GUIDEBOOK

36TH. ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

UPPER DEVONIAN SEDIMENTATION IN SUSQUEHANNA COUNTY

and

ENVIRONMENTAL GEOLOGY OF THE WYOMING-LACKAWANNA VALLEY

OCTOBER 8 and 9, 1971
WILKES-BARRE, PA.

Hosts: PENNSYLVANIA STATE UNIVERSITY
and
U.S. GEOLOGICAL SURVEY

Guidebook for the 36th Annual Field Conference of Pennsylvania Geologists

October 8-9, 1971

UPPER DEVONIAN SEDIMENTATION IN SUSQUEHANNA COUNTY

By

Stephen A. Krajewski, Pennsylvania State University
Eugene G. Williams, Pennsylvania State University

and

HYDROLOGY, GLACIAL GEOLOGY AND ENVIRONMENTAL GEOLOGY OF THE WYOMING-LACKAWANNA COUNTY

By

Jerrald R. Hollowell, U. S. Geological Survey

Hosts: Pennsylvania State University
U. S. Geological Survey

Headquarters Motel: Treadway Inn, Wilkes-Barre

Guidebook Distributed by:

Bureau of Topographic and Geologic Survey
Department of Environmental Resources
Harrisburg, Pennsylvania 17120

Arthur A. Socolow, State Geologist

CONTENTS

FIGURES

Figure		Page
15	Flagstone quarry density map of Susquehanna County	27
16	Isopach map of the elevational interval over which the flagstone quarries occur	28
17	Graph of the number of flagstone quarries versus the elevational interval over which they occur	30
18	Isopotential map for locating a quarry in Susquehanna County, Pennsylvania	31
19	Aerial photograph 60-46 from the Interim Soil Survey Report, Volume II for Susquehanna County	33
20	Typical landscape in Susquehanna County showing the relationship between the parent material and the pattern of soil development	35
21	Location of the twenty-six flagstone quarries sampled	39
22	Mean deviation map of matrix	44
23	Mean deviation map of total cement	45
24	Mean deviation map of opaques	46
25	Mean deviation map of modal grain size	47
26	Mean deviation map of percentage water absorption	48
27	Mean deviation map of the disintegration index	49
28	The relationship between hill geometry, parting lineation, external geometry, and the direction to mine flagstone deposits	61
29	Upper road-cut along I-81 south of New Milford	67
30	Middle road-cut along I-81 south of New Milford	68
31	Lower road-cut along I-81 south of New Milford	69

TABLES

UPPER DEVONIAN SEDIMENTATION IN SUSQUEHANNA COUNTY

AND ITS APPLICATIONS IN THE PREDICTION AND MINING OF FLAGSTONE

by

Stephen A. Krajewski and Eugene G. Williams

(Pennsylvania State University)

INTRODUCTION

General Statement

This research was initiated by the Small Industries Research (SIR) group of the Pennsylvania State University and the Pennsylvania Bluestone Association to investigate and answer many of the geologic questions concerning the origin, occurrence, and properties of Pennsylvania flagstone. It presents a discussion of the geology, composition, texture, and physical properties of the flagstones. Its aim was to provide for the quarrymen and those interested in the technical aspects of flagstone production and utilization a basis for a better understanding of the flagstone resources of Pennsylvania and of the properties of the flagstone that affect their discovery, development, and use. Material for this guidebook was taken from a Master's thesis by Stephen Krajewski which was presented to the Department of Geosciences of the Pennsylvania State University.

Glaeser (1969) made a preliminary study of the flagstone deposits in Susquehanna County. He interpreted most of the flagstone as beaches and recognized the significance of overburden relationships as a basis

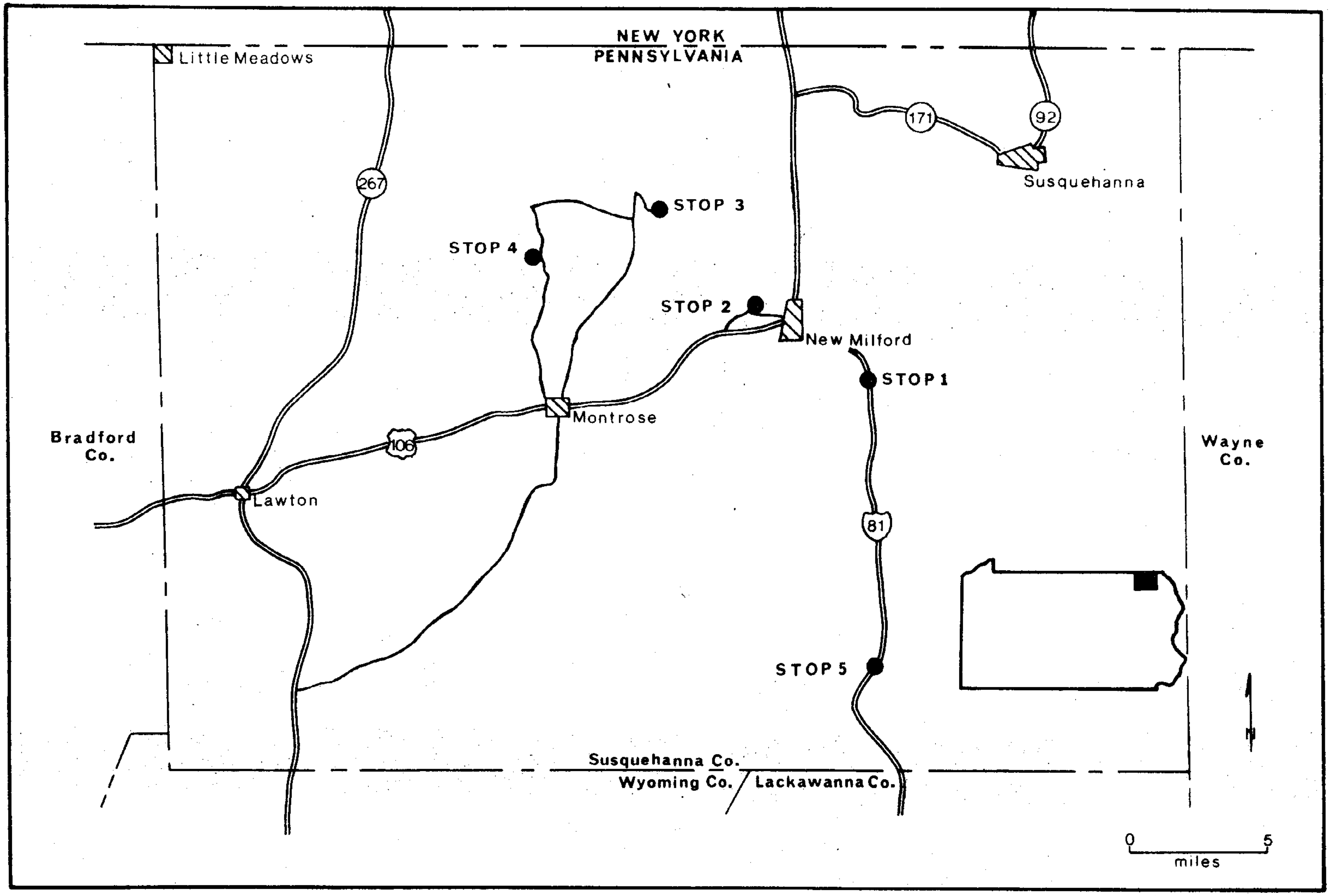


Figure 1. Location map of stops.

for quarry classification. In addition, he used parting lineation and flagstone deposit geometry as a basis for increasing mining efficiency. His work was not of sufficient detail to have significant predictive value. This was the principle objective of the present research.

The Flagstone Units

Although considerable variability in the composition, texture, and color of the flagstone was observed while visiting many of the producing quarries, all were found to be dense, compact sandstones in deposits between one and twenty feet thick which split (part) along well defined planes of weaker cohesion that were parallel to the original bedding; therefore, the flagstones can be mined in large slabs or sheets which have a very smooth upper and lower parting surface. (This type of bedding is called planar, horizontal bedding.) When a layer of the flagstone was traced laterally within the deposit, it commonly wedged or pinched out.

Usually within the upper layers of the deposit, the partings develop naturally. As the overburden thickness increases, the partings become less pronounced. In most deposits, however, the flagstone can be split along certain dark streaks, or reeds, which are also parallel to the parting surfaces.

Each slab or sheet of flagstone was found to generally have a set of parallel ridges and depressions on the parting surface. These are referred to as the grain direction by the quarrymen, and as the parting lineation by the geologist. This characteristic is a result of the alignment of the elongate grains within the stone with their long axes parallel; therefore, providing another inherent weaker zone along which the stone can be broken (Allen, 1964).

It is these qualities that have made the flagstone valuable as a dimenstion stone, and it is also these properties that provide the key to the origin of the flagstone.

Flagstone is a commercial name for a variety of sandstone having properties sufficiently characteristic and distinctive to justify in recognition as a separate type of dimension stone. The term was first applied to certain "bluish" colored sandstones quarried in Ulster County, New York in the mid to late 1800's. With the development of the industry, it was found that stone of similar character was abundant in various other localities in New York and Pennsylvania. Today, most of the flagstone is produced in Pennsylvania from Susquehanna County with minor amounts being quarried from Wayne, Bradford, Wyoming and Lackawanna Counties (Figure 1). Production of the stone has been gradually declining as a result of the inability to locate and efficiently mine new economic deposits of flagstone to meet the current and future market demands.

STRATIGRAPHY

Bradford Willard (1939) presented a sketch map, Figure 2, to illustrate the paleogeography of Pennsylvania in Upper Devonian time. His map presented an "early Chemung shoreline" which essentially represents the boundary of the marine facies to the west (the Chemung and Portage), and, the dominantly continental facies to the east (the Catskill). The river systems presented on this diagram are diagramatic; however, the location of the southwest to northeast trending shoreline was defined on the presence or absence of marine fossils so that the map does have substantial validity. The study area is located at this contact.

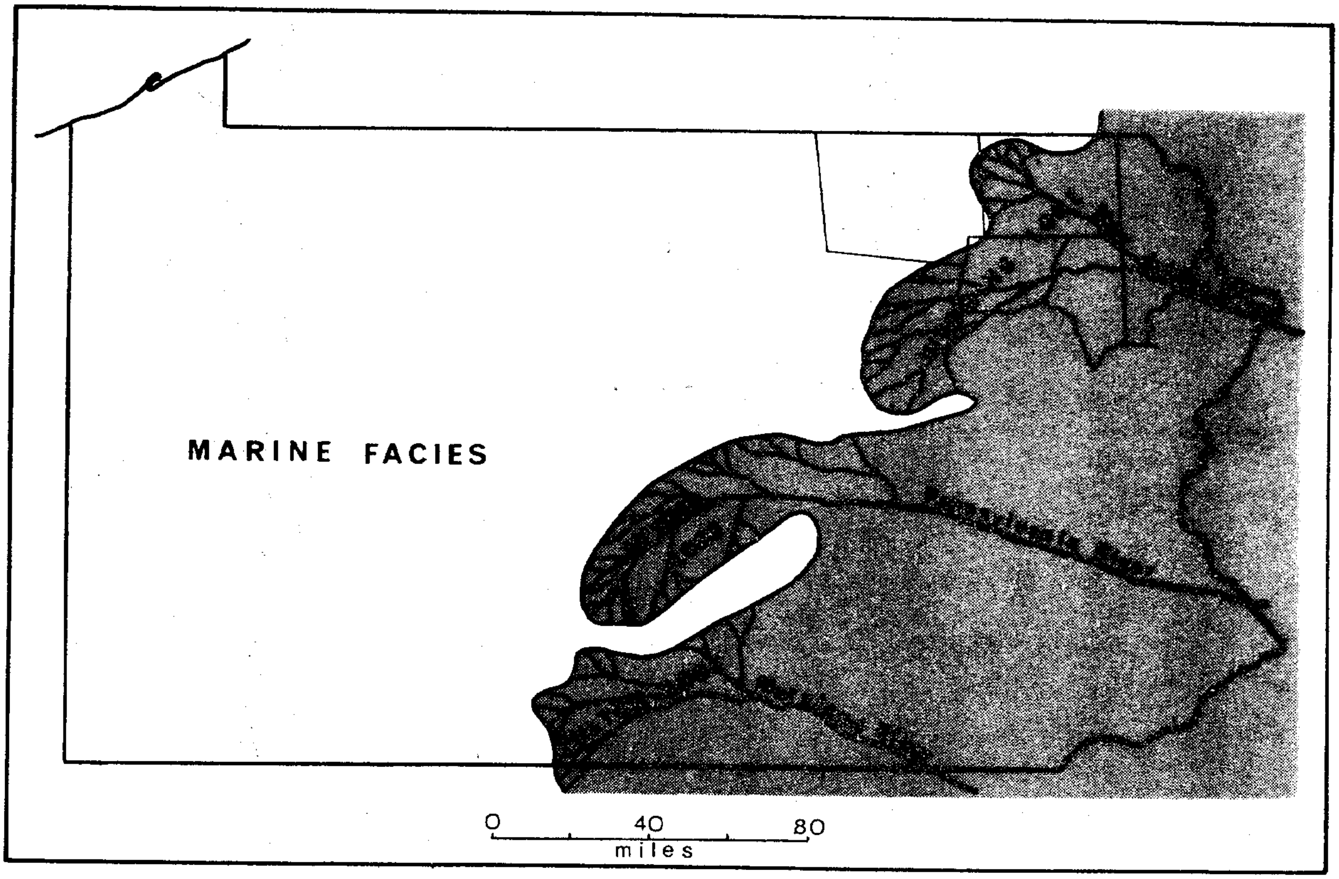


Figure 2. Sketch map to illustrate the position of the early Chemung shoreline. (adapted from Willard, 1939)

The second trend in the rock units that can be observed from Figure 3 is that the continental units extend, or prograde, over the marine facies. This would indicate that the "Chemung shoreline" with its respective associated sedimentologic environments migrated westward during the Upper Devonian time.

Because this "Chemung shoreline" is expressed in the area, it is reasonable to conclude that it was prograded by more landward facies of the Catskill and that this landward facies would contain sediments of tidal flat or lower delta plain origin. In the classical stratigraphic terminology of Willard (1939) this landward facies was called the New Milford. It occurs stratigraphically above and passes westward into rocks referred to as marine upper Devonian deposits in this report (i.e., the Chemung). The New Milford of Willard reaches a thickness of 400 to 500 feet and is best expressed around the town of New Milford in Susquehanna County. It consists largely of green to grayish-green, cross-bedded, flaggy, sandstones. It has, however, a basal red shale member and a thin, local limestone at the top. A more detailed breakdown of the New Milford is as follows:

Member	Thickness
Luther's Mills Coquinite	variable
New Milford Upper Sandstone	20 feet
New Milford Middle Sandstone and Shale	300 feet
New Milford Lower Sandstone	20 feet
New Milford Red Shale	100-200 feet

The upper two units contain totally marine fossils; however, the lower three units contain abundant marine and land plant fossils indicating a transitional and probably fluctuating marine to fresh water environment. It is this formation which is exposed over much of Susquehanna County, Figure 4, and from which almost all of the flagstone is produced.

The remaining members of the Catskill above the New Milford do not relate to this study and a complete discussion of them may be found in Willard (1939). This study is not concerned with the many stratigraphic complexities which exist because of the intertonguing between the subaerial deposits (Catskill) and marine deposits (Chemung) in the upper Devonian of the region. Several studies now in progress or recently published have shown that it is necessary to establish a local rock-stratigraphic framework suitable for mapping in a given area, (Woodrow, 1968; Fletcher and Woodrow, 1970; Sevon, Glaeser and Epstein, in press). In addition, Glaeser (1969 and in press) has recognized that stratigraphic units of regional significance have distinctive environmental origins and can be recognized in both surface and subsurface sections. It is clear from the amount of work presently in progress in upper Devonian sedimentary rocks of New York and Pennsylvania, that stratigraphic terminology is in a state of flux.

Origin of the Flagstone

Planar bedding and parting lineations can only be produced by water currents that are undergoing high regime flow. (Allen, 1970). This means that the water flowing over the sediments is traveling very

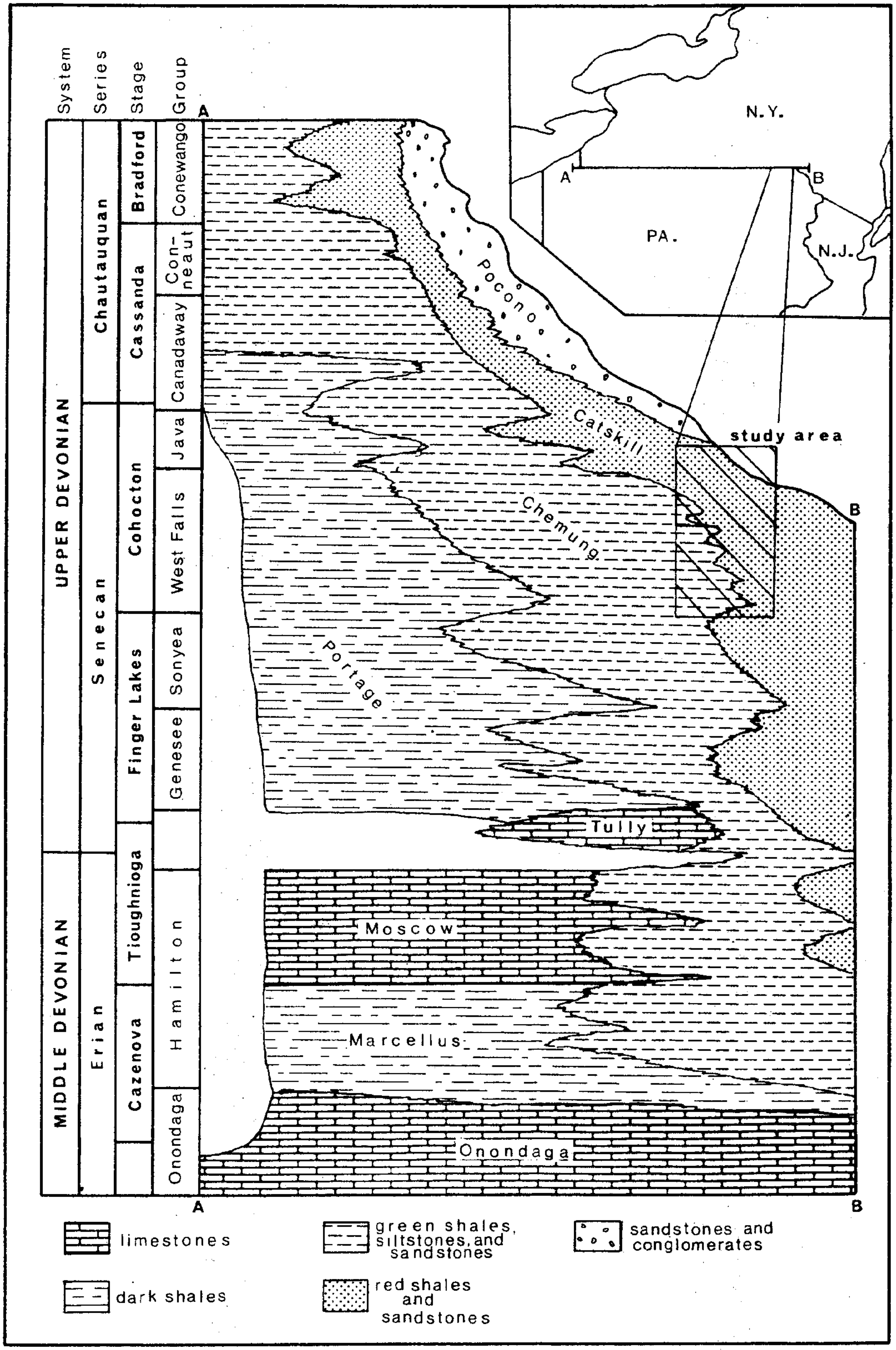


Figure 3. Facies correlation chart of the Middle and Upper Devonian rocks along the New Yprk-Pennsylvania border. (adapted from Rickard, 1964)

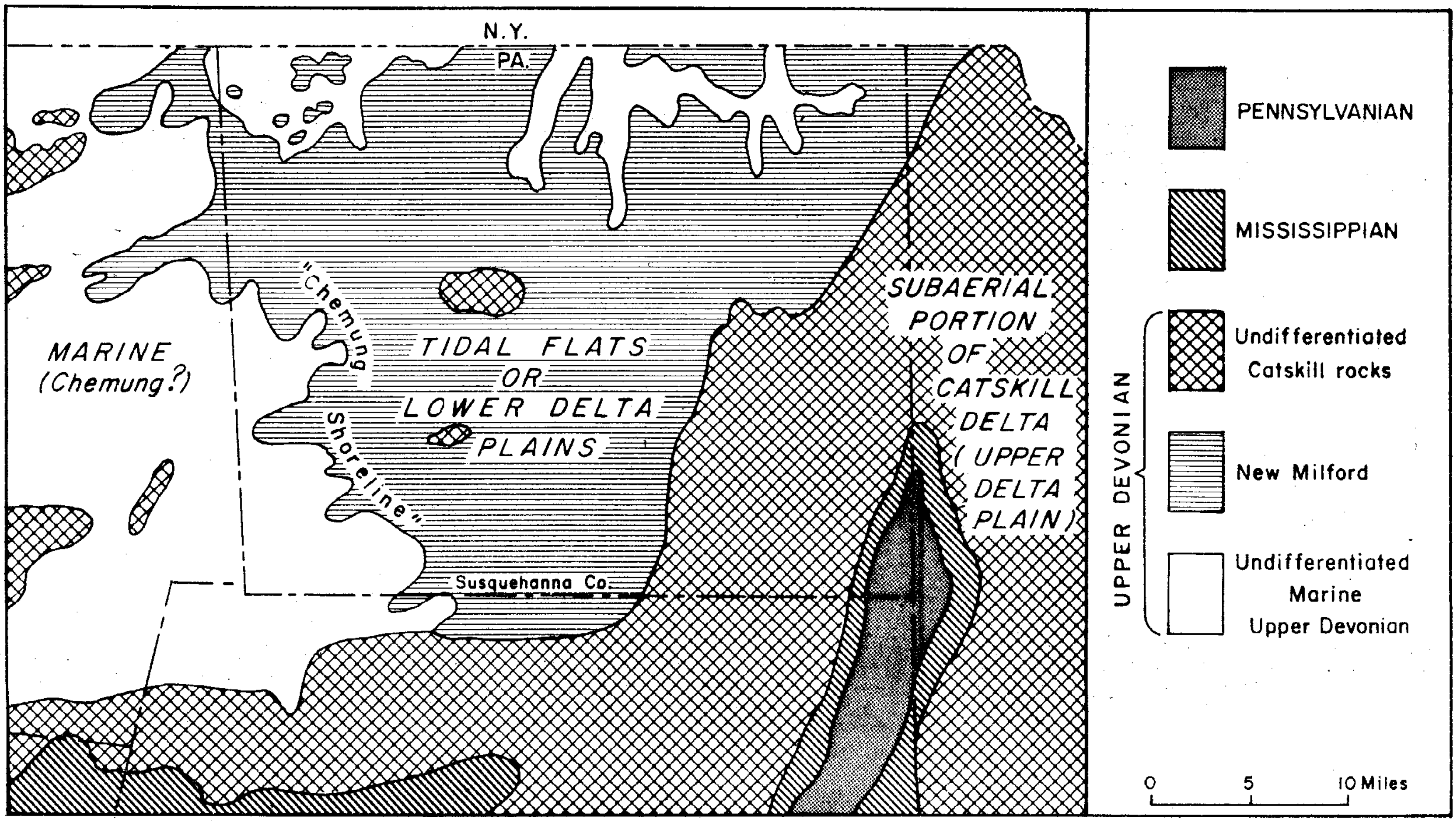


Figure 4. Geologic map of northeastern Pennsylvania to indicate the distribution of the three major Upper Devonian facies. Distribution of New Milford from Willard (1939).

rapidly in essentially a straight line so that it is experiencing very little, if any, turbulence. This is shown in Figure 5A. These flow conditions can only be produced under certain hydraulic conditions within specific enviornments. If these flow conditions are operating to a lesser degree, of if they are exceeded, the sediments will not be deposited in planar beds but in cross-beds that form as various types of ripples, Figure 5A.

The cross sections in Figure 6 indicate four hydraulic environments (or types) in which planar bedding and parting lineations can occur. These are:

Type 1 - on the tops of the offshore bars where incoming and outgoing tides rush across the bar.

Type 2 - on the swash zone of a beach where the waves are constantly washing over the sands.

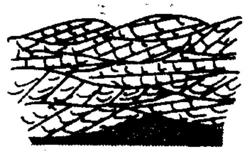
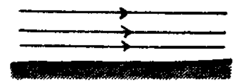
Type 3 - within large bars that form in intrachannel areas, either tidal or alluvial, where the rivers are experiencing abnormally high flow conditions.

Type 4 - as small planar parts of other bedforms within the channel.

The characteristics for the offshore bar can readily be seen in the cross section in Figure 6. Figure 5B and C are more detailed "idealized" cross sections of the channel and beach environments, and relate the specific rock unit's geometry and association with the surrounding units.

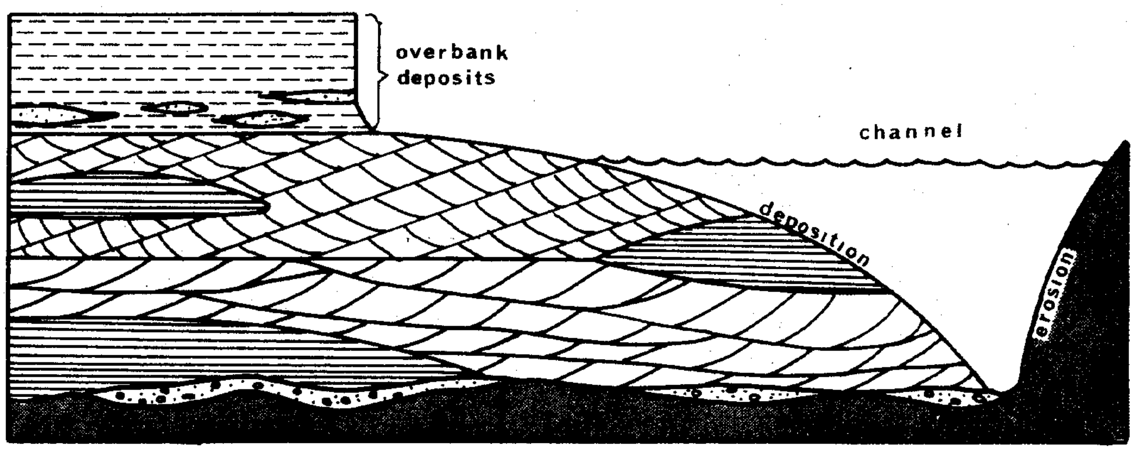
Since all of these types have planar bedding, the important differentiating characteristic between each of these areas will be their association with the surrounding units. The offshore bar, Type 1,

A. Summary of the hydraulic conditions that produce fossil bedforms.

Fossil Bedform			
Bedform Produced From	**small scale ripples**	**large scale ripples**	**plane beds**
Fluid Motion Over Bedform			
Flow Regime of Water Over Bedform	**low intensity lower flow regime**	**high intensity lower flow regime**	**upper flow regime**

(Allen, 1968)

B. CHANNEL MODEL



(Allen, 1970)

C. BEACH MODEL

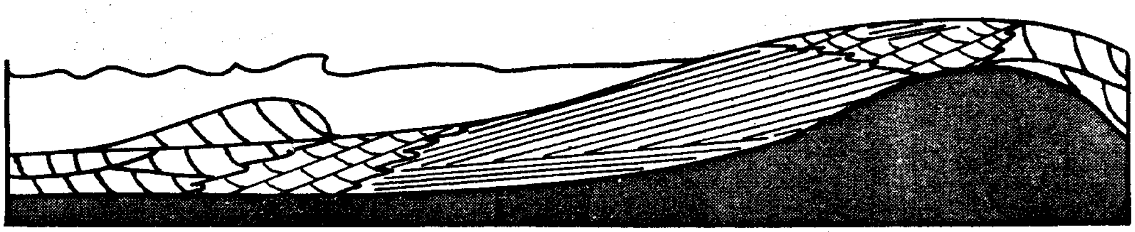


Figure 5. Summary of the hydraulic conditions that produce fossil bedforms and two models where these features can occur.

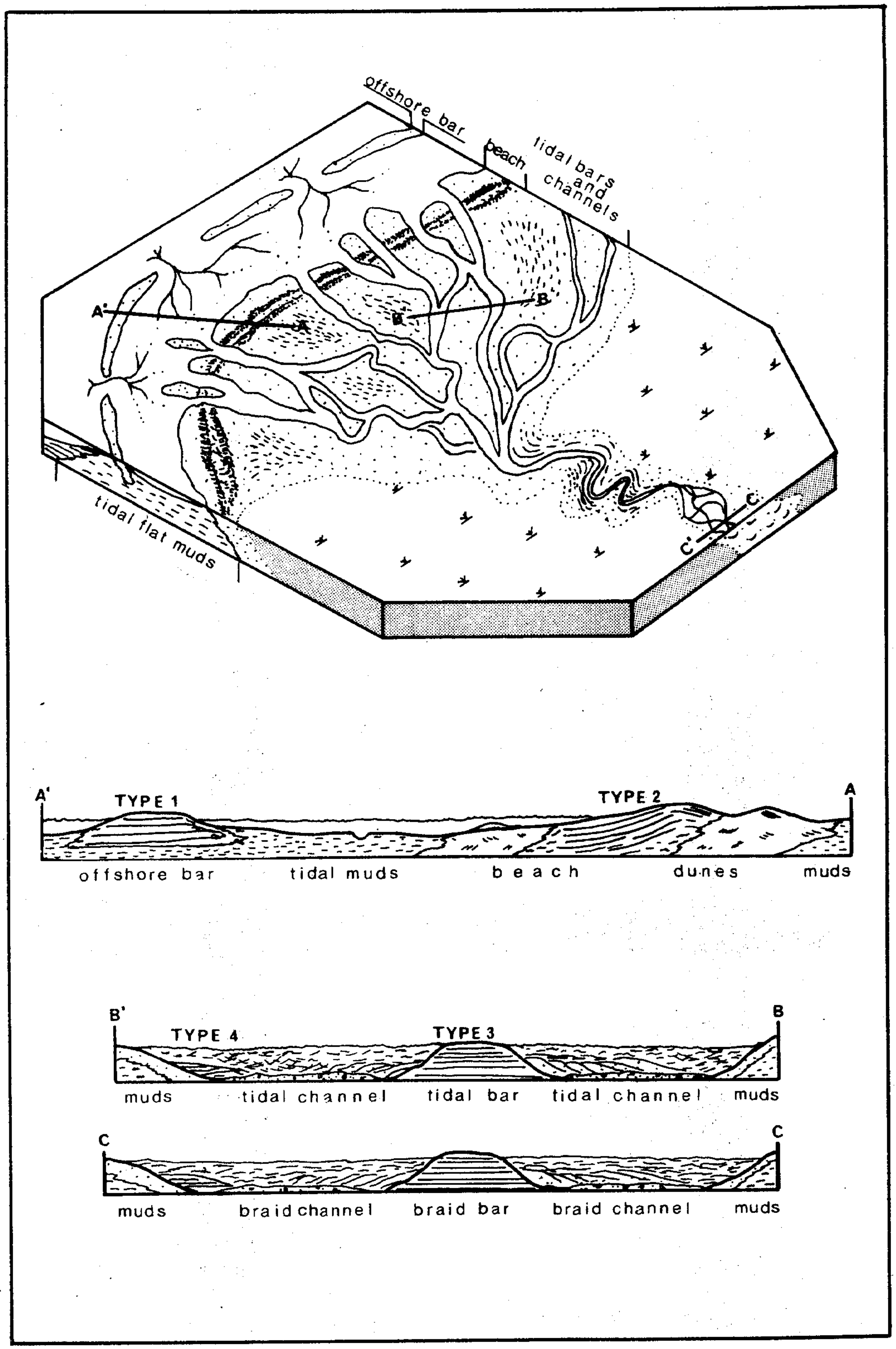


Figure 6. Paleogeographic model and cross sections illustrating the origin of flagstone.

will be surrounded by muds. The beach, or more specifically the swash zone, Type 2, will have cross-bedded sand features on its landward and seaward sides. These are produced respectively in the beach berm and in smaller offshore bars. The intrachannel bars, Type 3, will either be surrounded by other channel units such as the coarser channel bottom material and the large or small scale ripples, or/and be cut and eroded by the channel as it migrated.

It is these associations that have been fossilized and are observable in the flagstone quarries; and therefore, were used in the regional mapping of the flagstone producing area.

Figure 7 is a map and profile of a typical Type 1 - offshore bar - flagstone quarry (STOP 3 in Roadlog). Characteristics of this type of quarry include:

a) a convex upper surface;

b) parallelism of the parting lineation orientation and the down dip direction of the cross-bedding;

c) a steep front in the seaward direction;

d) replacement seaward (northwestward) by darker, fossiliferous, marine shales;

e) replacement landward (southeastward) by siltstones, small scale rippled sandstones, and red shales; and,

f) uniformness and regularity of the joint systems (the high walls of the quarry parallel the joint systems).

Two offshore bars are visible in the diagram, the larger lower one, and another smaller one in the south end of the quarry. The long direction, or paleogeographic trend, of these bars would be

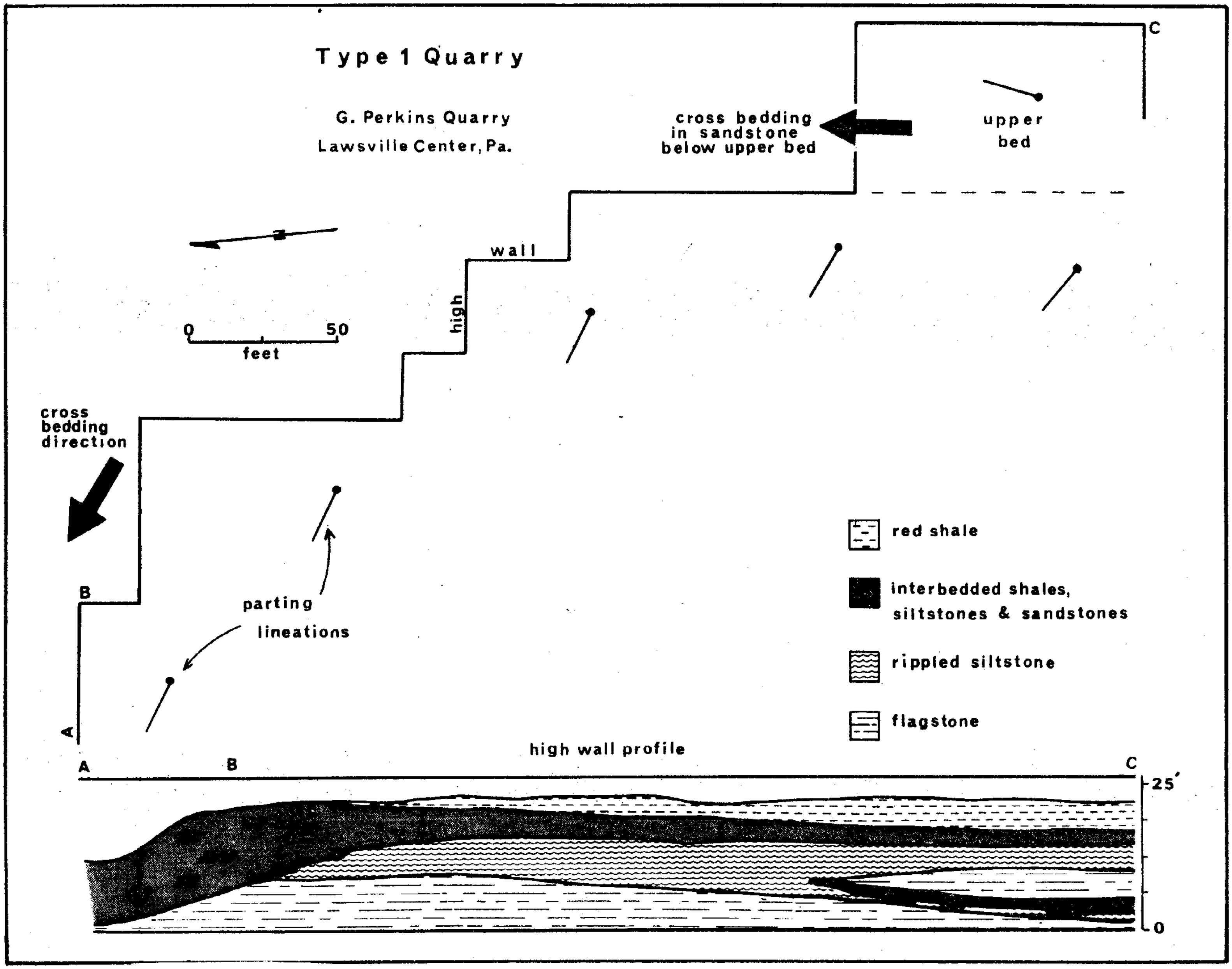


Figure 7. Plan view and profile of a typical Type 1 - offshore bar - flagstone quarry.

perpendicular to the parting lineation shown in the diagram, or northeast-southwest and east-west for respectively the lower and upper bars. The rock sequence represents a marine transgression onto the tidal flats and shore zone.

A map and profile of a Type 2 -beach- quarry is shown in Figure 8 (<u>STOP 4</u> in Roadlog). Typical characteristics of this type of quarry are:

a) a lensoidal cross section

b) complexly cross-bedded sandstones (bars) overlying the flagstone.

c) sub-parallelism of the parting lineation orientation direction and the cross-bedding in the overlying sand bars (Figure 9A).

d) that the deposits are inclined with the front (landward) being higher than the back (seaward).

e) worm burrowings in the tops of some of the overlying bars.

f) uniformness and regularity of the joint systems which the high walls parallel.

The beach, as shown in Figure 8, is orientated with its long direction, that is, its paleogeographic trend, in a north-south direction. The sequence of rocks exposed in the quarry represent a marine transgression of lower tidal-flat sand waves and bars over the beach.

Figure 10 represents a Type 3 -intrachannel bar- flagstone quarry two miles east of Auburn Center on Twp. Route 57102. Characteristics of this type of quarry include:

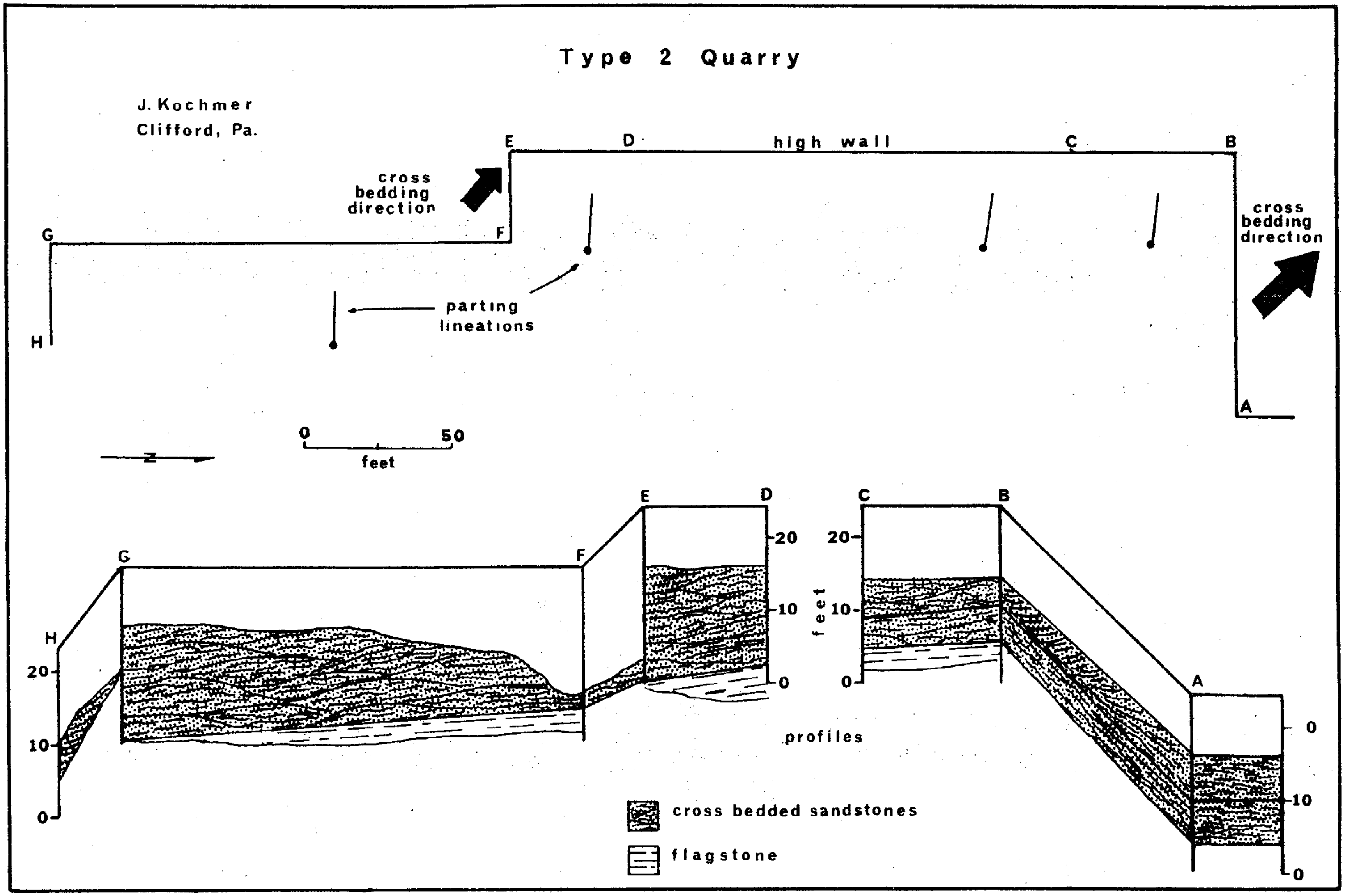


Figure 8. Plan view and profile of a typical Type 2 - beach - flagstone quarry.

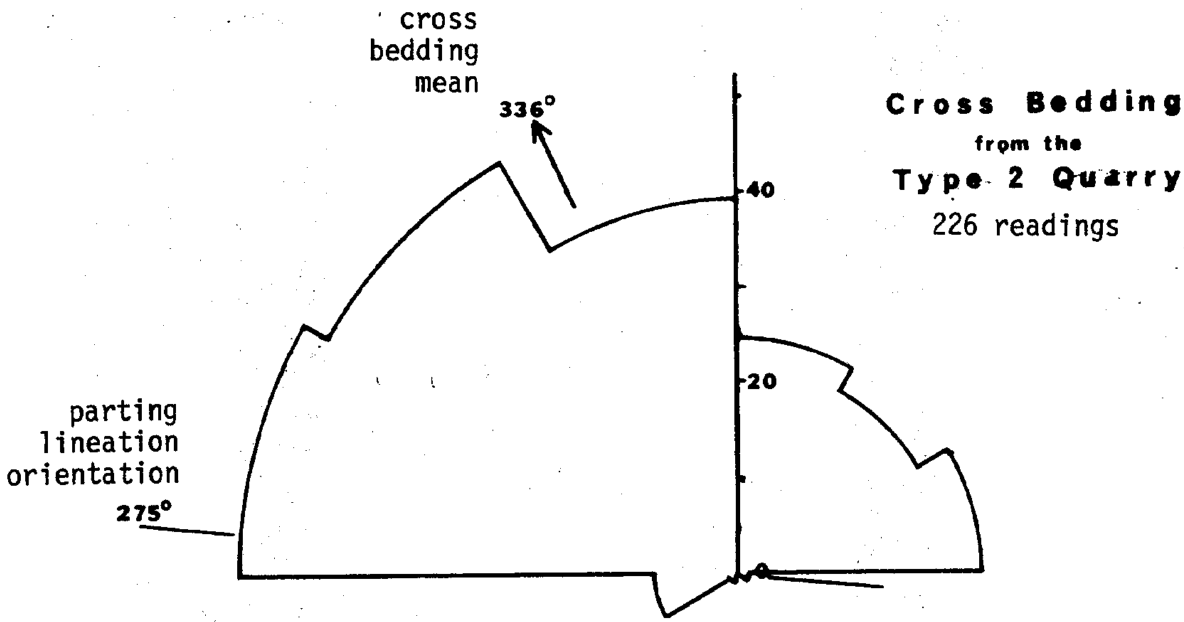


Figure 9A. Relationship between the cross-bedding direction frequency and the parting lineation orientation in the Type 2 quarry illustrated in Figure 8.

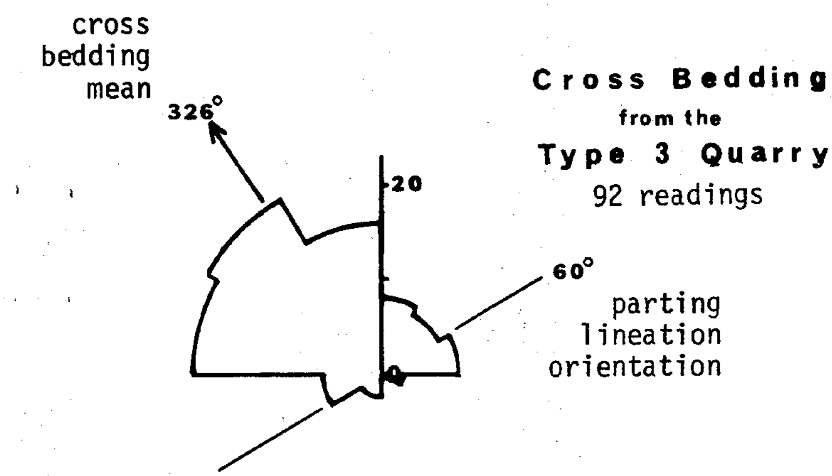


Figure 9B. Relationship between the cross-bedding direction frequency and the parting lineation orientation in the Type 3 quarry illustrated in Figure 10.

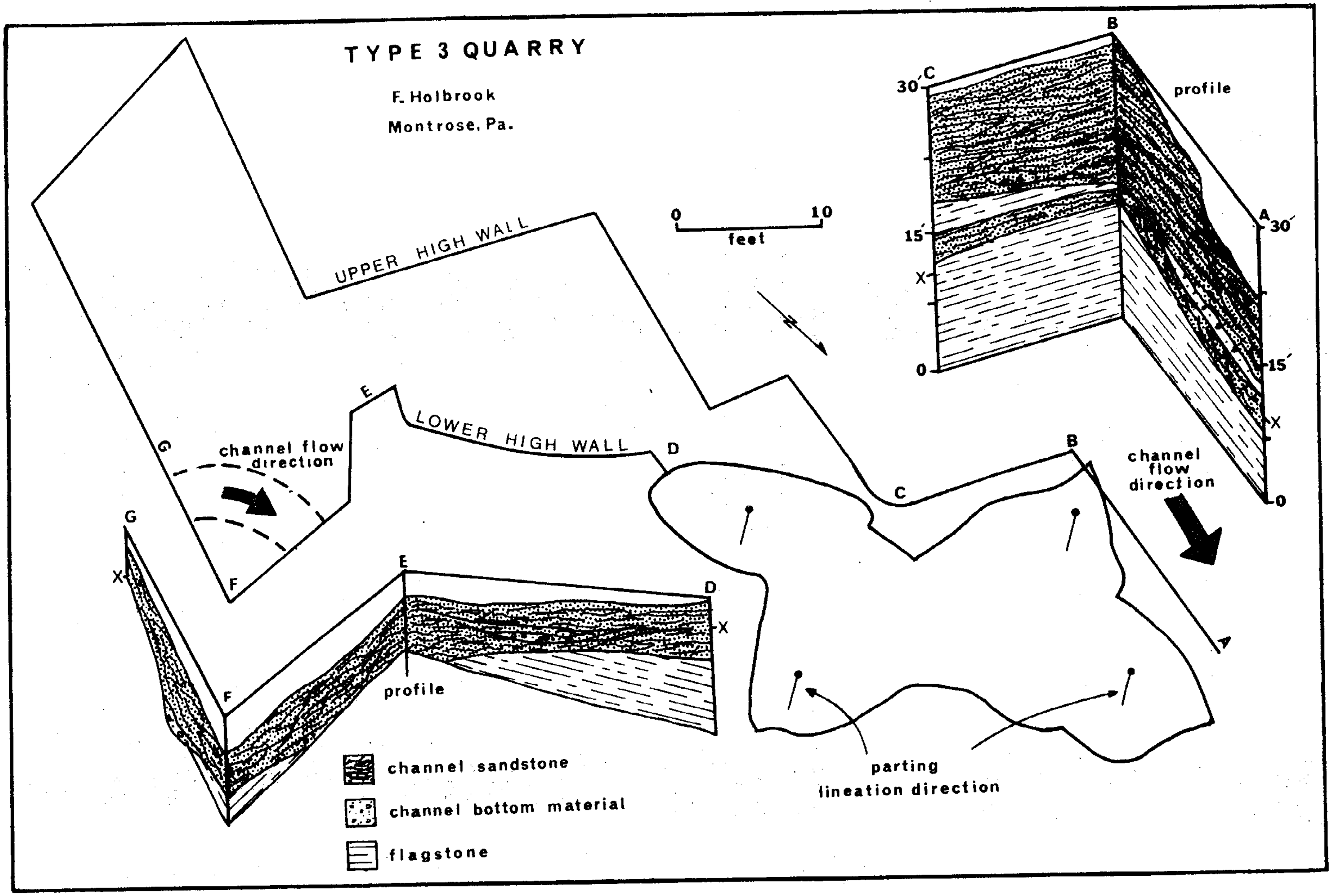


Figure 10. Plan view and profiles of a typical Type 3 - intrachannel bar - flagstone quarry.

a) a convex upper surface;

b) the overburden consisting of channel lag material, cross-bedded sandstones, and rippled siltstones as illustrated in Figure 5A;

c) the flagstone being cut (eroded) by the channels on either side;

d) the parting lineation orientation and cross-bedding direction are almost at right angles (Figure 9B);

e) some broken marine fossils found in the channel lag material, however the predominant fossils found in these quarries are plants; and

f) lack of uniformness or regularity in the joint system.

The intrachannel bar illustrated in Figure 10 is orientated with its upstream direction, or thickest part, to the south.

Figure 11 is a comparison of the geometries and internal morphologies of each of these deposits. (The drawing is not to scale.) Of the three types, the Type 2 will have the greatest volume and will be most likely to have the least internal and external variability. The Type 3 deposits will be the smallest in size and have the greatest internal and external variability. The Type 1 deposits will be intermediate in both characteristics.

The geographic distribution of the three quarry types should be as shown in Figure 6, that is, the Type 3, Type 2, and Type 1 sequence would be found in a landward to seaward traverse for any particular time plane during the Upper Devonian period. Unfortunately, individual time planes can not be traced across the producing area upon which the quarry

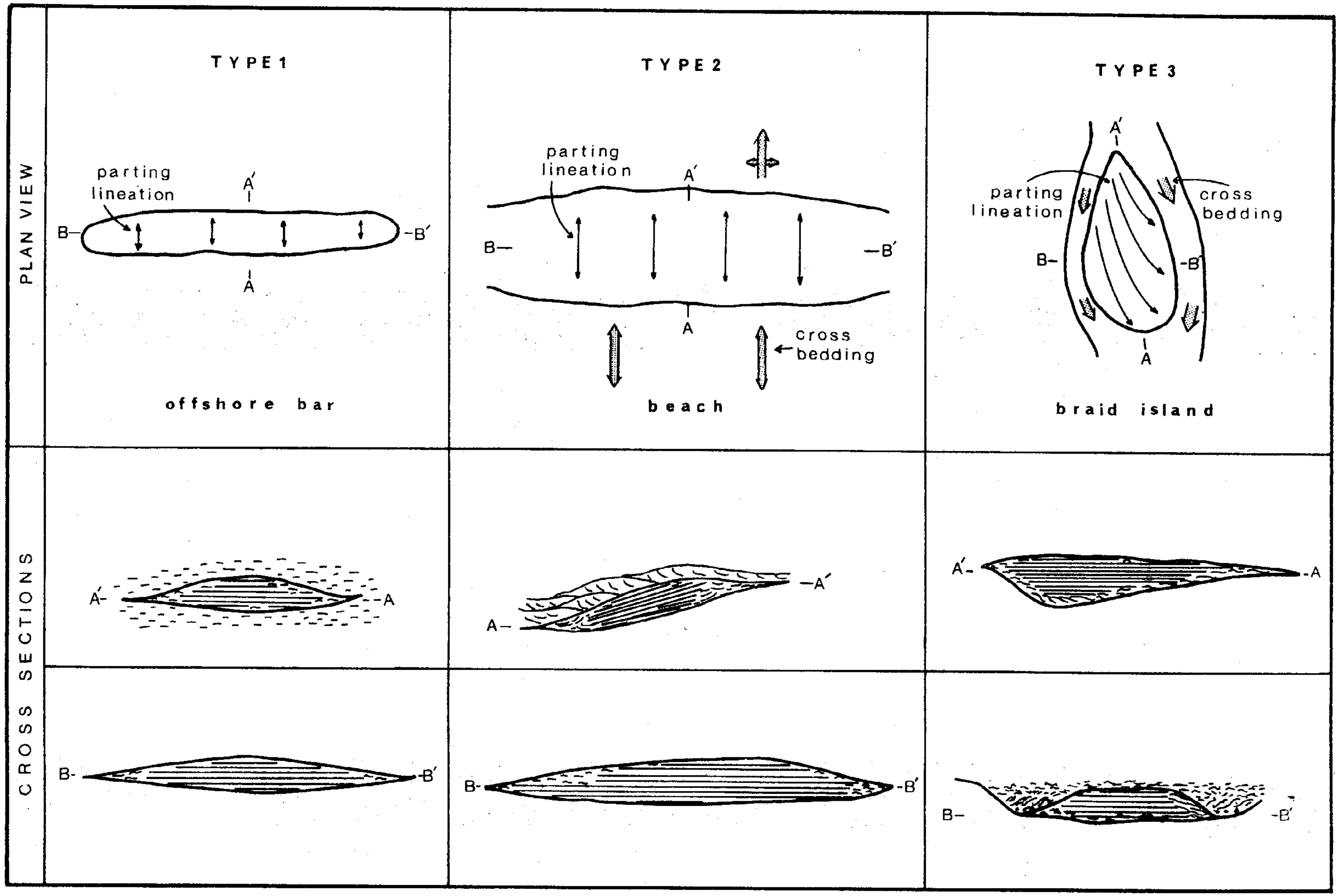


Figure 11. Summary of the external geometry, internal morphology, parting lineation orientation, and cross-bedding direction for the three types of flagstone quarries.

type distribution could be mapped; however, if the model, Figure 6, operated during all of Upper Devonian time throughout the producing region, areas should appear that have a preponderance of one particular quarry type.

QUARRY TYPE DISTRIBUTION

One hundred and sixty quarries were visited throughout the county and classified according to the three types to determine if a pattern did exist that would reflect the paleogeographic model. A grid was placed over this classification map and the number of each type of quarries within the grid was recorded.

If there was a preponderence of any one quarry type (more than 50 percent of one type) within the square, it was designated as being representative of that type of environment. Figure 12 illustrates the results of this analysis. Definite areas appear which have a concentration of a particular quarry type; therefore, it can be concluded that the respective environment prevailed within this area throughout most of Upper Devonian time. The regional, geographic pattern of this map presents the same geographic relationships, that is, intrachannel bar, beach, and offshore bar, along a westward traverse as that presented in the initial paleogeographic model, (Figure 6); and, essentially substantiates that initially presented by Willard, Figure 4. Figure 12, can therefore, be used as a probabilistic indicator of the type of flagstone quarry that might be expected if prospecting within a particular

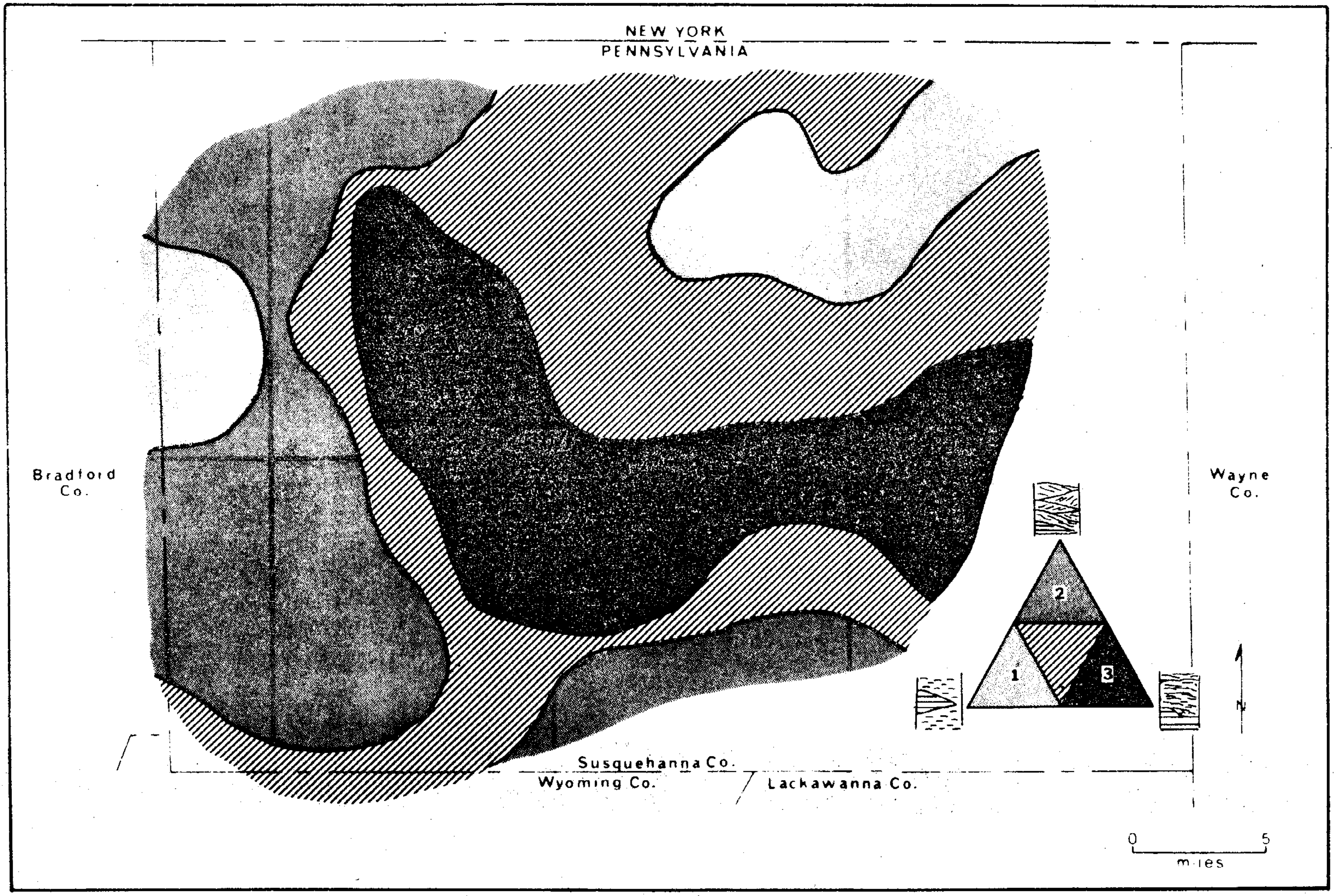


Figure 12. Moving average paleoenvironmental map of Susquehanna County based on the distribution of the three quarry types.

area. The center triangle, designating a mixed area, would represent an area of equal probability of finding any type of quarry.

Another test of this model is an analysis of the parting lineation directions. Since this feature is a result of the long axes alignment of the individual grains by the transporting currents, its direction, when combined with the down-dip inclination direction of the cross bedding, can be used as an indicator of the flow direction of the paleo-currents. These latter directions are referred to as directional parting lineations. Figure 13 indicates the distribution and mean direction for both directionl, and non-directional parting lineations for each of the three quarry types and their combined totals. The individual directional readings were summarized into a moving average map, as was made for the quarry type distribution map, and is presented in Figure 14. A frequency diagram was also made from these readings and a mean was calculated. This direction, 278°, is the paleoslope direction or general direction in which the Upper Devonian rivers were flowing. Also, it is the direction of the migration of the early Chemung shoreline which resulted in the stratigraphic rise of the Chemung-Catskill facies contact.

QUARRY DISTRIBUTION

A total of 811 flagstone quarries were located within the 836 square mile area of Susquehanna County. All of these quarries are not presently active but represent flagstone mining since the late 1880's.

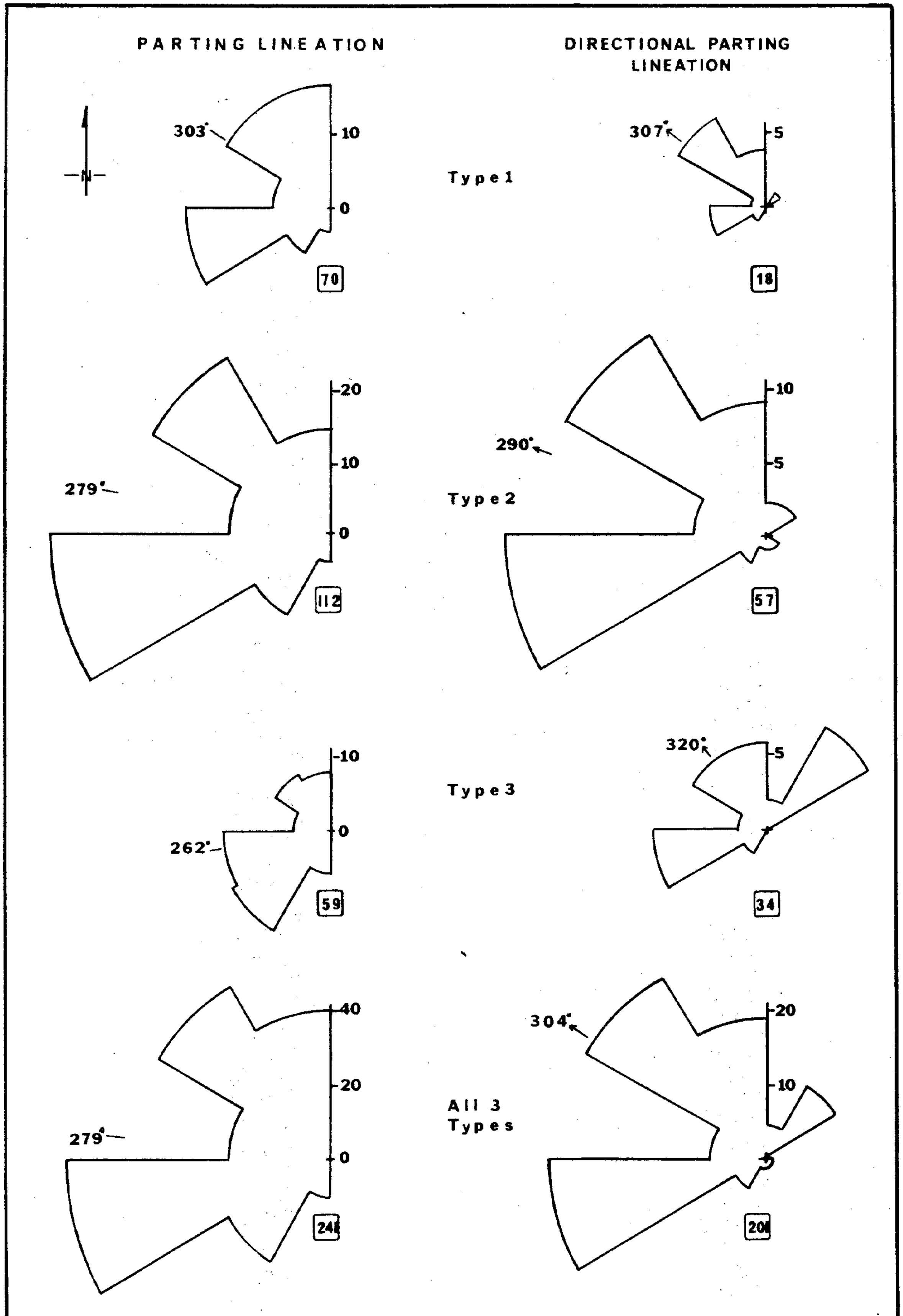


Figure 13. Distribution of nondirectional and directional parting lineations for each of the three quarry types and for all three types combined.

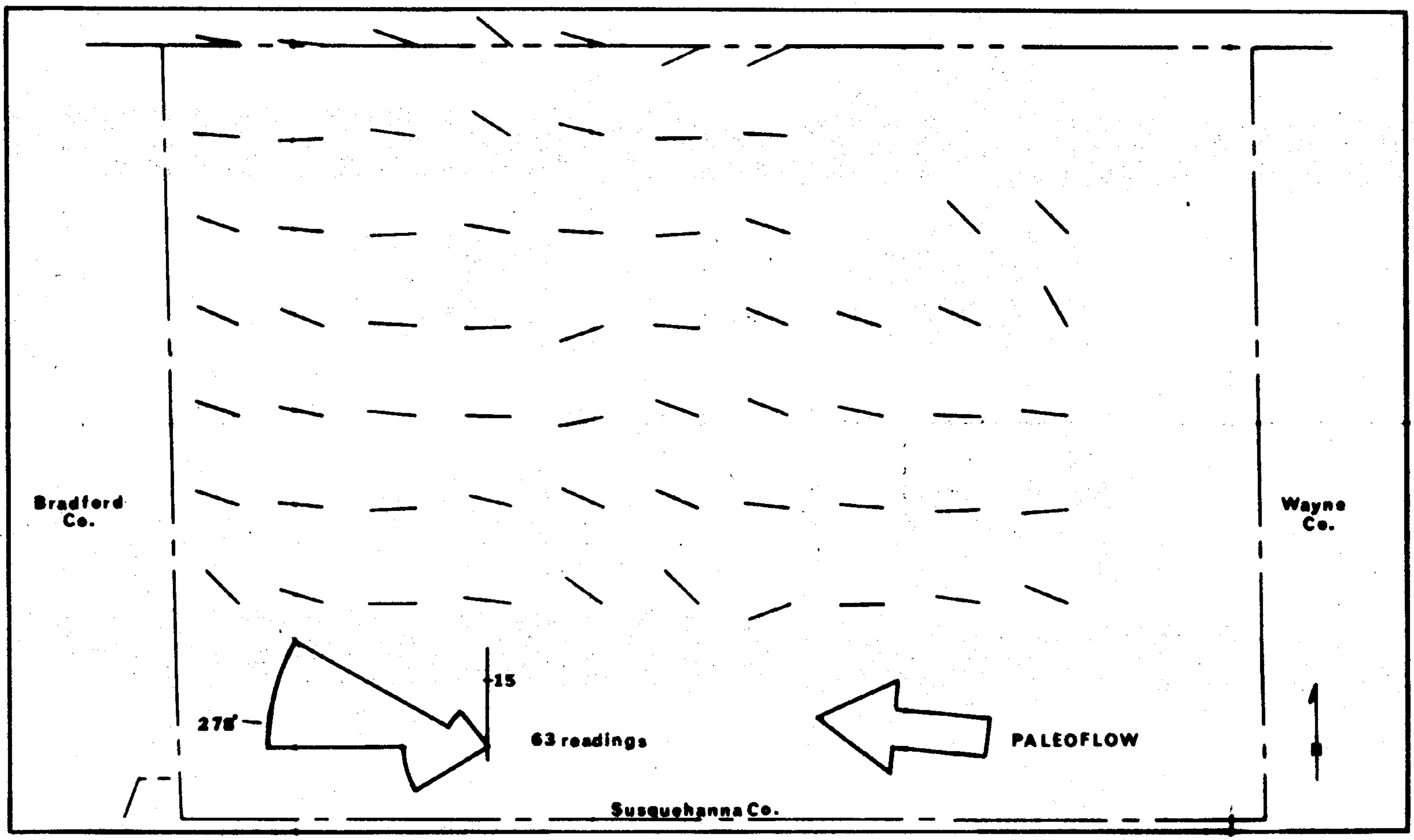


Figure 14. Moving average map of the directional parting lineations in Susquehanna County, Pennsylvania.

Using this map, prospecting techniques were developed similar to those which could be made using the paleoenvironmental map, Figure 12.

Figure 15 is a moving average quarry density map. Three conclusions may be drawn from this diagram:

a) definite high and low density areas appear.

b) A general trend from high density to low density occurs radially respectively from the east to west.

c) The pattern that develops more or less approximates that shown in the paleoenvironmental map, Figure 12, with the higher density areas occurring within the mixed quarry areas.

The elevation of each of the quarries was also noted and analyzed as was done for the density map. Figure 16 is an isopach map of the elevational interval over which the quarry distribution occurs. The same conclusiosn reached above can be drawn from this map, with the most important being that the greater intervals correspond to the mixed quarry areas of Figure 12.

The general decrease in the density of quarries and in interval thickness within the Type 3 - fluvial - area is probably due to the eroding and migrating character of the fluvial system operating in this area.

Since the same intersection points were used for both of the above maps, a graph of the thickness of the flagstone producing interval plotted against the number of quarries within the interval was constructed. Figure 17 is this graph. A direct relationship occurs between these two variables, that is, as the thickness interval increases so does

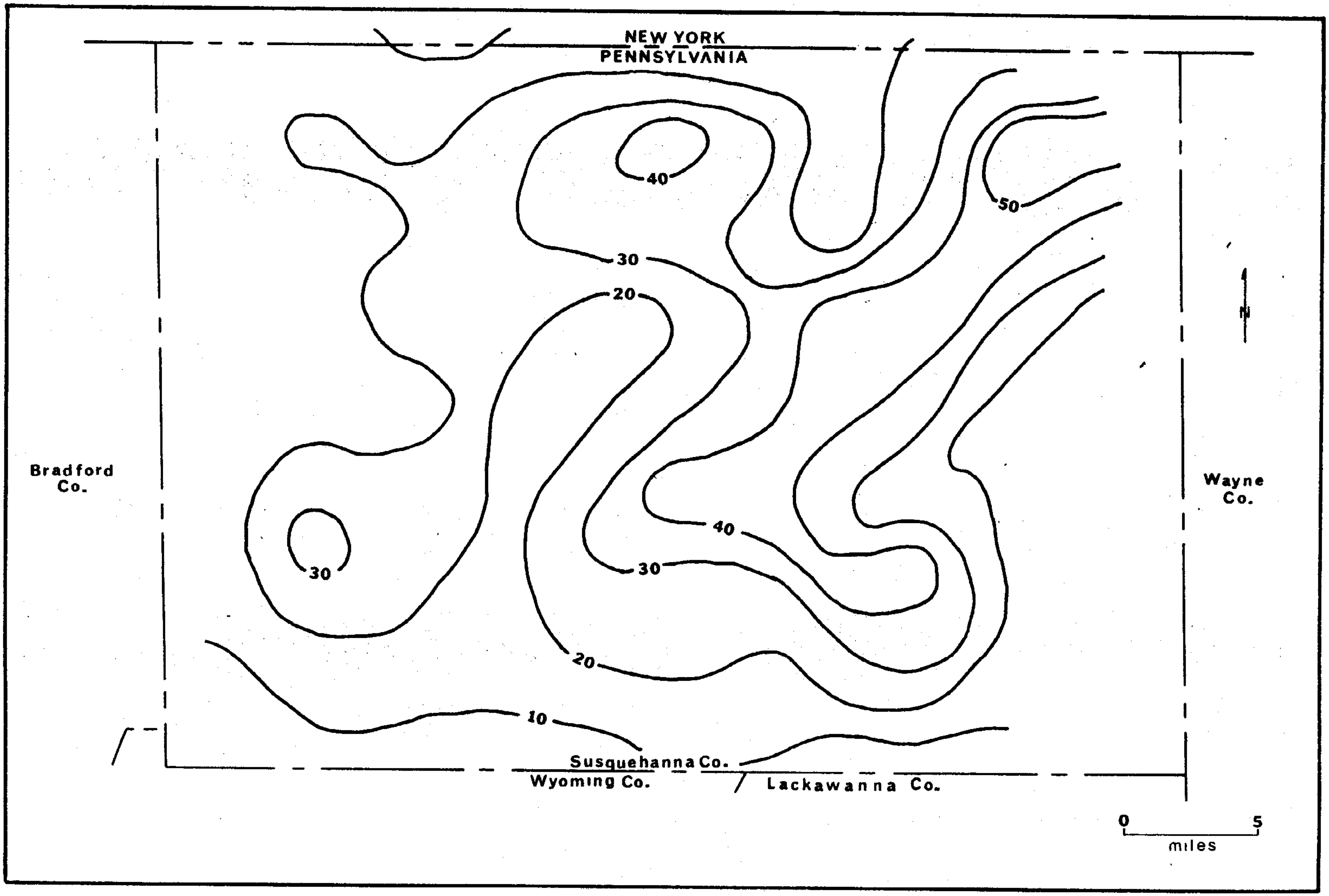


Figure 15. Flagstone quarry density map of Susquehanna County, Pennsylvania.

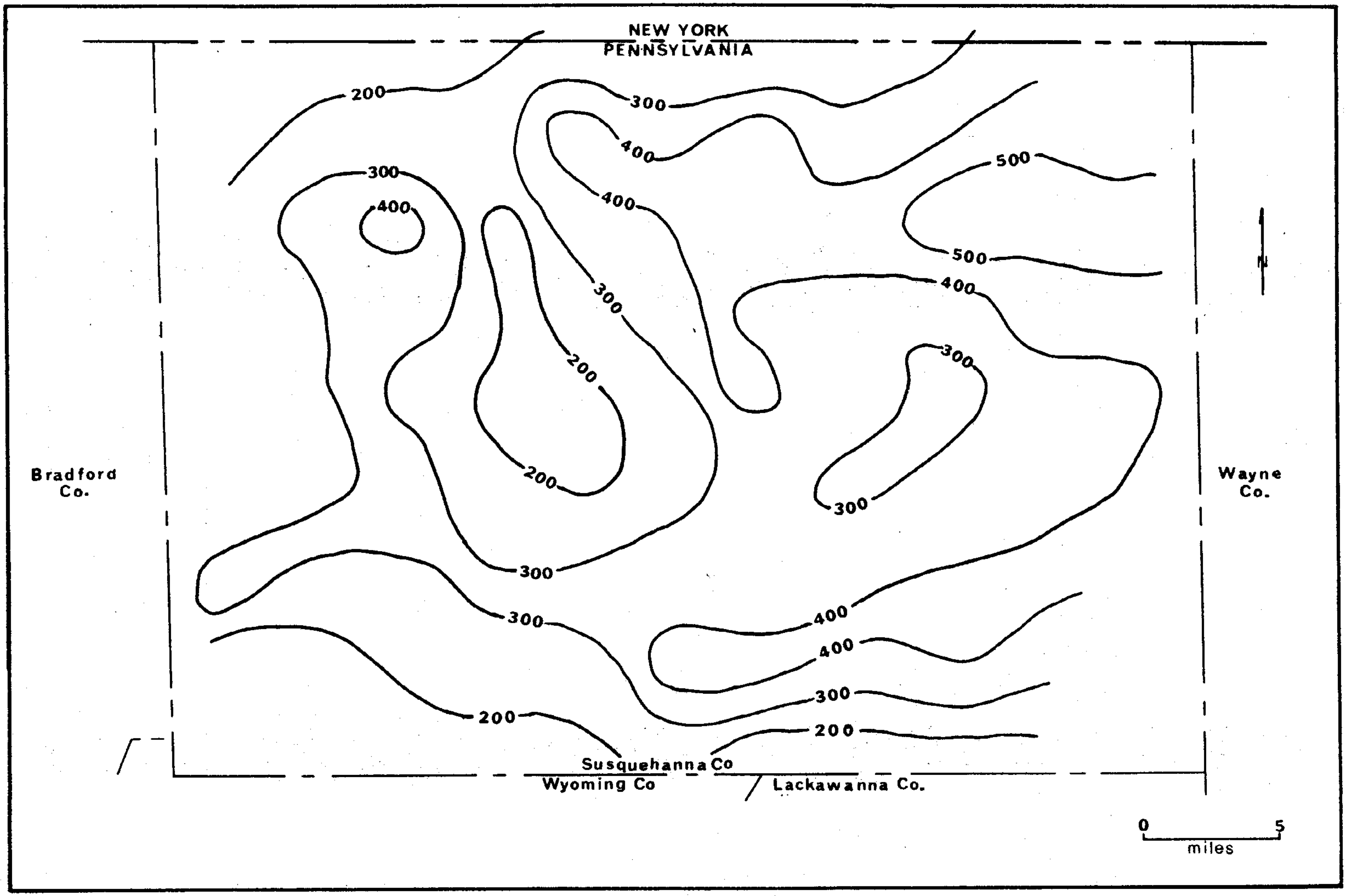


Figure 16. Isopach map of the elevational interval over which the flagstone quarries occur.

the number of quarries within the total interval (The number of quarries within a given unit interval, however, was essentially the same). This relationship can be used to predict the number of quarries that would be expected within a given elevation interval. The initial measured intervals were then looked at again to see how the actual number of quarries occurring within the interval compared with that which might be expected for that quarry interval. The differences between these two values were assigned to each of the respective grid intersection points and then contoured, Figure 18. This map is an isopotential map delineating areas that have a higher number of quarries (high positive values) than expected within the elevational interval, and areas with a lesser number of quarries (high negative values) than expected. When comparing this figure to the paleoenvironmental map, Figure 12, it can be seen that approximately 80 to 90 percent of the areas designated as Type 3 and mixed areas fall within, or above, the zero isopotential line. Thus, the results of these maps, Figure 15, 16 and 18, would tend to indicate that the best area to prospect for a quarry would be in the mixed areas on Figure 12, the paleoenvironmental map, since this area has the greatest number of quarries occurring over the greatest interval.

The locations of most of the quarries, 475, used in constructing the quarry density map were obtained from the Interim Soil Survey Report - Volume II for Susquehanna County, Pennsylvania, published by the United States Department of Agriculture in 1969. This report

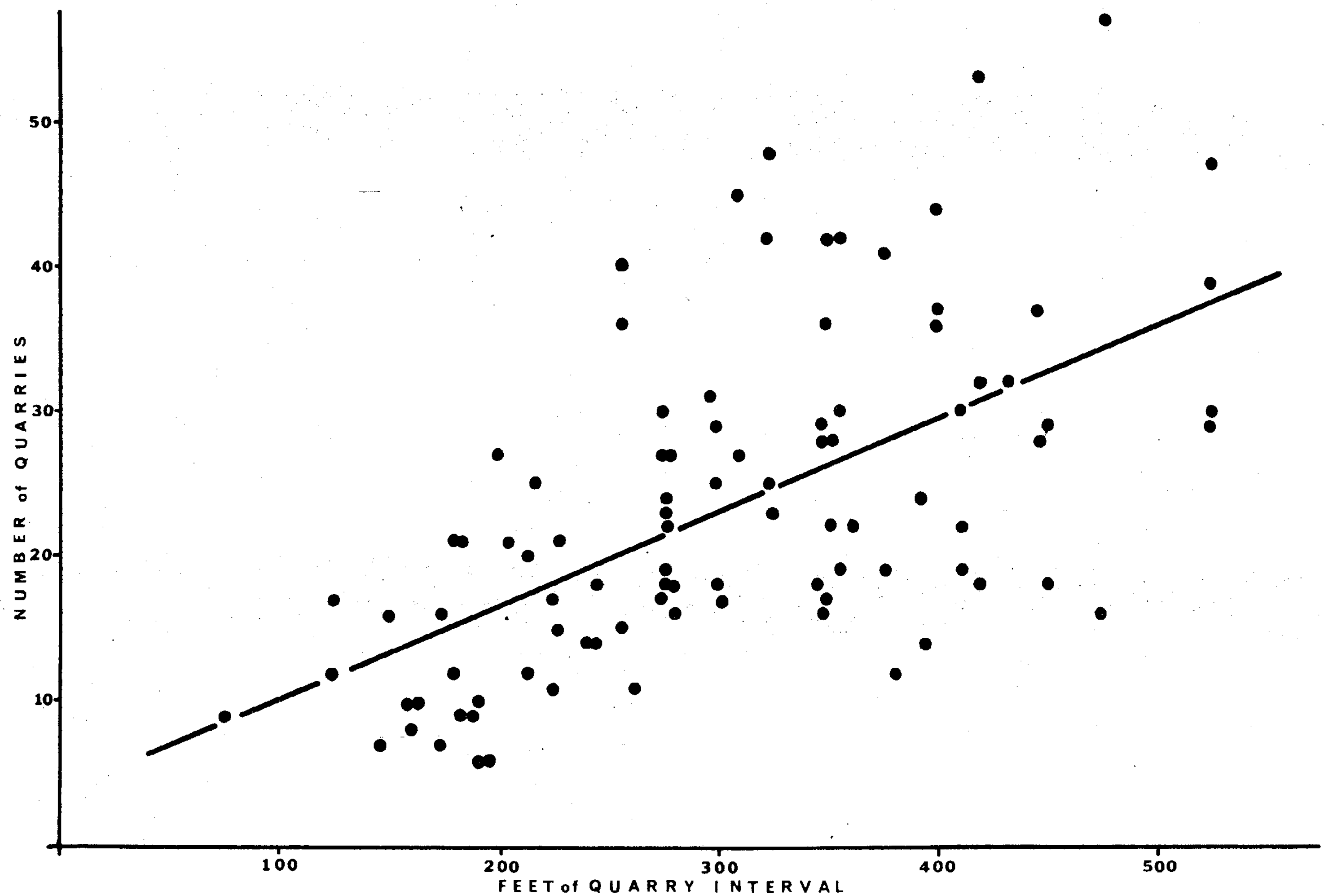


Figure 17. Graph of the number of flagstone quarries versus the elevational interval over which they occur.

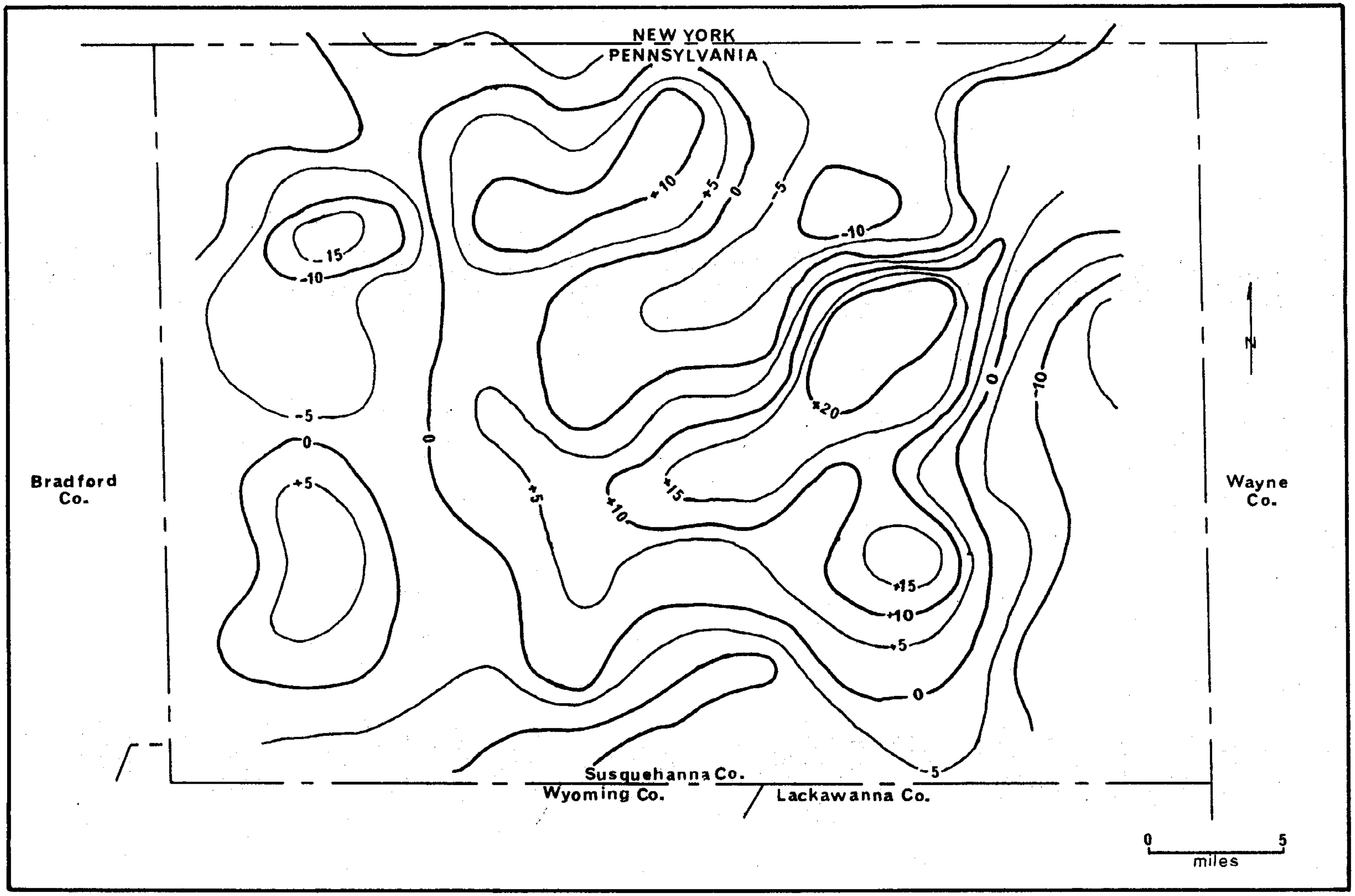


Figure 18. Isopotential map for locating a quarry in Susquehanna County, Pennsylvania.

consisted of a series of aerial photographs at the scale of 1 foot = 1320 feet for all of Susquehanna County. The distribution of the soil types and 475 quarry sites are plotted on these photographs. Figure 19 is one of the aerial photographs (number 60-46) used in this report.

An analysis of these photographs was made to determine if the quarries were occurring upon a particular type of soil within the county so that another prospecting technique might be developed.

Table 1 lists the nineteen soil types and their mapped acreage within Susquehanna County. Figure 20 is a block diagram illustrating where some of these soil types occur upon the mountain sides within the county.

The classification of the soil types is based upon the type of parent material from which the soil develops, and upon the drainage development within the soil. Table 2 summarizes the characteristics producing the various soil types found within the county. Each of the major soil series can be subdivided into submembers on the basis of variations in the grain size of the material in the soil, and the slope upon which the soil occurs.

Of the 475 quarries located on the aerial photographs, 448, or 94.3 percent, were on one particular soil series, the Lordstown Series; also shown are the number of quarries occurring upon each submember, and, on the other soil series. To further check this relationship, one hundred quarries that were located independently of the aerial photo-

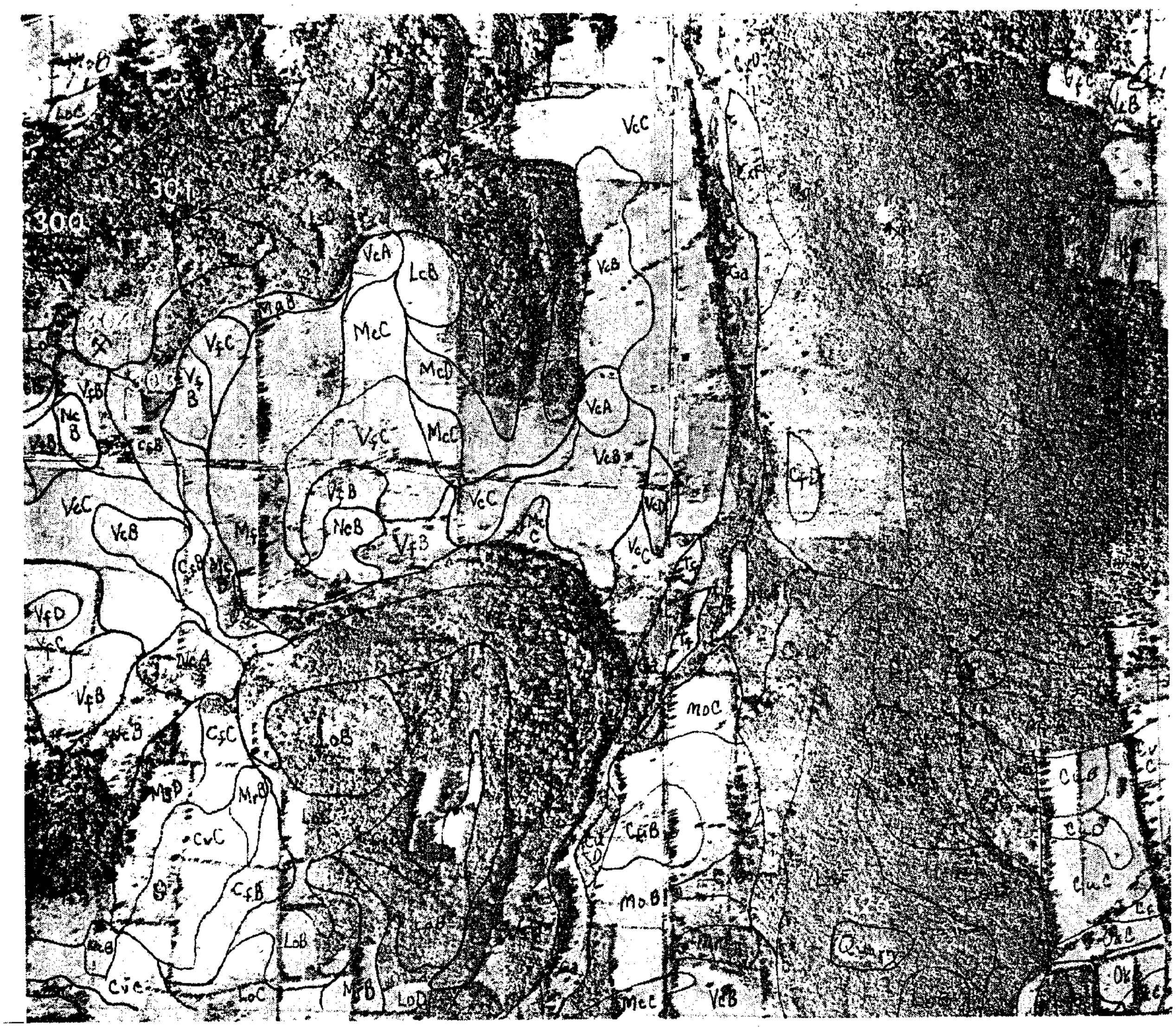


Figure 19. Aerial photograph from the Interim Soil Survey Report, Volume II, for Susquehanna County, Pennsylvania. (The first letter of the various mapped areas designates the soil series; therefore, the areas of Lordstown Soil are those areas that have a map symbol beginning with a L. Note that all six of the flagstone quarries lies on the Lordstown Soil and that five of the six are on the Very Stony Submember, areas beginning with Ls. The photograph can be located by comparing the quarry reference numbers with those on Plate I.)

graphs were plotted on the photographs, and the type of soil upon which they occurred noted. Of these one hundred quarries, 97 percent of the, Table 3, were located upon the Lordstown Soil. It should also be noted that most of the quarries, 72 percent, were located on the Very Stony submember of the Lordstown Soil.

Since the Lordstown Soil Series covers only 27.5 percent of the area of the county, Table 1, it provides another valuable prospecting technique for the quarrymen. The areas mapped as Lordstown Soil within Susquehanna County were plotted on a topographic map of the county and can be found as Plate II in Krajewski, 1971.

TABLE 1.

Soil Types and Mapped Acreage of Each in Susquehanna County

Soil Type	Mapped Acres		
Barbour Series	2,037	Moris Series	73,541
Bath Series	19,201	Norwich Series	5,255
Chenango Series	9,157	Peat	1,324
Cut and Fill	1,813	Terrace Escarpments	497
Holly Series	2,767	Undadilla Series	1,532
Lackawanna Series	21,679	Volusia Series	86,293
Lordstown Series	147,308	Wellsboro Series	74,077
Mardin Series	74,363	Wyalusing Series	6,854
Mixed Alluvial Land	4,873	Total	535,040

PETROLOGY AND PHYSICAL PROPERTIES

A detailed analysis of samples collected from several flagstone quarries was conducted to determine their mineralogic composition, textural characteristics, and physical properties, Table 4.

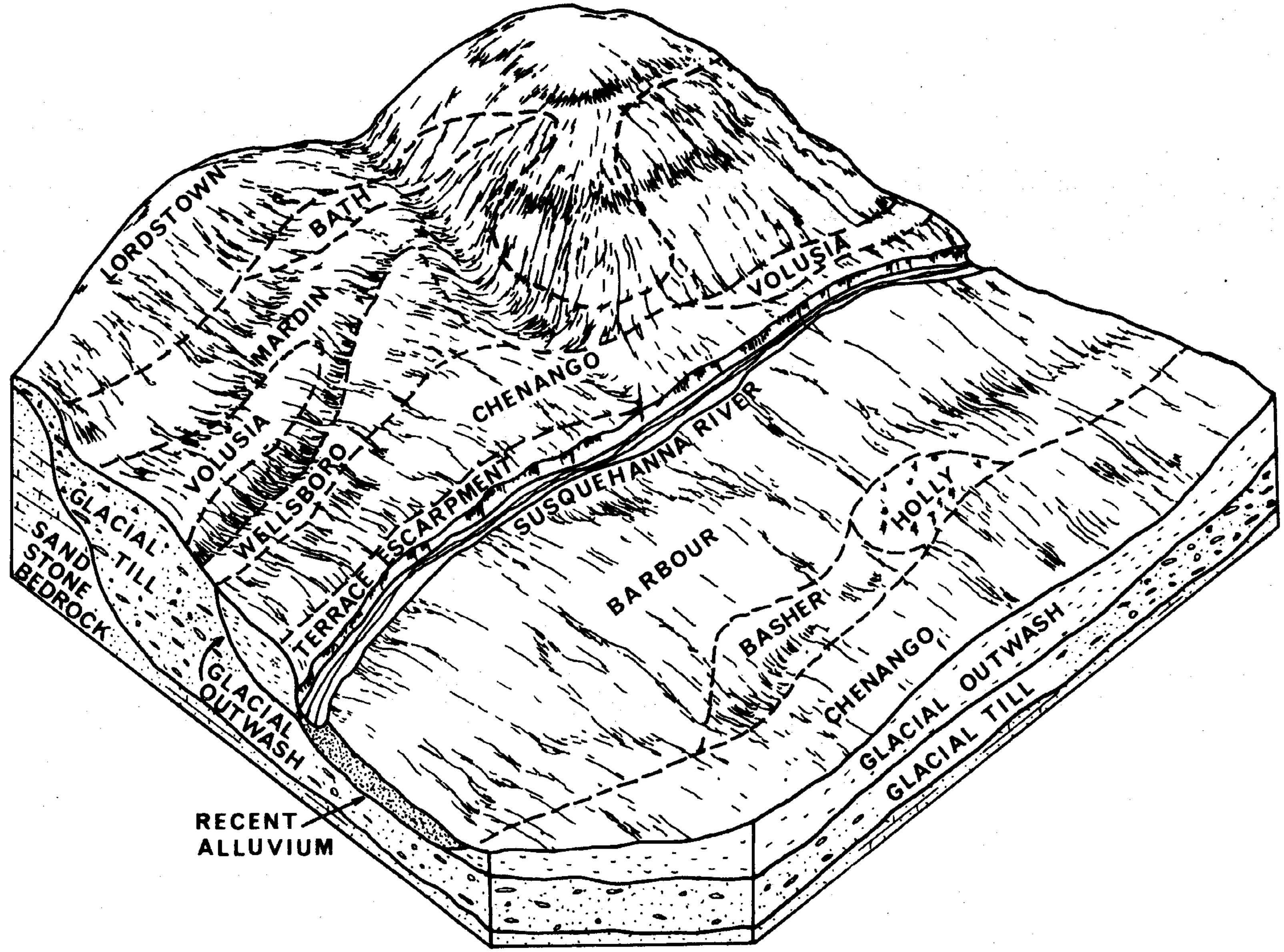


Figure 20. Typical landscape in Susquehanna County showing the relationship between parent material and the pattern of soil development. (adapted from the forthcoming final soil survey report for Susquehanna County)

TABLE 2. Summary of Characteristics Producing the Soil Types in Susquehanna County

Position	Parent Material	Well Drained: bedrock depth: shallow	Well Drained: bedrock depth: moderate	Well Drained: deep	Moderately Well Drained	Poorly Drained: somewhat	Poorly Drained: moderately	Poorly Drained: very poorly
Uplands	Gray and red sandstones, siltstones, and shales (no glacial cover)	Lordstown	--------)					
Uplands	Gray and red sandstones, siltstones, and shales (glacial cover)			Bath	Mardin	Volusia	--------)	Norwich
Uplands	Red shale and some sandstone (thin glacial cover)	Oquaga	-----------)	Lackawanna	Wellsboro	Morris	--------)	Norwich
Terrace	Flaciofluvial material			Chenango & Unadilla				
Floodplain	Mixed glacial material		(-------	Barbour	Basher	-------)	(-------Holly	
Floodplain	Alluvium from bedrock						(-------Holly	

TABLE 3. Quarry Distribution on Lordstown and Other Soil Series

	Soil Type	Slope %	Acres Mapped	Quarries Located on Aerial Photographs (number)	Distribution of Additional 100 Quarries	Total Number of Quarries	Acre/ Quarries
LORDSTOWN SERIES	channery silt loam	3-12	8,795	16	5	21	419
	channery silt loam	12-20	5,491	7	7	14	392
	channery silt loam	20-30	1,729	2	4	6	288
	flaggy silt loam	3-12	10,845	41	3	44	246
	flaggy silt loam	12-20	9,510	20	4	24	396
	flaggy silt loam	20-30	6,300	20	10	30	210
	very stony silt loam	0-12	20,860	73	10	83	251
	very stony silt loam	12-30	46,648	172	35	208	224
	very stony silt loam	30-70	37,130	105	19	124	299
	Other Series	0-60	387,732	27	3	30	1,292
		Totals	535,040	475	100	575	931

Twenty-six samples of flagstone were collected from quarries in Susquehanna (24 quarries), Lackawanna (1 quarry) and Wyoming (1 quarry) Counties. The number of samples from each of the quarry types was as follows: ten from Type 1 - offshore bar - quarries; seven from Type 2 - beach - quarries; and, nine from Type 3 - intra-channel bars - quarries. Figure 21 is a location map of the sampled quarries.

Tables 5, 6 and 7 summarize the results of the compositional, textural and physical property analyses. Table 8 shows how flagstone samples from the three quarry types are ranked using this data.

TABLE 4

Petrographic and Physical Properties

I. Petrographic Properties

   A. Mineralogic Composition

      1. Total Grains
         a) quartz
         b) r. fragments
         c) feldspar
         d) mica

      2. Matrix

      3. Total Cement
         a) quartz
         b) carbonate

      4. Opaques

   B. Texture

      1. Grain Size
         a) long axis mode
         b) long axis mean
         c) short axis mean
         d) long axis skewness
         e) long axis kurtosis
      2. Grain Sorting
      3. Grain Shape

   C. Color

II. Physical Properties

   A. Bulk Specific Gravity

   B. Apparent Specific Gravity

   C. Percentage Water Absorption

   D. Permeability

   E. Durability
      a) percentage weight loss in sodium sulfate soundness test
      b) disintegration index

   F. Number of Laminations

   G. Tensile Strength

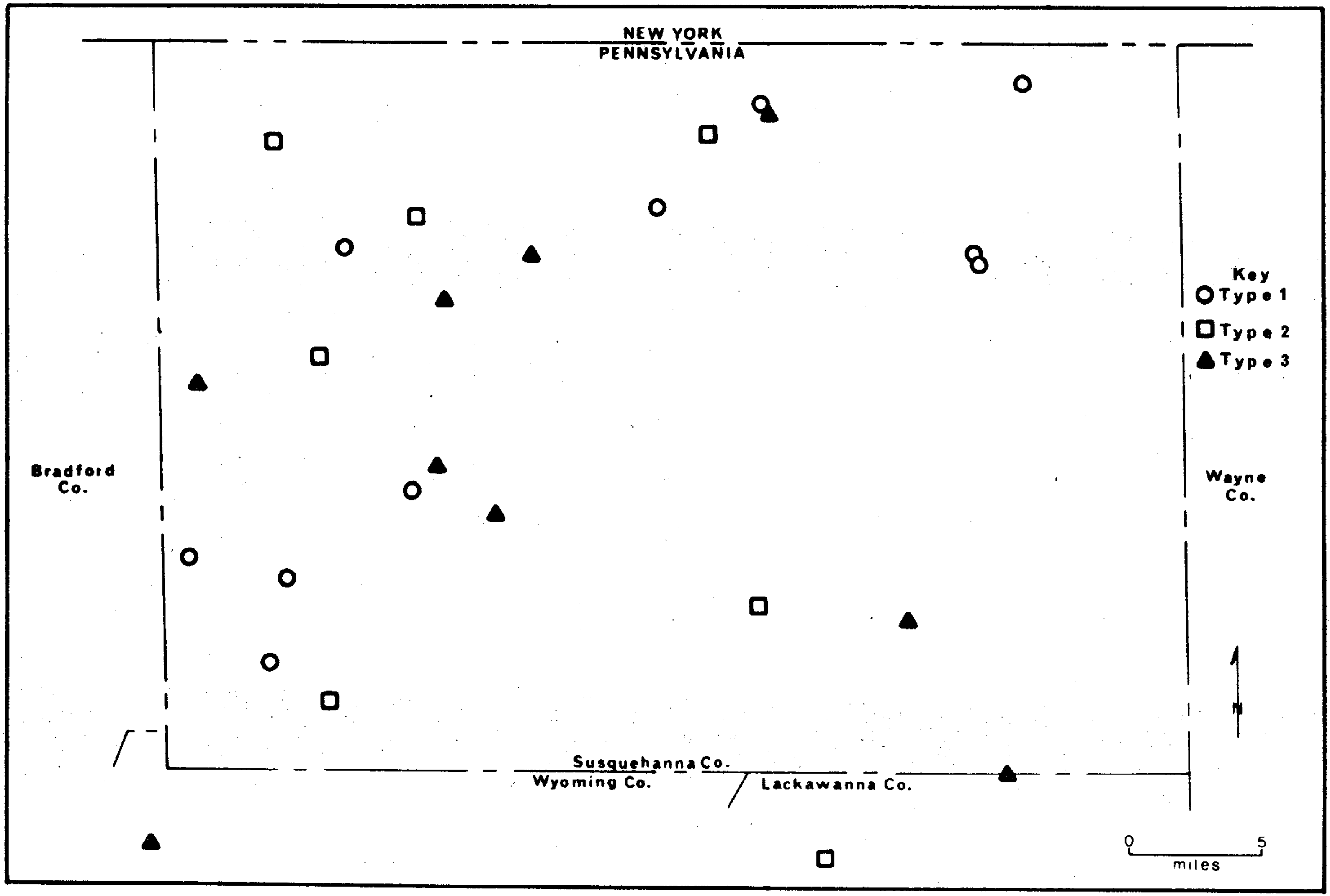


Figure 21. Location of the twenty-six flagstone quarries sampled.

QUARRY TYPE		PARAMETERS									
		GRAINS					MATRIX	CEMENT			OPAQUES
		Total Grains	Quartz	Rock Fragments	Mica	Feldspar		Total Cement	Quartz	Calcium Carbonate	
Total	$\bar{X}$	65.2	34.9	22.9	3.8	3.5	22.1	11.8	9.4	2.4	1.8
	σ	9.7	5.83	6.01	1.31	2.00	10.60	3.31	2.02	3.49	2.38
Type 1	$\bar{X}$	60.5	31.5	22.1	3.8	3.1	26.7	10.2	8.7	1.5	2.6
	σ	5.25	6.22	6.21	1.09	1.43	6.4	2.68	1.86	2.24	3.52
Type 2	$\bar{X}$	74.9	38.5	26.5	4.2	5.1	14.1	13.3	9.1	4.2	1.2
	σ	3.44	2.39	4.60	1.30	1.64	5.26	3.81	1.85	4.86	1.53
Type 3	$\bar{X}$	62.8	35.9	21.0	2.66	3.40	23.3	12.5	10.3	2.1	1.5
	σ	11.77	5.61	6.11	2.19	1.57	14.18	3.18	2.18	3.30	0.89

Type 1 = Offshore Bar   Type 2 = Beach   Type 3 = Intrachannel Bar

TABLE 5. Means for the Compositional Data from the Three Quarry Types

Quarry Type		PARAMETER						
		Long Axis M	Long Axis $\bar{X}$	Short Axis $\bar{X}$	Long Axis σ	Long Axis SK	Long Axis K	Shape b/a
	Total							
	$\bar{X}$	3.0	3.07	3.78	0.63	0.33	2.91	0.54
	σ	0.37	0.35	0.38	0.07	0.20	0.44	0.02
	Type 1							
	$\bar{X}$	3.25	3.19	3.91	0.63	0.27	2.90	0.52
	σ	0.21	0.29	.31	0.07	0.19	0.51	0.01
	Type 2							
	$\bar{X}$	2.50	2.81	3.50	0.65	0.44	2.92	0.54
	σ	0.24	0.18	0.19	0.06	0.18	0.33	0.02
	Type 3							
	$\bar{X}$	3.00	3.13	3.84	0.62	0.30	2.91	0.55
	σ	2.92	0.42	0.48	0.07	0.22	0.49	0.02

Type 1 = Offshore Bar　　Type 2 = Beach　　Type 3 = Intrachannel Bar

TABLE 6. Means for the Textural Data from the Three Quarry Types

Quarry Type		PARAMETER						
		Bulk Specific Gravity	Apparent Specific Gravity	Percentage Water Absorption	Permeability	Durability (% Weight Loss)	Number of Laminations	Tensile Strength
Total	$\bar{X}$	2.48	2.73	5.30	48.85	13.78	3	926
	σ	0.18	0.16	2.64	1.34	15.51		230.00
Type 1	$\bar{X}$	2.37	2.71	6.40	49.34	17.70	3	867
	σ	0.17	0.20	3.84	0.97	24.73		261.20
Type 2	$\bar{X}$	2.56	2.78	4.48	49.49	11.71	2	914
	σ	0.17	0.05	0.96	0.92	5.36		114.28
Type 3	$\bar{X}$	2.53	2.72	4.42	47.80	11.04	4	1000
	σ	0.14	0.17	1.36	1.42	3.37		260.93

TABLE 7. Means for the Physical Property Data from the Three Quarry Types

Table 9 shows the statistical interactions among the physical properties, composition, and texture; and Table 10 illustrates the interrelations between the various physical properties. These data show that percent water absorption is an important factor in predicting the other physical properties; for example, weight loss or durability. The percentage of opaques (organic material) is the main factor related to the percentage water absorption. Opaques also appear as a significant parameter in bulk specific gravity, tensile strength, and weight loss. Furthermore, organics are most abundant in Type 1 quarries and least abundant in Type 2. Therefore, as shown in Table 8, Type 1 flagstones have the least desirable properties.

Figures 22, 23 and 24 show the regional variation of some of the compositional parameters; Figure 25 of modal grain size; and Figures 26 and 27 of percentage water absorption and disintegration index. All of these maps exhibit a westward branching pattern. Areas to the west of the mean line exhibit higher values of water absorption and disintegration index. This is generally the area of the Type 1 quarry. The compositional and textural maps show that this area has more matrix and opaques, less total cement, and is finer grained than areas eastward of the mean.

The variations shown by the above maps would seem to suggest two basic types of flagstone rather than three types based on the nature of the associated strata. The first would correspond to the offshore bar type and the second to the beach and intrachannel bar type.

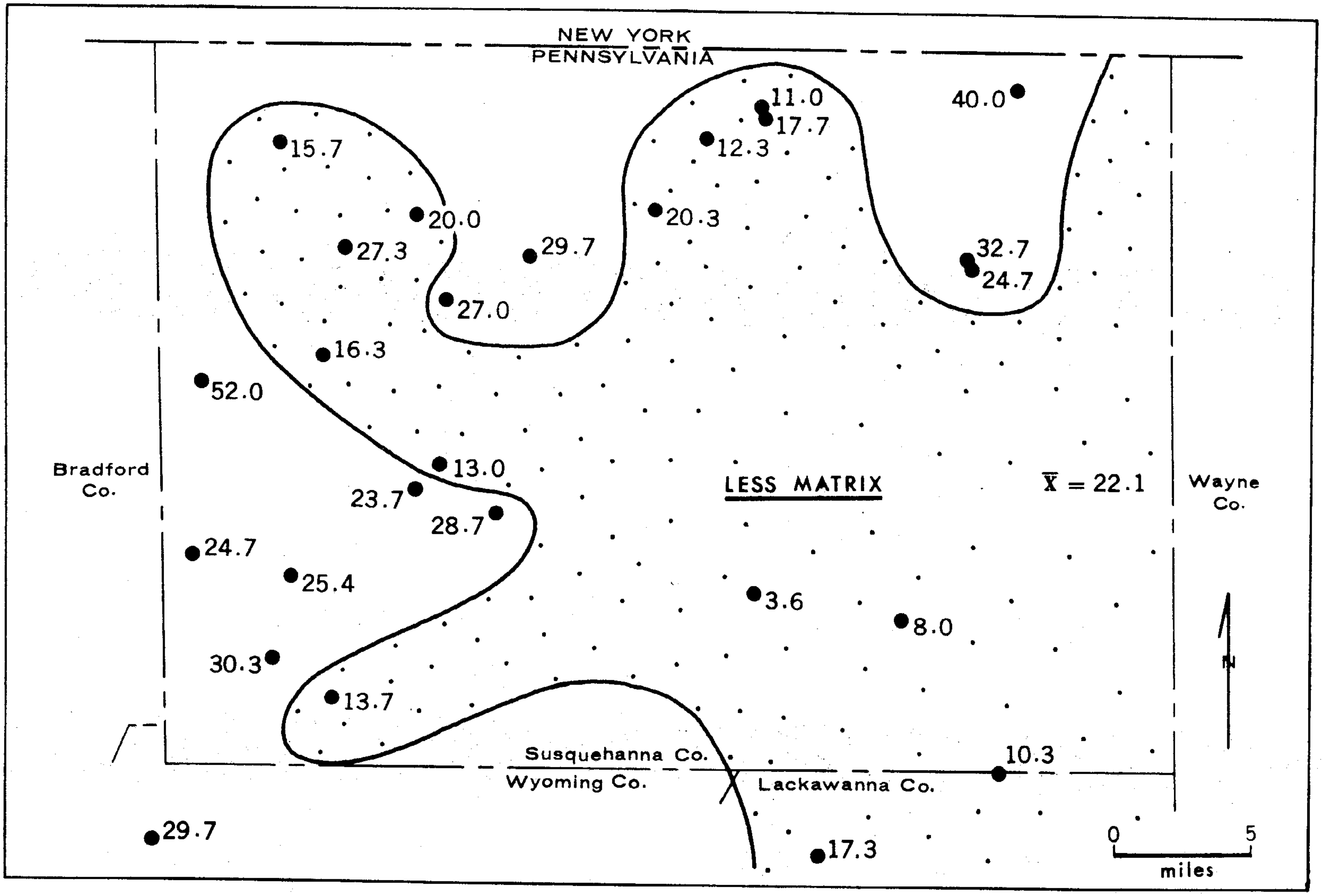


Figure 22. Mean deviation map of the matrix.

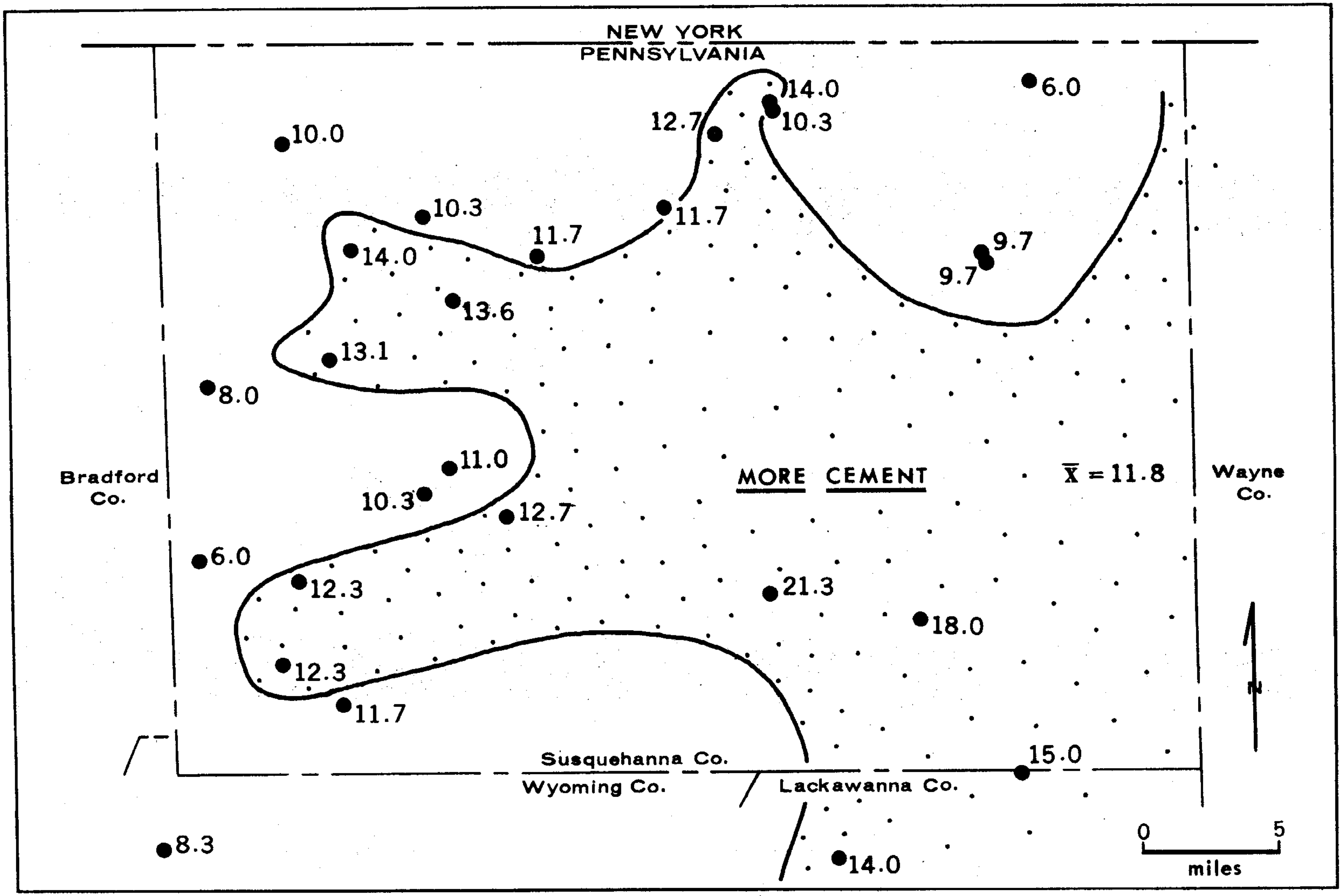


Figure 23. Mean deviation map of the total cement.

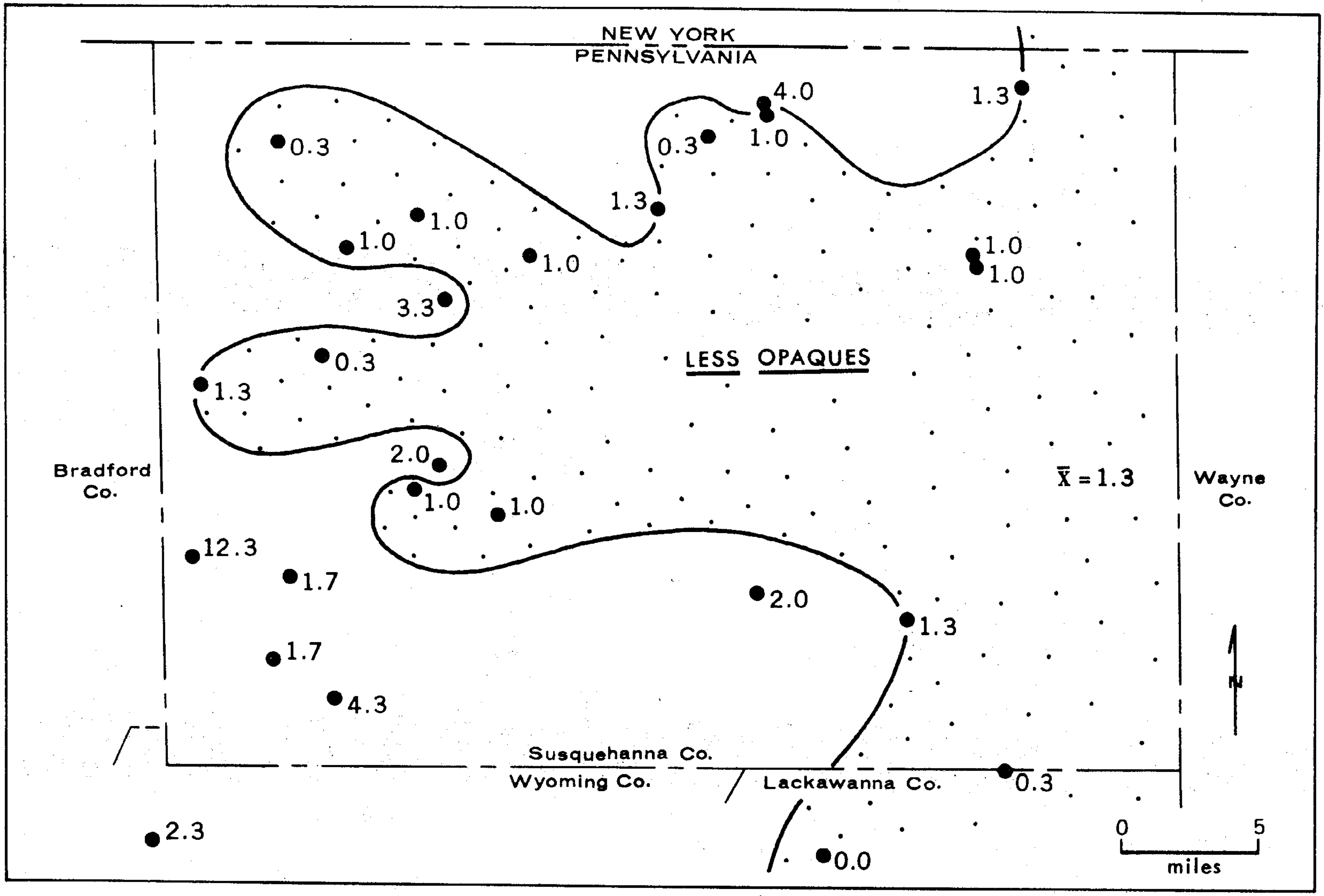


Figure 24. Mean deviation of the opaques.

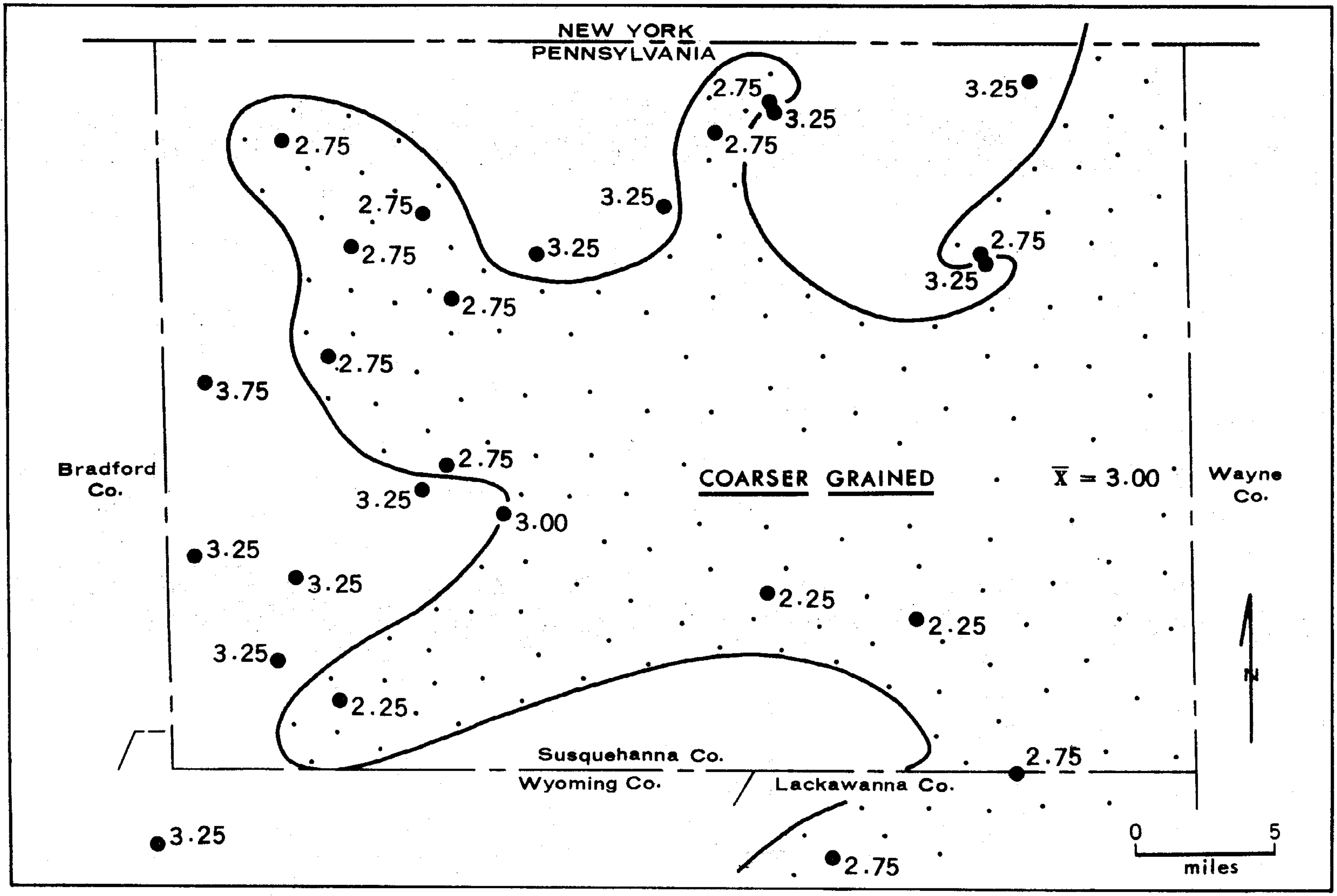


Figure 25. Mean deviation of the modal grain size.

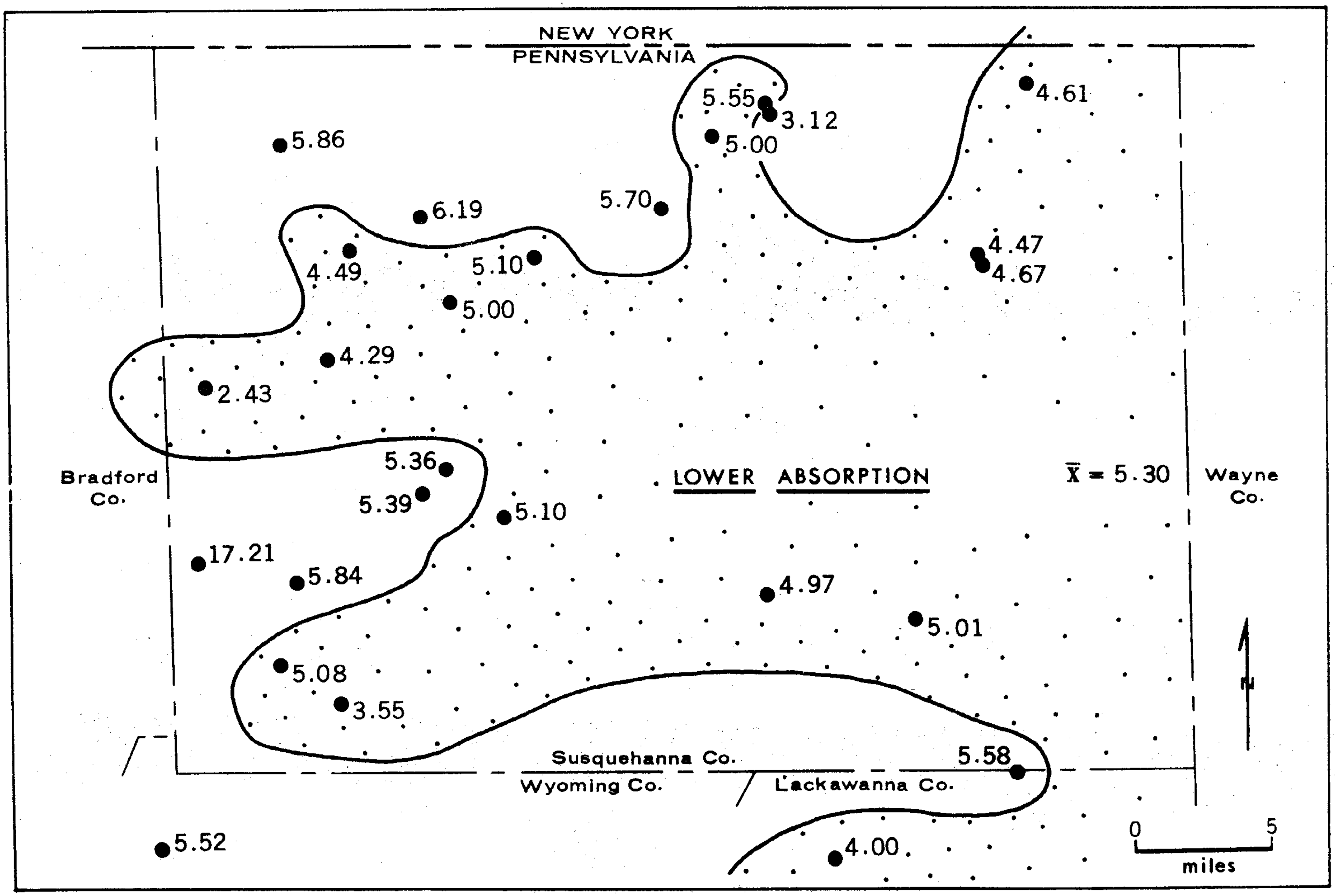


Figure 26. Mean deviation map of the percentage water absorption.

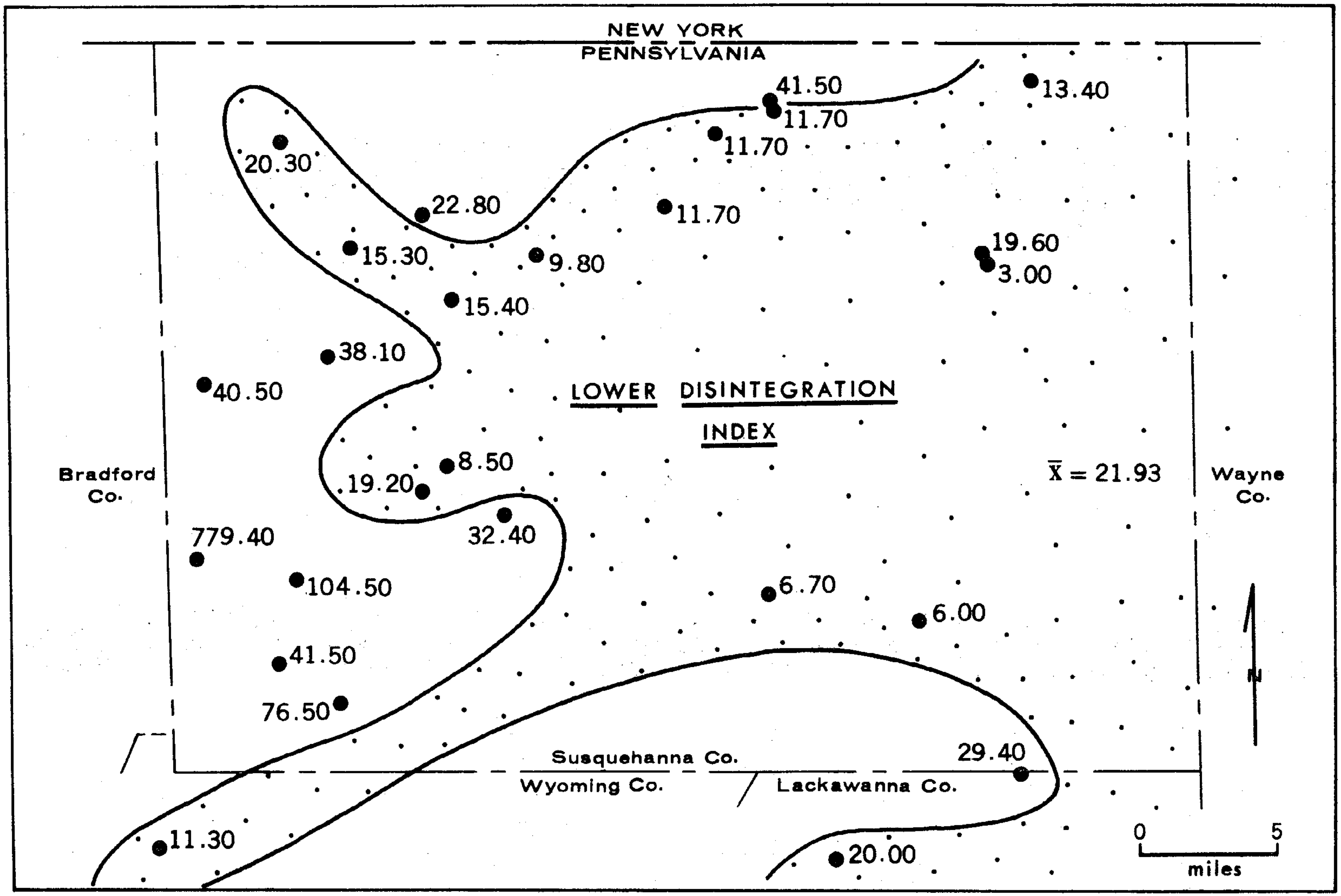


Figure 27. Mean deviation map of the disintegration index.

TABLE 8.

Quarry Type Ranks for Measured Data

	Parameter	RANK Least	Intermediate	Most
Composition	Total Grains	1	3	2
	Quartz Grains	1	3	2
	Rock Fragments	3	1	2
	Feldspar	3	1	2
	Mica	3	1	2
	Matrix	2	3	1
	Total Cement	1	3	2
	Quartz Cement	1	2	3
	Carbonate Cement	1	3	2
	Opaques	2	3	1
Texture	Long Axis Mode	1	3	2
	Long Axis Mean	1	3	2
	Short Axis Mean	1	3	2
	Long Axis Skewness	1	3	2
	Long Axis Kurtosis	1	3	2
	Shorting	2	1	3
	Shape	1	2	3
P. Properties	Bulk Specific Gravity	1	3	2
	Apparent Specific Gravity	1	3	2
	Percentage Water Absorption	3	2	1
	Durability (% weight loss)	1	2	3
	Number of Laminations	2	1	3
	Tensile Strength	1	2	3
	Permeability	3	1	2

1 = Offshore Bar Quarry Type
2 = Beach Quarry Type
3 = Intrachannel Bar Quarry Type

TABLE 9. Summary Statistics From Regression Analysis

Regression Analysis For	Step	Variable Entering	Multiple Correlation Coefficient	Standard Error of Estimate	Fraction of Explained Variance	Partial Correlation Coefficient*
Bulk Specific Gr.	1	Opaques	0.56815	0.15225	0.32280	-0.5682
	2	Long Axis M	0.64678	0.14413	0.41833	-0.5513
	3	Quartz	0.70959	0.13615	0.50352	-0.6162
	4	Long Axis σ	0.78260	0.12312	0.61247	-0.7179
	5	Long Axis SK	0.81601	0.11715	0.66588	-0.7451
	6	Quartz Cement	0.83970	0.11292	0.70510	-0.7511
Apparent S.G.	1	Long Axis SK	0.32579	0.15283	0.10614	0.3258
	2	Long Axis K	0.52402	0.14064	0.27460	0.5220
% Water Absorp.	1	Opaques	0.81882	1.5444	0.67046	0.8188
	2	Feldspars	0.85361	1.4316	0.72865	0.8533
	3	Long Axis M	0.87451	1.3628	0.76478	0.8654
	4	Mica	0.89395	1.2890	0.79915	0.8855
	5	R. Fragments	0.90875	1.2300	0.82582	0.8995
	6	Long Axis K	0.92162	1.1734	0.84939	0.9062
Permeability	1	Feldspar	0.43053	1.2316	0.18536	0.4305
	2	Cement	0.59339	1.1219	0.35211	0.5792
T. Strength	1	Opaques	0.36524	218.52	0.13340	-0.3652
	2	Mica	0.49758	208.00	0.24758	-0.4286
Durability	1	Opaques	0.84721	8.4121	0.71776	0.8472
	2	Feldspar	0.87368	7.8640	0.76362	0.8738
	3	Matrix	0.89693	7.3130	0.80448	0.8953

*For first variable chosen when other variables added are held constant at their mean values.

TABLE 10

Results of the regression analysis of the physical properties (dependent variables) against each other.

Dependent Variable	Independent Variable	Percentage of Explained Variance
Bulk Specific Gravity	weight loss	49.9
Apparent Specific Gravity	none	
Percentage Absorption	weight loss	76.9
Permeability	none	
Weight Loss	percentage absorption	76.9
Tensile Strength	percentage absorption	22.8

Color

A wide range of different colored flagstones was observed throughout the producing area and sometimes within a single quarry. These colors included the desired "blue" flagstone, which is really a steel blue-gray, and various shades and combinations of gray, green, brown, and red or maroon.

A representative sample of blue, green, brown, and red flagstones was chosen for chemical analysis. The results of the analysis are presented in Table 11.

The most important of the oxides as a coloring agent is iron oxide (Van Houten, 1948) which occurs as:

a) ferric iron oxide (Fe_2O_3) either as:
   1. the hydrous form, limonite (Fe_2O_3 H_2O) which has a brown or yellowish-brown color, or,
   2. the anhydrous form, hematite (Fe_2O_3) which has a maroon or reddish-brown color.

b) hydrous ferrous iron oxide (FeO) which has a natural, steel gray color.

From the above, and the results of the chemical analyses for iron oxides, the following may be concluded:

a) The red flagstones do not owe their red color to a greater total iron content.

b) For the flagstone to be red, there must be an excess of ferric over ferrous iron oxides. The ratios of the ferric to ferrous iron oxide for each of the samples are as follows:

Sample	Fe_2O_3/FeO
red	1.92
brown	0.97
green	0.57
blue	0.26

These conclusions are based upon and substantiate those of Dorsey (1926) for other red beds.

Petrographic analysis shows that all red flagstones contain appreciable amounts of finely dispersed hematite; the non-red rocks contain no hematite. In these flagstones, illite and chlorite are the main constituents of the matrix.

Variation in the degree of weathering has an important effect on within quarry variation in color. Usually the blue-colored stone is found either deeper within the quarry or in the center of large blocks. Greener-colored flagstones are found along the outer edges of most blocks in almost every quarry. Here, the ground water moving vertically along the joints, and laterally along the parting surfaces has had an opportunity to slightly alter the chemcial composition of the matrix minerals, micaceous rock fragments and organic material so

TABLE 11. Chemical Composition of the Different Colored Flagstones

Formula	Red	Brown	Green	Blue
SiO_2	71.5%	76.6%	69.6%	73.7%
Al_2O_3	13.5	11.6	12.5	11.4
	5.09	3.91	5.02	4.92
FeO	1.68	1.87	2.99	3.58
Fe_2O_3	3.22	1.82	1.70	0.94
MgO	1.19	1.02	1.34	1.31
MnO	0.06	0.03	0.06	0.07
CaO	0.75	0.22	0.45	1.38
TiO_2	1.03	1.15	0.81	1.66
Na_2O	1.54	0.57	0.59	0.69
K_2O	2.80	2.24	2.58	1.88
H_2O	2.13	2.17	2.89	2.26
	99.59%	99.51%	99.90%	95.21%

that a corresponding color change occurs. The brown flagstones are a result of further chemical breakdown of the micaceous minerals, alteration of the matrix and organic material, and occur in the areas of maximum ground water movement, that is, adjacent to the joints. The hematite in the red flagstone is a very stable mineral so that the moving ground waters would have very little altering effect upon it. The alterations of the constituent minerals by migrating ground water probably explains most of the color variation found within the flagstone produced from a single quarry.

Lastly, the overall color of the flagstone will be lightened by the precipitation of the dissolved minerals in the "quarry water" when this water is evaportated from the flagstone upon its exposure to the atmosphere after being quarried. The most common mineral precipitated in this manner is a white form of calcium carbonate which is usually found on the parting surfaces of many flagstones.

PROSPECTING FOR A QUARRY

Table 12 is a qualitative ranking of some desirable properties of flagstone deposits. A linear ranking was used which was based on the data collected, that is, the rank of "one" was used for the quarry type which best demonstrated the desirable property, a rank of "two" was used for the intermediate quarry type, and a rank of "three" for the quarry type that was least desirable for that property. This ranking may not be the most appropriate and it is hoped that future work will develop and establish more realistic standards.

Examination of the table will show that the Type 1 - offshore - bar environment - quarries rank first (or best) in the color of stone (more of the deep blue-colored stone), and in block size, and block uniformity; second in total volume; and third in all other properties. Therefore, in overall quality, Type 1 would be considered the poorest stone. However, if blueness of color and block size are the more desirable qualities, then they may outweigh the other less desirable qualities of the stone. This is a real possibility since the blue-colored stone is in more demand and is more easily marketed, which, therefore, illustrates one of the shortcomings of the ranking system.

The Type 2 - beach - quarries have the greatest volume of stone, and have other properties intermediate between the other two types which leads to the condition that when all of the other properties are considered in the ranking, Type 2 seems to be the most desirable type of quarry to locate and develop.

The outstanding feature of the Type 3 - intrachannel bar - quarries is that they have the best durability (lowest disintegration index).

Depending on the property or combination of properties desired in the stone, prospecting may be guided by reference to Figure 12, the quarry type distribution map. For example, if blue-colored stone is desired, one has the greatest chance of finding this quality in the Type 1 areas, which occur in the northeastern and extreme western parts of the map; however, since the probability of finding a quarry is not only dependent upon the proportions of any one given type within that area, and upon the deviation from expected frequencies within that area, it is possible that the probability of finding a Type 1 quarry is equally as great in the mixed area as it is in the area designated as Type 1.

TABLE 12

Comparison of Desirable Properties in The Three Flagstone Types

	Type 1	Type 2	Type 3
Color (Blue)	1	2	3
Quarry Volume	2	1	3
Block Size and Uniformity	1	2	3
Number of Laminations	3	2	1
Reed Variability	3	1	2
Water Absorption	3	1	2
Disintegration Index	3	2	1
Totals	16	11	15

Rank Meaning

1 = Best
2 = Intermediate
3 = Worst

Type 1 = Offshore Bar
Type 2 = Beach
Type 3 = Intrachannel Bar

After consideration of the compositional, textural, and physical property maps from the sampled quarries, and assuming that these maps are representative of the most probable quarry type within that area, one might again conclude that the mixed area would be the best one in which to prospect.

Assuming that one has decided to prospect within the mixed area, the next step would be to consult the Lordstown Soil Distribution Map (see Krajewski, 1971). Only those areas should probably be examined in the field that are covered by this soil type; and probably prospecting should further be confined to those areas within the Lordstown that are covered by the Very Stony submember since it was found to have the highest number of quarries, Table 3.

One might then attempt to relate those features which he can observe outcropping in the field to those shown on the quarry cross sections and photographs of the quarry types and evaluate the specific sites' potential as a potential flagstone quarry.

Once the site is chosen, the following four factors are critical in most efficiently exploiting a flagstone quarry:

a) the joint pattern

b) the geometry of the hill upon which the quarry is to be developed

c) the parting lineation direction

d) the external geometry of the flagstone deposit to be developed.

It has been observed that the joint patterns are predominately orientated north-south and east-west. The north-south set is usually the better developed (more linear) set and controls the orientation of the drainage and mountain ridge pattern throughout the area. This is clearly shown on Plate I or II of Krajewski (1971). It has been stated earlier that the joint pattern and surfaces are more regular in the Type 1 - offshore bar - quarries than in the Type 3 - intra-channel bar - quarries (Figures 7, 8 and 10 illustrate this); therefore, the ease of quarrying and the recovery of stone will be greater in the Type 1 quarries.

The relationship among the hill geometry, parting lineation, external geometry of the deposit, and the direction of mining is illustrated in Figure 28.

Two cases have been illustrated. Case I shows offshore bars, or beaches, located on the east and south sides of a hill, and Case II illustrates intrachannel bars located on the east, west, and south sides of the hill. These deposits have been orientated in their respective orientations so that they conform to the regional paleogeographic interpretations made earlier. It must be emphasized that the cases used are statistical generalities used here for the purpose of illustration.

Within the diagram, the numbered arrows adjacent to each deposit indicate the direction of mining to be followed. It is apparent that Case I-A would yield the greatest volume of stone. In terms of volume of stone obtainable, the other cases would be ranked as follows: second, Case I-B; third, Case II-B, and last, Cases II-A and II-C.

Referring again to Case I-A, that is, an offshore bar or beach which has its greatest potential volume perpendicular to the parting lineation direction (Figure 11), the mining procedures would be as follows:

a) The quarry would be initially extended parallel to the parting lineation until the thickest part of the deposit is passed.

b) It is then extended perpendicular to the parting lineation adjacent to the thickest part of the deposit.

This method should insure the greatest volume of recoverable stone, and also, result in a minimum of uneconomical overburden removal.

In the case of II-B, that is, when an intrachannel bar is to be mined, it has its greatest potential volume parallel to the parting lineation direction (Figure 11) until the deposit starts to thin, or until the overburden becomes too great and the reeds start to thicken. After this occurs, a limited amount of quarrying can take place perpendicular to the parting lineation direction and adjacent to the thickest blocks before attempts to locate a new quarry are made. (It has been observed that with increasing overburden, reed thickness also increases. It is thought that this is due to the increased weight of the overburden. This is the reason why the Case I-B quarry is not further developed.) From this, it should be apparent that the total volume of stone that can be removed in this quarry is less than that from Case I-A.

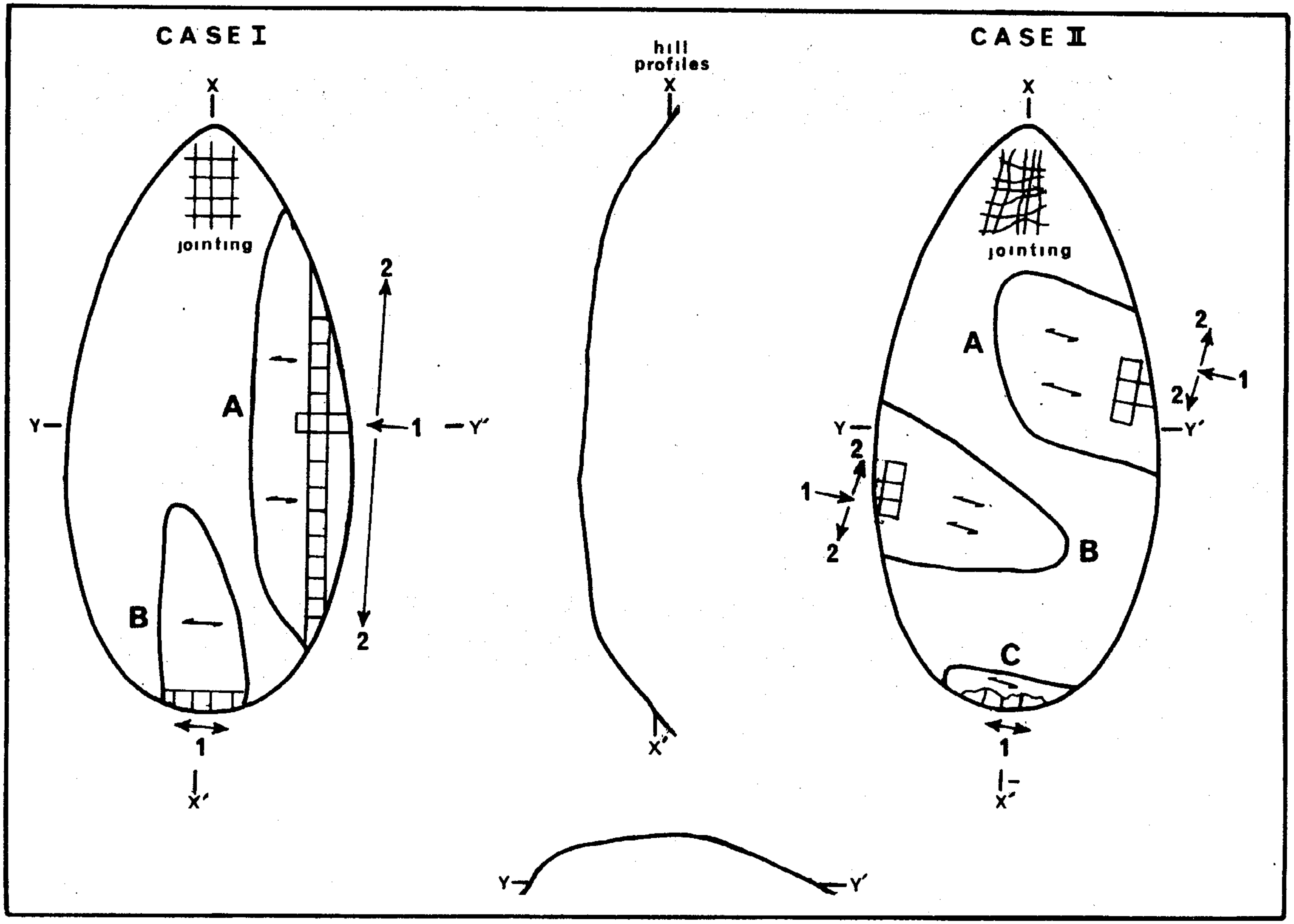


Figure 28. The relationship among hill geometry, parting lineation orientation, external geometry, and the direction to mine flagstone deposits.

A comparison of Case II-B with II-A or C would suggest that II-B would be the more favorable case to mine since the intrachannel bar thickens upstream (the direction of paleotransport is from east to west). In other words, in Case II-B, a thickening deposit would be mined; whereas in Case II-A or C, a thinning deposit would be mined.

Reference Cited

Allen, J.R.L. (1964), Primary Current Lineation in the Lower Old Red Sandstone (Devonian), Anglo-Welsh Basin, Sedimentology, v. 3, p. 89-108.

_________ (1968), Current Ripples, North-Holland Publishing Co., Amsterdam, 433 p.

_________ (1970), Studies in Fluviatile Sedimentation: A Comparison of Fining-Upwards Cyclothems, with Special Reference to Coarse-Member Composition and Interpretation, Journal of Sedimentary Petrology, v. 40, no. 1, p. 298-323.

Dorsey, G. E. (1926), The Origin of the Color in Red Beds, Journal of Geology, v. 34, p. 131-143.

Glaeser, J.D. (1969), Geology of Flagstones in the Endless Mountains Region, Northeastern Pennsylvania. Pa. Geol. Survey, 4th series, Information Circular 66.

_________ (1969), Correlation of Catskill Sedimentary Environments and its Economic Significance, abstracts with programs for 1970. G.S.A., Part 1, p. 21.

_________ (in press), Stratigraphy, Sedimentation and Regional Correlation of Upper Devonian Rocks in Northeastern Pennsylvania, Pa. Geol. Survey 4th series, General Geology Report 63.

Fletcher, F. W., and D. L. Woodrow (1970), Geology and Economic Resources of the Pennsylvania Portion of the Milford and Port Jervis 15-Minute Quadrangles, Pa. Geol. Survey, 4th series, Atlas 223.

Krajewski, S. A. (1971), The Relationship among the Bedforms, Occurrence, Composition, Texture, and Physical Properties of the Upper Devonian Flagstones (Bluestone) from Northeastern Pennsylvania, M.S. Thesis, Pennsylvania State University.

Rickard (1964), Correlation of the Devonian Rocks in New York, New York State Museum and Science Service.

Sevon, W. D., J. D. Glaeser and J. B. Epstein (in press), Geology and Mineral Resources of the Southern Half of the Lehighton 15-Minute Quadrangle, Carbon County, Pennsylvania, Pa. Geol. Survey, 4th series, Atlas 197 C and D.

Willard, B. (1939), The Devonian of Pennsylvania, Pa. Geol. Survey, 4th series, General Geology Report 19.

Woodrow, D.L. (1968), Stratigraphy, Structure, and Sedimentary Patterns in the Upper Devonian of Bradford County, Pennsylvania, Pa. Geol. Survey, 4th series, General Geology Report 54.

ROAD LOG

Friday, October 8, 1971

<u>Mileage</u>

0.	Leave Treadway parking lot. Turn RIGHT on Pa. Route 315.
5.6	Enter Interstate 81.
51.0	<u>STOP 1</u>

Road cuts, 2.75 miles south of New Milford exit on Interstate 81. Park well off the highway. Watch for high-speed traffic.

The three road cuts at this locality (Figures 29, 30 and 31) are excellent illustrations of Allen's fining upward cycles. (See Figure 5 B, for Allen's concept.) Three complete cycles are exposed, one in each roadcut. Also clearly visible is the complex lateral intertonguing of all the units of the cycle, a phenomenon which supports Allen's idea of cycle genesis by migrating channels. The direction of intertonguing and of accretion cross bedding suggest that, in the uppermost roadcut, Figure 29, channel migration was from north to south; whereas in the lower two cuts, Figure 30 and 31, it was from south to north. Current cross bedding and parting lineation show that overall current direction was to the northwest.

Basal sandstones of the cycles are often conglomeratic; the best example shown in Figure 29. The pebbles are largely calcium carbonate nodules of local derivation, since they have been observed in the burrowed or rooted upper parts of adjacent red siltstones and mudstones.

Plane beds with parting lineation occur in two forms; on the shallow sides of migrating alluvial bars and in the central parts of symmetrical bars. The former, best seen in the middle cut, Figure 30, vary from a few inches to a foot in thickness. Volumetrically these are too small to be mined. The more symmetrical bars, best exposed in the uppermost cut, Figure 29, have a maximum thickness of four to five feet and are several hundred feet long. These might be potential sources of flagstone.

The exposures at this locality are typical of those designated as type 3 (alluvial) shown on the quarry type distribution map, Figure 12.

<u>Mileage</u>

53.6	Continue north on Interstate 81 to New Milford exit; down ramp to Pa. 492 and turn LEFT.
54.4	West on Pa. 492 to intersection with U.S. 11; straight across intersection to "Y" intersection. Bear LEFT on township (T) 617.
54.7	"Y" intersection bear RIGHT on T 617.
55.5	West on T 617; bear RIGHT on T 619 at "Y" junction.
56.2	West on T 619; turn RIGHT on T 684 at "T" junction.
56.3	North on T 684; turn RIGHT on T 621.
56.8	East on T 621; turn LEFT between barn and farm house.
57.1	Continue to quarry, <u>STOP 2</u>. Park on quarry floor away from working equipment.

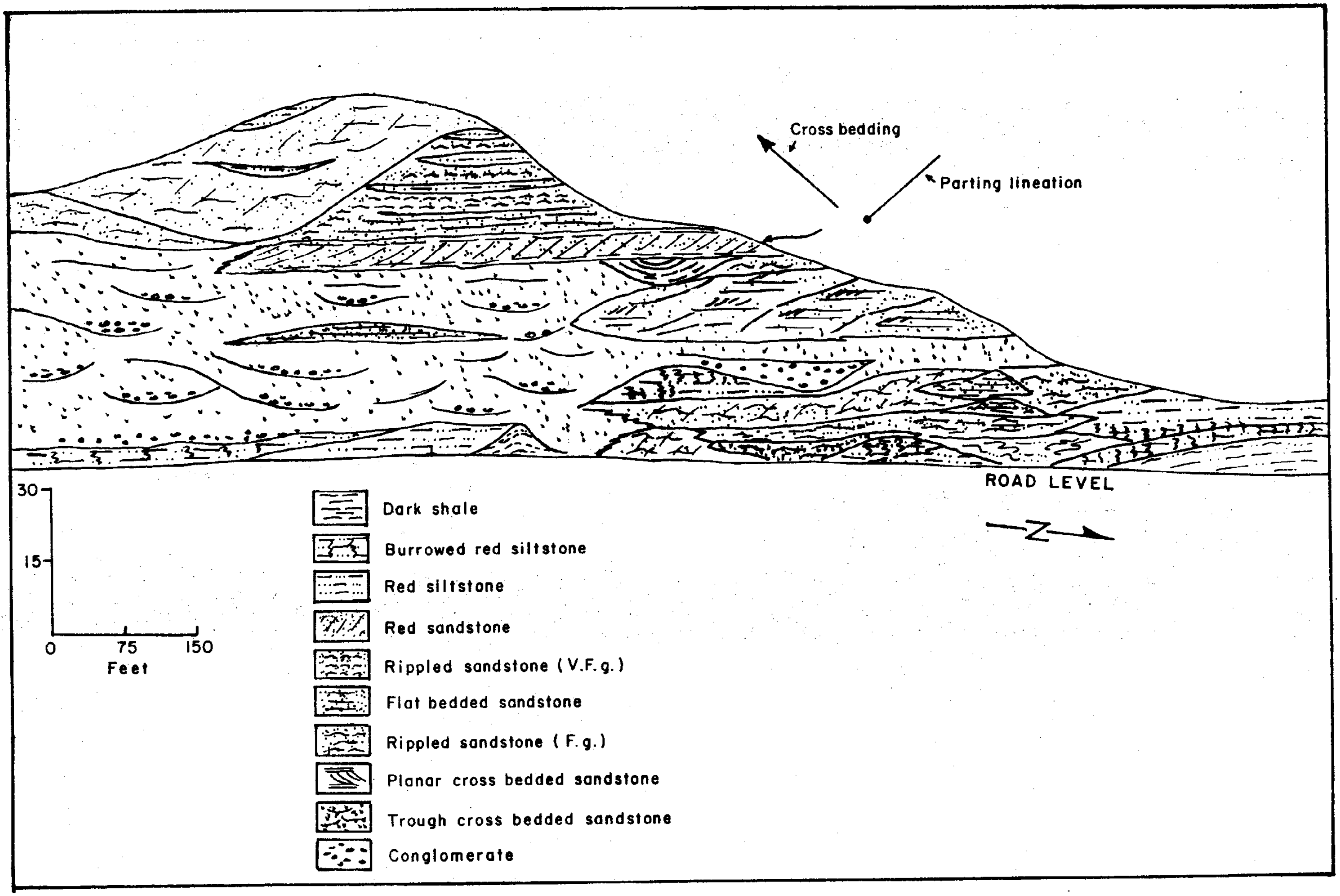


Figure 29. Upper road-cut along I-81 south of New Milford.

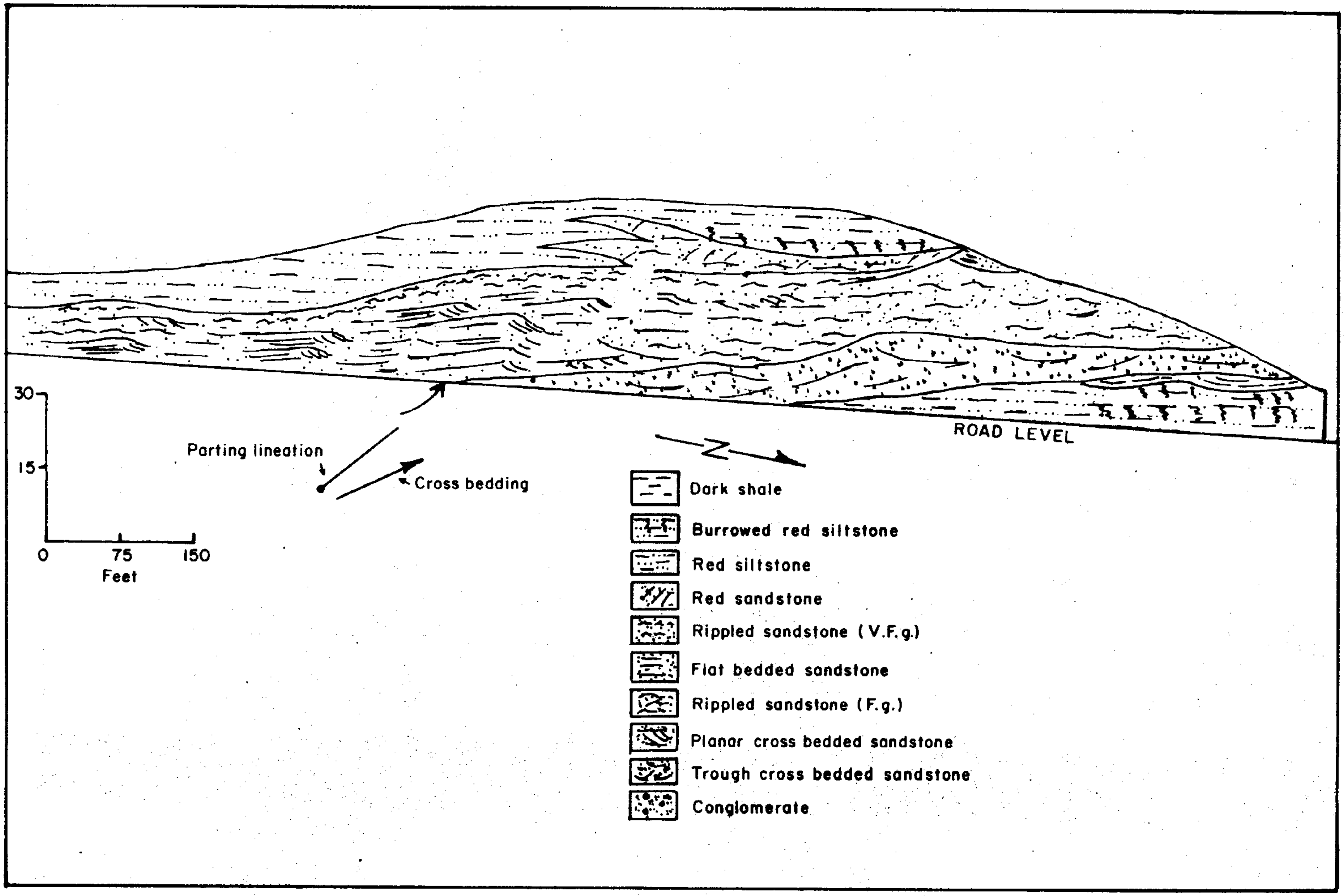


Figure 30. Middle road-cut along I-81 south of New Milford.

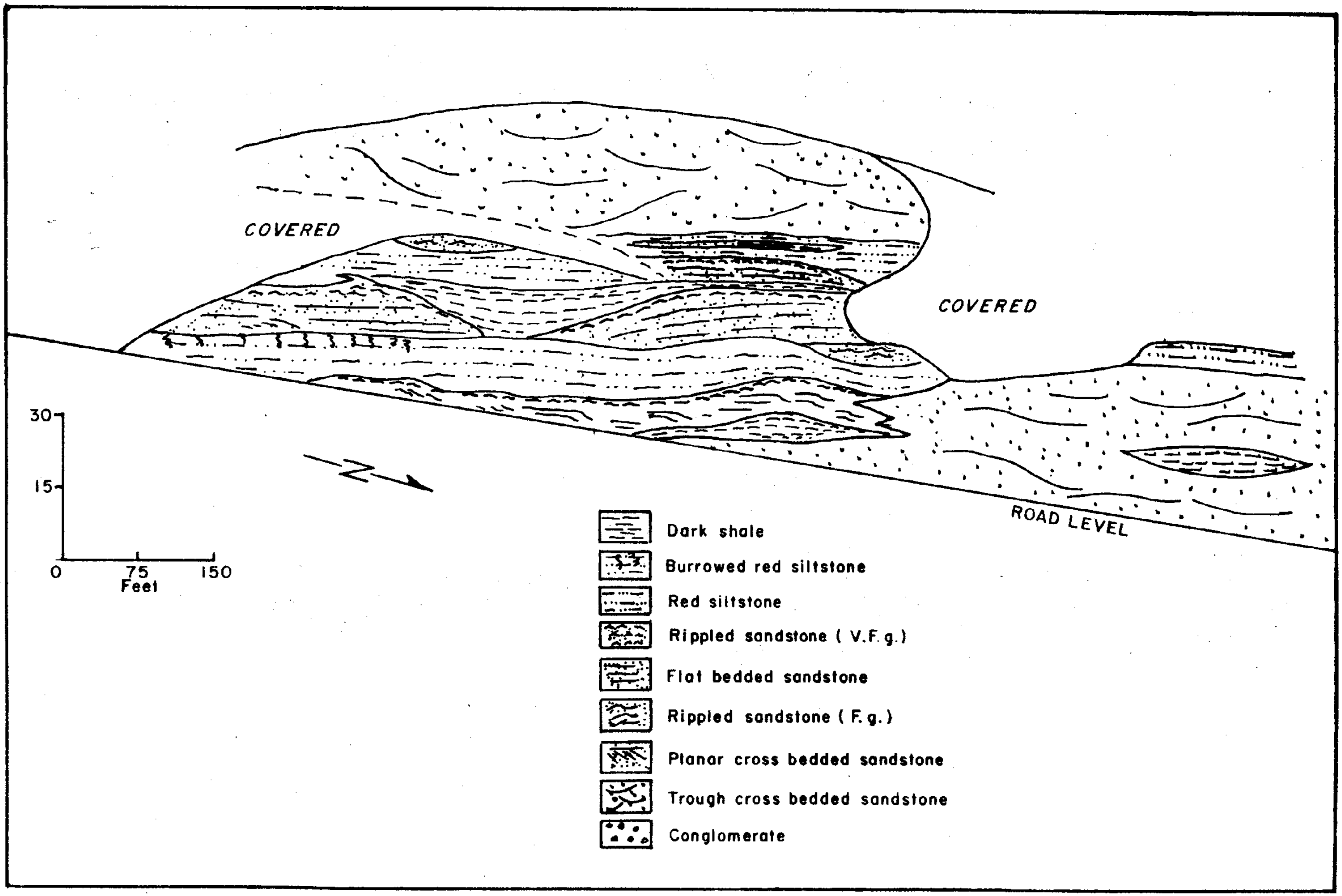


Figure 31. Lower road-cut along I-81 south of New Milford.

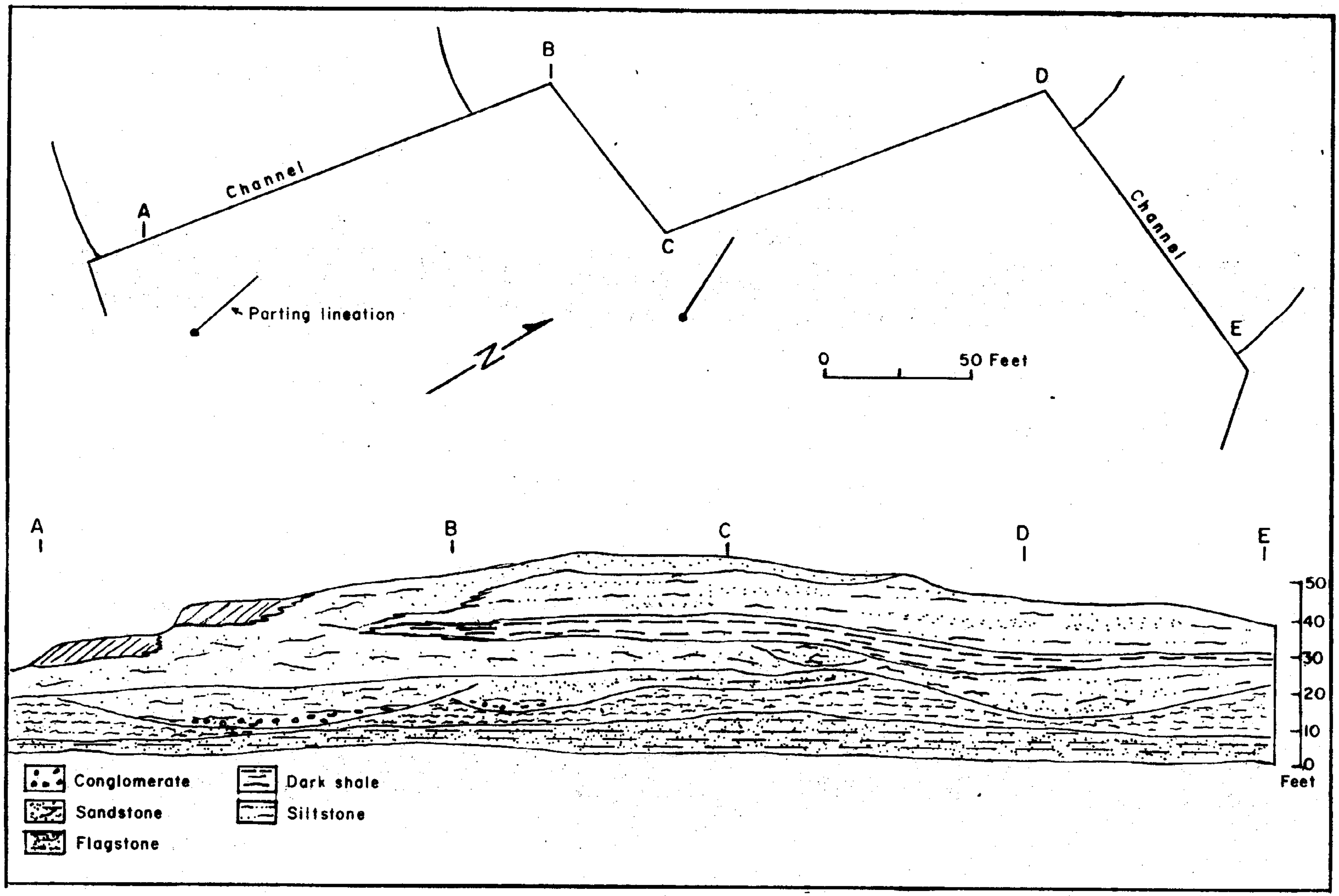


Figure 32. Flagstone quarry diagram of STOP 2.

STOP 2

Refer to Figure 32 for illustration of exposed rocks at this locality and Figure 1, for location. The flagstone mined here has a maximum thickness of 10 feet and a length of approximately 400 feet. It shows a marked thinning to the northwest and thins at a lesser rate to the northeast. Although the flagstone has no fossils or other visible diagnostic features which would permit an exact environmental designation, it has been interpreted to be an alluvial bar on the basis of the associated overburden. In the central part of the quarry, the flagstone is overlain by minutely rippled sandstone, which has locally been eroded by well defined channels. Overlying the channel sandstones is a complex sequence of lenticular, planar and trough cross bedded sandstones, and interbedded siltstones and dark shales. This complex of rocks resembles the outcrops at Stop 1 except for the paucity of red shales and siltstones in the former.

All flagstone quarries exhibiting similar sequences have been classified as alluvial; the distribution of this type, designated as type 3, is shown on Figure 12.

Other features of interest are the pebble conglomerate in the base of the channel at the northwest end of the quarry.

Also observe the two major joint sets, which strike approximately north-south and east-west. These joint sets are of regional extent and are better developed in the other two quarry types.

Mileage

57.4	Return to T 621; turn RIGHT.
57.9	West on T 621; turn LEFT on T 684.
59.0	South on T 684 to U. S. 106; turn RIGHT.
62.4	Junction with Pa. 167. Continue straight on U. S. 106.
64.6	Junction with Pa. 29; turn RIGHT.
71.9	North on Pa. 29 to Lawsville Center; turn RIGHT on T 57075.
73.4	East on T 57075; turn LEFT at gray house, red garage on the right.
73.7	Hard pull uphill to quarry - STOP 3.

Refer to Figure 7, for illustration of exposed rocks.

Figure 7 is a map and profile of a typical Type 1 - offshore bar - flagstone quarry. Characteristics of this type of quarry include:

a) a convex upper surface;

b) parallelism of the parting lineation orientation and the down dip direction of the cross-bedding;

c) a steep front in the seaward direction;

d) replacement seaward (northwestward) by darker, fossiliferous, marine shales;

e) replacement landward (southwestward) by siltstones, small scale rippled sandstones, and red shales; and,

f) uniformness and regularity of the joint systems (the high walls of the quarry parallel the joint systems).

Two offshore bars are visible in the diagram, the larger lower one, and another smaller one in the south end of the quarry. The long direction, or paleogeographic trend, of these bars would be perpendicular to the parting lineation shown in the diagram, or northeast-southwest and east-west for respectively the lower and upper bars. The rock sequence represents a marine transgression onto the tidal flats and shore zone.

Mileage

74.0	Return downhill to T 57075; turn RIGHT.
75.5	West on T 57075 to Pa. 29; turn LEFT.
77.0	South on Pa. 29 to Franklin Forks; turn RIGHT on T 57075 past antique shop.
80.9	West on T 57075 to Pa. 167; turn LEFT.
83.0	South on Pa. 167 to Fisk Mill; turn RIGHT on T 57138 at Dark Hollow Shooting Preserve sign.
83.4	West on T 57138 to T 700; turn LEFT at sharp turn.
83.8	South on T 700 to quarry on right, STOP 4. Park in field area to left of road. Walk 100 feet into quarry. Refer to Figure 8 for illustration of exposed rocks.

A map and profile of a Type 2 - beach - quarry is shown in Figure 8. Typical characteristics of this type of quarry are:

a) a lensoidal cross section.

b) complexly cross-bedded sandstones (bars) overlying the flagstone.

c) sub-parallelism of the parting lineation orientation direction and the cross-bedding in the overlying sand bars (Figure 9A).

d) that the deposits are inclined with the front (landward) being higher than the back (seaward).

e) Worm burrowings in the tops of some of the overlying bars.

f) Uniformness and regularity of the joint systems which the high walls parallel.

The beach, as shown in Figure 8, is orientated with its long direction, that is, its paleogeographic trend, in a north-south direction. The sequence of rocks exposed in the quarry represent a marine transgression of lower tidal-flat sand waves and bars over the beach.

<u>Mileage</u>

84.2	Continue south on T 700 to Pa. 167; bear RIGHT at "Y" junction.
87.9	Continue on Pa. 167 to U. S. 106; turn LEFT.
88.1	STOP LIGHT in Montrose; continue on U. S. 106.
96.5	East on U. S. 106 to U. S. 11; turn LEFT.
97.7	North on U. S. 11 to Pa. 492; turn RIGHT.
98.2	East on Pa. 492 to entrance ramp to I-81; turn RIGHT.
110.4	South on I-81 to Lenox Interchange; continue on I-81.
111.7	STOP 5. Park on right side of road opposite outcrops. Watch for high-speed traffic. Cross to outcrops only under direction of leader and road guards.

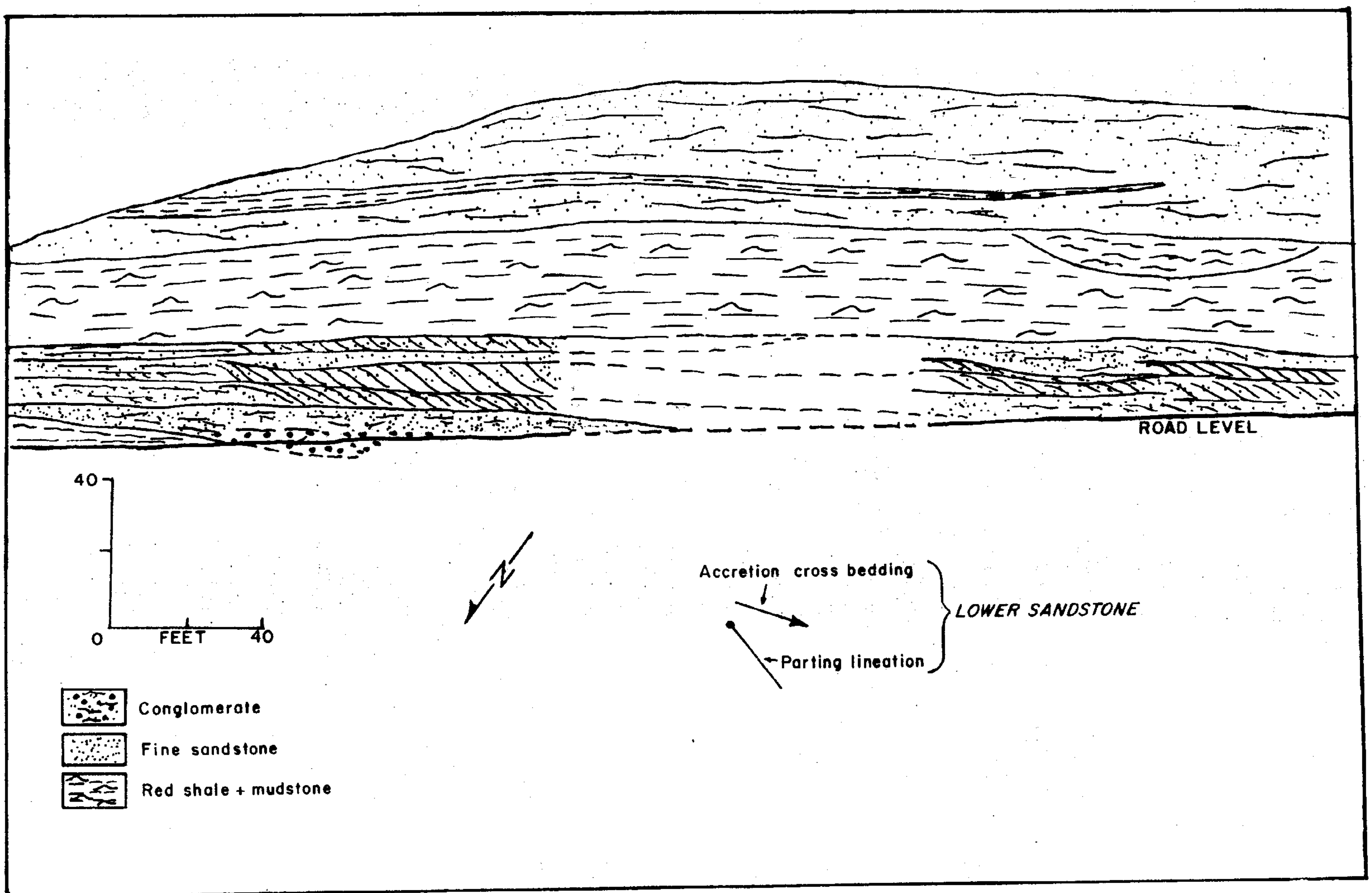


Figure 33. Middle part of road-cut south of Lenox, Pennsylvania, on I-81.

Refer to Figure 33 for illustration of exposed rocks and to Figure 1, for location. A complete fining upward alluvial cycle is well exposed. Of special interest is the relatively thick pebble conglomerate at the base and the overlying planar cross bedded sandstone. The cross bedding in this sandstone is believed to be of accretion origin since the parting lineation and cross bed direction in the same set are not parallel. Thus, the bars migrated from east to west.

Unlike Stop 1, the units at this locality have greater lateral continuity.

<u>Mileage</u>

151.6	Continue on I-81 and Pa. 315 to Treadway Motel.
	End of trip.

HYDROLOGY, GLACIAL GEOLOGY AND ENVIRONMENTAL GEOLOGY OF THE WYOMING-LACKAWANNA VALLEY

by

Jerrald R. Hollowell

(U. S. Geological Survey)

INTRODUCTION

Purpose and Scope

The Wyoming-Lackawanna Valley is probably best known to geologists as the Northern Anthracite Field. Because the valley is underlain by many beds of anthracite it has long been the site of extensive geological investigations. Most geological work was done to solve structural and stratigraphic problems incident to the removal of coal. More recent investigations describe Pleistocene geology and landforms. (Itter, 1938; Peltier, 1949).

The purpose of this trip is to show environmental problems resulting from the removal of coal and exposures of Pleistocene deposits (rapidly being removed from the scene). In addition to the stops, many of the environmental problems resulting from the removal of coal can be seen from the buses.

Field work that provided the data for this field trip was accomplished under a cooperative project between the U. S. Geological Survey and the Pennsylvania Geological Survey and published as Bulletin W-28 (Hollowell, 1971) of the latter organization.

Acknowledgments

Information relating to mine fires was provided by the U. S. Bureau of Mines, Environmental Affairs field office, Wilkes-Barre, Pa. Thanks are extended to Dr. Donald M. Hoskins for his assistance in preparing the Road Log. The Pennsylvania Geological Survey typed the final copy of the manuscript and drafted the illustrations.

BEDROCK GEOLOGY

The bedrock in the Wyoming-Lackawanna Valley is made up of well-indurated thin- to massive-bedded sandstone, shale, siltstone, conglomerate, and coal. The bedrock exposed along the margin of the valley consists of the following formations, from the oldest to the youngest: The Pocono Formation of Early Mississippian age, the Mauch Chunk Formation of Mississippian and Pennsylvanian (?) age, and the Pottsville and Llewellyn Formations of Pennsylvania age.

Stratigraphy

Pre-Llewellyn Formations

Three pre-Llewellyn Formations crop out on either side of the valley. The Pocono Formation, about 600 feet thick in the Wyoming Valley thins to the northeast until it disappears near Blakely. It forms the outer ridge and is predominantly a gray, hard, massive, cross bedded conglomerate and sandstone interbedded with some siltstone and shale. The Mauch Chunk Formation ranges in thickness from a few feet to about 1,000 feet in the Wyoming Valley and thins to the northeast until it disappears south of Scranton. It occupies the valley between the inner and outer ridges formed by the coarser grained rocks. It is predominantly a red shale interbedded with some brown and greenish-gray flaggy siltstone and sandstone. The Pottsville Formation thins to the northeast and ranges from 35 to 300 feet thick. It forms the inner ridge and is light gray to white coarse-grained sandstone and conglomerate.

Llewellyn Formation

The Llewellyn Formation underlies the Wyoming-Lackawanna Valley and flanks lower parts of the surrounding slopes. The formation is nearly 2,200 feet thick in the Wyoming Valley and 850 feet in the Lackawanna Valley. It is composed of interbedded light-gray, quartz pebble conglomerate; light- to medium-gray, fine- to coarse-grained sandstone; light- to dark-gray shale and siltstone; medium-gray claystone; dark gray carbonaceous shale; and anthracite coalbeds.

The strata between the coal beds commonly exhibit extreme lateral changes in thickness and lithology, and are characterized by cross bedding, truncated bedding, and channel deposits. The coalbeds are the most persistent strata and range in thickness from a fraction of an inch to 27 feet. At least 26 coalbeds are represented in the Llewellyn Formation (Ash, 1954). The lowest coalbed in the Formation crops out on the mountain slopes on each side of the valley at an elevation of 1,000 to 1,600 feet.

The Llewellyn is covered with unconsolidated glacial deposits and exposures are scarce. It may be seen, however, in resistant ridges, where the glacial deposits have been removed by erosion, in roadcuts, and where excavation for coal has removed the surficial material.

Structure

The Wyoming-Lackawanna Valley lies in a large synclinorium whose axis trends about N 50° E. The synclinorium is slightly crescent shaped in plan and is concave on the northwest side (Figure 1).

The rocks bordering the Wyoming Valley suggest a simple synclinal structure. However, the area is structurally anomolous to the Appalachians and the rocks within the valley are complexly folded and faulted, and contain many subparallel anticlines and synclines and related faults. These features are discontinuous, and are seldom over a few miles in length. The deepest part of the synclinorium is about 1 mile east of Nanticoke. The trough becomes shallower toward its nose, about 9 miles southwest of Nanticoke, and toward a high point (Moosic Saddle) northeast of Pittston, immediately east of where the Lackawanna River flows into the Susquehanna River. This high point effectively culminates the Wyoming Valley and divides the synclinorium into two substructures. The Lackawanna Valley lies northeast of the Moosic Saddle, and becomes shallower toward its nose 12 miles north of Carbondale (Figure 1).

GLACIAL GEOLOGY

Origin of the Buried Valley

The Wyoming-Lackawanna Valley was invaded by glacial ice in Illinoian time and again in the Wisconsin time. Evidence of the early glacial activity in the valley has been obliterated by the more recent glaciation (Itter, 1938, p. 19). During the greatest advances of the glaciers the ice crossed the valley and the mountains to the south. As the ice moved into the valley from the north it was turned westward by the mountains that flanked the valley on the south. All the ice within the valley flowed in a southwest direction nearly parallel to the axis of the valley. The turning slowed the flow and caused the ice to pile up and increase in thickness over the valley. The increase in thickness added to its erosive powers, and the ice quarried up to 300 feet of rock from the valley (Itter, 1938, p. 67). The greatest excavations occurred in the Llewellyn Formation because the brittle anthracite beds in this formation were easily fractured and dislocated, facilitating the breaking and removal of the adjacent beds. This overdeepened part of the Wyoming Valley has since filled with sediment and is locally referred to as the buried Valley (Ash, 1950).

Unstratified Drift

Till occurs only locally as a thin veneer in the Wyoming Valley. It consists of a heterogeneous mass of clay, silt, sand, gravel, boulders, and coal. Sand usually comprises most of the material in the unstratified sediments.

Stratified Drift

Stratified drift in the Wyoming Valley is classified as either proglacial sediments, those that were deposited beyond the limits of the glacier as outwash sediments and lake sediments, or ice contact sediments (kame terraces).

Kame terraces

Remnants of kame terraces occur on both sides of the Susquehanna River in the Wyoming Valley and on the north side of the Lackawanna Valley between Scranton and Peckville. The elevation of the upper surface is about 685 feet near Pittston and is about 10 feet less at the lower end of the valley; in the upper end the highest terrace is at 745 feet (Itter, 1938). The terrace on the northwest side of the river is nearly continuous and can be traced from West Pittston to Plymouth (Stop 4). On the southeast side of the river it is discontinuous and poorly exposed. The kame terrace deposits range from 10 to 100 feet in thickness and consist of stratified sand and gravel, with a coarse gravel layer at the top. Locally, erratic boulders and pockets of till are incorporated within the deposits.

These kame terrace deposits are economically valuable as a sand and gravel source throughout northeastern Pennsylvania. In the Wyoming Valley they have been mined nearly to depletion.

Lake sediments

These deposits consist of deltas, moraines, bottom deposits, rafted erratics and thick clay beds that were deposited in a lake that stood at an elevation of about 560 feet.

Sediment was transported from the melting ice to the glacial lake by major streams entering from the Susquehanna River valley and the Lackawanna Valley, and by minor tributary streams along the sides of the Wyoming Valley. As the swift, sediment-laden streams entered the quiet water of the lake their velocity was greatly reduced. The reduction in velocity caused a reduction in their ability to carry sand and gravel and these coarse sediments were deposited at the mouths of the streams as deltas. The finer particles remained in suspension until they reached quieter water where they were deposited on the lake bottom and accumulated to form thick beds of silt and clay (Stop 5). The depositional environments changed from time to time and from place to place so that clay beds alternate with thin beds of very fine sand and silt, medium sand and silt, or coarse sand and gravel. Some of the deposits were eroded away by later down-cutting by the river.

Outwash sediments

Outwash sediments occur as extensive deposits of well-sorted sand and gravel that are primarily found underlying the broad flat plain in the northeastern half of the Wyoming Valley. Their thickness ranges from a fraction of an inch to 30 feet. Good exposures of these deposits can be seen in excavation pits in the valley (Stop 5). The sediments are generally free of silt and clay and some were sorted to the degree that the sands were removed and a clean pebble-size gravel was deposited. "These characteristics, coarseness and a high degree of sorting, are *** features of glacial outwash. They are *** the result of the regimen of glacial rivers (when the glaciers terminus was north of the valley) which commonly have diurnal flood of short duration during the summer. These floods were occasionally augmented by the runoff of heavy rains which fell over the glacier." (Peltier, p. 9, 1949).

Alluvial fan deposits occur along the north side of the valley where the larger tributary streams issue from the ridges and enter the Wyoming Valley. The fans are composed of a mixture of silt, sand, and gravel.

ENVIRONMENTAL PROBLEMS RESULTING FROM THE REMOVAL OF COAL

Man has been engaged in removing coal from the Wyoming-Lackawanna Valley for over 150 years and in the process of mining he has marred the region with waste rock dumped on the surface, with deep gashes, and cast piles from stripping and silt banks.

A large amount of waste rock was brought to the surface with the coal. These waste heaps or culm banks may reach over 100 feet high and present a huge mass of broken rock and coal on which little or no vegetation takes root. At one time there were 150 collieries in the valley, with most of them having an independent waste heap. Many of these culm banks are burning or have burned.

A coalbed is a large mass of combustible fuel. Mining makes oxygen available and all that is required to initiate combustion is a source of heat. In many areas, usually along the lower mountain slopes, "stripping" of the coal has exposed many coalbeds as well as providing convenient refuse dumps. The most common cause of the coal mine or culm bank fires is the practice of burning trash or rubbish in strip pits or near the banks.

Mine and bank fires not only have a demoralizing effect upon the community, but they pose a menace to public health and safety by emitting noxious gases and fumes, endanger surface lands and property, and destroy valuable resources. In the valley there are presently eight underground fires and four burning culm banks. Two underground fires and one burning bank were recently extinguished by State and Federal agencies.

Silt banks, another undersirable environmental feature, developed as a result of processing coal for market. A great quantity of water is used in cleaning and sizing coal, and in the process large amounts of fine dirt and silt are derived that must be returned to the surface streams (a procedure no longer permitted by Pennsylvania's Clean Streams Law, as amended), underground mines, or desilting basins. Formerly, colliery operators dumped much of this refuse directly into the streams. At one time this load was so great that stream channels were filled and exhibited "braided" channels. Later most collieries constructed desilting basins, each covered several acres. These abandoned desilting basins are now being eroded by wind and heavy rainfall.

Mining also affected the topography by causing subsidence. Where little or no effort was made to support the overlying formations mine subsidence has occured in many places. In densely populated areas the coal companies left pillars to support the overlying formations, but some subsidence occurred due to failure of pillar support. Filling of mines with water helped stabilize the pillars in the abandoned mines and consequently reduced subsidence. Pillars are more subject to failure by sloughing above the water than below. Surface subsidence resulting from underground mining has caused loss of life and millions of dollars of damage to buildings, streets, water mains, and sewage lines in the built-up areas. In the Wilkes-Barre and Kingston area it was necessary to construct dikes along the river to protect homes from flood waters. Many of these dikes built for land protection have had to be raised because of subsidence. In addition, subsidence disrupts drainage patterns and permits surface water to penetrate the underground workings more readily. When this water returns to the surface it pollutes the Lackawanna and Susquehanna Rivers.

MINE-WATER HYDROLOGY

Water from surface streams infiltrates underground workings mainly by leakage from streambeds through broken strata overlying the mine openings (Stop 1.). Precipitation and overland runoff enter the mines mainly through surface strippings and crevasses along steeply dipping beds where the surface has caved into voids below. From the points of entry, water flows through the mine workings to underground pools. These pools are bodies of water enclosed vertically between the floor and roof of the mine openings, and horizontally by barrier pillars, other unmined areas of coal and the bedrock structure. Barrier pillars are bodies of unmined coal that are left in each coalbed along the company property lines.

Mining practices with regard to barrier pillars varied greatly prior to enactment of a public law in 1891 establishing and defining the specification for barrier pillars (Ash and others, 1949, p. 9).

Barrier pillars were inadvertently weakened or breached in many mines, and there is no assurance that any one pillar has remained stable. During and after the filling of the mines with water, it is apparent from the elevations of the pools that there is leakage through the barrier pillars. Stable conditions in an operating mine change during filling of a mine and become unstable. Wetting of previously dry surfaces and several hundred feet of hydrostatic head causes minor weaknesses to become pronounced. Collapse often occurs and eventually subsidence many cause local breakings of barriers and of man-made dams in barrier openings.

Generally, all the mines in the valley are interconnected to some degree; however, the pattern of flow between the water-filled mines is extremely complex. Known openings, discussed by Ash (1954), are useful for defining the flow path through most mines, but the effectiveness of the barrier pillars in restricting the movement of the water obviously cannot be evaluated. The movement of water through individual mine pools is generally, in the sequence of flow, from the highest pools north of Scranton to the lowest pools near Nanticoke (Figure 34). Water movement in mid-Wyoming Valley is controlled by pumping from the Delaware-Pine Ridge mine pools to prevent subsidence in the south Wilkes Barre-Parsons area.

REFERENCES CITED

Ash, S. H. (1950), Buried Valley of the Susquehanna River, U. S. Bur. Mines Bull. 494, 27 p. 35 figs.

________ (1954), Barrier pillars in the Wyoming Basin, Northern Field, U. S. Bur. Mines Bull. 538, 251 p.

Ash, S. H. and others (1949), Water pools in Pennsylvania anthracite mines, U. S. Bur. Mines Tech. Paper 727, 78 p.

Hollowell, J. R.(1971), Hydrology of the Pleistocene sediments in the Wyoming Valley, Luzerne County, Pennsylvania, Pa. Geol. Survey, 4th ser., Bull. W-28, 77 p.

Itter, H. A. (1938), The geomorphology of the Wyoming-Lackawanna region, Pa. Geol. Survey, 4th ser., Bull. G-9, 82 p.

Kehn, Thomas M. and others (1966), Geology of the Ransom Quadrangle, Lackawanna, Luzerne, and Wyoming Counties, Pennsylvania, U. S. Geol. Survey Bull. 1213, 81 p.

Peltier, L. C. (1949), Pleistocene terraces of the Susquehanna River, Pennsylvania, Pa. Geol. Survey, 4th ser., Bull. G-23, 198 p.

White, I. C. (1883), The geology of the Susquehanna River region in the six counties of Wyoming, Lackawanna, Luzerne, Columbia, Montour, and Northumberland. Pa. Geol. Survey 2nd, Rept. G-7, 464 p.

ROAD LOG

Saturday, October 9, 1971

Departure from the Treadway Inn, Wilkes-Barre, Pennsylvania, at 8:00 a.m. Field trip will follow the route shown in Figure 35.

Mileage	
0.0	Leave Treadway Inn parking lot. Turn RIGHT onto Pa. 315.
0.1	Exposure on right in Llewellyn Formation. Overlying the Llewellyn, where undisturbed, is glacial till.
0.7	STOP LIGHT.
1.0 to 1.5	Exposure of till which contains glacially eroded coal.
3.3 to 3.5	Exposures in the Llewellyn Formation.
4.6	Underpass under I-81.
4.8	Underpass under Pa. Turnpike.
5.3	Enter I-81 (to Scranton).
6.3	Exposure of till.
7.3	Exposure of Llewellyn Formation.
9.2	Pass Exit 50 of I-81 (to Moosic and Pa. 502).
9.7	Overpass over Pa. Turnpike.
9.9	Exposure of Llewellyn Formation.
10.3 to 10.7	Exposure of Llewellyn Formation showing thin coals.

Mileage

11.6	Pass Exit 51 of I-81.
11.9	Exposure of Llewellyn Formation.
12.0	Exposure showing coal seam on right.
12.3	Exposure of Pottsville Formation.
13.1	Exposure of Pottsville Formation
13.7	Pass Exit 52 to I-81.
14.3	Pass Exit 53 of I-81 (central Scranton Expressway).
14.5	Exposure of Pottsville Formation. On left, Roaring Brook deeply entrenched into Pottsville. Course adopted after glaciation (Itter, 1938, p. 30).
14.9	Pottsville conglomerate on medial strip.
15.7	Llewellyn Formation on left.
16.1	More Llewellyn. On right beautiful automobile graveyard.
16.6	Large silt bank on right. Source of stream pollution.
16.9	Pass Exit 54 of I-81 (to Stroudsburg).
18.1	Bear RIGHT off I-81 at Exit 55E to Pa. 347N (to Throop).
18.7	STOP LIGHT.
19.2	Turn RIGHT off 347N onto Sanderson Street.
19.9	Electric power station. Turn Left. Park in flat area south of station.

STOP 1.

Disappearing Creek and Throop Mine Fire Project. The purpose of this stop is to illustrate the source and magnitude of unnecessary recharge to the underground mine pools. Eddy Creek enters the valley from the east, and at a point just west of the Erie-Lackawanna spur to the Industrial Park it flows north around the stripped area of the project. About halfway around the stripped area the creek disappears underground. The stream channel beyond the stripped area shows little evidence of ever having carried storm runoff. This condition existed since the initial stripping during the 1950's.

Eddy Creek is just one of 27 streams that enter the Lackawanna River valley and cross the coal measures to the Lackawanna River. More than half the streams loose their water into the underground workings mainly by leakage from stream beds through broken strata overlying the mine openings.

Coincident with this stop is the site of the Troop Mine Fire. The restored area has been completely stripped out to extinguish burning coal in the New County and Clark beds. The fire is believed to have started in a partially backfilled strip pit that was used for years as a refuse dump. Burning refuse probably ignited exposed coal pillar remnants in the high wall of the pit. The exploration and excavation were carried out by the U. S. Bureau of Mines under the Appalachian Regional Development Act of 1965. The Commonwealth of Pennsylvania and Lackawanna

County were cooperators. More than 50 boreholes were drilled to determine the nature and extent of the fire. The project was completed in June 1969 after 1.2 million cubic yards had been excavated at a total cost of 1.5 million dollars.

Temperatures obtained from the boreholes drilled to the voids in the New County bed were as high as 1,000°F. Later, a sharp temperature rise recorded in a borehole constructed down to the Clark bed indicated that the fire had spread to the Clark bed. Several of the boreholes remain at the site and are monitored regularly by U. S. Department of Mines' personnel.

Leave the parking area and turn RIGHT on Sanderson Street.

Mileage	
20.7	STOP SIGN. Cross 347N (Cypress Street).
20.8	STOP SIGN. Turn LEFT on 347S (Dunmore Street).
21.4	STOP LIGHT.
21.8	Bear RIGHT to enter I-81.
23.0	On the left is the Marvin Culm Bank that was on fire. It was extinguished in July 1970 by the Commonwealth of Pennsylvania.
23.2	On the left is the Marvin Breaker and an unburned culm bank.
23.6	Pass Exit 56 on I-81.
24.7	Bear RIGHT off I-81 at Exit 57E to U. S. Route 6 (to Carbondale).

Mileage	
25.1	STOP LIGHT. Shopping mall on the right.
25.6	Exposure of till on the left.
26.5	View of the burning Olyphant culm bank on the right. Bank is currently being extinguished by the Commonwealth of Pennsylvania.
27.7	View of unburned culm bank on right.
27.9	Junction with Pa. Route 347.
29.5	Exposure of till on the left.
29.9	Junction with Pa. Route 247. STOP LIGHT.
30.1	STOP LIGHT. More till on left.
30.5	Cast piles from strippings on right.
30.8	Llewellyn Formation on left. Note mine opening.
31.0	Turn RIGHT off Route 6. Enter Archbald Pothole State Park.

STOP 2. Archbald Pothole State Park. For a description of this stop see the brochure enclosed with your guidebook, or provided at the Park. Return to I-81 by same route.

37.4	Bear RIGHT enter I-81 south.
38.2	Stripped area both sides of road for next half mile.
41.5	Exit 51. Bear right and follow I-81S (to Wilkes-Barre).
42.6	Skyline straight ahead on south side of I-81 is dip-slope on Pottsville Formation.

Mileage

44.2	Pass Exit 53. Exposures of the Pottsville Formation.
47.0	Exposure of the Pottsville Formation.
49.1	Exit 50. Bear RIGHT to U. S. Route 11. Follow signs to Moosic and Pa. Route 502. Exposures of the Llewellyn Formation.
50.3	Railroad crossing.
50.4	Junction with Route 502, continue on U. S. 11.
50.8	Turn RIGHT on Spring Street in Moosic (to Old Forge).
51.0	Railroad crossing.
51.1	Homes on left on top of kame terrace. Terrace is pictured and described by Itter (1938, p. 70-71).
51.2	STOP SIGN. Straight ahead behind homes is new sewage-treatment plant serving the Scranton-Moosic area. The first in its history. Turn LEFT on Main Street.
51.3	Bear to the RIGHT across small bridge. Lackawanna River is on the right.
51.7	STOP SIGN. Turn LEFT on Main Street in Old Forge.
51.9	At this street a right turn will take you to the Lackawanna River. Upstream from the bridge, on the left, is the borehole that was drilled into the Old Forge Mine to allow the mine pool to overflow and prevent the basements of

Mileage

homes in Old Forge from being flooded by mine water. The discharge from this 36-inch borehole ranges from 30 to 40 thousand gallons per minute.

52.3 Entering Duryea.

52.8 STOP LIGHT.

53.3 RIGHT turn off Main Street onto dirt lane. Park in area where trucks and heavy equipment are stored.

STOP 3.

Duryea overflow. To reach point of mine-water overflow, walk west from buses along railroad embankment 300 yards past the white house. The Duryea overflow is a natural mine discharge created by the filling of the Seneca mine. The Seneca mine, unlike the mines upgradient, has no underground overflow points capable of transmitting to downgradient mines the volume of water entering the mine from the south (Ash, 1954). Thus the head built up on the pool to a point where it forced the overflow to the surface through the strip pit. There are five other such major discharges in the Lackawanna Valley besides the aforementioned Old Forge Borehole. The overflow ranges from 15,000 to 25,000 gallons per minute, but before construction of the Old Forge Borehole it was more than 30,000 gallons per minute. The overflow began in 1961 soon after the stripped area was filled and restored by the Commonwealth of Pennsylvania. The filling of the pool coincided with the cessation of mining operations in the area.

Return to Main Street. Turn RIGHT toward Pittston.

Mileage	
53.5	Cross over railroad.
53.6	Underpass under railroad.
53.9	Road to the right leads to Coxton Yards, Campbell Ledge, and Ransom. Important geologic work here started with I. C. White (1883) and has since been continued with the most recent completed work of Kehn and others (1966).
55.0	Exposure of the Llewellyn Formation.
55.4	"Y" intersection. Bear LEFT.
55.5	STOP LIGHT. Turn RIGHT on U. S. Route 11S. Cross the Susquehanna River. On right: Susquehanna River Gap and Campbell Ledge.
55.7	Junction with Pa. Route 92N. LEAVE U. S. 11, FOLLOW 92N.
56.2	Railroad crossing.
56.5	Sullivan Trail Breaker on right.
57.0	Bear LEFT off Route 92. Cross railroad, turn LEFT on Slocum Street. Exposure of kame-terrace deposits may be seen all along the north side of this street.
57.7	Exposures of kame deposit. Fox Hill Golf Course is on the hill to the left. This is kame deposit mentioned by Itter (1938, p. 21).
58.0	Exposure of kame terrace on right.
58.3	Beginning grade up to top of alluvial fan.

Mileage

58.6	Source of fan material is the gap on right. (Schooley Street).
58.9	Borrow pit exposing kame terrace showing glacially eroded coal.
59.3	Kame terrace exposed behind homes.
59.4	Kame terrace behind homes.
59.6	Turn RIGHT off Slocum Street into borrow pits in kame-terrace deposits.

STOP 4. Kame-terrace deposits - LUNCH

Exposures of kame-terrace deposits in large borrow pit. Structures seen here include: Fore-set and top-set beds, cross-bedding, till, and collapse structures. Glacially eroded coal accents bedding features. An occasional coal pebble or boulder may be seen in exposure. Because the coal weathers so rapidly, the coal pebbles or boulders do not remain long. The glacially striated bedrock has been recently exposed, but it is rapidly weathering away. One half to three-quarter inch layers of the rock surface are exfoliating.

Return to Slocum Street. Turn RIGHT.

59.7	STOP SIGN. Continue on Slocum Street. Cross alluvial fan next half mile.
60.8	Turn LEFT from Slocum Street onto dirt lane. Proceed 0.1 mile. Park near borrow pit.

Stop 5.

Outwash deposits and sanitary landfill. At this site vast amounts of sand and gravel have been removed from a glacial outwash deposit. Not hampered here by high water table the area provided an extremely good source of sand and gravel. A sanitary landfill occupies the center part of the south pit. It was ordered closed in 1967 by the Pennsylvania Department of Health, because of probable contamination of the underground aquifer. Clay was exposed in pit, however, due to subsequent filling by tailings from sand- and gravel-cleaning operations, the exposures were buried. A recently constructed drainage ditch exposed some clay on the west side of the sanitary landfill. The outwash deposit shows typical bedding, with interbedded coarse sand and gravel layers and a fine-grained layer near the surface. The underlying clay is part of an extensive lake deposit (Hollowell, 1971).

Return to Slocum Street. Turn LEFT

Mileage	
61.9	On the right are kame-terrace deposits and exposures of glacially striated bedrock.
62.5	Turn LEFT onto Dennison Street
62.6	Railroad crossing.
63.0	Mine water-level recording instrument installed in borehole next to small creek.

Mileage

63.2	STOP LIGHT. Wyoming Avenue. Wyoming Avenue runs from Plymouth northeast of West Pittston. Throughout most of its length it represents, on the surface, the property boundary between the underground mines. As required by law (Ash and others, 1949, p. 9), a barrier pillar was left beneath Wyoming Avenue. Complete mining on either side of the barrier pillar subsequently caused surface subsidence. This subsidence may be seen along the avenue. Undulations in the avenue and the sloping of the land away from the avenue is the surface expression of subsidence. Many of the homes along the edge of the avenue are tilted. Those homes away from the avenue, for the most part, were unaffected by the subsidence.
64.0	STOP LIGHT.
64.2	Turn LEFT onto River Street
64.5	On left, sheet piling dike put in by U. S. Army Corps of Engineers to protect homes in low-lying areas of Forty Fort, and added onto at a later date because of mine subsidence.
64.8	Dip in road due to mine subsidence.
65.1	STOP LIGHT. Turn RIGHT onto Rutter Avenue.

Mileage	
65.3	Dike on left, put in after 1936 flood, to prevent flooding of the area by the Susquehanna River.
65.5	STOP LIGHT. Turn LEFT onto Church Street (Forty Fort).
66.1	Road bear to right.
66.3	Road bears right. Straight ahead pumping plant put in to pump sewage and storm runoff into the river during the flood stage.
66.9	STOP LIGHT. Pierce Street. Turn LEFT.
67.2	Bridge over Susquehanna River. Note orange colored riverbed caused by precipitation of Ferric Oxide (Yellowboy). Breaker on left, inactive.
67.5	STOP LIGHT. Luzerne County Courthouse on right.
67.7	STOP LIGHT. Main Street, Wilkes-Barre. City square three blocks to the right.
67.8	STOP LIGHT. Washington Avenue.
67.9	STOP LIGHT. Turn RIGHT onto Pennsylvania Avenue.
68.3	STOP LIGHT. East Market Street
68.5	STOP LIGHT. Turn LEFT onto East Northampton street.
68.6	Railroad tracks. Near here was the Pennsylvania Canal used to ship coal from the anthracite region.
68.9	STOP LIGHT.
69.2	STOP LIGHT. Empire Street.

Mileage

69.5	Underpass under Highway 309. Entering Georgetown.
69.7	Underpass under I-81.
69.9	Exposure of Llewellyn Formation on the right showing steep southward dip.
70.1	Railroad tracks. The southern limit of the Laurel Run mine-fire project. One hundred-fifty homes, formerly making up the Community of Laurel Run, have been removed because gas fumes leaking up through basements from the burning mines below caused explosions and cave-ins, making it dangerous to live in this area.
70.3	Turn LEFT onto dirt road.
70.5	STOP 6.

Laurel Run Mine Fire. Proceed on foot up road on left. It winds up the hill and eventually rejoins East Northampton Street. About 300 yards up the hill proceed about 200 yards east along a small dirt road that crosses an open area. Smoke can be seen in the near distance. This area is the largest surface exposure where extreme heat and smoke can be seen.

The mine fire has been burning in the abandoned Red Ash mine since 1915. The mine is on the slope of the East Mountain of Wyoming Valley about 1 mile southeast from the center of the city of Wilkes-Barre, Luzerne County, Pennsylvania. The mine has a surficial area of 367 acres and a crop line of the lowest bed measuring about 8,000 feet along the north slope of the mountain. The mine is bounded on the east by the abandoned Baltimore mine and on the north and west by the abandoned Hollenback-Empire and Stanton mines.

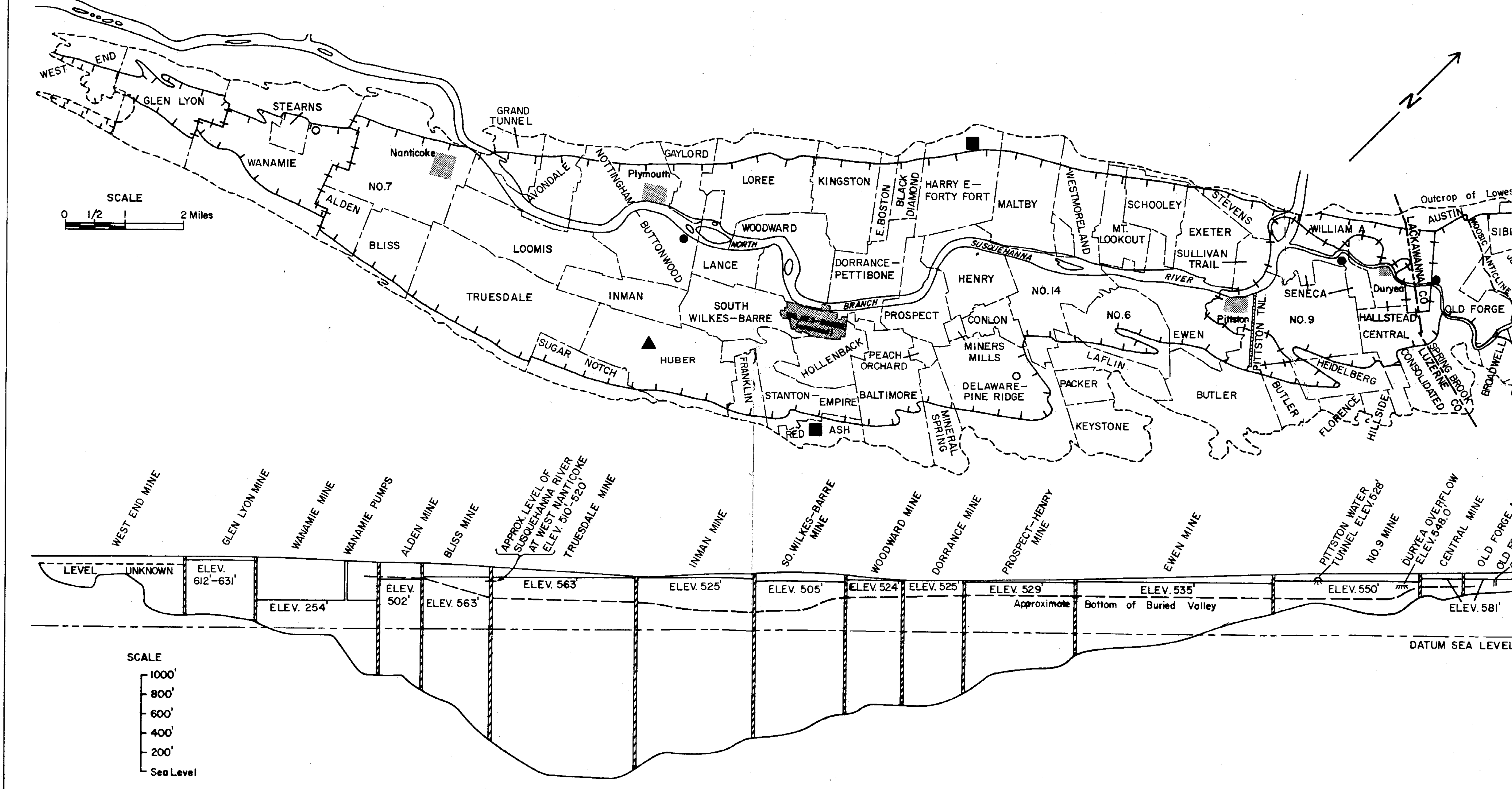
For many years the fire area was believed to be confined to the mined-out workings in the three beds of the Red Ash mine (Bottom Ross - Top and Bottom Red Ash) by barrier pillars and fire seals, but there was some evidence that the fire was about to cross or had already crossed over these barriers at one or more points and threatened to spread to the workings of the Stanton-Empire mine. The spread of the fire to these workings would not only endanger the community of Georgetown, which lies over the workings of the Stanton-Empire Mine, but would pose a much greater danger of ultimately spreading to adjoining abandoned mines that underlie several important communities in Wyoming Valley. The Top Ross bed crops out beyond the fire area and is presently not affected or endangered by the fire.

The danger of the fire spreading northward under Wilkes-Barre stopped with the filling of the mines with water after the Blue Coal Corp. closed their Huber mine. Sand seals were put in by the Pennsylvania Department of Mines to prevent the fire from spreading through the barrier pillars to the east and west. Current work on the project is to reinforce these sand seals and flush and grout under the railroad tracks on the east end. This work is being carried out by the U. S. Department of Mines with Appalachian funds. The cost to excavate the mine fire is prohibitive because of the great depths (300 feet) to which the fire had advanced.

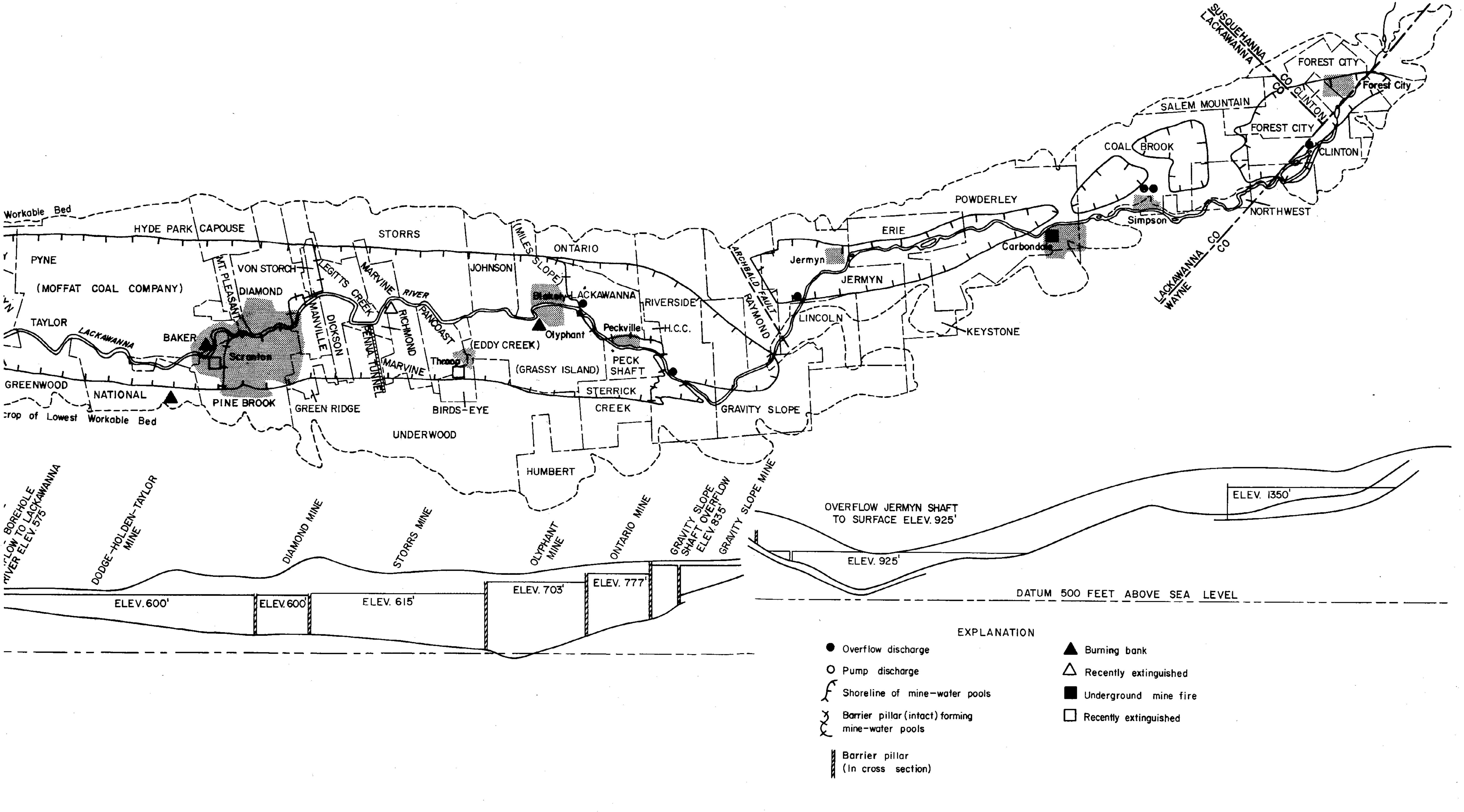
Leave STOP 6 by turning LEFT on dirt lane due west from parking area to return to Northampton Street.

Mileage	
70.7	Open borehole in abandoned street used to test mine fire temperature (recent measurement - 1,000°F).
70.8	Turn RIGHT on Northampton Street.
70.9	Railroad crossing.
71.4	Turn RIGHT on New Street. Follow signs to U. S. Route 309.
71.5	Bear LEFT to Pa. Route 309. Continue on 309 (Spring Street).
73.3	Bear RIGHT. STOP LIGHT to Junction with Pa. Routes 115 and 315.
73.8	STOP LIGHT.
74.1	"Y" Junction, Route 115 and 315 separate. Turn LEFT on Route 315.
74.8	RIGHT turn into Treadway Inn parking lot. END of trip.

Figure 34. Map and Profile Showing Location and Elevation of Mine-water Pool
Also Shows Location of Burning Culm Banks and Underground Fires.



in the Northern Anthracite Field, July 1971,



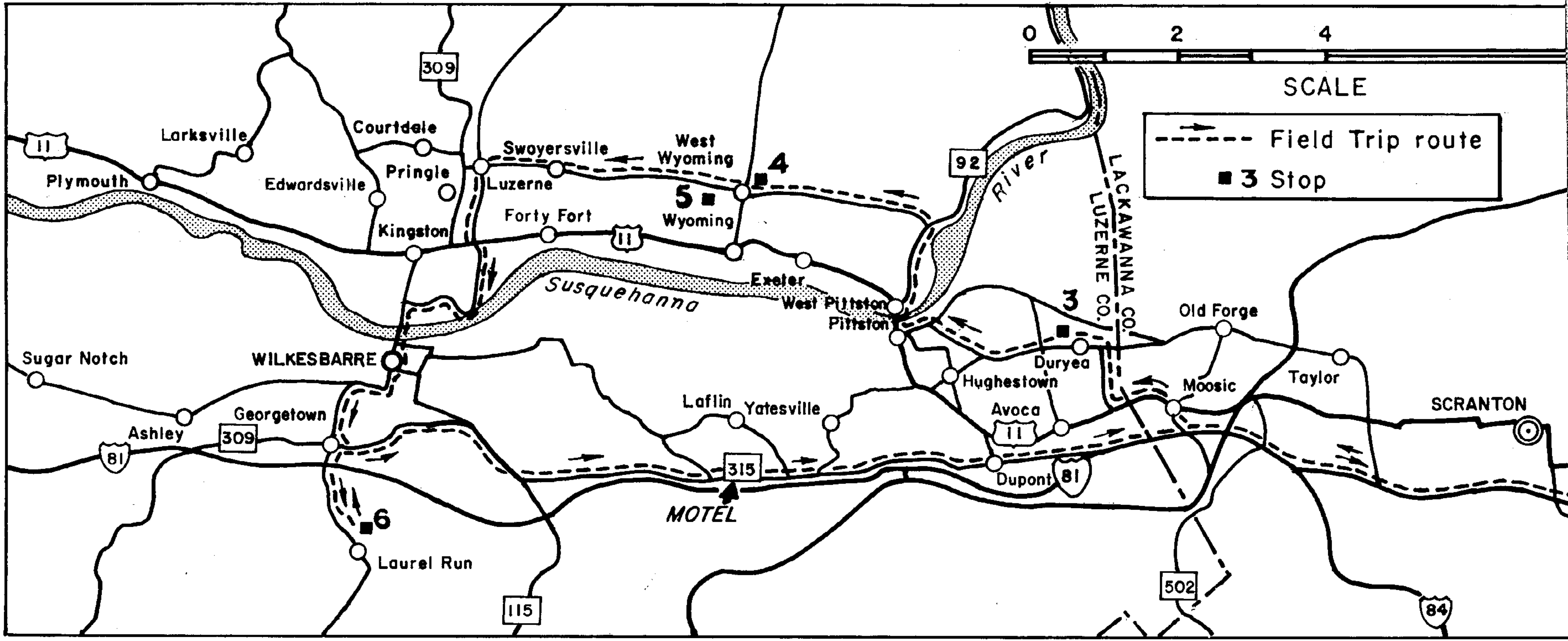
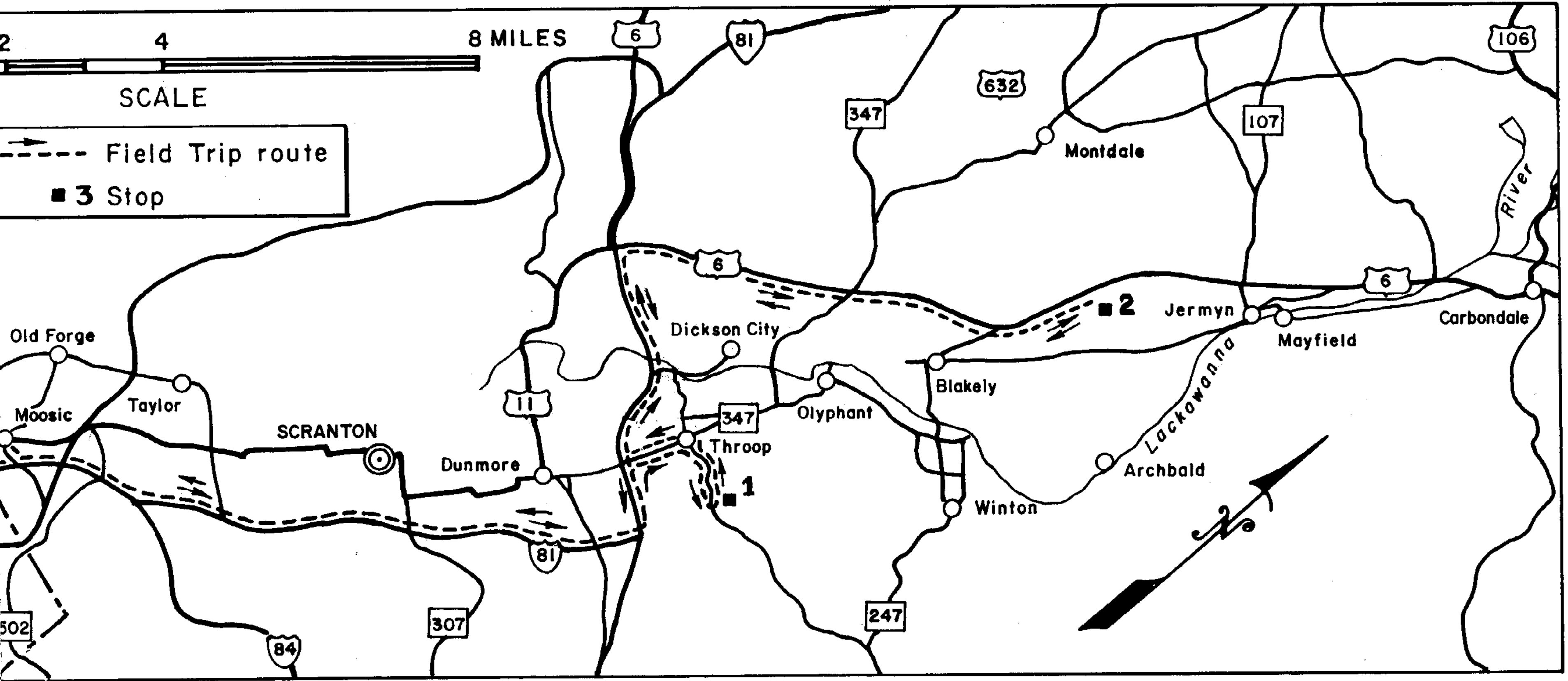


Figure 35. Map of Wyoming-Lackawanna Valley Showing Field Trip Route and Stops.


2
4
8 MILES
SCALE
Field Trip route
■ 3 Stop
6
81
632
347
107
106
Montdale
River
Dickson City
Old Forge
Moosic
Taylor
SCRANTON
Dunmore
11
347
Throop
Olyphant
Blakely
■ 2
Jermyn
Mayfield
Carbondale
Lackawanna
Archbald
Winton
■ 1
81
307
84
502
247
N

stops.