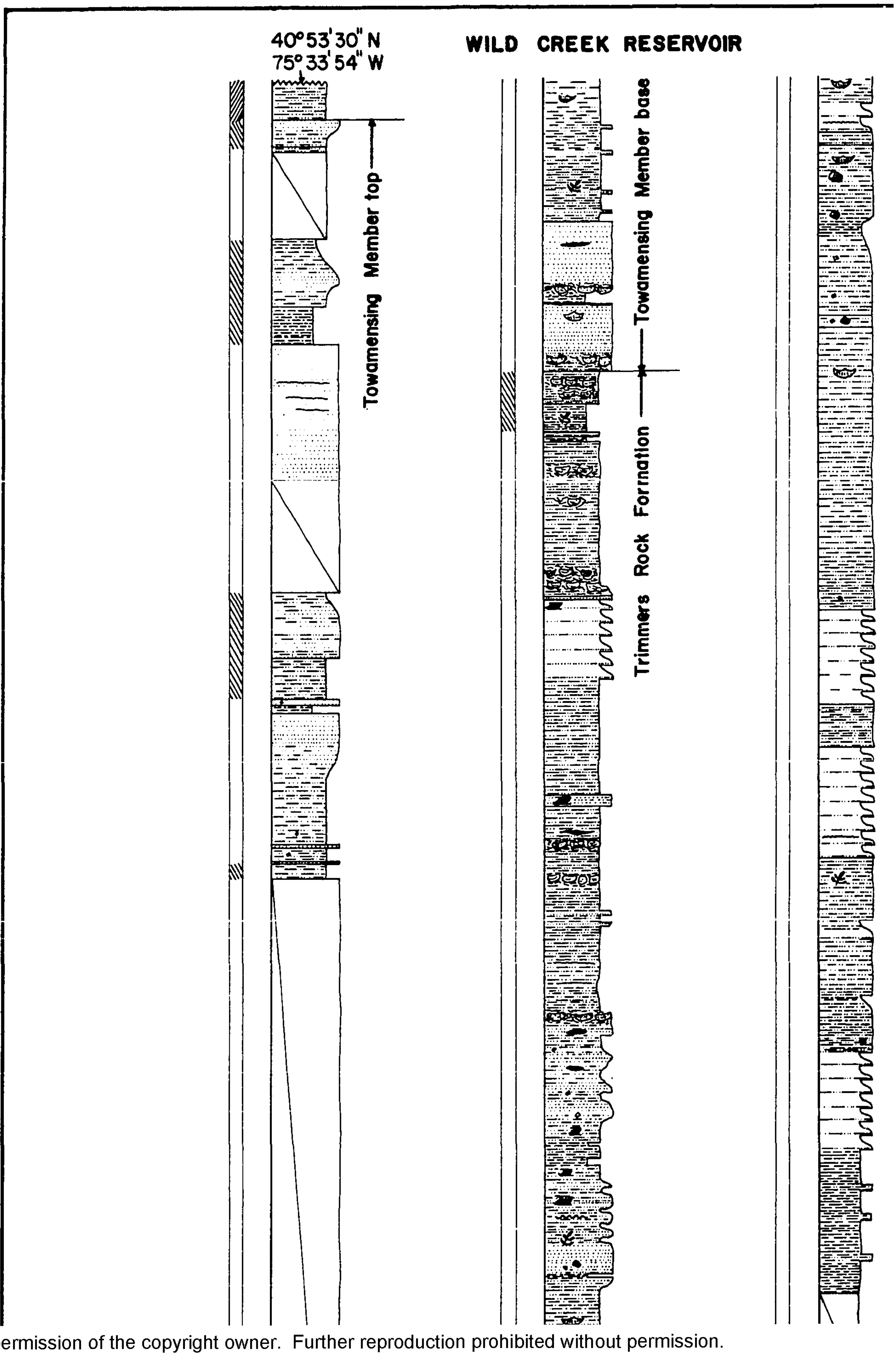
(section measured by Sevon, Pennsylvania Geological Survey; reviewed and modified by author)

Section 2.

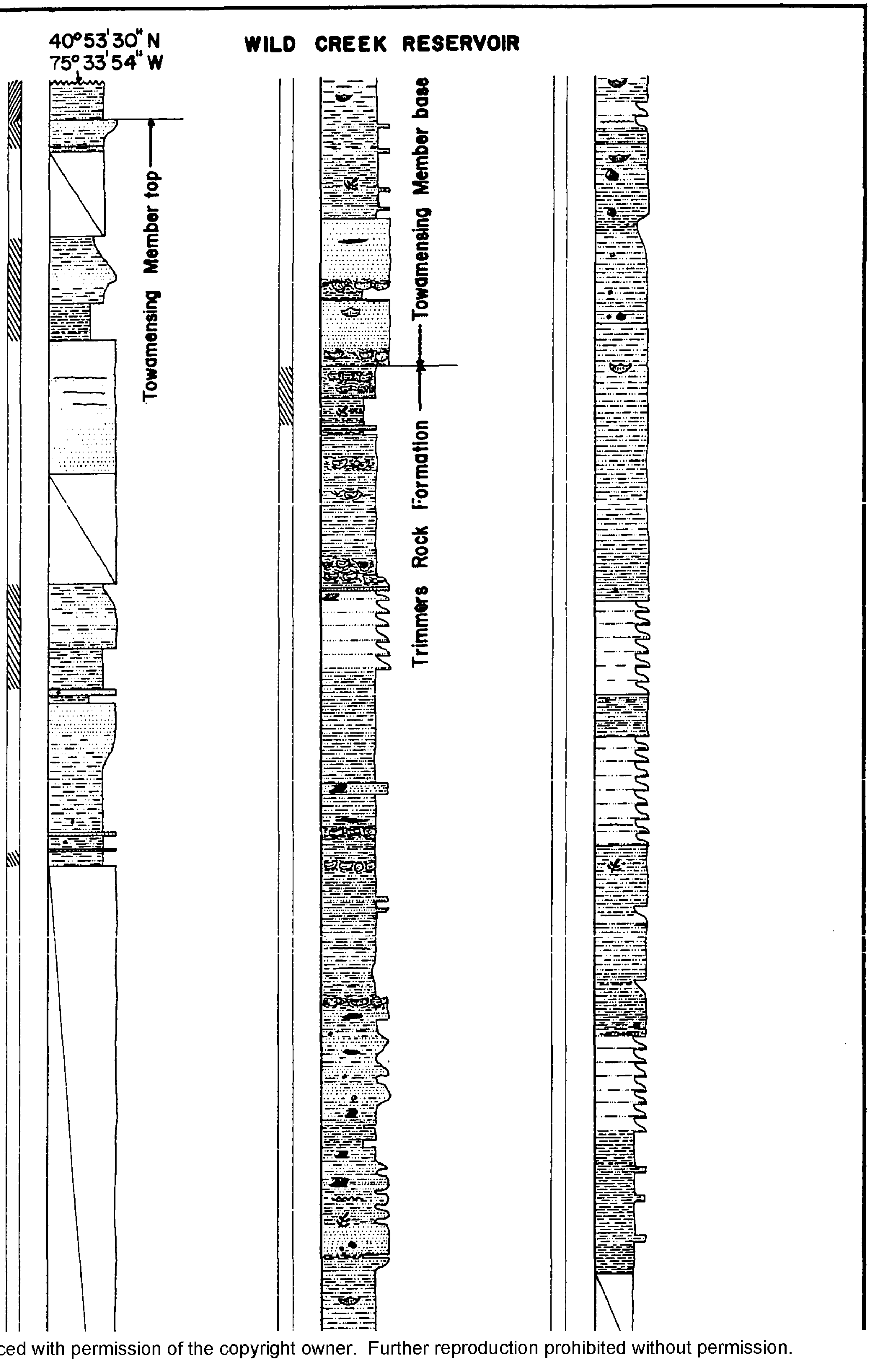


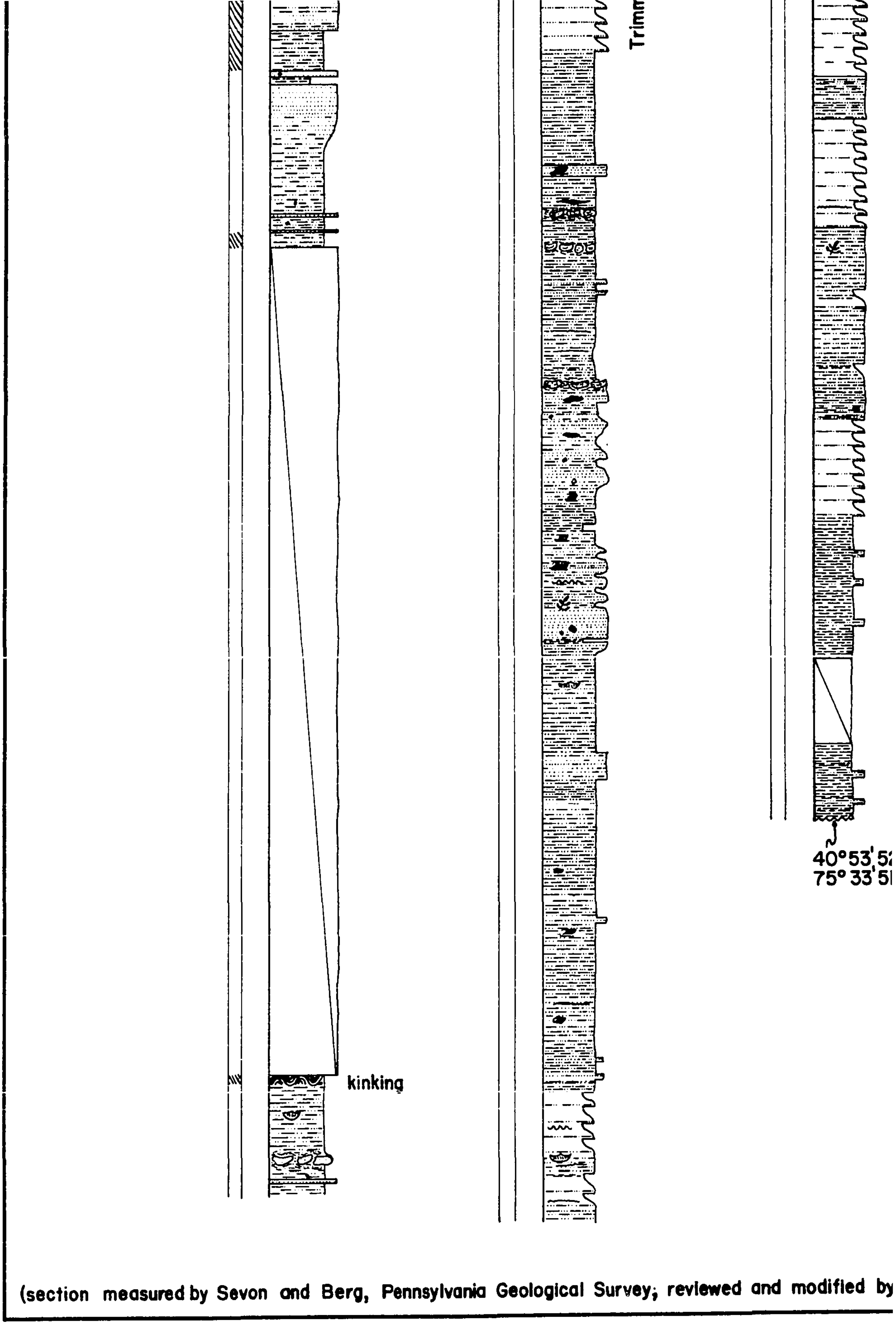
asured by Sevon, Pennsylvania Geological Survey; reviewed and modified by author)

Section 2.

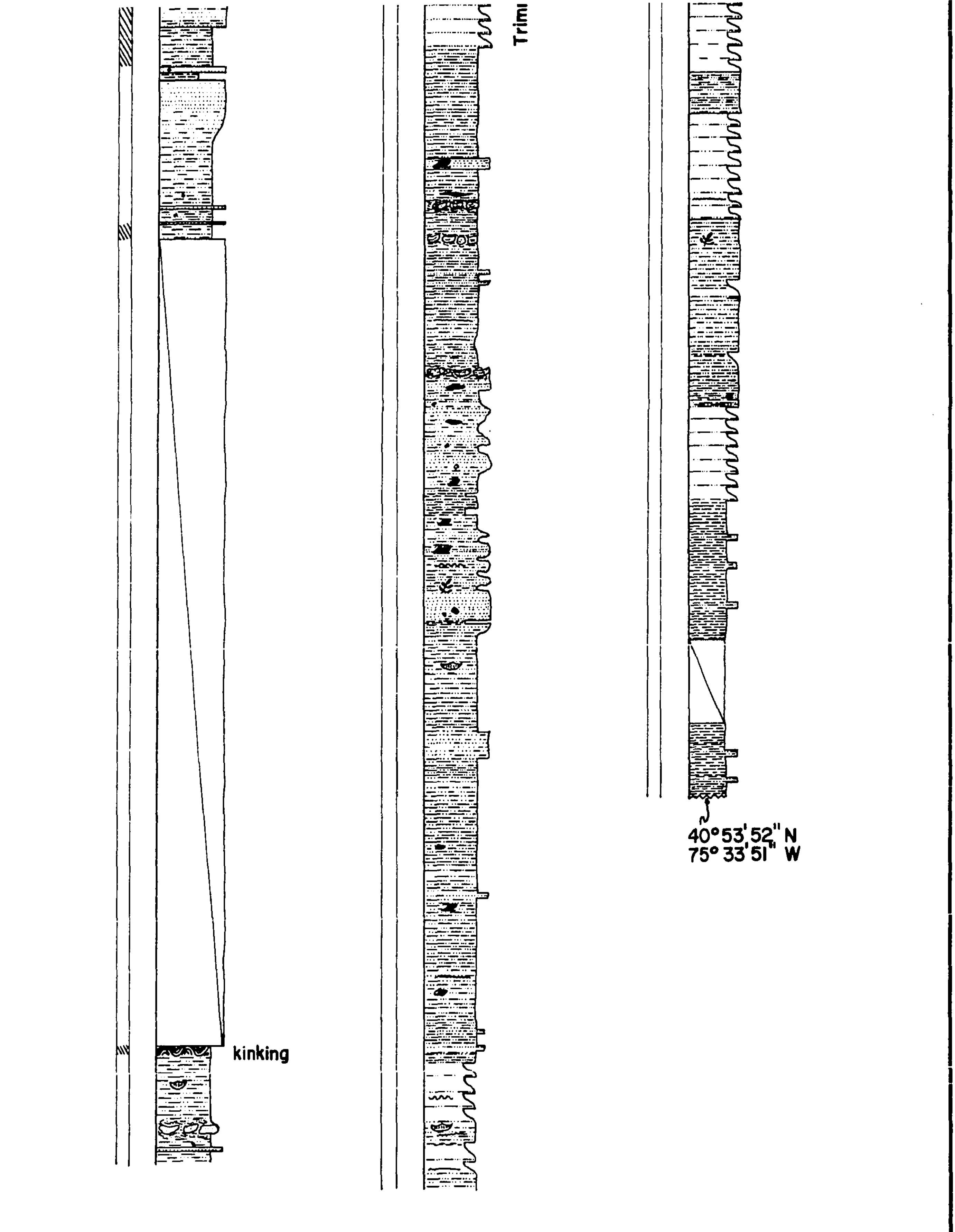


40°53'30" N
75°33'54" W
WILD CREEK RESERVOIR
Towamensing Member top
Towamensing Member base
Trimmers Rock Formation


40°53'30" N
75°33'54" W
WILD CREEK RESERVOIR
Towamensing Member top
Towamensing Member base
Trimmers Rock Formation


Trimm
kinking
40°53'52
75° 33'5
(section measured by Sevon and Berg, Pennsylvania Geological Survey; reviewed and modified by

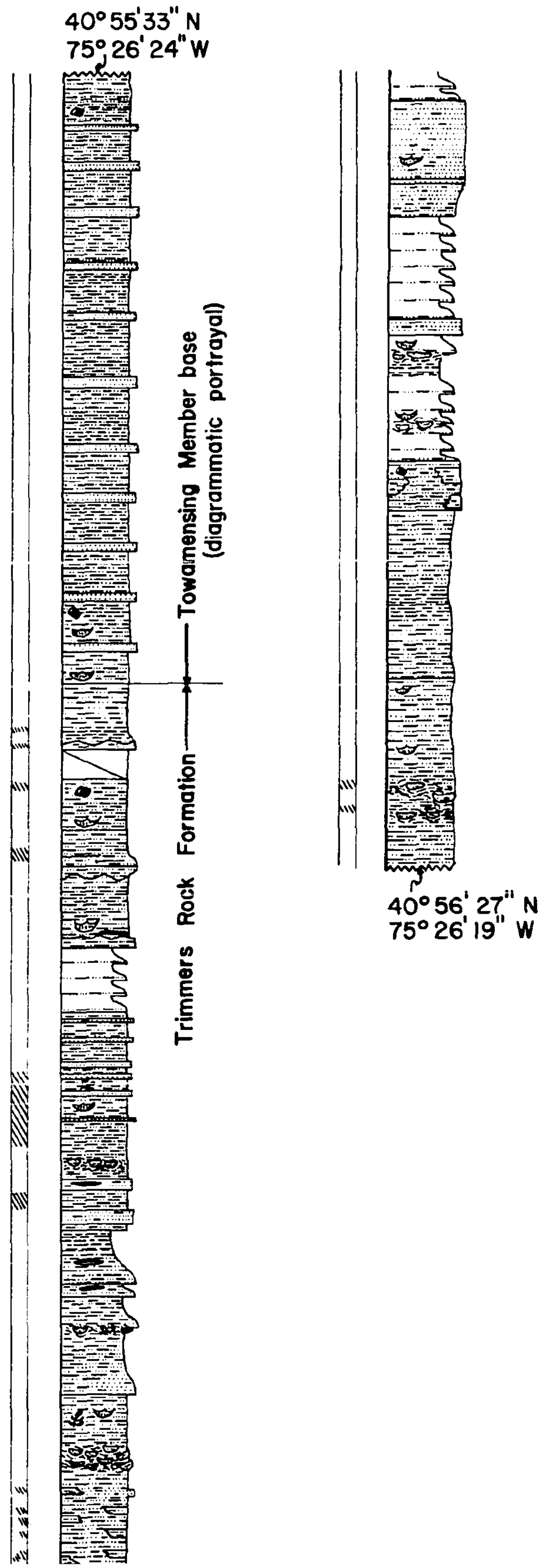
Section 3.



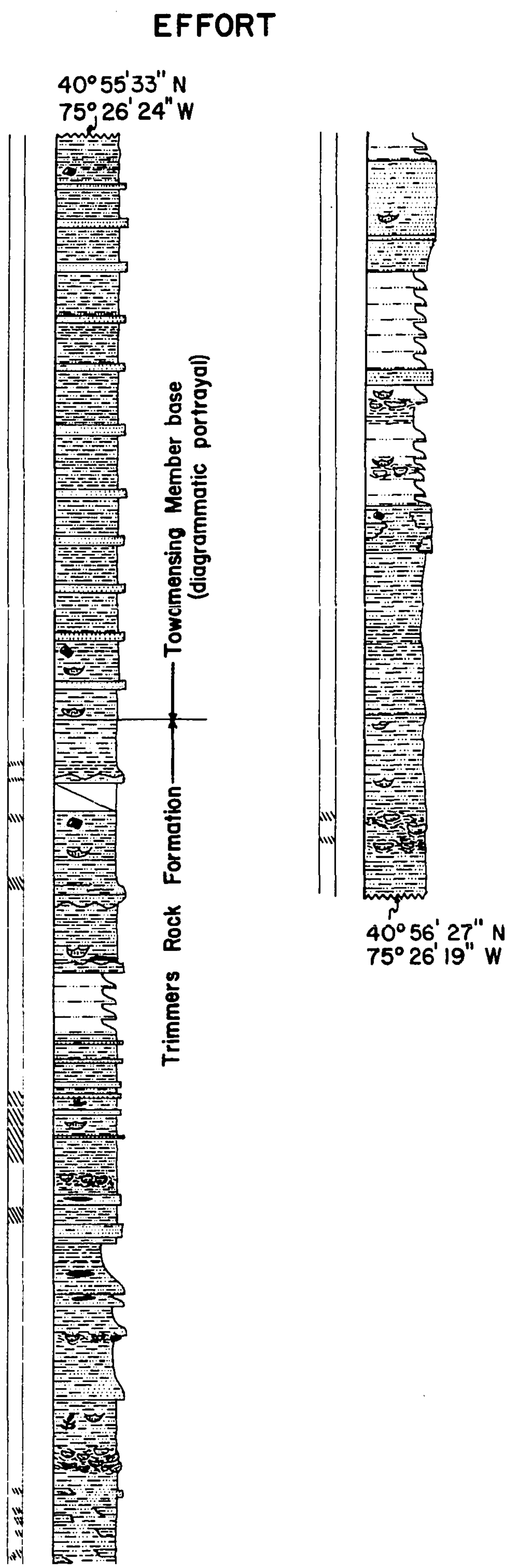
measured by Sevon and Berg, Pennsylvania Geological Survey; reviewed and modified by author)

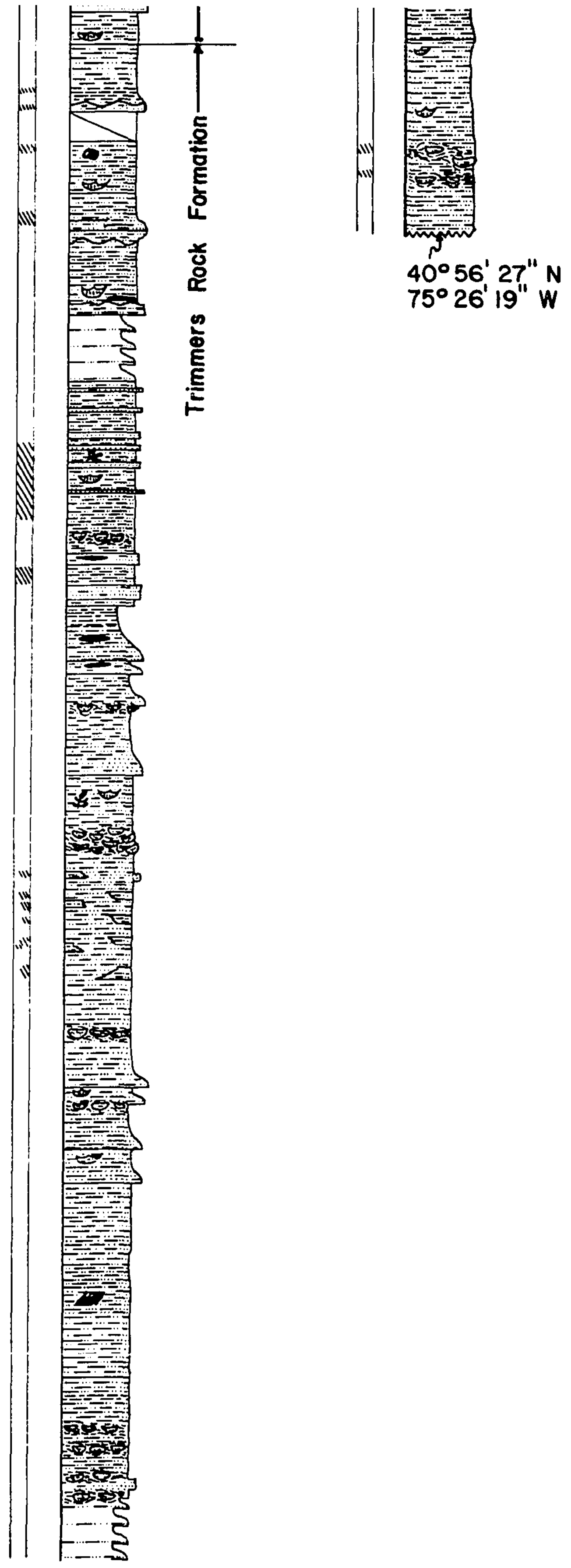
Section 3.

EFFORT



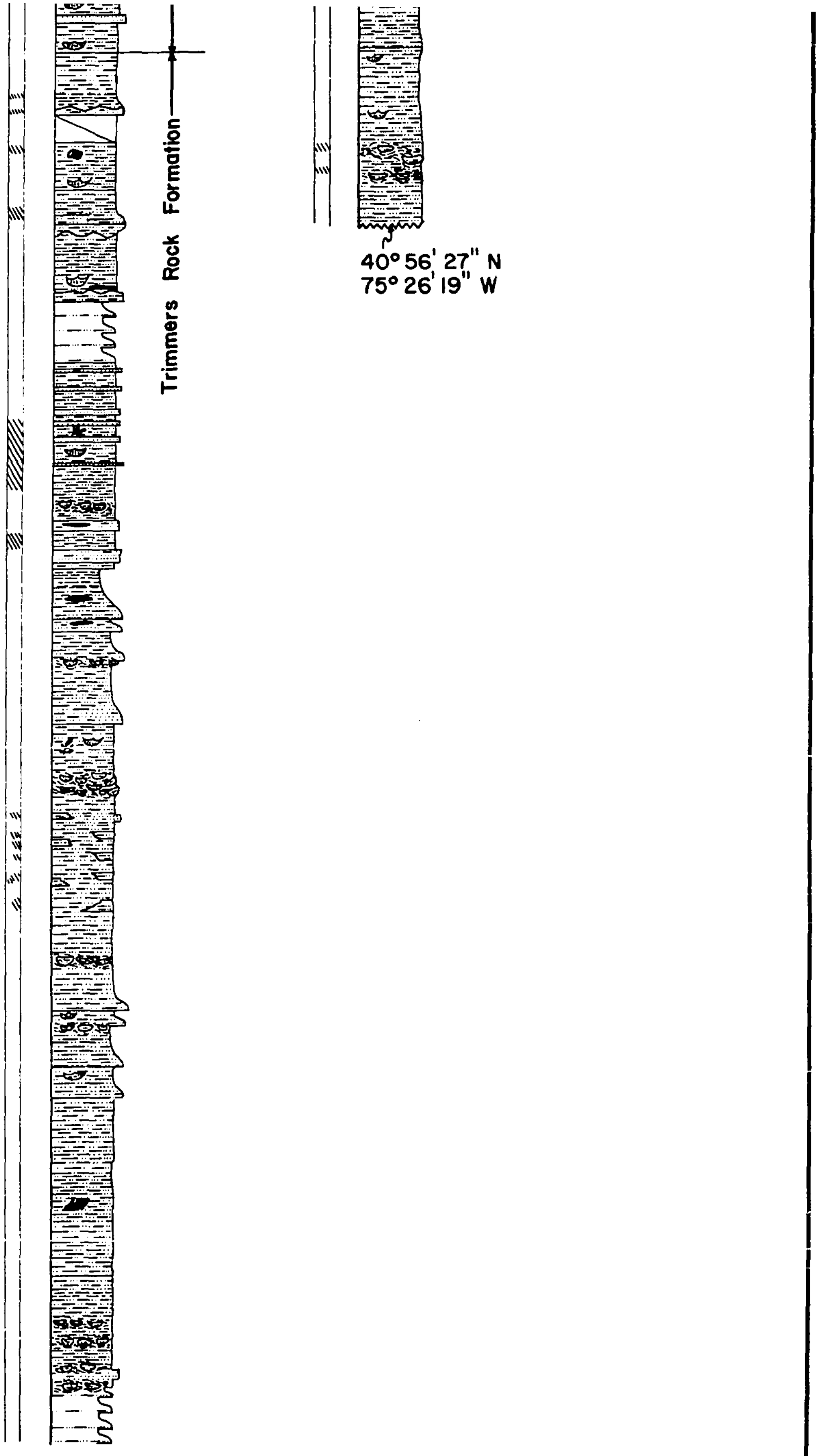
40°55'33" N
75°26'24" W
Towamensing Member base
(diagrammatic portrayal)
Trimmers Rock Formation
40°56'27" N
75°26'19" W


EFFORT
40° 55' 33" N
75° 26' 24" W
Towamensing Member base
(diagrammatic portrayal)
Trimmers Rock Formation
40° 56' 27" N
75° 26' 19" W



(section measured by Berg, Pennsylvania Geological Survey; reviewed and modified by author)

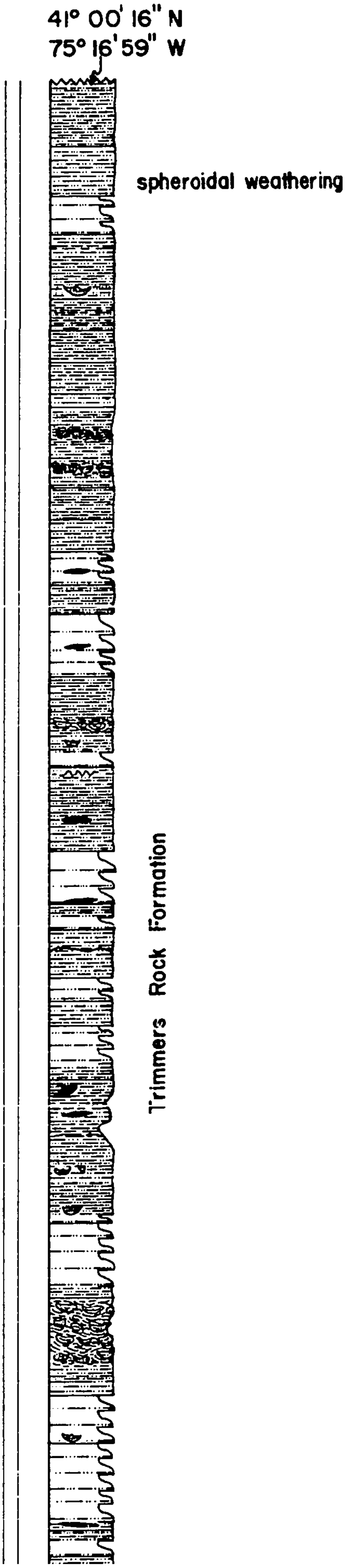
Section 4.

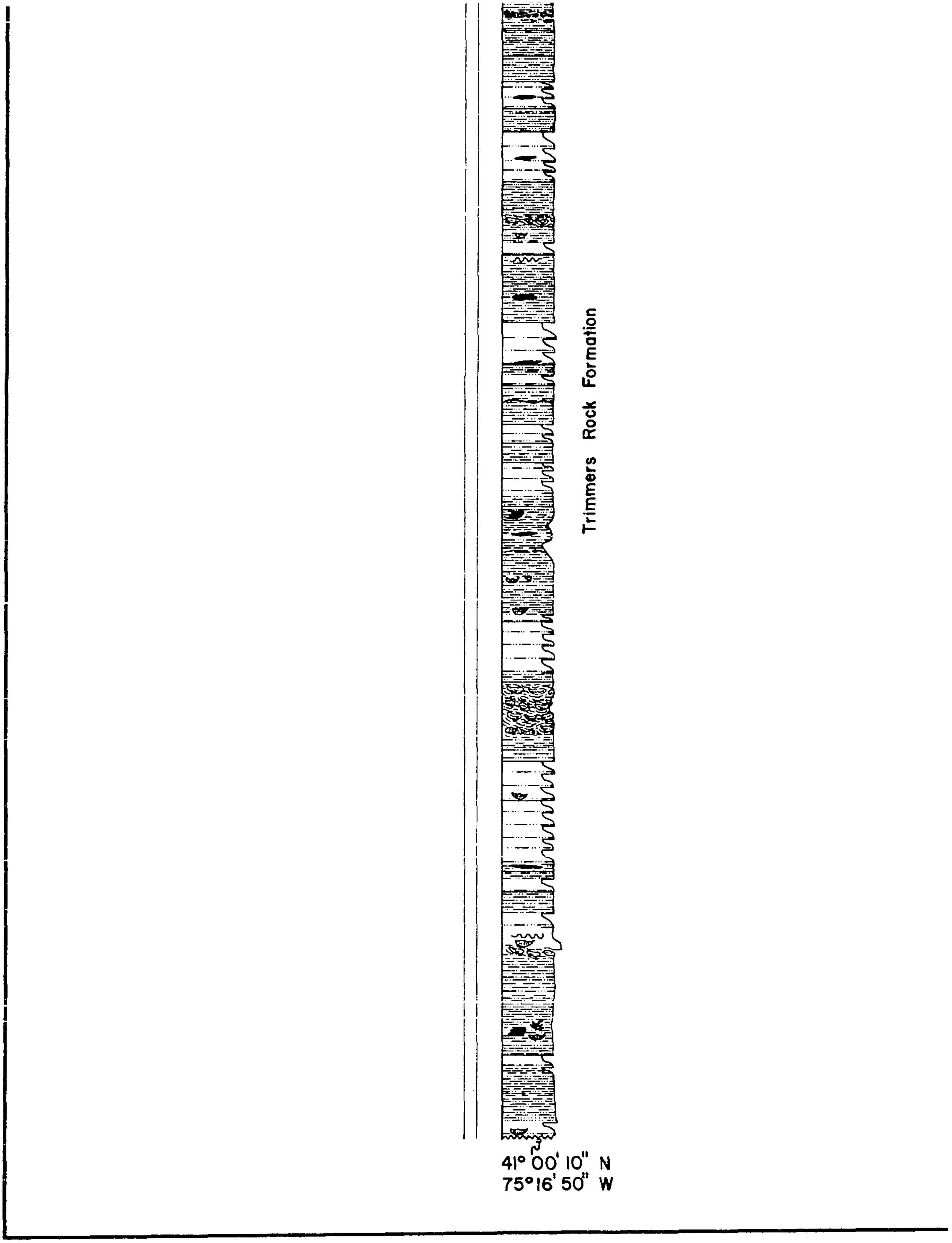


easured by Berg, Pennsylvania Geological Survey; reviewed and modified by author)

Section 4.

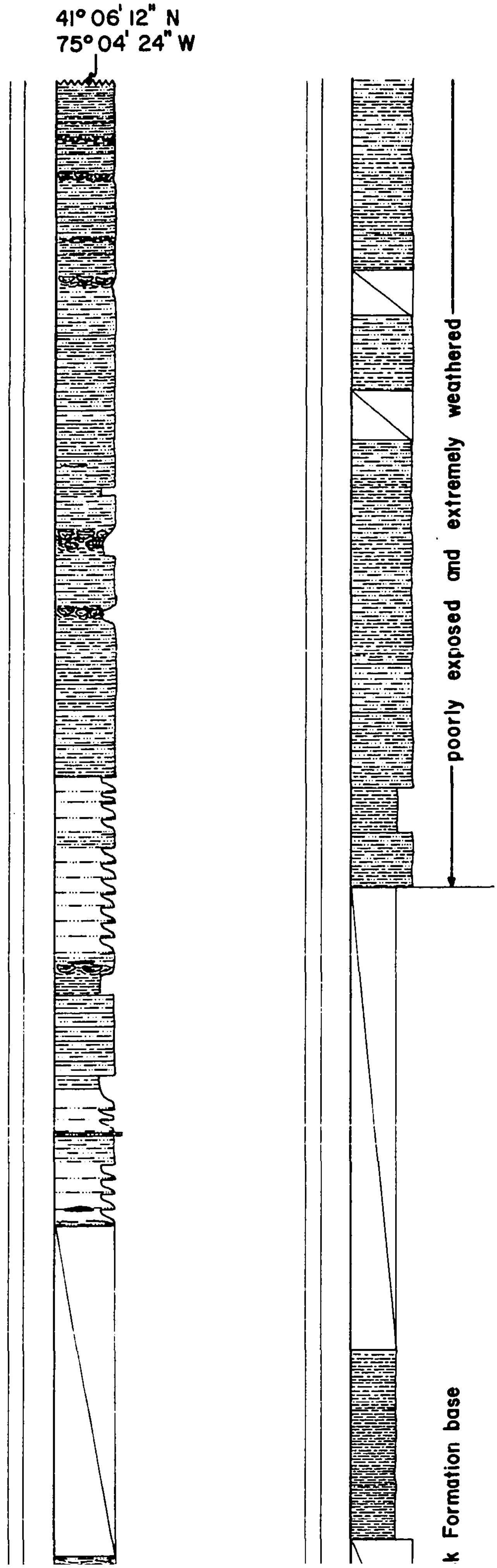
BARTONSVILLE

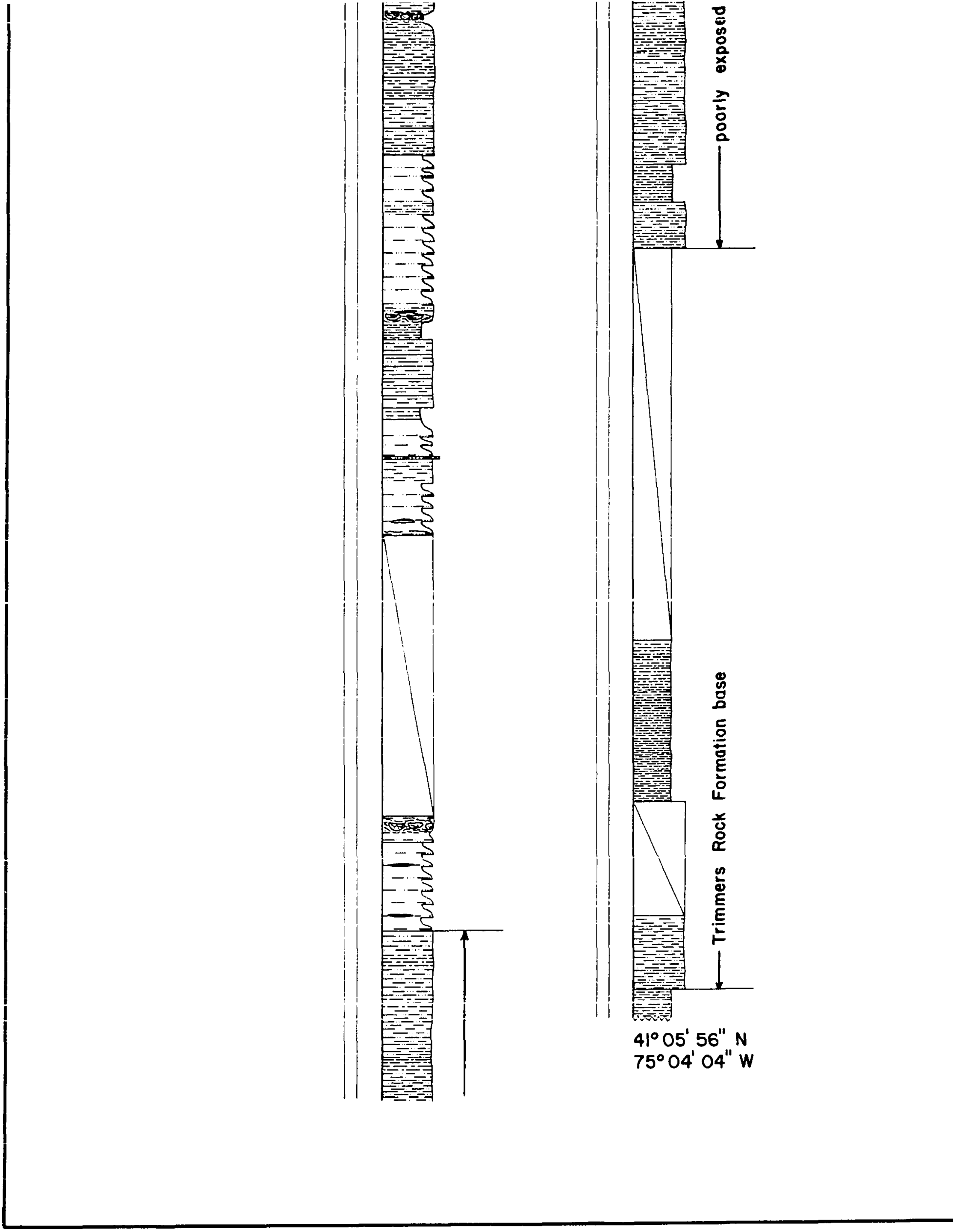




Section 5.

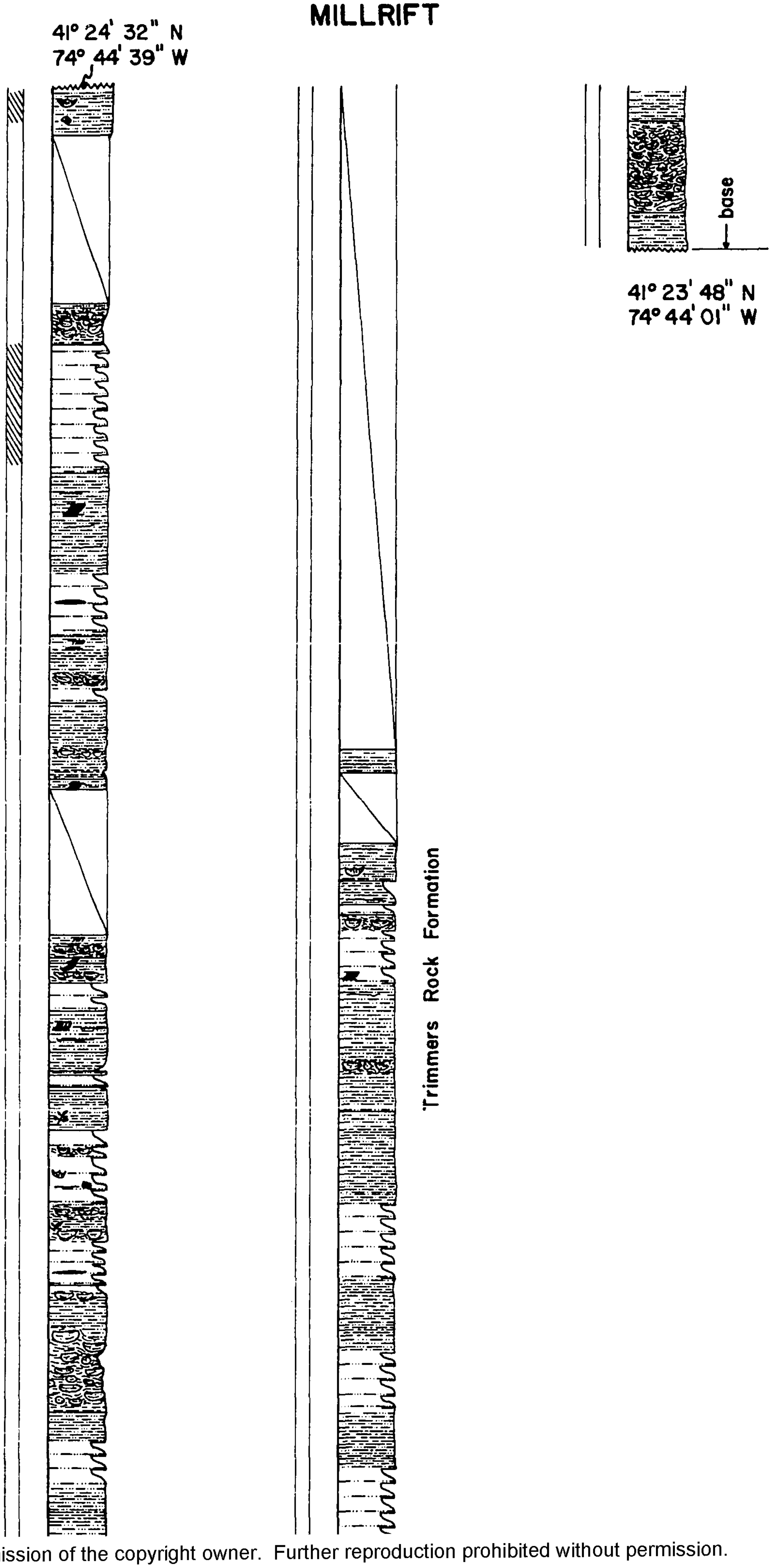
BUSH KILL CREEK

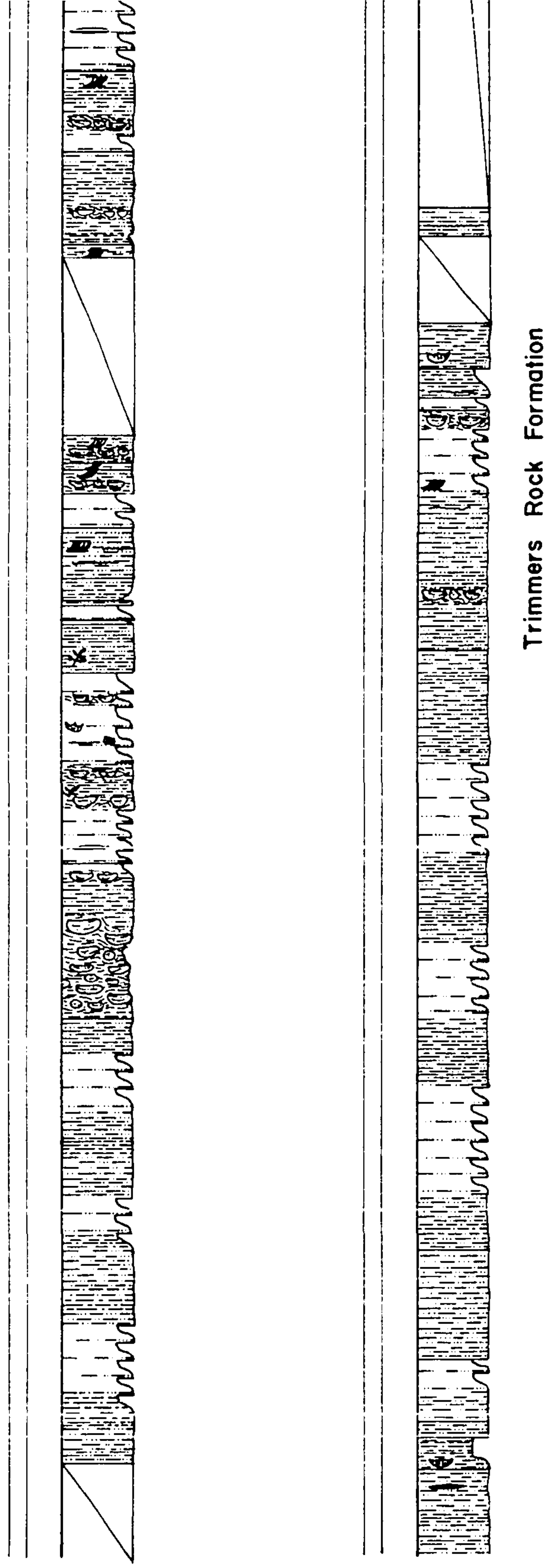



poorly exposed
Trimmers Rock Formation base
41° 05' 56" N
75° 04' 04" W

Section 6.

MILLRIFT


41° 24' 32" N
74° 44' 39" W
base
41° 23' 48" N
74° 44' 01" W
Trimmers Rock Formation



Section 7.

Point Count Data of Siltstone Framework Components
(based on 300 point counts)

Sample No.	Location	% Sand	% Silt	% Matrix
2-3	Section 1	3	32	65
2-9	Section 1	0	41	59
2-5	Section 1	0	48	52
2-13	Section 1	0	34	66
5-18	Section 5	0	43	57
5-19	Section 5	0	38	62
5-22	Section 5	0	44	56
5-25	Section 5	0	45	55
5-23	Section 5	0	31	69
5-26	Section 5	0	31	69
M-238	S.E. Pike Co.	0	41	59
M-248	S.E. Pike Co.	0	43	57
M-263	S.E. Pike Co.	0	34	66
7-32	Section 7	5	40	55
7-30	Section 7	0	54	46
7-27	Section 7	0	43	57

Point Count Data of Siltstone Framework Minerals
(based on 400 point counts)

Sample Number	Location	% Quartz	% Rock Fragments	% Plagioclase	% K-fds	% Pyrite	% Muscovite	Other
2-3	Section 1	95	3	1	1	---	---	Garnet-trace
2-9	Section 1	92	6	trace	---	---	1	---
2-5	Section 1	93	6	1	---	---	---	---
2-13	Section 1	92	5	1	1	---	---	---
5-18	Section 5	92	6	1	1	---	---	---
5-19	Section 5	90	6	1	1	trace	trace	---
5-22	Section 5	92	6	1	---	trace	---	---
5-25	Section 5	93	5	1	trace	---	---	---
5-23	Section 5	94	5	1	---	---	---	---
5-26	Section 5	94	4	---	---	trace	trace	---
M-238	S.E. Pike County	93	5	1	1	trace	trace	---
M-248	S.E. Pike County	94	5	trace	---	trace	trace	---
m-263	S.E. Pike County	95	3	1	trace	---	1	---
7-32	Section 7	92	5	1	1	~1	---	---
7-30	Section 7	94	4	1	trace	trace	---	---
7-27	Section 7	95	4	trace	---	trace	---	---

VITA

Lane Donald Schultz was born October 20, 1944, in Sellersville, Pennsylvania. He is the son of Milton R. and Fern V. Wolf.

He attended public elementary schools in Emmaus, Pennsylvania, and was graduated from Perkiomen School, Pennsburg, Pennsylvania, in June, 1962. He entered Franklin and Marshall College in the fall of 1962 and was graduated with an A.B. in June, 1966. His major was in geology. In September, 1970, he entered Lehigh University and the Master of Science Degree in Geological Sciences was conferred upon him in June, 1972. While at Lehigh he was the recipient of a Graduate Teaching Fellowship.

Mr. Schultz was inducted into the U.S. Army in August, 1966. While serving in the Republic of Vietnam, he was commissioned a Second Lieutenant, Military Intelligence Branch, in February, 1968. Mr. Schultz was awarded the Army Commendation Medal for meritorious service and honorably discharged from active duty, holding the rank of First Lieutenant, in January, 1970.

He was employed as an Instructor in geology by Dickinson College during the academic year 1970-71. Mr. Schultz was employed as a staff geologist by the Lehigh-Northampton Counties Joint Planning Commission during the summer of 1971.

He has been engaged as a field geologist by the Pennsylvania Geological Survey to assist in surficial and bedrock mapping of Pike County, Pennsylvania, since May, 1972.

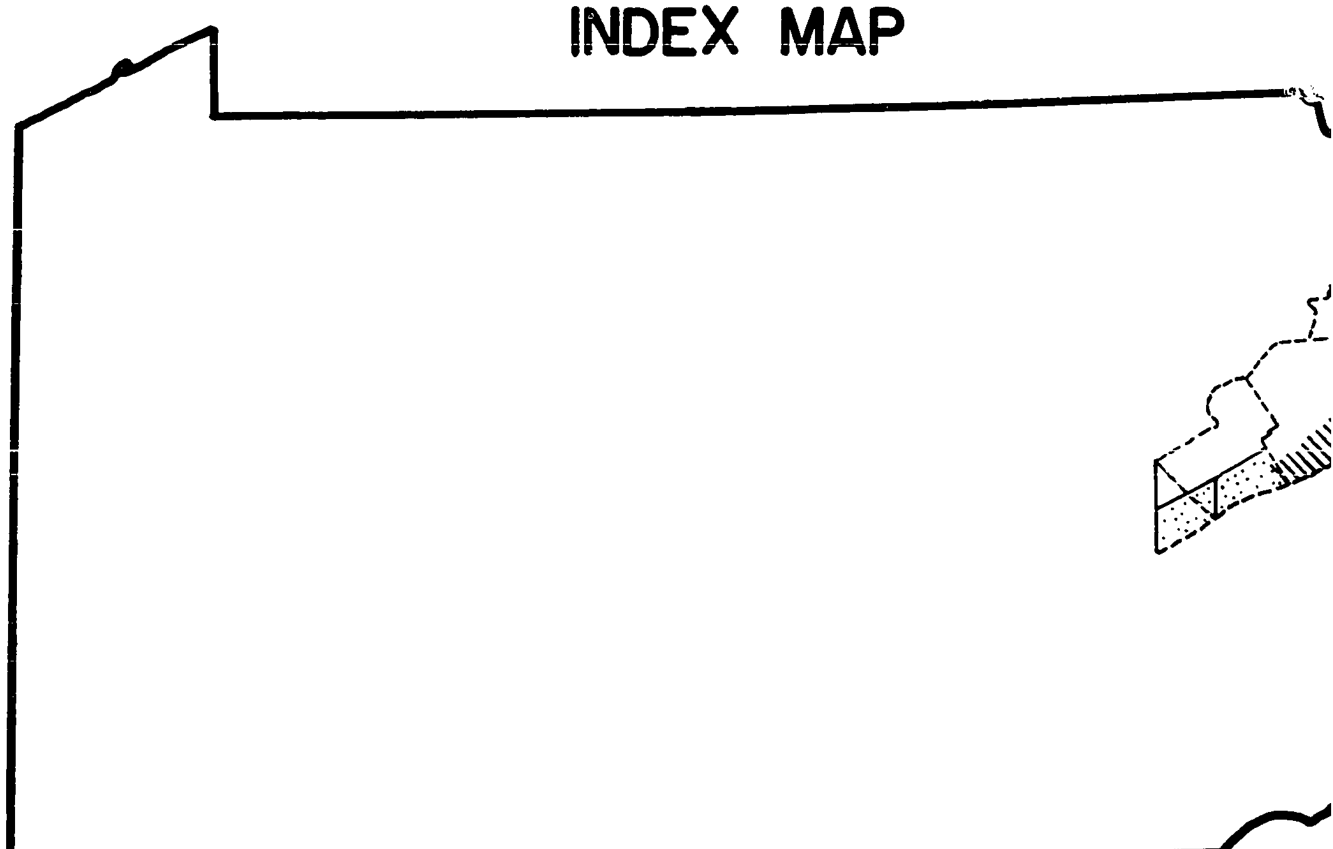
Mr. Schultz is an associate member of the American Association of Petroleum Geologists, and of the Lehigh Chapter of the Society of the Sigma Xi. He is a student member of the Geological Society of America and the American Society of Photogrammetry.

Mr. Schultz and Sandra Louise (nee) Fanseen were married in February, 1968. They became the parents of a daughter, Amey Lane Schultz, in July, 1973.

PLATE I OUTC
TRIMMERS
IN NORTHEA

SOURCE OF DATA

INDEX MAP

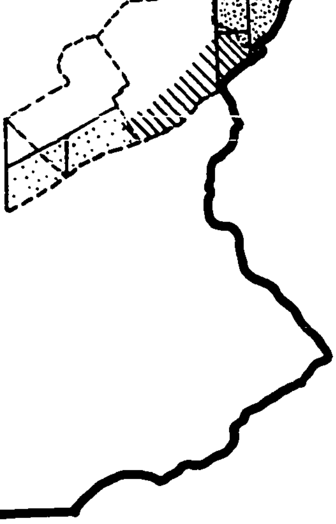


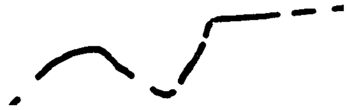
LEGEND

TCROP BELT OF TH

RS ROCK FORMATION

EASTERN PENNSYLVAN

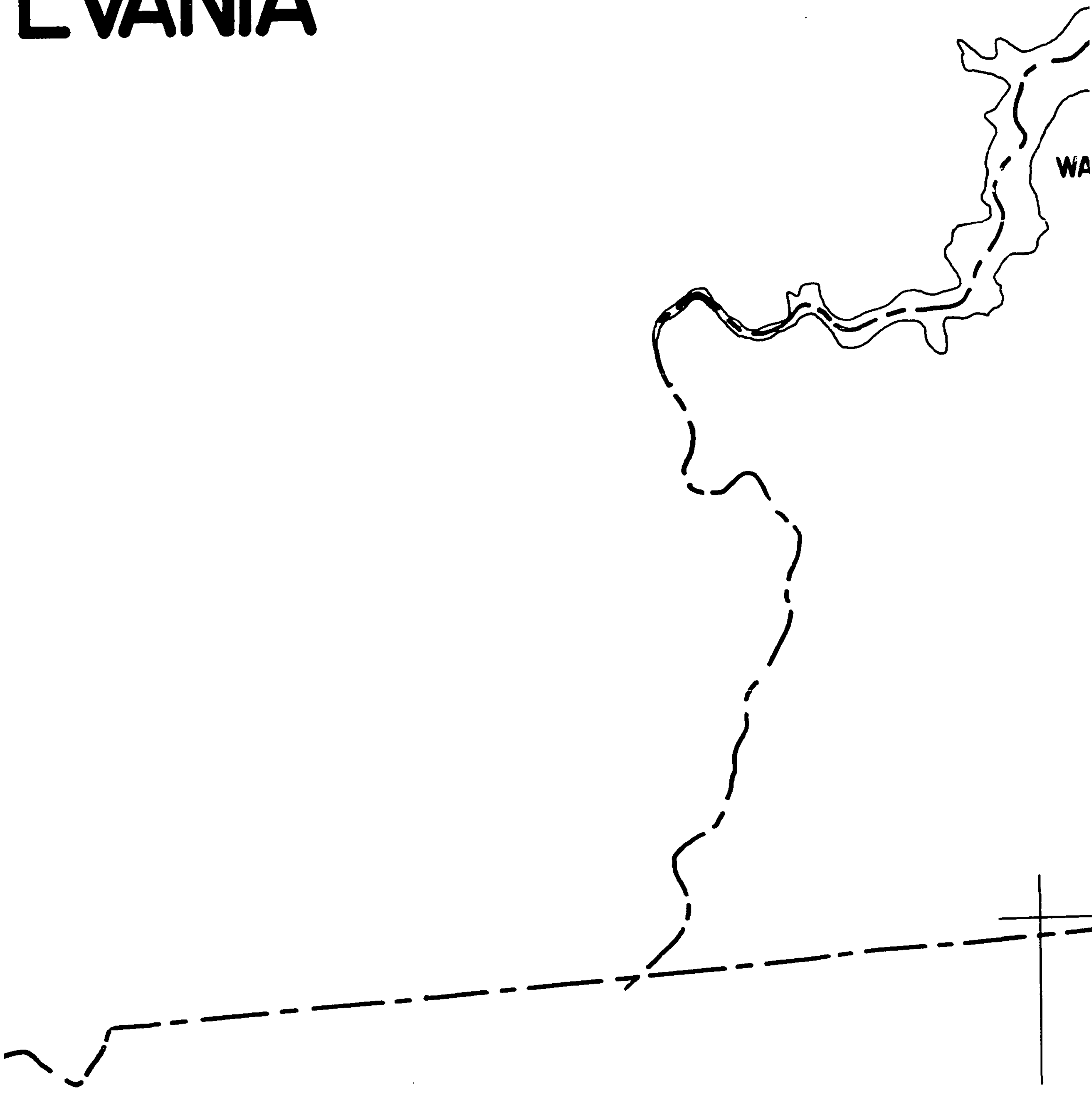


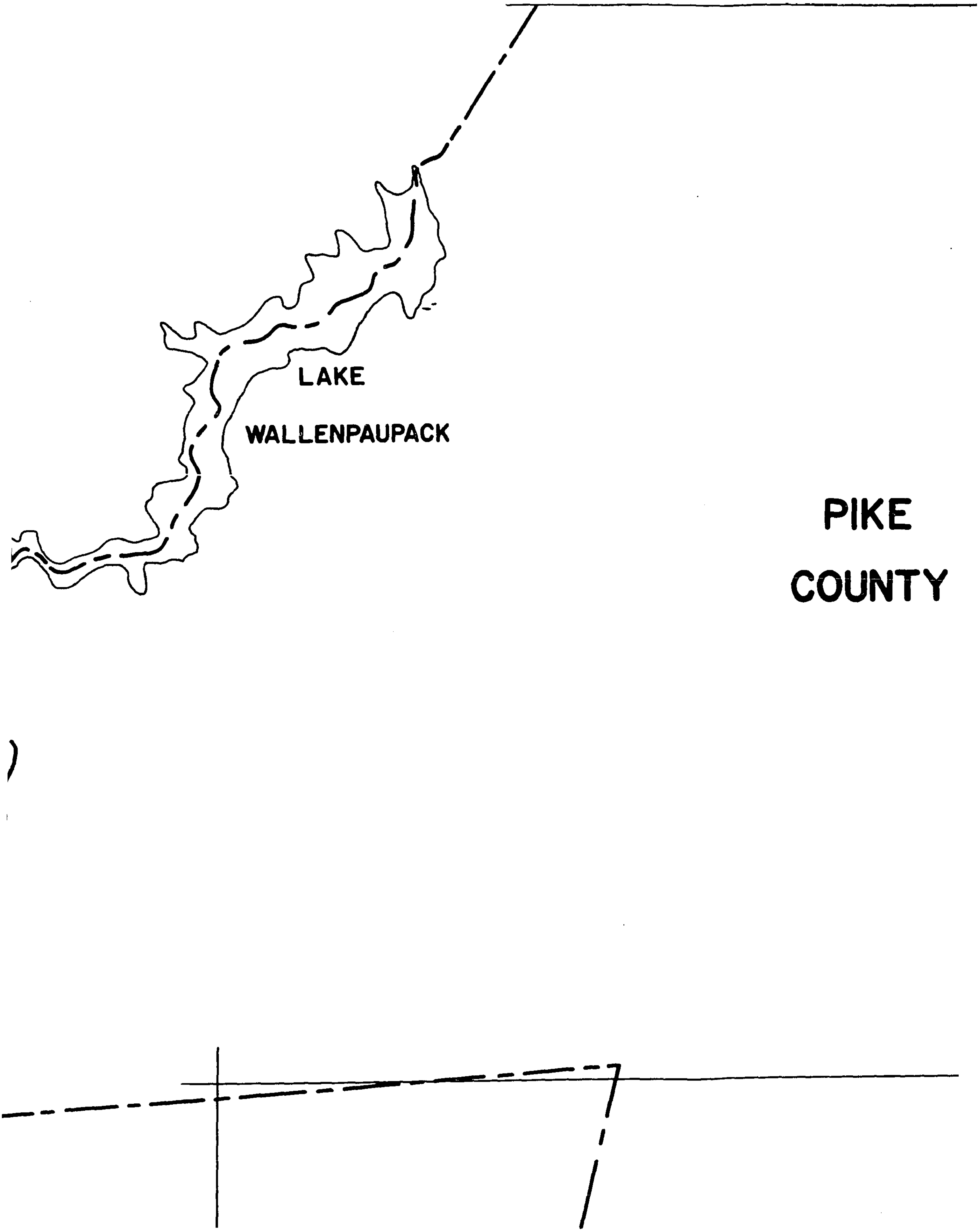


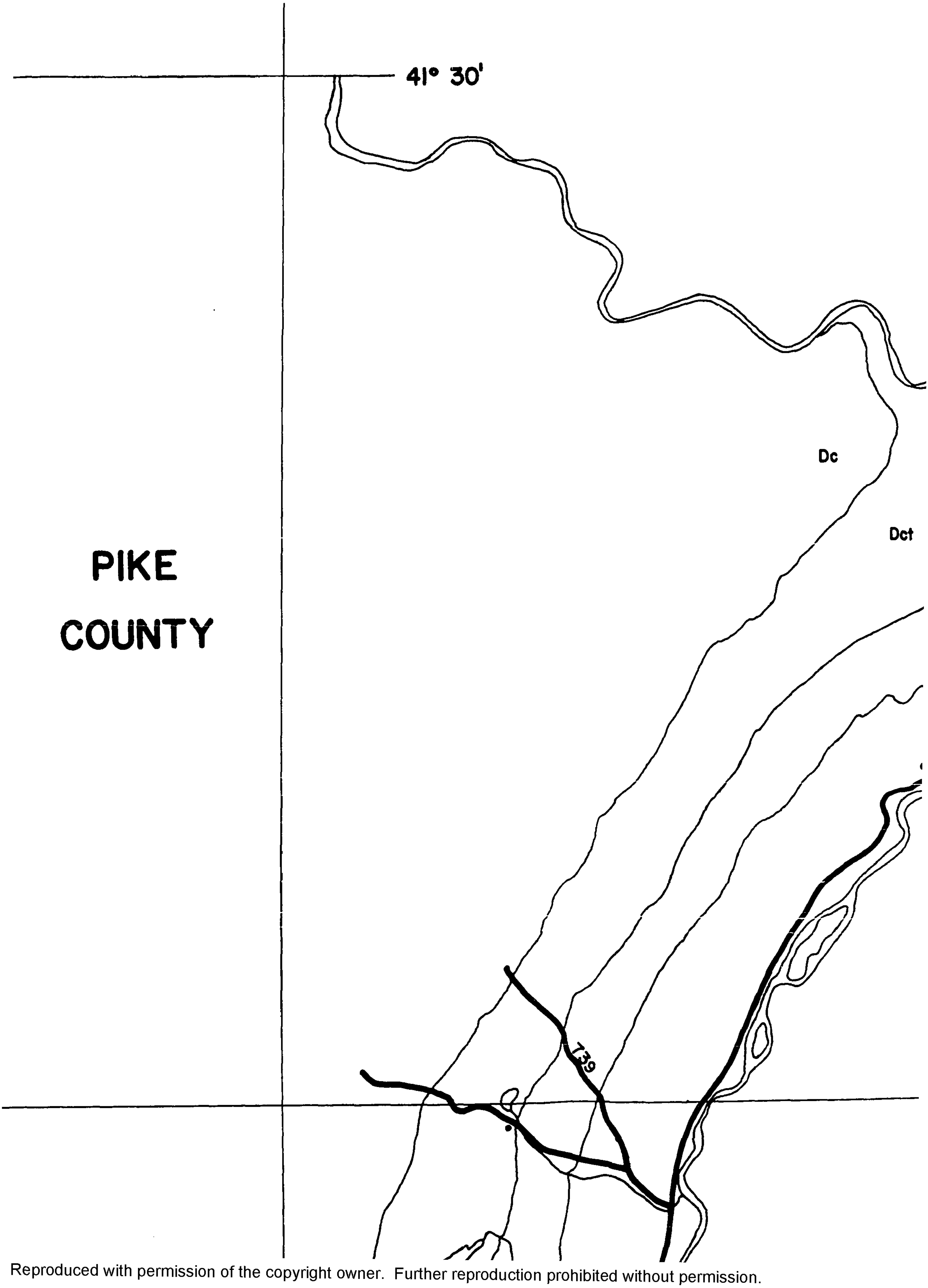
THE

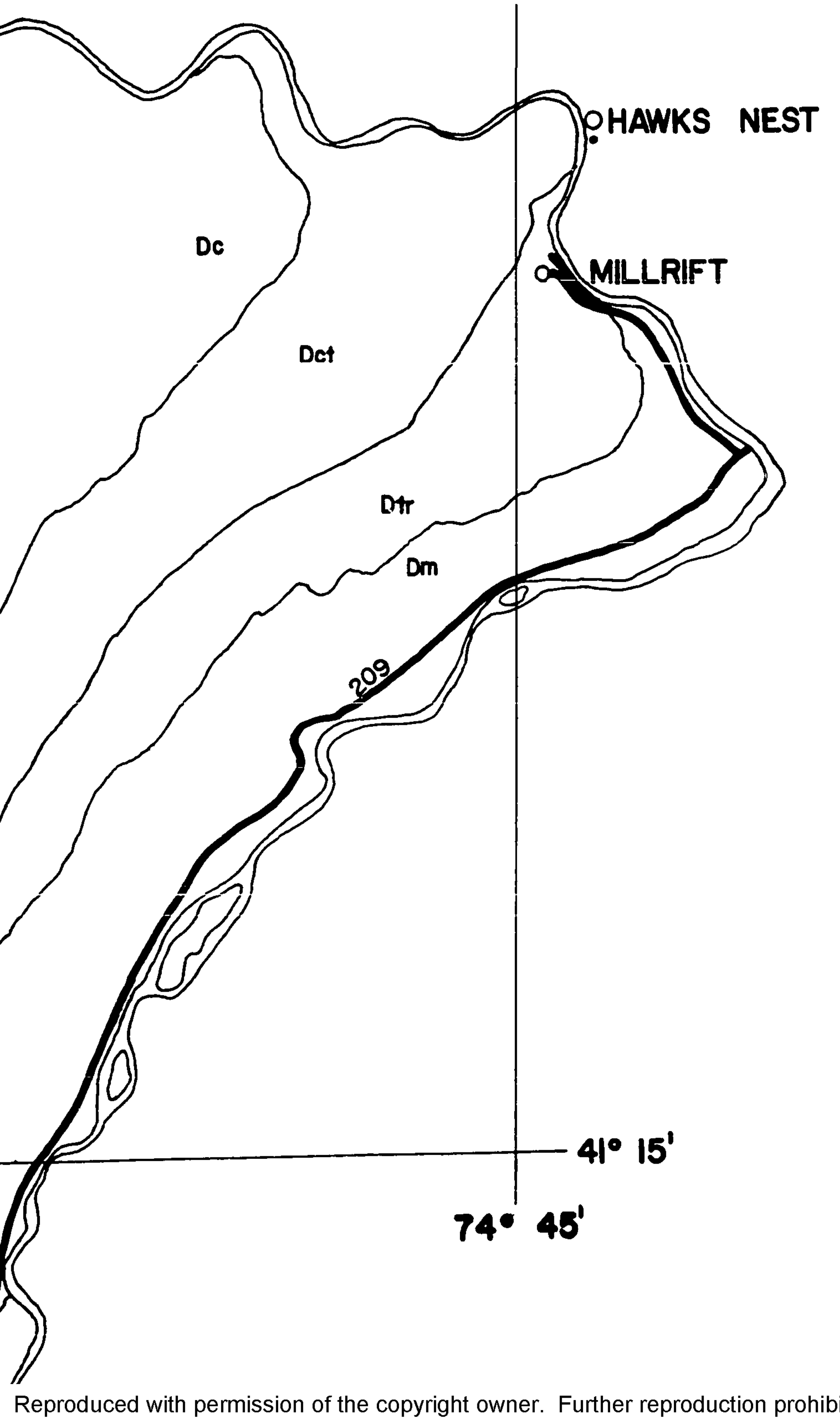
ON

LVANIA




LAKE
WALLENPAUPACK
PIKE
COUNTY

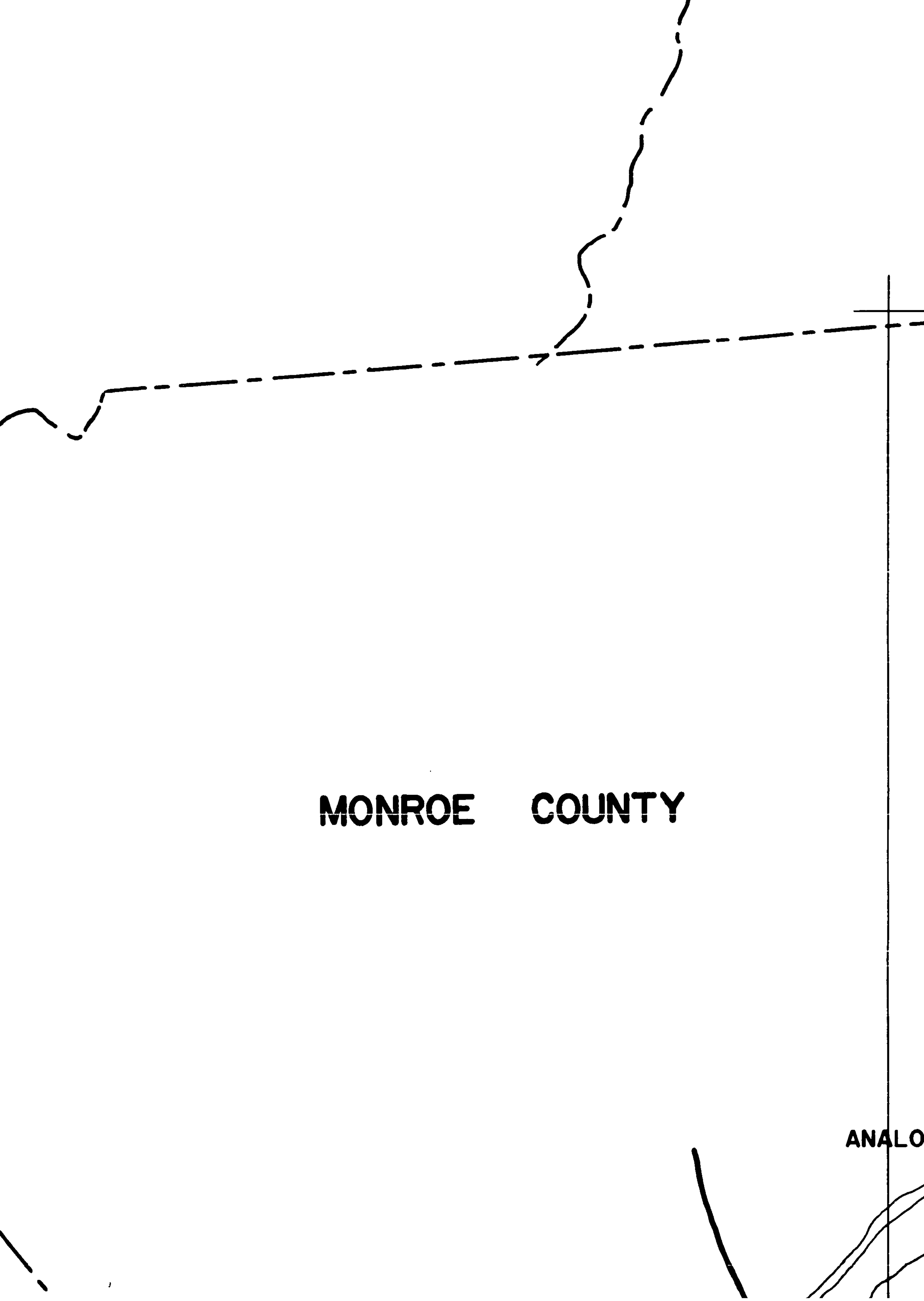

41° 30'
Dc
Dct
PIKE
COUNTY
739

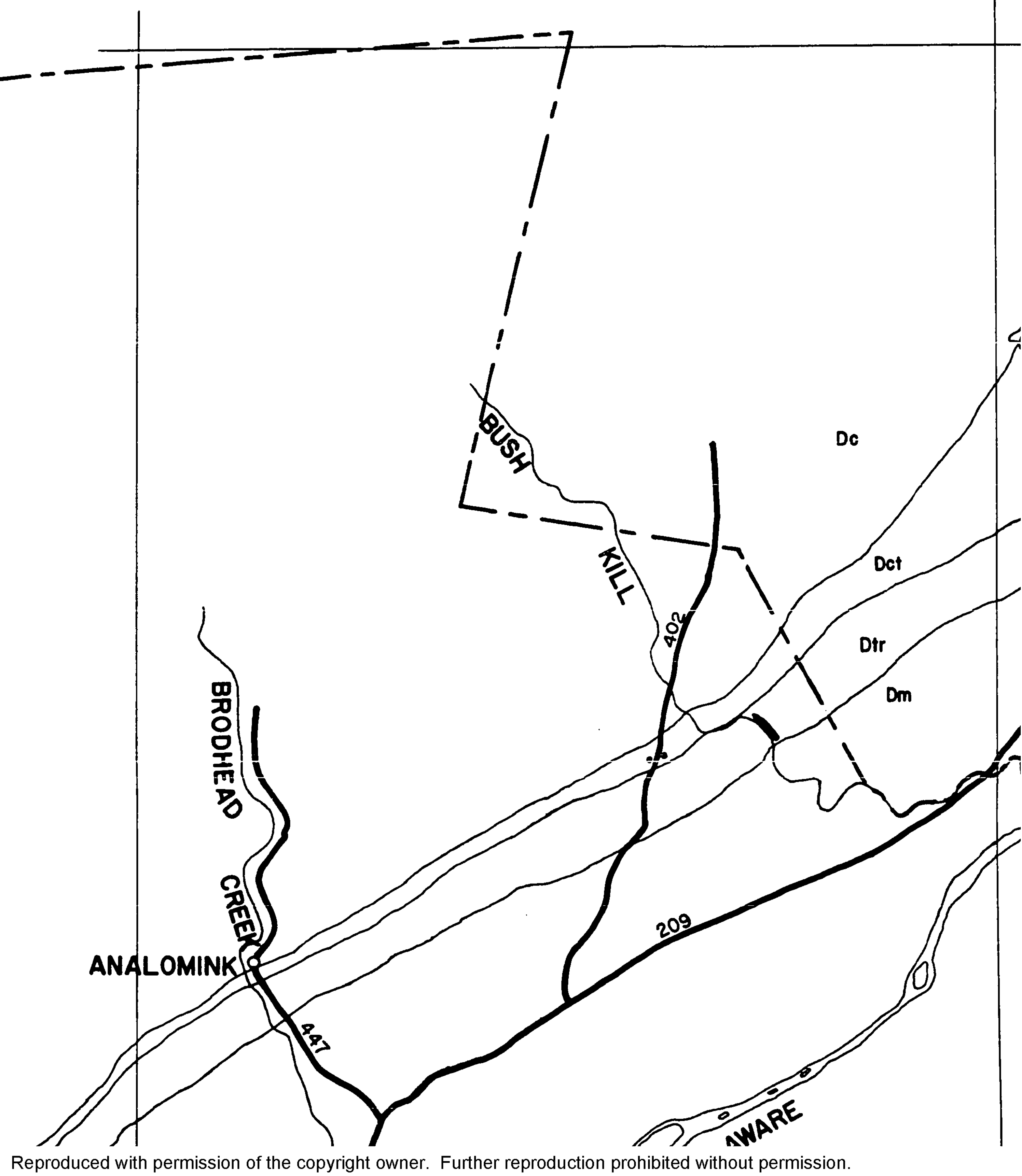

HAWKS NEST
MILLRIFT
Dc
Dct
Dfr
Dm
209
41° 15'
74° 45'

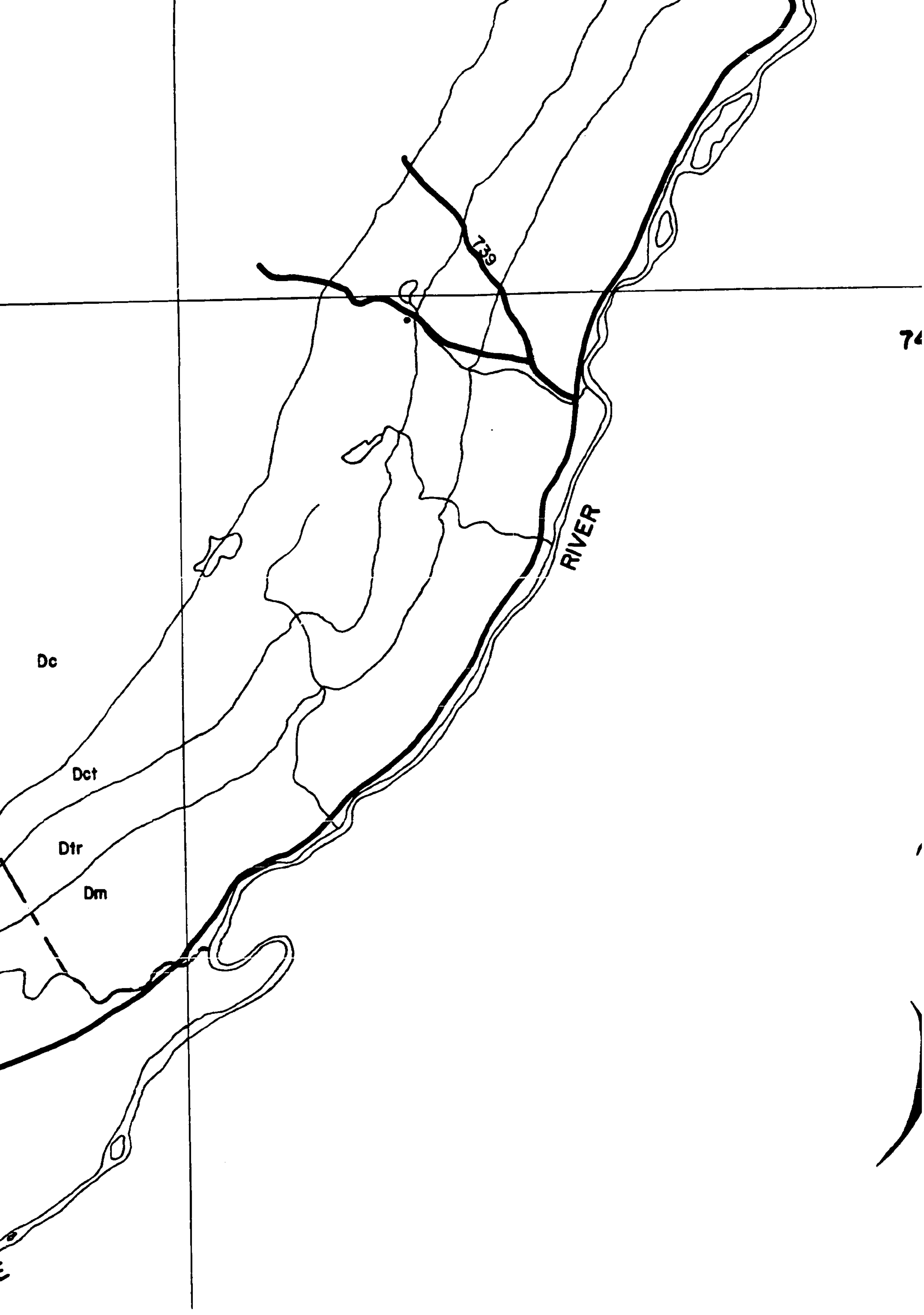
LEGEND

- Fletcher and Woodrow, 1970
- Sevon, Epstein, and Berg, 1973
- Schultz, 1972 & 1973
- Modified Pennsylvania Geologic Map (1960) on basis of field checks, adjacent mapping, personal communications, and stratigraphic thickness measurements.

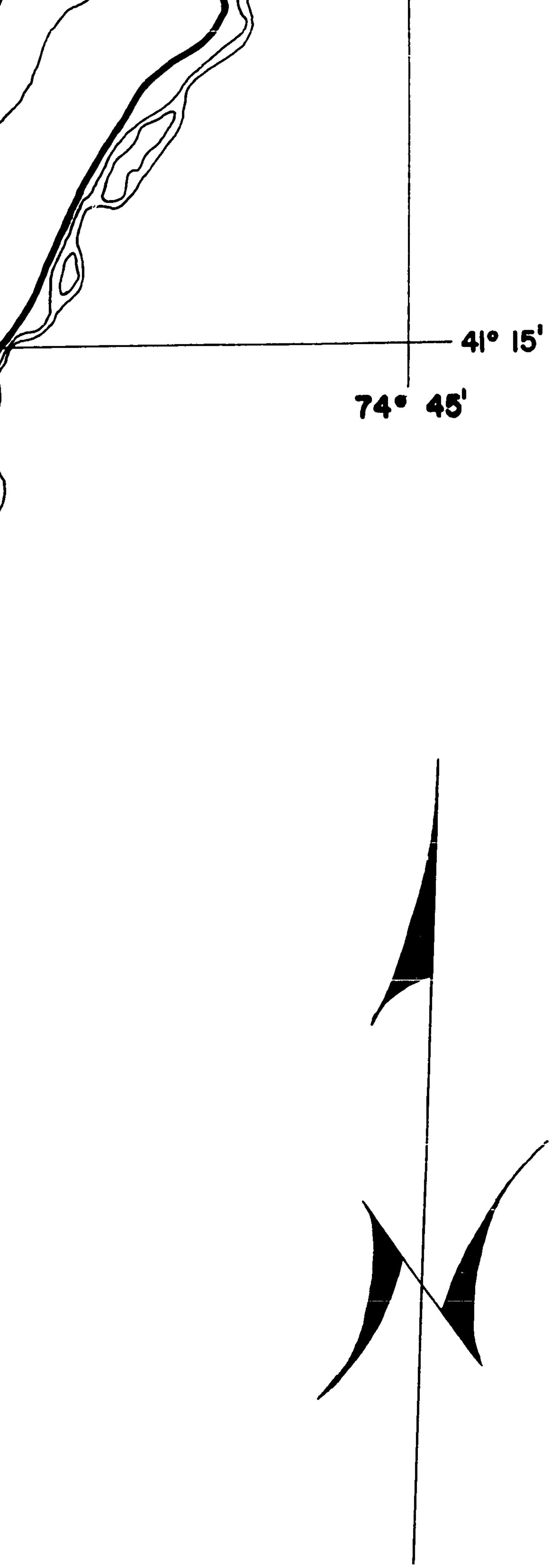

D
973
gic
d


MONROE COUNTY
ANALO

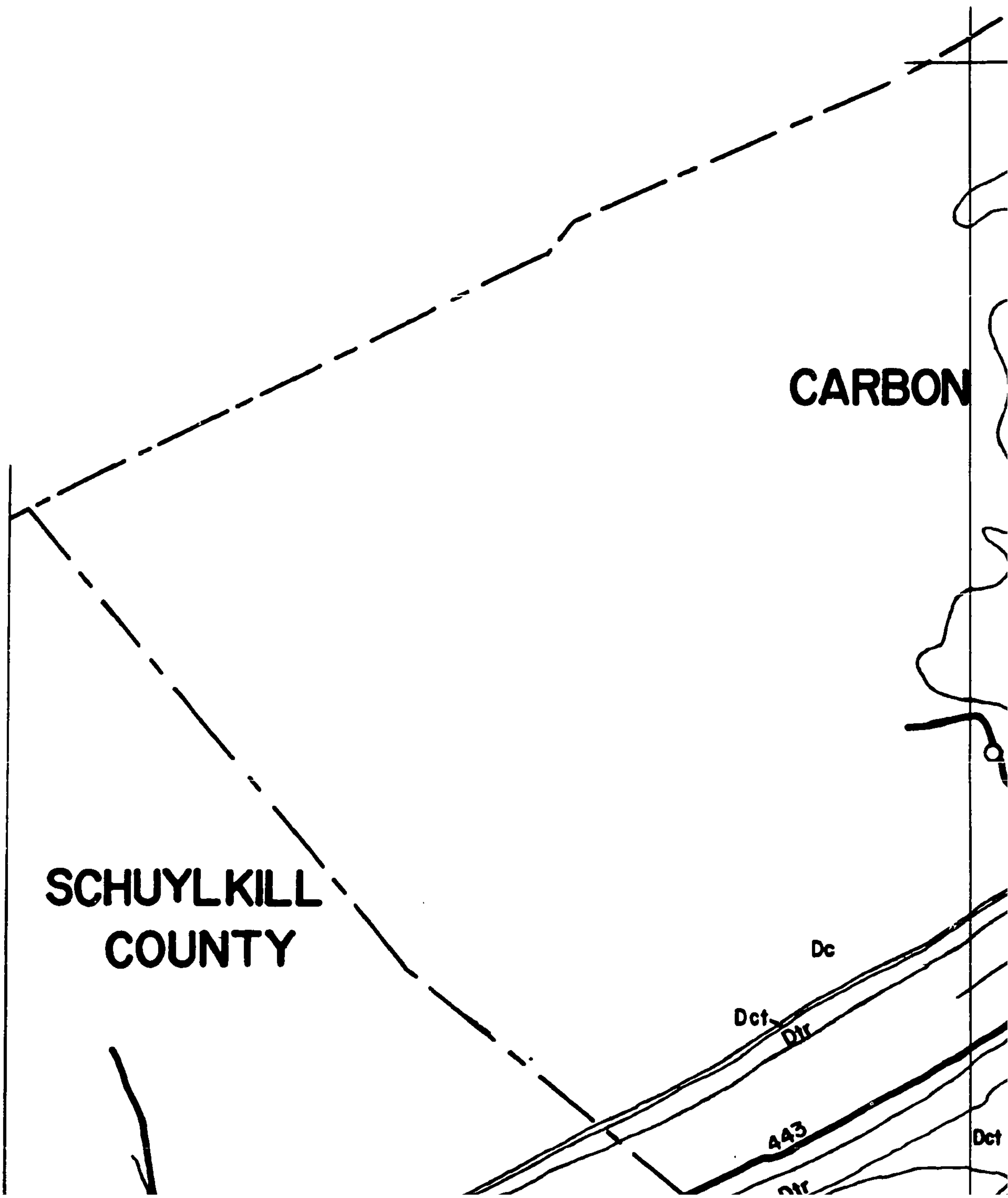

BUSH
KILL
BRODHEAD
CREEK
ANALOMINK
402
209
447
Dc
Dct
Dtr
Dm
AWARE

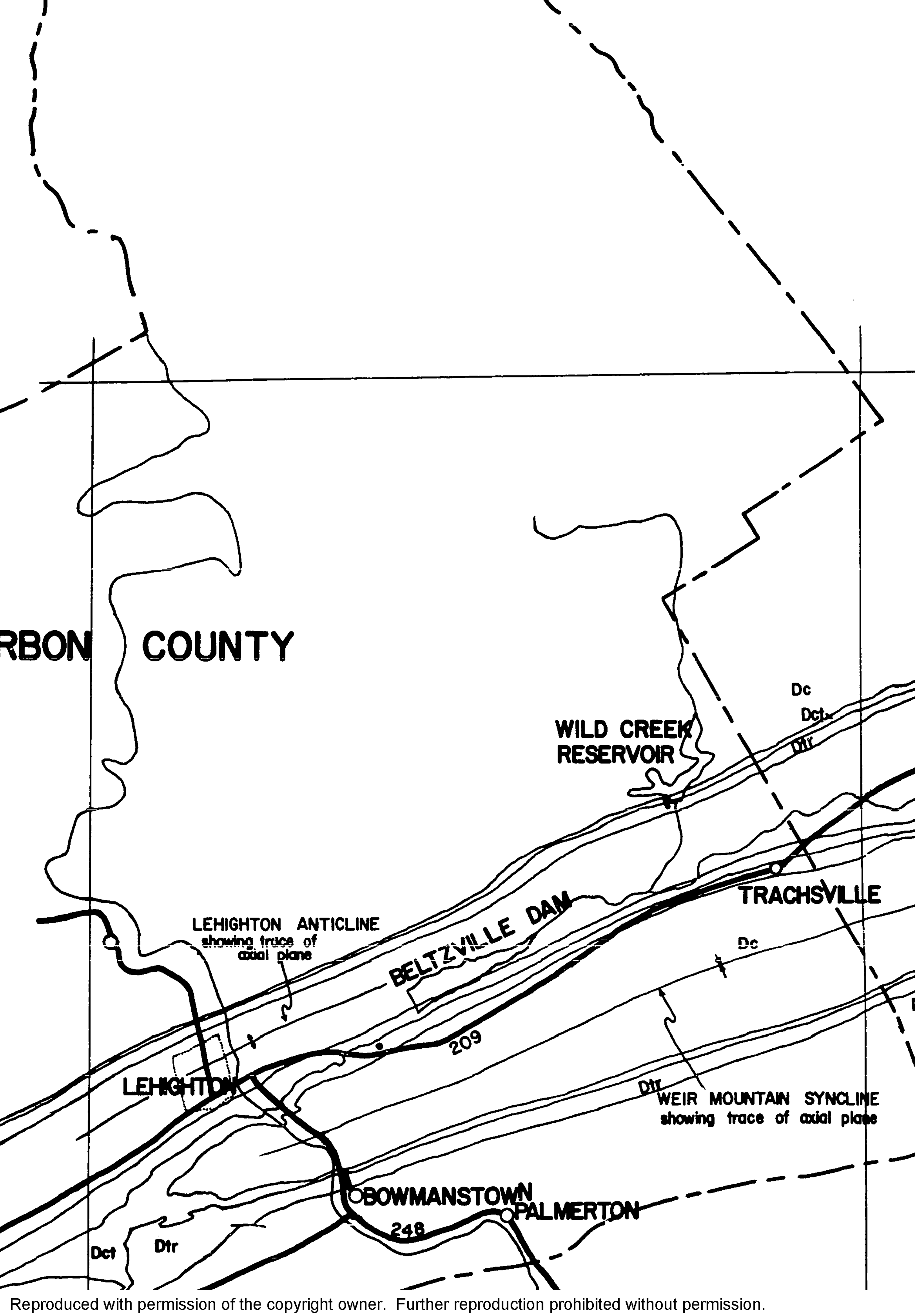


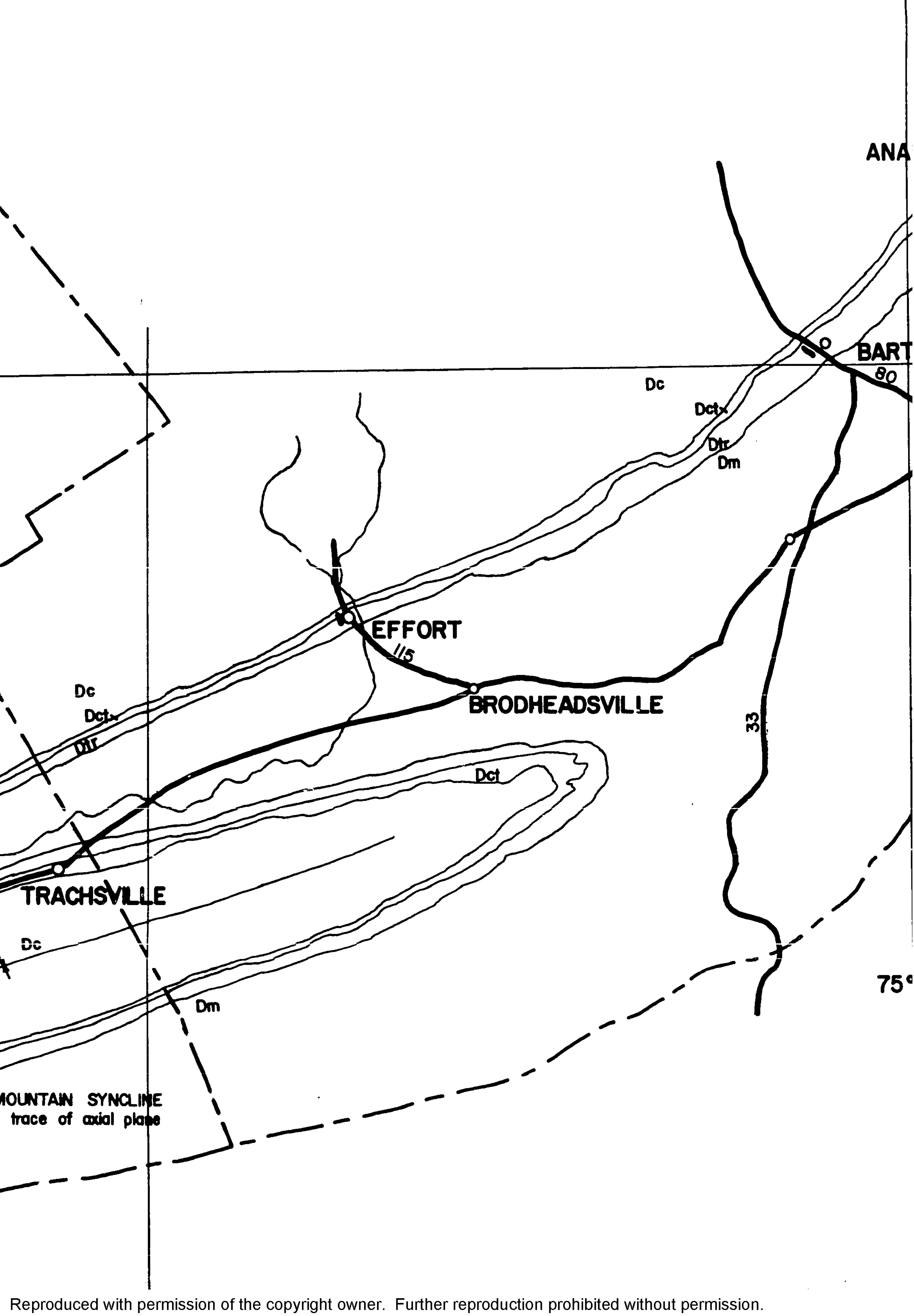
739
74
RIVER
Dc
Dct
Dtr
Dm

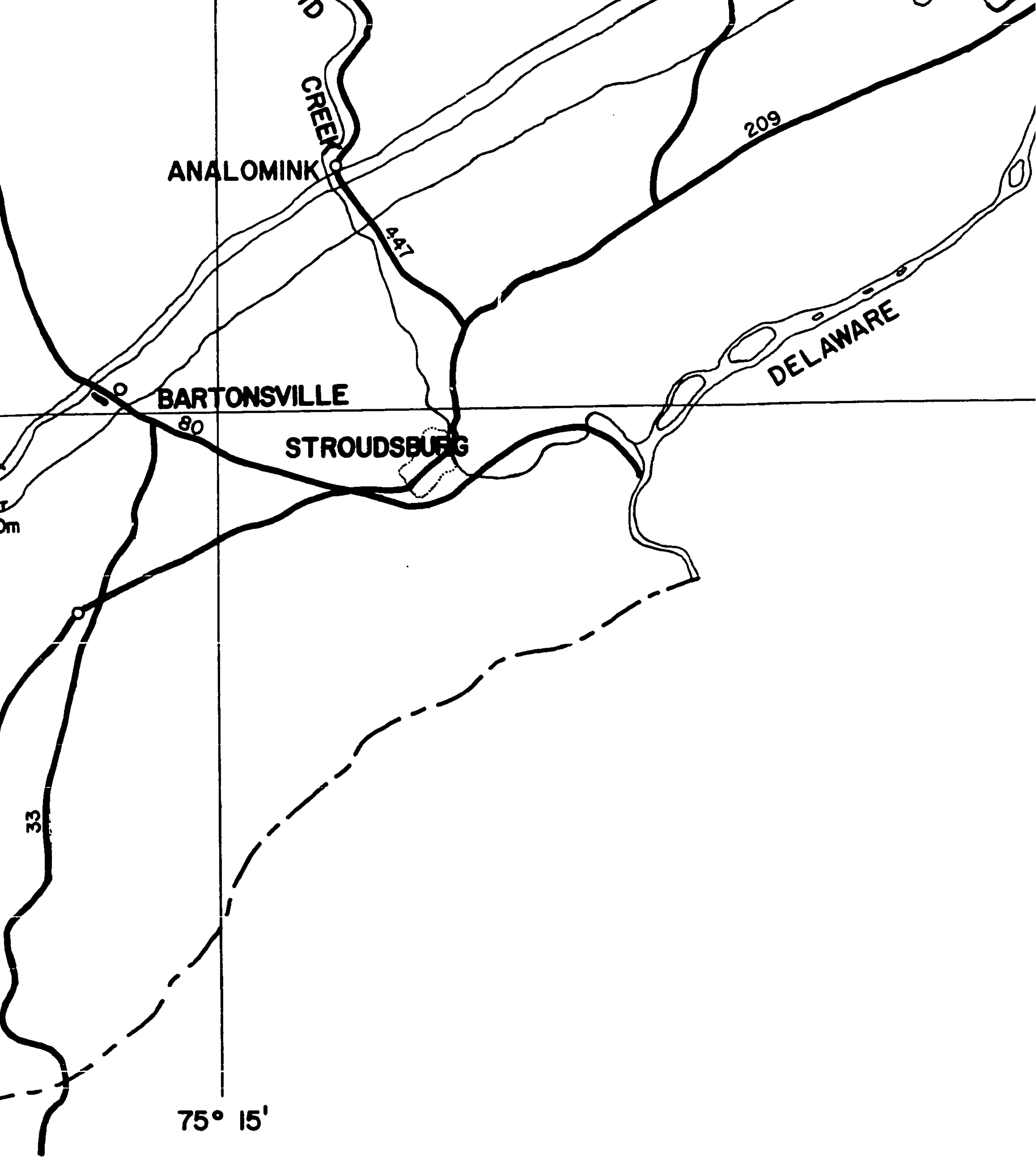

41° 15'
74° 45'

personal communications, and stratigraphic thickness measurements.

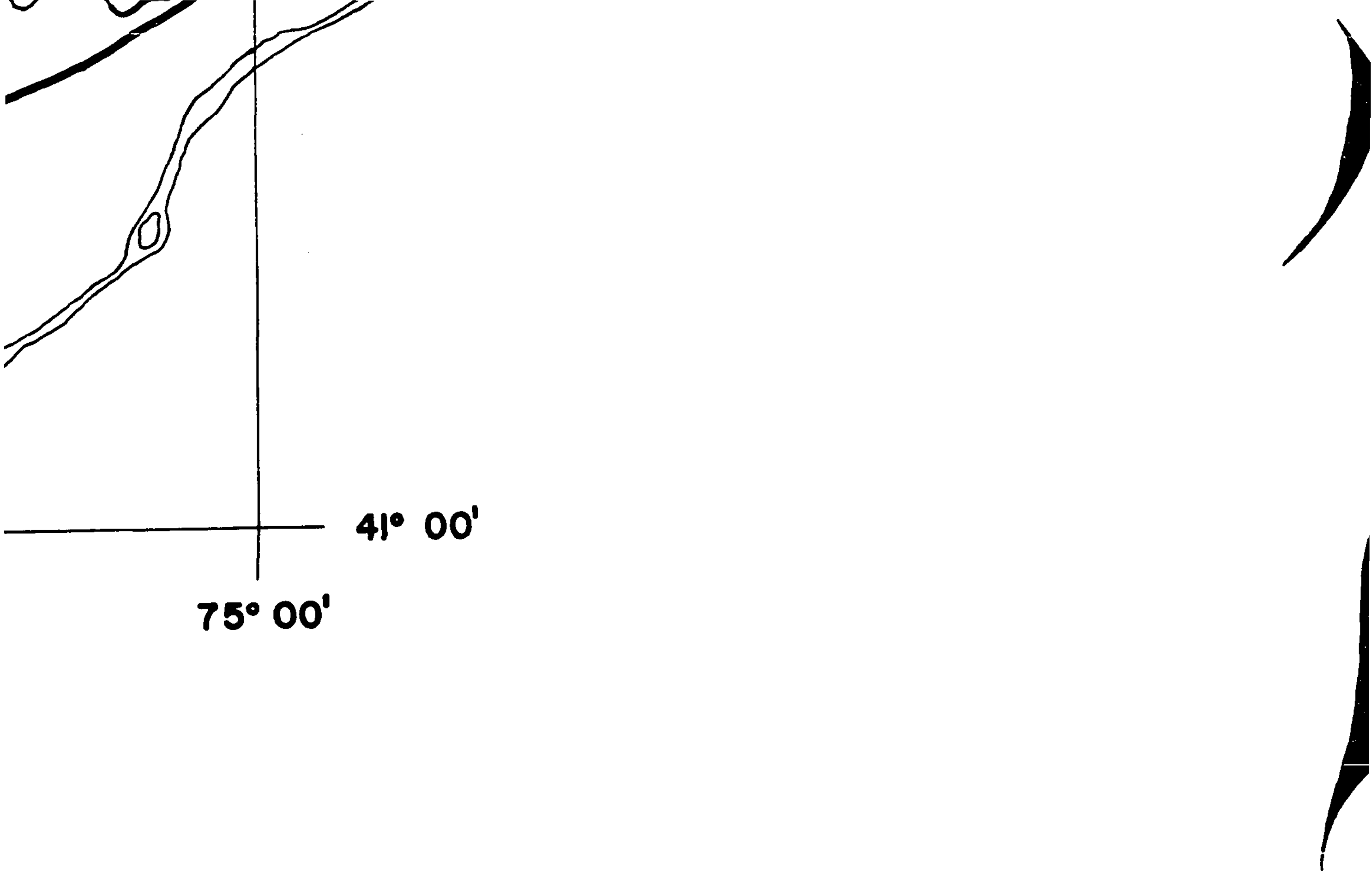



RBON COUNTY
WILD CREEK RESERVOIR
Dc
Dct
Dtr
LEHIGHTON ANTICLINE
showing trace of axial plane
BELTZVILLE DAM
TRACHSVILLE
Dc
209
LEHIGHTON
Dtr
WEIR MOUNTAIN SYNCLINE
showing trace of axial plane
BOWMANSTOWN
PALMERTON
248
Dct
Dtr


ANA
BART
80
Dc
Dctx
Dtr
Dm
EFFORT
115
BRODHEADSVILLE
Dc
Dctx
Dtr
Dct
33
TRACHSVILLE
Dc
Dm
75°
MOUNTAIN SYNCLINE
trace of axial plane



CREEK
ANALOMINK
447
209
BARTONSVILLE
80
STROUDSBURG
DELAWARE
33
75° 15'

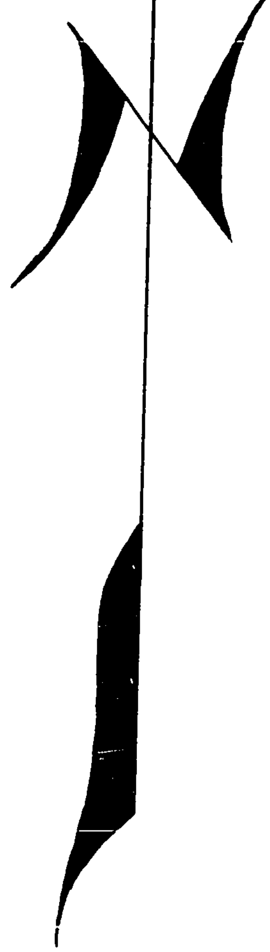


EXPLANATION

Dc CATSKILL FORMAT

Dct TOWAMENSING MEM

Dtr TRIMMERS ROCK F

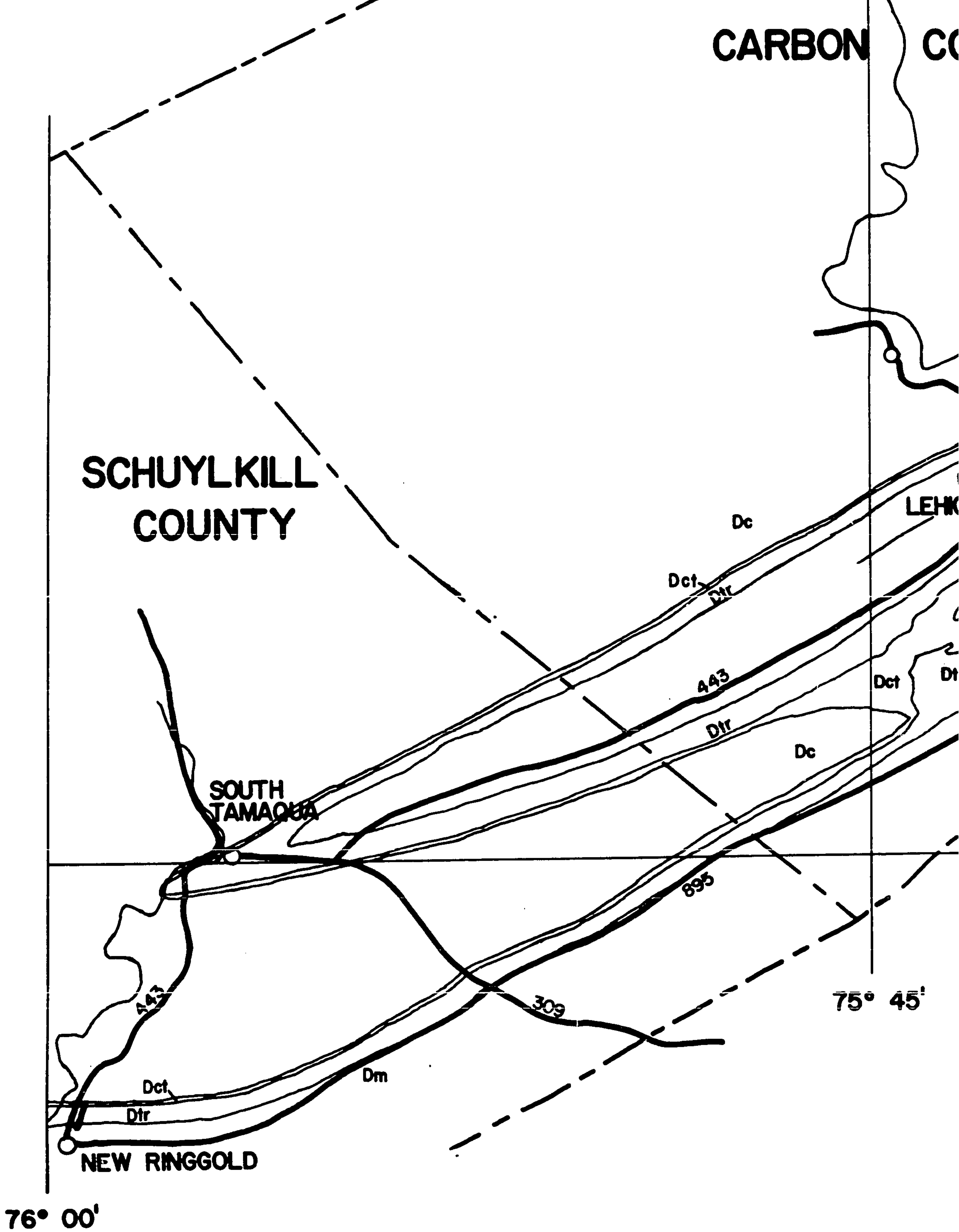


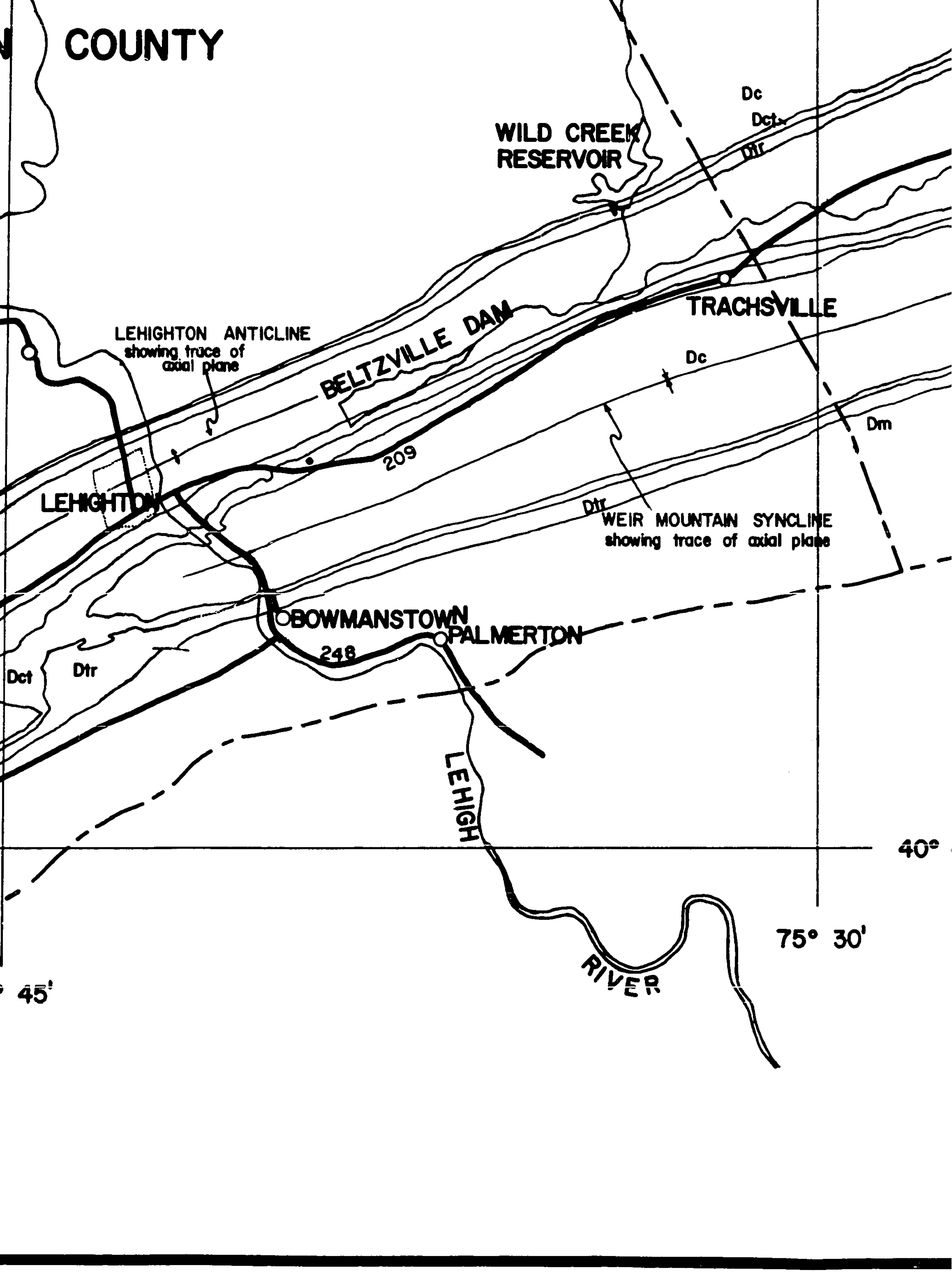
EXPLANATION

ATSKILL FORMATION, undifferentiated

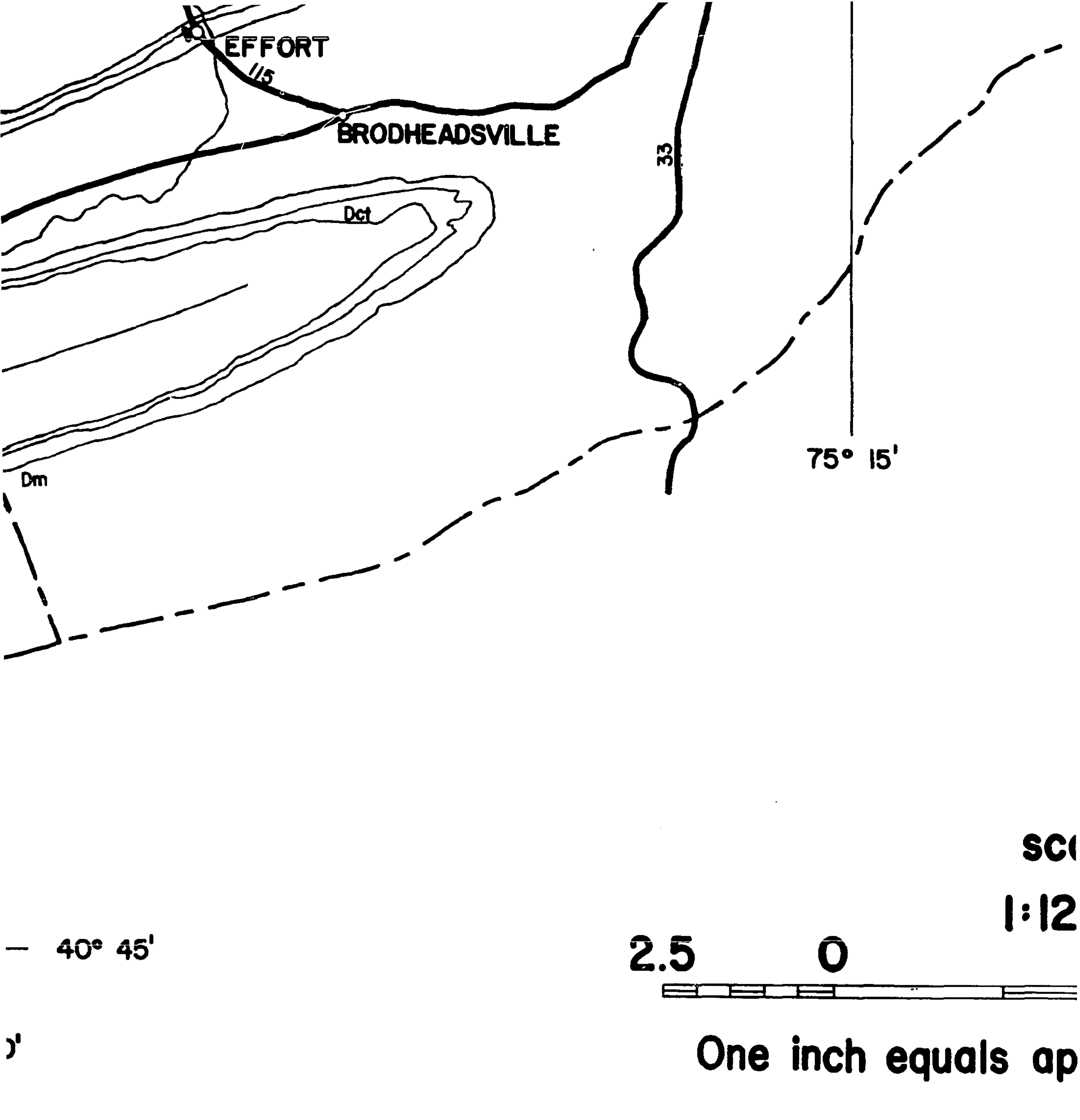
OWAMENSING MEMBER, CATSKILL FORMATION

RIMMERS ROCK FORMATION


CARBON
CO
SCHUYLKILL
COUNTY
LEHIG
Dc
Dct
Dtr
443
Dct
Dt
Dtr
Dc
SOUTH
TAMAQUA
895
309
75° 45'
443
Dct
Dtr
Dm
NEW RINGGOLD
76° 00'



COUNTY
WILD CREEK RESERVOIR
Dc
Dct
Dtr
LEHIGHTON ANTICLINE
showing trace of axial plane
BELTZVILLE DAM
TRACHSVILLE
Dc
Dm
209
LEHIGHTON
Dtr
WEIR MOUNTAIN SYNCLINE
showing trace of axial plane
BOWMANSTOWN
PALMERTON
248
Dct
Dtr
LEHIGH
RIVER
40°
75° 30'
45'


EFFORT
115
BRODHEADSVILLE
33
Dct
Dm
75° 15'
40° 45'
SC
1:12
2.5
0
One inch equals ap

scale

1:125,000

5 10 miles

s approximately 2 miles.

EXPLANATION

Dc	CATSKILL FORMATION, undifferentiated
Dct	TOWAMENSING MEMBER, CATSKILL FORM
Dtr	TRIMMERS ROCK FORMATION
Dm	MAHANTANGO FORMATION
——	Location of measured sections
•	Location of <u>Archanodon</u>, sp.

EXPLANATION

TSKILL FORMATION, undifferentiated

WAMENSING MEMBER, CATSKILL FORMATION

IMMERS ROCK FORMATION

HANTANGO FORMATION

cation of measured sections

cation of Archanodon, sp.