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A NATURAL HISTORY SURVEY OF THE PROPOSED TOCK'S ISLAND RESERVOIR NATIONAL RECREATION AREA

(This report is NOT FOR PUBLICATION: It was prepared for the specific purpose of providing personnel of The National Park Service with a compendium of material that presumably will be of some use in planning the recreation area and in developing files for subsequent use in interpretation services. The materials were derived mainly from available publications and supplemented by limited field studies. In no case does the originator consider the result sufficiently definitive, exhaustive, or innovative for publication nor to serve purposes beyond that of the original charge by The National Park Service. This copy is made available to a responsible member of the scientific community who has indicated an interest in participating in the planning and utilization of the Recreation Area through a prospective Scientific Advisory Council that may be developed to advise the Park Service. The Water Resources Association of the Delaware River Basin has provided the funds for making these copies, with the cooperation of the National Park Service and the originators of the report materials. It is understood that this copy will be used in the interest of the Scientific Advisory Counil and The National Park Service).

GEOLOGY:

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SEPARATES: For geologic reference, the map submitted in manuscript form was derived principally from published maps of Pennsylvania and New Jersey, including the map accompanying the U. S. Army Engineer District, Philadelphia, Delaware River Basin Report, December 1960, Rev. 1961.

INTRODUCTION

A. Purpose of the Survey

Companion bills (H.R. 12246-S. 3530) were introduced in the last session of Congress and will be reintroduced in the next session to authorize the Tock's Island National Recreation Area. The basis for such legislation was established by the portions of the Delaware River Basin Report (U.S. Army, Corps of Engineers, December, 1960) prepared by the National Park Service with the cooperation of other Federal and State agencies. These investigations developed not only the economic and social values of the recreation potential of the area, but also identified ten sites or use "areas" comprising some 40,000 acres in addition to the approximately 12,000 acres of water surface of the reservoir. Specifications of uses contemplated in these areas are clearly based upon considerable knowledge of the physical characteristics and natural history.

Between the stage at which the National Recreation Area was seriously proposed and its realization and operation, much additional investigation will be required. This report is one part of the investigation. Its purpose is to set forth the present state of knowledge of the geology, flora, and fauna of the area.

The prospective uses of this report to our knowledge are several. Some of the material may be used in the development of preliminary information brochures. Presumably the data will be useful in preliminary designs for the uses of the Recreation Area. Finally, the materials will be available to future interpretation personnel for use in the operations of the Recreation Area.

B. The Study Area

The proposed Delaware Valley National Recreation Area will be centered on the reservoir created by the Tock's Island Dam. Although the exact location of the dam has not been defined, it will be approximately five miles above Delaware Water Gap. The long-term storage pool will be stabilized near elevation 410 feet above MSL. The backwater will therefore extend almost to Matamoras, a distance of over 30 miles. The short-term flood storage pool will raise the water level to 428 feet, with backwater extending to just above Matamoras and Port Jervis on the Delaware and considerably above Port Jervis on the Neversink. There also will be an extensive backwater up Flat Brook and a lesser one on Bush Kill.

The Recreation Area should certainly encompass the reservoir and its shoreline. Fortunately, considerations have extended well beyond the thought of confining the area to immediate shoreline. Rather, the preliminary studies have included the Worthington Tract and contiguous lands extending south and southeast of the river to the south flanks of Kittatinny Mountain. A sufficient part of Kittatinny Mountain on the west side of the River is included so that Delaware Water Gap itself is encompassed in the proposed area.

Similarly, from Tock's Island northward, preliminary plans are concerned with zones rarely less than one-half mile, and normally one to two miles wide on both sides of the reservoir. These zones place all of the banks in a variety of forms from low and gently sloping to steep cliffs, and all of the approaches to the reservoir, within the Recreation Area. In general, the area outlined coincides on the west with the edge of the Pocono Plateau, and on the east with the first or second rises of the Valley and Ridge province, which lie between the river and the summits of the New Jersey highlands.

The essence of these physiographic relations is illustrated by the several photographs of Plate I. These were taken from a single position at the crest of the Milford Cliffs, on the west side of the valley. Photo A is directed southwest, parallel to the course of the river. The notch in the farthest ridge is Delaware Water Gap. The picture particularly illustrates the prominence of the escarpment of the edge of the Pocono Plateau forming the west valley wall. Not visible in the picture is the major enclave in the escarpment by the valley of the Bush Kill, opposite the identifiable Wallpack Bend reach of the River.

Photos B and C, taken toward the south and southeast respectively, show the striking difference in physical features on the New Jersey side. As noted, these are the successive ridges and valleys that lie between the Delaware and the New Jersey Highlands on the horizon. Photo D, taken to the northeast, directly upstream, suggests the continuation of the basic differences in physical conditions between the Pennsylvania and New Jersey sides of the valley.

C. Scope of Report

The purpose of summarizing the present "state of knowledge" in several areas of natural science makes it inevitable that the materials of this report are not uniform in character. In a few cases the known information is comparatively complete at least for the immediate uses of the study. For most of the topics, the known information, including that developed by the limited field work that could be undertaken in this investigation, consists of materials that are distinctly reconnaissance in scope and content.

Chapter II, Physiography, presents a reasonably adequate and explicit description of the terrain. Chapter III is concerned with the major aspects of the geology, for which the extant information, although largely developed some time ago, is comprehensive.

Chapters IV and VI are concerned with the biota. In particular, Chapter IV treats the dominant plant communities and their distribution, while Chapter VI gives annotated checklists of the flora and fauna.

Chapter V, pertaining to both geologic features and the plant communities, identifies areas that have special natural interest.

It is to be expected that more detailed work will modify the details of plant communities, expand the annotated lists, and very

likely also expand the list of areas having particular interest. Similarly, there are a number of problems in the geology that will deserve further attention. These considerations are elaborated in Chapter VII.

Finally, Chapter VIII provides a topical bibliography, which includes all of the known major contributions. Where pertinent and useful, the citations have been referred to in the text materials. Maps and miscellaneous illustrative materials are included in the report as separates.

PHYSIOGRAPHY

From Port Jervis, New York, to the Delaware Water Gap, the course of the Delaware River carries it through a region of uncorrupted beauty and primitive charm. The green valleys and ridges of the Appalachian and adjacent Pocono Plateau are world famous. In large part, the natural splendor of the region is due to the uniqueness of its land forms.

The physiographic character of the Delaware River Valley is largely controlled by two natural factors, both related to geologic events of the past. These are 1) the structures of the underlying bedrock, and 2) the effects of Pleistocene glaciation in this region.

The Appalachian Mountain chain which extends from Alabama to Nova Scotia crosses Pennsylvania in a slightly arcuate belt which generally follows a northeast - southwest trend. The layered rocks of this region have been deformed into a series of folds or convolutions, so that any given layer bears some resemblance to a corrugated tin sheet. Since all of the successive layers of rock are folded thinly, the geologic column resembles a stack of corrugated sheets, neatly fit together and piled one sheet on top of another. The whole has been subjected to an exceedingly long period of erosion and so the present day topography has been formed as a result of wearing down of the stack of corrugated layers. Some of the layers are harder and more resistant to erosion than others -- such layers, therefore, have not been worn down as rapidly as those which weather and erode more easily. The hard layers form ridges, the softer layers form valleys. Because of the nature of the folds or corrugations, the ridges and valleys are elongate and parallel. Consequently, the region characterized by such land forms is known physiographically as the Valley and Ridge Province.

The area northwest of the Valley and Ridge Province, the so-called Appalachian Plateau, is underlain by rocks which are generally flat lying. Erosion of this area has resulted in land forms of quite a different type. The original drainage pattern of dendritic streams has been enlarged, the stream valleys have deepened into steep sided canyons, and the interstream areas remain as rounded highlands. In eastern Pennsylvania, the Appalachian Plateau is referred to as the Pocono Plateau (or popularly, but incorrectly, as the Pocono Mountains).

From Port Jervis, New York to Bushkill, Pennsylvania (nearly the entire area covered in this report) the Delaware River flows from northeast to southwest along the boundary between the Pocono Plateau on the Pennsylvania side of the river, and the Valley and Ridge Province on the New Jersey side. High cliffs on the west side of the river mark the very edge of the Plateau.

At Bushkill, the Delaware River makes a peculiar looping bend, briefly flowing northeast, then again reversing course to flow southwest (see map). This bend -- known as Wallpack Bend -- is another uniquely fine example of the control on the course of the river exerted by the structure of the bedrock. At this locality,

the river meets Godfrey Ridge, a typically northeast - southwest trending ridge in the Valley and Ridge Province. The main course of the river from this point is through the similarly trending Cherry Valley on the southeast side of Godfrey Ridge. To follow this course, the river loops around the north edge of the ridge. It is possible that at some earlier time, the course of the Delaware actually was along the west side of Godfrey Ridge -- extensive deposits of Quaternary Alluvium, largely glacial but partly stream alluvium, occur in this area. Possibly the river was forced to change its course as a result of glacial till having been deposited in the old river bed during the last period of Pleistocene ice advance.

At Minisink Hills, Pennsylvania, the Delaware sharply changes its course from one parallel to the strike of the bedrock to a southward direction across the strike of the bedrock. From Minisink Hills, the river passes from Cherry Valley through the Delaware Water Gap and thence continues southeast across the slate belt. The peculiar behavior of the river in thus cutting through Kittatinny Ridge rather than continuing southwest along the back of the ridge gives us a clue as to the ancient history of the River. The Delaware must have been in existence before the final stages of uplift of the Appalachians, and its course in the vicinity of Delaware Water Gap must have been essentially similar to that we see today. As the uplift of the land proceeded, the flow of the river was strong enough to allow it to maintain its original course. Thus, the Delaware Water Gap was cut through Kittatinny Ridge. The Lehigh River, The Schuylkill, the Susquehanna, and others in like fashion cut gaps in Kittatinny Ridge further to the west.

At least two of the great continental ice sheets of the Pleistocene Epoch reached this area. Although here, near the most southerly edge of the sheets, the ice was comparatively thin, the glaciers left their effects, modifying the topography largely by dumping quantities of unconsolidated glacial till over the landscape. Remnants of till and glacial outwash still exist in this area. Many of the lakes in the Poconos also have a glacial origin. This subject will be discussed in greater detail in Chapter III, Section A: Stratigraphy.

The processes which shape the land surface are still in operation. Since the retreat of the last glacier about 11,000 years ago, the whole area has been subject to continued weathering and erosion. Soils developed on rock surfaces laid bare by moving, rasping ice sheets. New tributaries drained the uplands, further dissecting and modifying the topography. Most of the smaller streams in the area are of this sort. In the Valley and Ridge Province, the streams draining the ridges flow directly downhill into the streams in the valley -- the whole creating a trellis-like pattern referred to as trellis drainage. The streams on the north slope of Kittatinny Ridge are particularly good examples of this type drainage.

CHAPTER III

GEOLOGY

Section A	Stratigraphy	J. Stewart Nagle
Section B	Systematic Paleontology	J. Stewart Nagle
Section C	Structural Geology	Paul B. Myers, Jr.
Section D	Historical Geology	J. Donald Ryan
Section E	Economic Geology	Richmond E. Myers
[Section F	Geologic Map	J. Stewart Nagle] OMITTED
Section G	Engineering Problems	George R. Jenkins

STRATIGRAPHY

INTRODUCTION

The procession of geologic events which in the past have acted upon the earth is revealed only through careful study of successive layers of rock which have formed during the long history of the planet. This is the science of stratigraphy.

The Delaware River has cut its valley through one of the most complete stratigraphic sections in North America. From its headwaters to Delaware Bay, the river flows over rocks which represent every geologic period on the geologic time scale except the Jurassic. The stratigraphic section between the Delaware Water Gap and Port Jervis is particularly important. In this area, the rocks range in age from Late Ordovician to Middle Devonian. Pleistocene glacial deposits and Recent river alluvium in places cover the older rocks. Many of the formations are abundantly fossiliferous, providing the student of geology or even the casual observer with a record of life as it existed in the dim and ancient past.

The sediments forming the rocks of this area were deposited under somewhat unique conditions. Preceeding the development of the Appalachian Mountains at the close of the Paleozoic Era, an elongate trench or furrow, called a geosyncline, apparently developed at the site of the present mountains. The Palaeozoic rocks of the Appalachian region were formed from sediments which were deposited in the geosyncline. At times the trench was quite deep, and the sediments accumulated hundreds of feet under water. At other times, the trench was filled or nearly filled with sediments, and sedimentation was under shallow water conditions.

In this section of the report, the author systematically describes the various rock units which are exposed in the area of study. The units described are those which appear on the geologic map (Plate 1).

The rocks of the Silurian System have been extensively studied by Swartz and Swartz (1931) and those of the Devonian System by Willard (1939). Pleistocene deposits in this area have been largely neglected.

DEVONIAN SYSTEM
Lower Devonian

Helderberg Group

The Helderberg group include four lithologically somewhat similar formations: the basal Coeymans formation, the New Scotland limestone, the Becraft limestone, and uppermost, the Port Ewen shale. Vanuxem named the Helderberg group in 1842 but his usage was more extensive. Ulrich (1912) and Swartz (1938) revised the

terminology to its present state. In the Delaware River Valley, the aggregate thickness of the four formations is 325 to 350 feet.

The Coeymans formation has two members: a lower member of dull gray, coarse, crinoidal limestone about 60 feet thick, and an upper member of gray, calcite-cememted, quartzose sandstone about 20 feet thick. These are succeeded by 80 feet of massively-bedded gray, slightly cherty limestone and limy shale comprising the New Scotland limestone. The Becraft limestone consists of light gray, massively bedded, crinoidal limestone, generally about 20 feet thick. The Port Ewen shale, ranging in thickness from 150 to 175 feet, is made up of gray limy shale with an impure cherty limestone at the base.

Helderberg rocks usually are richly fossiliferous. Brachiopods, crinoids, and bryozoa are especially abundant. Helderberg lithologies and fossil remains suggest a shallow water marine environment of deposition.

All four formations of the Helderberg group (and some younger formations) are well exposed along the abandoned railroad cut on the east bank of Brodhead Creek at Minisink Hills. Fossils can be collected from each of the formations at this locality.

Good exposures of the sandstone member of the Coeymans formation, containing abundant fossil brachiopods, are located in a roadcut about one-fourth mile south of Wallpack Bend (see map).

The New Scotland is well exposed about 300 feet northeast of the intersection of the River Road and a small country road just west of Shawnee on the Delaware (see map). This outcrop contains at least 8 species of brachiopods and several species of bryozoa.

ORDOVICIAN SYSTEM

Upper Ordovician

Martinsburg Formation

The Martinsburg formation, named by Mather in 1840, is an extensive sequence of interbedded gray shale or slate and graywacke sandstone. It forms an outcrop belt from 3 to 15 miles wide which extends for a distance of 400 miles throughout the Central Appalachian from Virginia through Maryland, Pennsylvania, and New Jersey to New York. In the area of study, the Martinsburg crops out along the southern slope of Kittatinny Ridge, south of Delaware Water Gap, where it is overlain unconformably by the coarse sandstones and conglomerates of the Silurian Shawangunk formation. The thickness of the Martinsburg is difficult to establish because of the complex nature of its structure. The most reasonable estimate seems to be that of Mackenzie (1961) who reported 3000 (?) feet.

In the Delaware Valley, the Martinsburg is composed primarily of dark gray to black slates, grading upward into interbedded slate and lenticular graywacke sandstone. Willard (1939) refers to the

graywacke in the upper part of the sequence as the Shochary sandstone. The Shochary sandstone does not appear in the Martinsburg along Kittatinny Ridge; either the sandstones were not deposited at this locality or they were removed by erosion before the deposition of the Shawangunk conglomerates and sandstone.

Fossils generally are not abundant in the Martinsburg slates and none were found by the author in the area of study.

A wide diversity of sedimentary structures has been reported in the Martinsburg formation (Van Houton, 1954; McBride, 1962). These include graded bedding, small scale cross-bedding, convolute bedding, groove casts, flute casts, and furrow casts. According to the authors cited above, these structures indicate deposition by means of turbidity currents in deep water.

Superimposed on the sediments are folds, cleavage, and other kinds of deformational structures -- these will be described in detail in Chapter III, Section C.

Most recent authors (Pettijohn, 1957; Van Houton, 1954; McBride, 1962) refer to sediments of the Martinsburg type as flysch deposits. Flysch deposits generally are thought to be representative of deposition under geosynclinal conditions.

SILURIAN SYSTEM
Lower Silurian
(Medinan Series)

Shawangunk Formation

The Shawangunk formation, named by Mather in 1840, comprises the entire Lower Silurian section in this area. Thick, ledge-forming, greenish-gray to gray conglomerates and lithic sandstones are interbedded with generally thin, dark gray shales. The formation is considerably more resistant to erosion than adjacent rocks and generally the bedding is nearly vertical; consequently the main belt of outcrop forms an elongate highland -- Kittatinny Ridge -- the most easterly major ridge of the Appalachian Ridge and Valley province. Throughout its extent in New Jersey and Pennsylvania, Kittatinny Ridge is underlain by Lower Silurian coarse-grained sandstones and conglomerates of more or less similar lithology. West of the Delaware Water Gap, rocks equivalent to the Shawangunk are placed in two formations: the Tuscarora formation, underlying, and the Clinton formation, overlying. The famous water gaps of Kittatinny Ridge (see Chapter II) are cut through these Lower Silurian rocks.

In the area of study, the Shawangunk formation is estimated to be about 1800 feet thick. At the Water Gap it can be divided into three stratigraphic units, each about 600 feet thick: a basal unit consisting predominantly of thick greenish-gray lithic sandstone and conglomerates with thin partings of dark gray argillite,

a middle unit of interbedded argillite and slabby sandstone beds, and an upper unit of thick sandstones and conglomerates. The upper unit grades into the red sandstones and shales of the overlying Bloomsburg formation. It is not known how far beyond the region of study this tripartite division of the Shawangunk can be recognized.

Cross beds, worm tubes, (Arthrophycus allegheneasis), and in places ripple marks are common in Shawangunk sandstones. Sparse eurypterid remains have been found in some of the shale beds. These features suggest a shallow water marine origin.

Nearly the entire thickness of the Shawangunk formation is well exposed in the Delaware Water Gap.

Middle Silurian
(Niagaran Series)

Bloomsburg Formation

A thick sequence of dull to deep red sandstones, siltstones, and shales with some thin layers of bright green shale (in places, calcareous) or sandstone overlies the coarse clastics of the Lower Silurian throughout eastern Pennsylvania and New Jersey. I.C. White (1883) referred to this sequence as the Bloomsburg red beds.

In the Delaware Valley, the Bloomsburg formation generally consists of rock units as described above. Because the top of the formation is not exposed in this area, the exact thickness is not known. Mackenzie's (1961) estimate of 600 feet seems reasonable.

The most common sedimentary structures are cross-beds in the sandstones and ripple marks in siltstones and shales.

Fossils, though rare, appear to be more abundant in the Bloomsburg than in most deposits of red beds. Hoskins (1961) has described foraminifera, bryozoa, brachiopods, molluscs, ostracods, and crinoids from the Bloomsbrug. Fish scales have been reported by Beerbower and Hait (1959). The author has collected brachiopods (those in calcareous layers) and ostracods in the area of study.

According to Hoskins, the various fossils suggest deposition under nearshore brackish water conditions. Others have suggested a continental origin. Possibly the Bloomsburg represents an ancient delta.

Some of the best folds in the area can be seen in outcrops of the Bloomsburg. The Bloomsburg is also characterized almost everywhere by the presence of an easily identified, but rude fracture cleavage oriented nearly perpendicular to bedding.

The best exposures of these rocks are located 1) immediately north of the Water Gap on either side of the river, and 2) on the west slope along the road between Milbrook and Flatbrookville.

Upper Silurian
(Cayugan Series)

Poxono Island Shale and Bossardsville Limestone

These two formations, though lithologically different, are mapped as a single unit since each is thin, exposures are poor, and there is essentially no difference in their respective modes of topographic expression. Both formations were named by I.C. White in 1883.

The Poxono Island shale, underlying the Bossardsville, consists of variegated buff and greenish-gray calcareous shales. The formation probably is stratigraphically equivalent to the lithologically similar Wills Creek shale of central and southern Pennsylvania and Maryland. Willard (oral communication) estimates the thickness of the formation at 215 (?) feet.

The Bossardsville limestone is a sequence of gray to buff thinly bedded ("ribbon") limestones with dark gray shale partings. It is probably stratigraphically equivalent to the more widespread Tonoloway limestone of southern Pennsylvania and Maryland.

The Poxono Island is generally barren of fossils except for ostracods. The ostracod Leperditia is common in the Bossardsville. Mudcracks are found in both but are especially well-developed in the Bossardsville. The two units are considered to be of shallow water marine origin.

The Poxono Island shale and the Bossardsville limestone underlie the Delaware River and its floodplain in the vicinity of Wallpack Bend. The bluffs on the north bank of the Delaware River just opposite Poxono Island contain the only good exposures of the Poxono Island shale in the area. Outcrops of the Bossardsville limestone are located on the River Road about one-fourth mile south of Shawnee on the Delaware.

Keyser Group

This group, named by C.K. Swartz in 1910, consists of three formations, each usually poorly exposed and offering little in the way of topographic expression. Consequently, the three formations have been mapped undifferentiated.

In the Delaware Valley, the Keyser consists of the Decker formation (varying from 20 to 90 feet in thickness), the Manlius limestone (about 30 feet thick), and the Rondout limestone (about 30 feet thick). The Keyser group can be widely traced throughout central Pennsylvania and Maryland but outside of eastern Pennsylvania is lithologically dissimilar to the Delaware Valley section.

All three formations are calcareous. The basal Decker formation consists of thickly bedded, fine grained, gray calcareous sandstone and impure limestone, the whole tending to weather brown.

The overlying Rondout limestone is composed of thinly laminated, argillaceous, blue-gray limestone and at least one dolomite bed. Finely crystalline, thickly bedded, dark blue limestone comprises the Manlius limestone, the youngest formation in the Keyser group.

Abundant fossil brachiopods, corals, cystoids, bryozoa, and molluscs, and a few trilobites and ostracods have been reported from the Keyser group. A list of the genera collected by the author is included in Section B of this chapter.

The lithology of the Keyser group and the fossil fauna clearly indicates a shallow water marine origin.

Several excellent exposures of Keyser rocks are found in the area of study. The entire sequence is exposed in the Nearpass Quarry about one and one-half miles south of Port Jervis, New York, and along the River Road south of Shawnee on the Delaware, beginning at the edge of town and continuing for a distance of about one-third mile. Along the same road just west of DePew Island at the base of the hill, good exposures of fossiliferous Decker formation are found; slightly beyond and uphill, an exposure of the Rondout limestone contains abundant fossils of the ostracod Leperditia.

Oriskany Group

This moderately thick sequence of orthoquartzites was named the Oriskany sandstone by Vanuxem in 1842. Generally the Oriskany forms low ridges throughout the Appalachian Valley and Ridge Province. In southern Pennsylvania, Maryland, and West Virginia, the Oriskany is extensively quarried as a source for glass sand.

The Oriskany in the proposed National Recreational Area is more calcareous than usual, grading from 120 feet of calcareous orthoquartzite and arenaceous limestone near Stroudsburg to 150 feet of cherty siliceous limestone near Port Jervis. With the increase in limestone comes a decrease in erosion resistance, so the same formation which underlies Godfrey Ridge near Stroudsburg underlies the valley east of Port Jervis. Contacts here are less well defined than elsewhere as limestone deposition was not sharply interrupted but rather, was continuous. The thickness of the Oriskany in the Delaware Valley is about 120 feet.

Fossils are common, large, and distinctive, usually enabling one to readily identify the formation. The assemblage containing Costispirifer arenosus, Acrospirifer murchisoni, and Hipparionyx proximus is recognized as Oriskany throughout the east.

Sedimentary structures such as flow marks, channel markings, and cross beds are sometimes observed in the sandstones. Generally, however, the Oriskany is massive and structureless.

The origin of the Oriskany is not completely understood. Un-

doubtedly, the sands were deposited under marine, shallow water shelf conditions, but it is difficult to assign a cause for the accumulation of such an extremely pure deposit of quartz sand.

Good exposures of Oriskany sandstones are located 1) along the abandoned railroad tracks on the east side of Brodhead Creek about one-fourth mile west of Minisink Hills, and 2) along the road between Dingman's Ferry and Layton, New Jersey about two and one-half miles due east of the toll bridge.

Middle Devonian

Onondaga Group

In eastern Pennsylvania and adjacent parts of New Jersey, the Onondaga group has generally been described as consisting of two formations, the Esopus shale underlying, and the Buttermilk Falls limestone overlying (Willard, 1939; Jones and Cate, 1957). Recently, Johnson and Willard (1957) proposed that about 25 feet of limy shale forming a gradational zone between the two formations should be assigned to the Schoharie formation. The Esopus was described as 250 feet of black shale, the Schoharie as 25 feet of limy shale characterized by the presence of abundant crinoid columnals, and the Buttermilk Falls as about 200 feet of cherty limestone. During the course of the present study -- possibly because outcrops are sparse -- the author was unable to substantiate the presence of the Schoharie defined as above as a mappable lithologic unit. Consequently, the Onondaga is herein defined as consisting of two formations: the Esopus shale and the Buttermilk Falls limestone.

The Esopus shale was named by Darton in 1894 for exposures in New York state of what had been known primarily as the Cauda-galli grit (Vanuxem, 1842). In the Delaware Valley, the Esopus is generally a dark gray gritty shale or slate. The formation is almost always characterized by the presence of a well-developed flow cleavage which tends to very nearly obscure bedding and other sedimentary structures. Fossils are fairly abundant, brachiopods being especially common. The Esopus shale is quite resistant to weathering and erosion and thus forms Godfrey Ridge.

Willard (1939) named the Buttermilk Falls formation after exposures at Buttermilk Falls on Marshall Creek in Monroe County, Pennsylvania. The formation consists of massive dark blue-gray cherty limestones. Chert occurs in bases or layers, generally two or three inches thick, or in nodules up to one foot in diameter. Fossil brachiopods and crinoid columnals are common, especially in layers where chert nodules are absent.

Both formations are considered to be of marine origin. Excellent exposures of the Esopus shale are located 1) on the north slope of Godfrey Ridge along Route 611, 2) in the railroad cut along Brodhead Creek west of Minisink Hills, and 3) in a small cut along the road between Dingman's Ferry and Layton, New Jersey, about two and one-quarter miles east of the toll bridge.

Especially good outcrops of the Buttermilk Falls occur 1) along the south side of highway 209 between Marshall's Creek and Oak Grove, 2) along the old mine road west of Flatbrookville, and 3) along the river bank and hillside just west of the toll bridge at Montague, New Jersey.

Hamilton Group

The Hamilton group in this area consists of two formations: the Marcellus formation below, and the Mahantango formation, above.

The Marcellus formation, named by Hall in 1839, is a thick sequence of dark gray to black shale cropping out -- in general -- in a narrow belt in the Valley and Ridge Province from Maryland to New York. In the Delaware Valley, its thickness is estimated by Willard at 800 to 900 feet. The lithology of the Marcellus is everywhere rather uniform, varying only slightly from place to place in color and grain size. Bedding commonly is obscured by cleavage but where visible generally consists of fine laminations. "Pencil structure" (i.e. a tendency for the rock to break into elongate pencil-like slivers) is fairly common in weathered outcrops due to intersection of cleavage and bedding. Some outcrops are massive and break along conchoidal surfaces.

The Mahantango formation, named by Willard in 1939, is lithologically somewhat similar to the Marcellus formation, consisting of dark gray shale, siltstone, and fine-grained sandstone. According to Willard (1939), the Mahantango is 1350 feet thick as measured at Brodhead Creek.

Both formations are characterized by zones in which fossils are numerous. The Marcellus is quite fossiliferous in the vicinity of Stroudsburg, Pennsylvania — the brachiopod *Leiorynchus limitare* and the pteropod *Styolina* are especially abundant. The most important fossil zone in the Mahantango, located approximately in the middle of the formation, is the so-called Centerfield coral zone which can be traced laterally from the Delaware River at least as far west as the Lehigh River. The Centerfield zone contains a very extensive fauna in which horn corals, bryozoa, crinoids, and brachiopods are most abundant. It has been called an ancient coral reef but this interpretation is doubtful. A second noteworthy fossil zone in the Mahantango occurs at the top of the formation; the brachiopod *Pustulina pustulosa* is the dominant form in this zone.

The origin of this dominantly fine-grained clastic sequence of marine rocks is seemingly comparable to that of the Ordovician Martinsburg shales. It probably marks a period during which there was a return to the relatively deep water geosynclinal conditions.

One of the best exposures of the Marcellus formation in this area is located at the intersection of routes 206 and 209 west of the toll bridge at Milford, Pennsylvania. The Mahantango is exceptionally well exposed along the high cliffs on the north side of the Delaware River between Bushkill and Matamoras.

Portage Group

In the area of study, the Portage group is represented by the basal Trimmers Rock sandstone, consisting of about 1500 feet of gray to brown, flaggy, fossiliferous sandstone. The Trimmers Rock grades upward into the Delaware River Flags just north of the limit of the geologic map.

Hall (1840) named the Portage group for rocks exposed in New York. The term Trimmers Rock was introduced by Willard in 1935.

Trimmers Rock sandstones generally are of the lithic graywacke type (i.e., composed of angular rock fragments, quartz, and feldspar in a chlorite matrix). Graded bedding, flute casts, and other structures characteristic of turbidities are common. The Trimmers Rock can be classified as part of the Devonian geosynclinal sequence.

A good exposure of the Trimmers Rock occurs in the roadcut at Unity Lodge just west of Bushkill, Pennsylvania.

QUATERNARY
Pleistocene and Recent

General

Surficial alluvial deposits of unconsolidated sand, silt, and gravel cover much of the bedrock in this area. These deposits are of two types: 1) glacial drift related to the great continental ice sheets which, during parts of the Pleistocene Epoch, covered much of North America and 2) stream alluvium on the river bottoms and flood plains of the Delaware and its tributaries.

Pleistocene glacial features

Evidence for glaciation is of two kinds -- depositional and erosional. Consequently, in this section both kinds of features will be described.

During the Pleistocene Epoch (a period of about 1,000,000 years duration which terminated about 11,000 years ago) vast ice sheets formed on the northern continents and on the highlands of continents south of the equator. This period of earth history is particularly important because it is now generally believed that it was during the Pleistocene that man, *Homo sapiens*, evolved.

Careful study of the superposition and degree of weathering of glacial deposits indicate that four main stages of ice advance can be recognized. Glacial deposits formed during the last two stages -- Illinoisan, the older; and Wisconsin, the younger -- can be recognized in the Delaware Valley. Most of the glacial deposits and associated erosional features in the area of the proposed National Park belong to the younger stage -- the Wisconsin. The older Illinoisan deposits are more important south of Kittatinny Ridge. In either case the region in the general vicinity of

Delaware Water Gap probably was quite close to the edge of the ice sheet. Excepting outwash, no glacial deposits are recognized south of Riegelsville, Pennsylvania.

In the area of study, the direction of ice movement apparently was structurally controlled (Ward, 1934). The glaciers moved along the valleys and even over the ridges from northeast to southwest, producing linear erosion features following this direction. Erosional features include roches moutonneé, glacial striae, scour cliffs, and general streamlining of the topography.

Streamlining is espcially well shown on the Lake Maskenozha 7½ minute quadrangle. Nearly all of the hills are greatly elongated northeast to southwest, and many small valleys in the area contain glacially scoured lakes.

Soil removal is especially evident on the Pocono Plateau area. Shales are exposed in small elongated domes several feet high and up to 300 feet long. Glacial striations usually can be seen on these domes. Since topography with this appearance bears resemblance to a herd of sheep, the name roches moutonneé (French for "sheep rocks") has been applied to it. On such topography most of the soil has been removed, and large areas of bare rock are exposed; other places have a thin soil developed, but the soil is very poor and few plants grow on it.

Roches moutonneés with striae are common on hills on the east of the plateau, bordering the Delaware River. The highlands west of the town of Bushkill show excellent erosion features, especially well exposed on the ridge at the top of the hill along the main highway.

With glacial melting and retreat, large quantities of poorly sorted, unstratified glacial debris called till were deposited. The till was deposited in the form of ground and end moraine, drumlins, kames and kame terraces, and kettle holes. Outwash and glacial lake deposits of well sorted and stratified drift were formed as a result of melt-water runoff.

Moraines result from direct deposition of a glacier's suspended load on the land surface. Ground moraine is a veneer of till relatively uniformly deposited over the entire land surface by a continuously retreating glacier; end moraine is glacial debris piled up at the terminus of flowing ice. Ground moraine is present over much of the area, but there is only one end moraine in the area. It is found at the Fisher School, one mile upriver from Dingman's Ferry on the New Jersey side. Here, a large unsorted rock mound extends northeast from the school to the summit of the hill (Happ, 1938).

Drumlins are streamlined hills of glacial debris, deposited during retreat, and elongated in the direction of flow. A drumlin cross section can be seen in the Bushkill quadrangle one-half mile east of the U.S. 209 intersection at Middle Smithfield where a road cuts through an elongated mound of poorly sorted, unconsolidated debris containing angular pebbles and cobbles.

Kettle holes form when a large block of ice which is deposited in morainal material melts. These vary from depressions a few feet deep and thirty feet across to voids forty feet deep and several hundred feet long. They can be seen on the Culver's Gap quadrangle, at the road intersection two miles south of Dingman's Ferry, where there are several ponds in depressions in the glacial tills.

Much of a glacier's suspended load is carried away by melt-water streams which emanate from the glacier; this load is shortly deposited downstream to form a valley train. Its sediments characteristically are limited to valleys downstream from glaciers, and contain partially rounded, moderately well sorted materials of varying sizes, from cobbles to clays. In cross section, evidences of the fluviatile origin of this material can be well seen in the prominent cross-bedding and planar upper surface of the deposits. These deposits may be two hundred feet thick, and fill the Delaware and Flatbrook Valleys. Their remains now are seen through the valleys as flat plains or bottom lands, with little relief.

According to Happ (1938) the Delaware Valley was filled with water during the late stages of glaciation; and the rivers flowing into the valley built deltas out into the lake. These delta deposits form fan shaped ledges at Dingman's Ferry, Milford, Port Jervis, and other towns up the Neversink River. Cross-bedding shows the streams flowed off the mountains into the valley, as most cross-beds dip toward the center of the valley. Excellent cross-bedding can be seen in a road cut at Dingman's Ferry, and the town of Milford is built on a typcial deltaic plain.

After glaciation and outwash deposition, the rivers cut into the new deposits, leaving a series of erosion terraces. Three such terraces can be seen at Matamoras, where flat plains occur at the 480, 430, and 420 foot levels.

<u>Recent stream alluvium</u>

Alluvium composed of sand and silt covers the river bottom and flood plain of the Delaware River and its tributaries. The thickness of these deposits is unknown.

SYSTEMATIC PALEONTOLOGY

Many of the rock sequences in the area of study are richly fossiliferous. This section lists in systematic form the various fossil assemblages that have been reported. Genera or species collected by the author are marked with an asterisk. Fossil-collecting localities are indicated on the geologic map, on file with NPS.

ORDOVICIAN SYSTEM
Upper Ordovician

Martinsburg Formation

(The fossils listed below include only those which have been reported by Willard (1949) from localities near the Delaware Water Gap in strata presumed to be equivalent to those exposed at the Gap.)

BRACHIOPODS

1. *Dinorthis* sp.
2. *Resserella multisecta*
3. *Sowerbyella rugosa*

CRINOIDS

1. Columnals

TRILOBITES

1. *Cryptolithus bellulus*

WORM TUBES

1. *Cornulites* sp.

SILURIAN SYSTEM
Lower Silurian
(Medinan Series)

Shawangunk Formation

EURYPTERIDS

1. *Dolichopterus otisius*
2. *Eurypterus maria*
3. *Hughmilleria shawangunk*
4. *Pterygotus* cf. *globiceps*
5. *Stylonurus* cf. *myops*

VERMES

*Arthrophycus alleghaniensis**

Middle Silurian
(Niagaran Series)

Bloomsburg Formation

FISH

1. *Archegonaspis van ingeni**

OSTRACODS

1. Ostracoda, indet.*

Upper Silurian
(Cayugan Series)

Pocono Island Shale and Bossardsville Limestone

OSTRACODS

1. *Leperditia* sp.*

Keyser Group

Decker Sandstone

BRACHIOPODS

1. *Atrypa reticularis**
2. *Dalmanella postelegantula*
3. *Dinorthis flabellites*
4. *Camarotoechia litchfieldensis**
5. *Chonetes jerseyensis**
6. *Rhynchospira formosa*
7. *Stenochisma deckerensis**
8. *Stenochisma formosa*
9. *Stropheodonta bipartita*
10. *Uncinulus keyserensis*

GASTROPODS

1. *Loxonema* sp.

Rondout Limestone

BRACHIOPODS

1. *Stenochisma deckerensis*
2. *Stropheodonta varistriata*

BRYOZOA

1. *Lichenalia* cf. *torta*
2. Bryozoa, indet.

CORALS

1. *Aulopora* cf. *tonolowayensis*
2. *Chaetetes* cf. *abruptus*
3. *Chaetetes* cf. *arbusculus*
4. *Enterolasma strictum*
5. *Zaphrentis roemeri*
6. *Coral, indet.*

OSTRACODS

1. *Hyattella lamellosa**
2. *Leperditia alta**
3. *Leperditia elongata**
4. *Leperditia gigantea**

PELECYPODS

1. *Pterinea* sp.

STROMATOPOROIDS

1. *Stromatopora* sp.

Manlius Limestone

BRACHIOPODS

1. *"Spirifer" vanuxemi**
2. *Stropheodonta varistriata*

PELECYPODS

1. *Megambonia aviculoidea*

PTEROPOD SNAIL

1. *Tentaculites gyracanthus**

DEVONIAN SYSTEM
Lower Devonian

Helderberg Group

Coeymans Formation

BRACHIOPODS

1. *Atrypa reticularis*
2. *Camarotoechia simplicata*
3. *Gypidula coeymanensis**
4. *Leptaena rhomboidalis*
5. *Leptostrophia planulata*

6. *"Spirifer" cyclopterus*
7. *Stropheodonta beckii*
8. *Stropheodonta varistriata*
9. *Strophonella leavenworthana*
10. *Strophonella punctulifera*
11. *Schuchertella woolworthana*
12. *Uncinulus mutabilis*
13. *Uncinulus pyramidatus*

CORALS

1. *Favosites helderbergiae*

CRINOIDS

1. Columnals*

TRILOBITES

1. *Dalmanites micrurus*
2. *Phacops logani*

New Scotland Formation

BRACHIOPODS

1. *Anoplea nucleata*
2. *Anoplotheca concava**
3. *Camarotoechia altiplicata**
4. *Chonstrophia helderbergiae*
5. *Delthyris perlamellosus**
6. *Eatonia medialis*
7. *Eatonia singularis**
8. *Eospirifer macropleurus**
9. *Isorthis perelegans**
10. *Leptaena rhomboidalis**

11. *Leptostrophia beckii*
12. *Leptostrophia bipartita**
13. *Leptostrophia planulata*
14. *Levenea subcarinata*
15. *Meristella arcuata*
16. *Meristella laevis*
17. *Nucleospira ventricosa*
18. *Rhipidomella assimilis**
19. *Rhipidomella oblata*
20. *Rhynchospira formosa*

21. *Schuchertella cf. becraftensis**
22. *Schuchertella woolworthana**
23. *"Spirifer" cyclopterus**
24. *Strophonella leavenworthana*
25. *Strophonella punctulifera*
26. *Trematospira multistriata**
27. *Uncinulus abruptus*
28. *Uncinulus vellicatus*

BRYOZOA

1. *Fistuliporella* (2 sp.)*
2. *Orthopora rhombifera*

CLAMS

1. *Nucula* sp.*
2. *Pterinea halli**

CRINOIDS

1. Columnals

TRILOBITES

1. *Phacops logani*

Becraft Limestone

BRACHIOPODS

1. *Levenea subcarinata*
2. *"Spirifer" cyclopterus*

Port Ewen Shale

BRACHIOPODS

1. *Acrospirifer murchisoni*
2. *Chonetes aroostookensis*
3. *Chonetes* sp.
4. *Leptostrophia oriskiana*
5. *Platyorthis planoconvexa*
6. *Rhipidomella musculosa*
7. *"Spirifer" concinnus*

OSTRACODS

1. *Thlipsurella multipunctata*

TRILOBITES

1. *Dalmanites* sp.
2. *Homalonotus vanuxemi*

Oriskany Group

BRACHIOPODS

1. *Acrospirifer murchisoni**
2. *Anoplea nucleata*
3. *Anoplotheca dichotoma*
4. *Anoplotheca flabellites**

5. *Chonetes hudsonicus*
6. *Chonostrophia complanata*
7. *Costispirifer arenosus**
8. *Cyrtina rostrata*
9. *Eatonia medialis*
10. *Eatonia peculiaris*
11. *Hipparionyx proximus**
12. *Leptaena rhomboidalis*
13. *Leptostrophia beckii*
14. *Leptostrophia magnifica*
15. *Leptostrophia planulata**

16. *Lingula* sp.
17. *Meristella lata**
18. *Metaplasia plicata*
19. *Orbiculoidea jervensis*
20. *Pholidops ovata*
21. *Rensselaeria suessana**
22. *Rhipidomella oblata*
23. *Straelenia barrandi*

CORALS

1. *Trachypora oriskiana*

GASTROPODS

1. *Diaphorostoma ventricosum**
2. *Orthonychia tortuosum*
3. *Tentaculites aculus*
4. *Tentaculites elongatus**

PELECYPODS

1. *Actinopteria textilis*

TRILOBITES

1. *Dalmanites dentatus*
2. *Phacops* sp.

Onondaga Group

Esopus Formation

BRACHIOPODS

1. *Amphigenia* cf. *elongata*
2. *Anoplotheca acutiplicata**
3. *Chonetes* sp.
4. *Eodevonaria arcuata*
5. *Lingula* sp.
6. *Orbiculoidea* sp.
7. "*Spirifer*" *duodenarius*
8. "*Spirifer*" *macrus* (?)
9. "*Spirifer*" sp.

CORALS

1. *Favosites* sp.

PELECYPODS

1. *Palaeoneilo emarginata*

PLANT (PROBLEMATICAL)

1. *Taonurus cauda-galli**

TRILOBITES

1. *Greenops anchiops*

Buttermilk Falls Limestone

BRACHIOPODS

1. *Anoplotheca acutiplicata**
2. *Atrypa reticularis*
3. *Chonetes mucronatus*
4. *Chonetes* sp.
5. *Cyrtina hamiltonensis*
6. *Leptaena rhomboidalis*
7. *Leptostrophia perplana*

BRYOZOA

1. *Fenestella* sp.

CEPHALOPODS

1. Tarphyceracone cephalapod indet.*

CORALS

1. *Cladopora* sp.
2. *Cyathophyllum* sp.
3. *Cystiphyllum* sp.
4. *Favosites* sp.
5. *Zaphrentis simplex*
6. *Zaphrentis* sp.

CRINOIDS

1. Columnals*

GASTROPODS

1. *Platyceras* sp.
2. *Tentaculites bellulus*

PELECYPODS

1. *Conocardium* sp.

TRILOBITES

1. Trilobite, indet.*

Middle Devonian

Hamilton Group

BRACHIOPODS

1. Ambocoelia umbonata*
2. Athyris spiriferoides*
3. Atrypa reticularis*
4. Camarotoechia congregata*
5. Camarotoechia prolifica
6. Chonetes coronatus*
7. Chonetes lepidus*
8. Chonetes marylandicus
9. Chonetes mucronatus
10. Chonetes scitulus*

11. Chonetes steiger*
12. Chonetes vicinus*
13. Cyrtina hamiltonensis
14. Elytha fimbriata*
15. Leiorynchus limitare*
16. Leiorynchus mesacostale*
17. Leptostrophia interstrialis*
18. Leptostrophia perplana*
19. Lingula sp.
20. Meristella nasuta

21. Mucrospirifer mucronatus*
22. Orbiculoidea lodiensis*
23. Platyrachella mesastrialis*
24. Productella spinulicosta*
25. Pustulina pustulosa*
26. Rhipidomella leucosia*
27. Rhipidomella penelope
28. Schuchertella variabilis
29. Spinocyrtia granulosus*
30. "Spirifer" audaculus*

31. "Spirifer" sculptilis
32. Stropheodonta demissa*
33. Stropheodonta inequistriata
34. Tropidoleptus carinatus*

BRYOZOA

1. Fenestella sp.*
2. Lichenalia sp.
3. Bryozoa, indet.*

CEPHALOPODS

1. Agoniatites expansus

2. Orthoceras aulax*
3. Orthoceras constrictum*
4. Orthoceras telamon*
5. Spyroceras crotalum*
6. Spyroceras nuntium*

CORALS

1. Pleurodictyum sp.
2. Zaphrentis simplex
3. Zaphrentis sp.*

CRINOIDS

1. Lasiocrinus sp. (?)*
2. Columnals

GASTROPODS

1. Bellerophon crenistria
2. Bellerophon leda
3. Bellerophon patulus*
4. Coleolus tenuicinctus
5. Cyrtolites sp.*
6. Loxonema hamiltoniae
7. Platyceras dumosum*
8. Platyceras erectum*
9. Platyceras cf. platystomum*
10. Platyceras cf. subfalcum*

11. Platystoma sp.*
12. Pleurotomaria sulcomarginata*
13. Styolinia fissurella*
14. Tentaculites bellulus

PELECYPODS

1. Actinopteria boydi*
2. Aviculopecten princeps*
3. Cypricardella bellistriata*
4. Cypricardina cf. indenta
5. Grammysia arcuata*
6. Leptodesma rogersi*
7. Modiomorpha concentrica*
8. Modiomorpha mytiloides*
9. Modiomorpha cf. subulata*
10. Nucula bellistriata*

11. Nucula corbuliformis*
12. Nucula lirata*
13. Nucula varicosa*
14. Nuculana diversa
15. Nuculana rostellata
16. Nuculites cuneiformis*
17. Nuculites oblongatus*
18. Nuculites triquester*
19. Nyassa cf. arguta*

20. *Orthonota undulata*
21. *Palaeoneilo emarginata*
22. *Palaeneilo plana**
23. *Panenka* cf. *costata**
24. *Paracyclas lirata**
25. *Parallelodon hamiltonae**
26. *Pterinea flabellum**
27. *Tellinopsis subemarginata**

PLANTS

1. *Taonurus* sp.
2. Land plant fragments*

TRILOBITES

1. *Greenops boothi**
2. *Homalonotus dekayi**
3. *Phacops rana**

PROBLEMATICAL

1. *Conularia* sp.*

Portage Group

(Because the middle-upper Devonian clastic sequence of the Delaware Valley is lithologically continuous, distinction between Hamilton and Portage rocks is very difficult. Only paleontological criteria can be used to determine the time boundary. Separation is made on the basis that uppermost Hamilton beds contain a *Pustulina pustulosa* fauna while the basal Portage holds a *Hypothyridina venustula* fauna (Willard, 1939, p. 208).

BRACHIOPODS

1. *Camarotoechia eximia*
2. *Camarotoechia horsfordi*
3. *Camarotoechia orbicularis*
4. *Chonetes lepidus**
5. *Echinocoelia ambocoelioides*
6. *Hypothyridina venustula**
7. *Leiorynchus mesacostale*
8. *Mucrospirifer mucronatus**
9. *Pustulina pustulosa*
10. *Rhipidomella vanuxemi*
11. "*Spirifer*" *mesastrialis*
12. "*Spirifer*" sp.

BRYOZOA

1. *Fenestella* sp.
2. Bryozoa, indet.*

CRINOIDS

1. Columnals*

GASTROPODS

1. *Pleurotomaria (Gyroma) capillaria*

PELECYPODS

1. *Actinopteria boydi*
2. *Actinopteria epsilon*
3. *Actinopteria subdecussata*
4. *Cypricardella bellistriata*
5. *Grammysia bisculata*
6. *Liopteria conradi*
7. *Liopteria* sp.
8. *Nyassa arguta*
9. *Palaeoneilo emarginata*

TRILOBITES

1. Trilobite fragments

Gypidula coeymanensis x 1

Minisink Hills

Tropidoleptus carinatus x 2

Matamoras

Athyris spiriferoides x 1

Matamoras

Grammysia arcuata x 1

anterior view

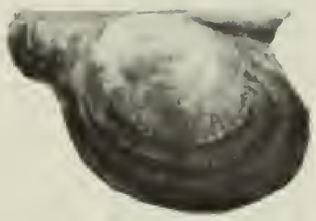
1 mile west of Dingman's Ferry

Panenka sp. x 1

$\frac{1}{4}$ mile west of Dingman's Ferry

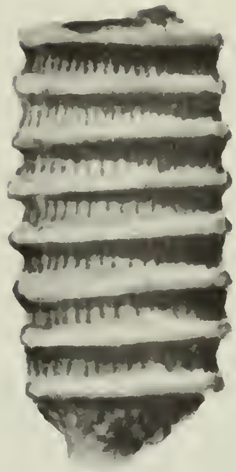
Nuculites triqueter x 2

$\frac{1}{4}$ mile west of Dingman's Ferry



Actinopteria cf. boydi x 2
$\frac{1}{4}$ mile west of Beaver Lake

Paracyclas lirata x 2
$\frac{1}{4}$ mile west of Dingman's Ferry



Spyroceras sp. x 3

Matamoras

Conularia sp. x 2

Matamoras

STRUCTURAL GEOLOGY

INTRODUCTION

Much of the current thinking of structural geologists has been developed from studies of the structure of the Appalachian Mountain system. The Appalachians offer a classic area for the study of folds, faults, cleavage, and the general tectonic development of a fold mountain system. The area included in the Tock's Island project is no exception to this. Both major and minor structural features are abundant within the project area and the new park would provide an excellent area for colleges and other groups to study the causes and effects of rock deformation.

There have been no detailed studies of the geological structure of the area, and the major structures have been only briefly considered in some stratigraphic studies such as those by Swartz and Swartz (1931), Willard (1939), and Trexler (1953). At the present time J. Epstein of the U. S. Geological Survey is working in the Delaware Water Gap area, and current studies of the Paleozoic rocks to the west of the project area by the Pennsylvania Topographic and Geologic Survey will contribute to the information on the geology of the Delaware Valley.

TECTONIC SETTING

On the basis of their structural behavior, the rocks of the project area can be divided into three distinct zones. These three zones are 1) the rocks of the Great Valley, 2) the rocks of the folded Appalachians exclusive of the great valley, and 3) the rocks of the Appalachian Plateau. The major portion of the area lies within the second zone, the folded Applachians of the Ridge and Valley physiographic province. The area is unique in that the belt of Appalachian folding is narrower than it is in any other portion of the Appalachian system.

Although the structures in the three divisions mentioned above are quite distinct from one another, they must eventually be integrated into a clear picture of the tectonics of the Appalachian system as a whole. At the present time the relationship of the structures in the great valley to those in the folded Appalachians is not well understood anywhere in the Appalachian system. It is possible that structural studies in the Delaware Water Gap area and along Kittatinny Ridge to the northeast of the gap could lead to a clearer understanding of this problem. Since, however, the relationships of the three structural zones are not clear at the present time, the structures in these zones will be discussed as three separate units.

STRUCTURES IN THE GREAT VALLEY

Only a small portion of the Great Valley structural division is included in the project area. It covers a small strip along the

southeastern portion of the proposed park in which there are scattered outcrops of the Martinsburg formation. Structures in the Martinsburg formation are highly complex. Berry (1927) has described recumbent folds and other structures in the Martinsburg formation, and in a detailed study of an area a few miles to the south of the project area Sherwood (1961) has described nappe-like structures in the Great Valley. Several periods of deformation are indicated in the Martinsburg formation by overturned folds modified by a later period of folding. Also, at least two, and locally three cleavages have been developed in the rocks.

The most obvious structural feature seen in the rocks of the Martinsburg formation is a well developed slaty cleavage which strikes roughly E-W and dips to the south at a moderate angle. Intersections of this cleavage and bedding planes produce a prominent lineation. Locally the cleavage has obscured the bedding. This cleavage has economic importance in that in some areas it is sufficiently well developed to give the rocks a good slate parting. Several abandoned slate quarries can be seen in the southernmost extent of the project area just north of the village of Slateford. Many of the structural features of the Great Valley such as overturned folds, flow cleavage, and bedding-cleavage relations can be seen in these quarries.

A "slip" cleavage can be seen in many outcrops of the Martinsburg formation and, where well developed, the slip cleavage is found to offset the slaty cleavage. These offsets commonly produce small wrinkles on the slaty cleavage planes parallel to the intersection of the two surfaces. This later cleavage strikes roughly ENE and dips at about a 45^o angle to the NW.

The most prominent folds in the Martinsburg formation have been produced by similar type folding and are overturned to the northwest. In extreme cases these folds have been overturned to the point of recumbency. The slaty cleavage is roughly parallel to the axial plane of these folds although a slight fanning of the cleavage can be seen in the more competent beds. Cleavage also appears to be refracted in the more competent sandy beds. It is not certain whether this is a true refraction of cleavage due to the different behavior of the sandy beds to the stresses producing cleavage or whether the difference in attitude represents a reorientation of cleavage due to a flexural slip movement of the sandy beds relative to the adjacent pelitic beds during folding. A later set of minor folds, the axial planes of which are parallel to the above mentioned slip cleavage, further complicates the structural pattern of the area.

Several small thrust faults can be seen in the Martinsburg formation in road cuts south of the project area. A major reverse fault cuts across the area just north of Portland, Pennsylvania. This fault has been described by Berry (1927). No faults have been seen in the Martinsburg within the project area, but undoubtedly small faults produced by adjustments of the incompetent Martinsburg formation along the contact of the competent Shawangunk formation do exist.

The Martinsburg formation in this area is especially well suited for the study of bedding-cleavage relationships, similar folding, and multiple or polyphase deformation.

THE FOLDED APPALACHIANS

The majority of the project area is underlain by rocks of the folded Appalachians. These rocks range from the basal Silurian Shawangunk formation which underlies Kittatinny Ridge along the southeastern border of the area up to the Devonian Mahantango formation which forms the front of the Appalachian plateau in the northwestern portion of the area. The rocks of this area show some excellent examples of Appalachian folding. Bedding is generally the most prominent structural feature in the rocks of this area in contrast to the Great Valley where bedding if often difficult to determine. The folds of this zone are generally asymetric and some in the southeastern portion of the area are overturned toward the northwest. The folds gradually decrease in amplitude and degree of asymetry toward the northwest and the Appalachian Plateau. Both similar and concentric folds are found in this area. Generally the similar folds are found in pelitic rocks while the concentric folds are found in the sandy, more competent rock units. The axes of both the similar and concentric folds strike about N 60 E and generally plunge gently to the southwest, although some northeast plunges have been observed. One of the best exposures of the folded structure is found along the highway through Delaware Water Gap on the New Jersey side of the river. Here, in addition to a good stratigraphic section in the Shawangunk formation, there are some excellent examples of minor and major structures produced by adjustments of the rocks to stresses created during folding. The Shawangunk formation is folded into a large syncline just north of the Gap and reappears at the surface forming small anticlines about one mile north of the Gap where Route 611 crosses onto the Pennsylvania side of the river. The Bloomsburg formation occupies the center of this syncline and has been crumpled into a series of smaller folds as the rocks have been squeezed between the limbs of the relatively massive Shawangunk formation. The folds in the Bloomsburg formation are a series of anticlines and synclines generally a few tens of feet from limb to limb. Adjustments of the rocks to folding in this area have produced a number of small bedding plane thrust faults which cut across section at the crests of anticlines and finally grade into smaller folds. Exposed in the Gap on the New Jersey side of the river there are two minor folds of particular interest. The southernmost of these is a disharmonic fold, synclinal in form, that occurs in incompetent thin bedded sandstones and black shales lying between massive quartzite beds. The lower quartzite beds have been concentrically folded and the less competent beds in the core of the fold have become highly contorted due to the decreased amount of space in this region produced by the concentric type of folding. A small reverse fault can be seen transecting the southern limb of this synclinal fold, produced by a further adjustment of incompetent beds to the lack of space in the center of the fold. This fault rises in section and finally

changes into a bedding plane fault in an overlying unfolded zone. The second fold of interest is to the north of the synclinal fold and is quite different in appearance. In this second fold the beds have been deformed into a large chevron fold. With the chevron type folds there is no decrease in the wave length of the fold as succeeding beds are traversed, and consequently no minor adjustments are necessary to accomodate material accumulated at the core of the fold and the fold merely transects the whole section with little change.

Cleavage in this whole area of the folded Appalachians is dipping southward at a moderate to steep angle. In the Esopus shale along the northern side of Godfrey Ridge, cleavage is developed to the point where bedding is almost completely obscured. In some areas this south dipping cleavage is not parallel to the axial planes of the folds. Possibly later movements have reoriented the cleavage, although this cannot be proven without a detailed structural study of the area. Cleavage becomes less distinct from southeast to northwest and is difficult to recognize or completely absent at the front of the Appalachian Plateau. A second cleavage can be seen in some areas of the folded Appalachians. This is particularly well developed in the black shales interbedded with sandstones at Delaware Water Gap. This second cleavage is horizontal to gently dipping north. Its origin is unknown although it has probably been produced by lateral displacement of one sandy bed relative to another.

Transcurrent faults are common in this portion of the project area. They can be recognized topographically by the displacement of ridges, and they can be traced in the field by the displacement of stratigraphic units. As far as can be determined, none of these fault planes is exposed in the field. Bedding plane slickensides, minor thrust faults, and overturned folds all indicate a direction of transport of material from southeast to northwest. The transcurrent faults are probably tear faults produced as an adjustment to stresses created during movement of rocks to the northwest.

APPALACHIAN PLATEAU

Only a small portion along the northwestern border of the project area is included in the Appalachian Plateau structural division. The rocks of this area include the uppermost portions of the Mahantango formation and the lower Portage rocks. Bedding in these units is easily recognized and has a fairly uniform gentle dip to the northwest. Cleavage is rare or absent. Many large waterfalls occur roughly at the contact between the folded Appalachians and the Appalachian Plateau. Jointing in the rocks is responsible for these waterfalls. The streams coming down off the plateau cascade over these joint surfaces forming the scenic waterfalls of the area.

SUMMARY AND SUGGESTIONS FOR FUTURE WORK

The project area includes excellent opportunities for the study of structural features. These include concentric and similar

folds, flow cleavage and fracture cleavage, reverse and thrust faults, and bedding and cleavage intersections. The interrelationships of these structural features as well as the relationships of the major structural zones needs to be studied.

From a reconnaissance study of the outcrops in the area it becomes obvious that the proposed park abounds in structural features. However, the detailed structural geology of this area is not known. The generally accepted idea that has developed out of stratigraphic studies in the area is that the Shawangunk formation underlying Kittatinny Ridge is a monoclinal ridge dipping to the north and gradually flattening out to the north until it finally merges with the structures of the Appalachian Plateau at depth. The overlying sediments are thought to reflect this major structure with minor folding only slightly complicating this simple picture. It appears, however, that the structure of this area is not quite as simple as this. A number of problems arise from reconnaissance mapping that are worthy of further study. For example, why is this portion of the folded Appalachians narrow when compared to the same structural belt at other localities; what is the relationship between the structures in the Great Valley and the folded Appalachians; and what is the relationship between the structures in the folded Appalachians and the Appalachian Plateau?

If the Appalachian fold structures persist under the plateau, these structures become excellent prospects for the entrapment of gas and oil. However, the major interest of the petroleum companies would probably be to the west of the project area because possible reservoir rocks are too close to the surface or crop out in the Delaware Valley. Other unsolved problems are as follows: What produces the uniform south dip of cleavage in the area? What structures are responsible for the thickening and thinning of Kittatinny Ridge along strike? What is the origin of the second generation cleavage in the Shawangunk black shales?

Many of these problems could probably be solved or at least partially answered by a detailed study of the structural geology of this portion of the Delaware Valley.

HISTORICAL GEOLOGY

The geological history of the Delaware River Valley began with the birth of the planet some four and one-half to five million years ago. However, here, as in all parts of the globe, only a small fraction of this history is recorded in rocks which are exposed.

The oldest rocks yet found in the Valley have an estimated age of 1150 million years (Tilton, 1960, and others). These are rocks of pre-Cambrian age located in the crystalline Piedmont belt, crossing the Delaware roughly in the vicinity of Philadelphia, and in the Reading Prong - New Jersey Highland complex, crossing the Delaware roughly in the vicinity of Easton. The next oldest deposits are sedimentary rocks of Cambrian age estimated to be about 600 million years old, and containing the oldest recognizable fossils in the region.* Cambrian rocks crop out in a belt just north of the Reading Prong. From here to the coal measures of the Pennsylvania Anthracite District, a nearly complete section of Paleozoic rocks is exposed. The Paleozoic rocks between the Delaware Water Gap and Port Jervis range in age from Silurian to Middle Devonian -- thus representing a period in earth history beginning about 425 million years ago and ending about 365 million years ago.

To understand the history of this period, one must consider the important geological concept of the geosyncline. It has long been recognized that all of the great mountian chains of the world are belts of abnormally thick accumulations of sedimentary rocks. Furthermore, most of the rocks in such areas contain characteristics which indicate that the sediments were deposited in shallow water. Sedimentary rocks must accumulate in depressed or low areas on the earth's crust -- thus the belts of abnormally thick sedimentary rock accumulation must represent portions of the earth's crust which have a long history of subsidence below sea level. In order to account for the shallow water characteristics of the sediments, it is necessary to assume that some sort of balance existed between the processes of subsidence and sedimentation, i.e., sedimentation must have kept pace with subsidence. We do not know exactly what the depressed area looked like, but in general one might visualize an elongate furrow adjacent to a land mass from which sediments could be derived. Such a furrow is called a geosyncline. It is believed that in general, geosynclines formed on the margins of continents and some at least were bordered on their outer edges by strings of islands. For reasons which as yet are not well understood, the sediment-filled geosyncline reaches a stage when uplift of the whole belt takes place on a grand scale and a mountain range is formed. The concept of the geosyncline was initially developed by James Hall, an American geologist, and was based on his studies of the Appalachians.

The Appalachian geosyncline had its birth at the beginning of the Paleozoic Era. In Early Cambrian times, the edges of the North American continent were depressed and covered by shallow water. The heartland of the continent remained as an exposed lowland. At first, extensive deposits of quartz sand were laid on the floor of

*In general this is true of Cambrian rocks anywhere in the world.

borderland seas -- later sedimentation of this sort virtually ceased and was replaced by a process of accumulation of the limy shells of organisms that lived in the sea.

Carbonate sedimentation under shallow water conditions continued in the Appalachian area until the upper Ordovician, at which time the geosyncline became much deeper and small but high land masses -- probably islands -- began to emerge in the east. The newly born islands were subjected to intensive erosion, again supplying the geosyncline with accumulations of mud and sand, forming what we now call the Martinsburg formation. At the close of Ordovician times, the sediments in some parts of the geosyncline were deformed by folding and uplift. The Taconic mountain range of New York state formed at this time. Probably the island chain east of the geosyncline also underwent renewed uplift, since the first sediments which were deposited after this period of deformation were the coarse clastics derived from the east which form the Silurian Shawangunk formation. Now the rate of sediment supply was in excess of the rate of subsidence of the geosyncline. The trough was filled by the deluge of sediments to the extent that in the area of this report, marine conditions no longer prevailed. The sediments of the Bloomsburg formation were deposited largely under continental conditions -- possibly in the form of a great series of deltas.

Thus the early Paleozoic history of this region is one of a long interval of submergence (Cambrian and Ordovician periods) followed by a relatively brief period of emergence of the land from beneath the sea (Early Silurian). This is sometimes referred to as the Lower Paleozoic Geosynclinal Cycle. In essence, the later Paleozoic history of the region is a repetition of this same sequence of events -- the post-Bloomsburg Paleozoic sedimentary rocks of the Appalachians are said, therefore, to belong to the Upper Paleozoic Geosynclinal Cycle.

Following deposition of the Bloonsburg sands and muds in the Middle Silurian, the region once more subsided below sea level. As in the previous cycle, the seas initially remained shallow and there followed a long period of carbonate sedimentation. The limestones and limy shales of the Poxono Island, Bossardsville, Keyser, and Helderberg were deposited during this period. Then in Oriskany times, land-derived detrital sediments began to reach the area -- the sands of the Oriskany formation and the silt of the Esopus formation were deposited. Perhaps these sediments reflect the beginning of another period of crustal instability indicating uplift of the land and increased erosion in the source area. Following a brief return to dominantly carbonate deposition (Buttermilk Falls limestone), the basin sank rapidly and deeper water conditions prevailed. Probably the source area continued to rise. Detrital muds and sands were poured into the trough to form the thick marine shales of the Hamilton Group and the Portage. Again the basin was filled and by the end of Portage times, once more the land surface was above water and sedimentation was under continental or terrestrial conditions. Such conditions continued in this area throughout the balance of Paleozoic times (Upper Devonian, Mississippian, Pennsylvanian, and Permian). The coal deposits of the nearby anthracite district are one manifestation of this condition.

The close of the Paleozoic Era was marked by folding of the sediments and uplift which raised the Paleozoic sediments into a mountain range which in elevation probably rivaled the loftiest peaks of modern-day mountain chains. The Appalachian Mountain, or mountains, had been born! The comparatively low ridges of the Appalachians which we see today are mere remnants of this once mighty chain.

Throughout most of this region, the post-Paleozoic history has been largely one of erosion and wearing down of the Appalachian peaks. However, in a few areas, sediments derived from the erosion of the highlands formed deposits which we can see today. During Triassic times, a great fault valley extended from Virginia to Connecticut. Eventually, this valley was filled with sediments derived from the red soils of the mountains -- these form the red shales and sandstones exposed, for example, in much of Bucks County, Pennsylvania. The Triassic period was one of general crustal instability in the Appalachian region -- along with the faulting there was also considerable igneous activity as evidenced by basalt flows, sills, and dikes intercalated with the Triassic sediments. During Cretaceous and Tertiary times, the edge of the continent received thick deposits of sand and mud, covering the older rocks and forming what we now call the Atlantic Coastal Plain.

About 1,000,000 years ago, at the beginning of the Pleistocene Epoch, a new series of natural events began to shape the face of North America. The climate became cool, and from various centers in the northlands where the snow had accumulated to great thicknesses, ice sheets formed and began to spread and coalesce. Eventually nearly the whole of Canada and large parts of the United States were buried by a thick layer of ice, moving slowly southward. The ice, like a giant plow, served as an agent of erosion, grinding and abrading the underlying land, modifying the landscape, leaving an indelible mark of its presence. Eventually, the climate changed and the great sheet began to melt and retreat to the north. As it melted, it served as an agent of sedimentation, dropping great loads of rock debris.

Four times during the Pleistocene Epoch, the glaciers advanced from the north. At least during the last two advances (the Illinoisan and the Wisconsin) ice lobes reached the Delaware Valley, producing the effects previously described in the section on Stratigraphy. The retreat of the last glacier took place only about 11,000 years ago. Has the age of glaciers passed? No one knows! Perhaps the next great geological event in North America will be a fifth advance of the icy visitor from the north.

SECTION E: THE ECONOMIC GEOGRAPHY AND GEOLOGY OF THE LOWER MINISINK COUNTRY: Richmond E. Myers

The area involved in this report is the valley of the Delaware River between Port Jervis, N. Y., and the Delaware Water Gap. For three centuries this valley has been known as the Minisink country, or Minisink flats, taking its name from the Minsi Indians who originally occupied the low land along the river. These Indians were one of three tribes that were known collectively as the Lenni-Lenape. When the Europeans first arrived on the scene, they gave the name "Delaware" to these tribes, taking this designation from the name of the river along which the Minsi lived.

Indian occupation reached beyond the present site of Port Jervis to the mouth of the Lackawaxen River where Shohola is now situated and this area is usually included in the term Minisink country. However, for the purpose of this report, we shall confine our study to the area directly related to the proposed Tock's Island dam and reservoir.

This portion of the valley is roughly forty miles in length. It can be divided into two distinct topographic regions. The first of these is the river flats over which the Delaware flows south-east as a subsequent stream through an alluvial filled basin. The second is formed by low parallel ridges bordering the flats and lying between the escarpment of the Pocono Plateau on the northwest and the Kittatinny (or Blue) Mountain on the southeast.

From Port Jervis to Walpack Bend the Delaware flows almost at the foot of the escarpment. At Walpack Bend the river in a large S-shaped swing cuts through the low ridges and continues to the water gap flowing at the foot of the Kittatinny Mountain. Thus the low ridges which parallel the valley lie on the New Jersey side above the bend and on the Pennsylvania side below the bend.

Economic geography and economic geology are both concerned with the natural resources of an area. The geographer's chief interest lies with man's exploitation of these resources and their significance in the development of the area's economy. On the other hand the geologist is primarily concerned with the origin of these resources, but he sometimes becomes involved with problems dealing with their extraction, although these are matters generally within the sphere of the mining engineer. Both geographers and geologists are concerned with the distribution of resources, their accessibility or inaccessibility, and their value with respect to possible utilization.

Many factors interweave to determine the culturescape of any given region. The natural resources of an area undoubtedly must be considered among the most significant of these factors. The resources of the Minisink country as defined above have played interesting roles in the story of the valley's human occupancy. They have not been decisive roles for other factors have been more important in determining man's way of life in the valley. Nevertheless their presence dare not be overlooked.

The chief natural resources of the Minisink country can be listed thus: One metal, copper, has been mined in the area. Gold has been reported from time to time, but never mined. Iron minerals are present, but no iron mining. The principal non-metallic product has been flagstone. Quantities of sand and gravel are present. The soils are a valuable resource having been the basis for lumbering and agricultural activities. Scenery is a very valuable adjunct to the region's economy, and of course water, including both surface and underground supplies, must not be overlooked.

Each of these resources is described in detail in the following pages.

COPPER

In the middle decade of the seventeenth century, Dutch explorers working their way westward from the Hudson Valley into the Minisink country, noted green stains and coatings on the rock outcropping on the northern slope of the Kittatinny Mountain a few miles east of the Delaware Water Gap. They recognized this green stain as an indication of copper and further probing revealed the presence of not only malachite, a carbonate copper mineral, but also chalcocite, a copper sulphide. A mine was opened at the site, a road was built from Esopus (Kingston) on the Hudson to the mine, and the Dutch were in the copper mining business.

It is regrettable that no records of this early mining activity were preserved. Our knowledge of the mine under Dutch operation is so sparse as to be almost legend rather than history. Yet work the mine they did. Their diggings were extensive. As described in Bulletin 455 of the U. S. Geological Survey (1911) they "comprised a tunnel driven for a distance of 200 or more feet, with a crosscut at the end, and two inclined shafts, 60 and 40 feet deep, sunk on the bed, presumably following pockets of ore." This was no small operation.

In 1860 and again in 1900 attempts to reopen the mine were made, but the ore proved to be too low grade and these operations were failures.

The copper-bearing rocks are the red and grey sandstones of the High Falls formation, Silurian in age. At the mine the estimated thickness of the formation is 800 feet. In a nearby ravine, where it is quite possible the Dutch first found the copper, the ore outcrops about 150 feet above the river. There the chalcocite impregnates the sandstone and can readily be seen and recognized. The copper bearing rocks have been traced for three miles along the northern slope of the mountain and have been shown by workings to reach a thickness of over 200 feet.

Although the structural geology of this deposit is quite simple the origin of the disseminated ore presents a problem. According to W. H. Weed in the Bulletin of the U. S. Geological Survey just cited, "The ore is supposed to be the decomposition of sulphides in older rocks." This, however, is a rather unsatisfactory statement. Undoubtedly circulating ground water played a role in the process of dissemination, but the source of the copper in the water remains unknown. The malachite was probably derived from the chalcocite.

Today the mine is frequently visited by mineral collectors, hikers, historically-minded folk, and occasionally photographers in search of unusual subjects. The likelihood that it will be visited again by miners bent on digging ore from the ground is extremely remote.

The mine, commonly called the "Dutch Copper Mine", is also known as the Pahaquarry Mine, and is thus mentioned in the literature.

GOLD

Tales of lost or hidden gold mines around the Minisink country have been told over camp fires and in the tap rooms of the region for many decades. There have been reports of alluvial gold in the river, and veins of gold outcropping in the hills. This is common talk in remote country. However, in "The Geology of the State of New Jersey" by Dr. C. H. Cook, published in 1868, we read on page 147 that near the contact of the Ordovician and Silurian rocks of the Kittatinny Mountain, "gold has been found over many square miles." He further states that "in places it has a value of as high as $11 a ton." Granted that this contact lies on the southern side of the Kittatinny Mountain, yet the authentic presence of gold there might readily have given rise to stories about gold on the northern slope of the mountain, and some copper ore might easily be mistaken for gold. In any case there never was a gold mine in the Minisink country, and never will be.

IRON

Iron has never been mined in the area. Iron minerals are not uncommon, but any large enough deposit to be considered as ore is lacking. In the Devonian limestones on the New Jersey side limonite stain is noted in a few places. Further search may reveal additional localities for this mineral, but no iron ore. Hematite stain is also associated with the sandstone ridges, but again, nothing worthy of the designation iron ore.

FLAGSTONES

Prior to the days when Portland cement came into common use as construction material for sidewalks, curbs, and gutters, one extractive industry flourished on the Pennsylvania side of the Delaware River in the Minisink country. This was the quarrying of flagstone, or "blue stone" as it was known in the trade. For decades this material was used extensively for paving and curbing, not merely locally but in quite a wide market area which embraced portions of northeastern Pennsylvania, southern New York, and northern New Jersey. Evidence of this use may be seen in many of the communities in this area today where flagstone sidewalks are still in use. In Milford and Matamoras splendid examples of flagstone paving may still be seen.

Flagstone may be defined as sandstone that separates readily, or splits into thin layers, parallel to its stratification or bedding planes. Considerable areas of northeastern Pennsylvania are underlain by rock suitable for use as flagstone. Along the edge of the Pocono Plateau, paralleling the Delaware River where it flows through the Minisink country, considerable quantities of sandstone that meet these specifications, are found. They outcrop along the bluffs above the Delaware River and its tributaries on the Pike County side of the river. These rocks are Upper Devonian in age and belong to the Chemung and Catskill formations.

When commercial quarrying began is difficult to pinpoint. Pioneer farmers worked flagstone on their own land for use as hearth stones. Undoubtedly farmers found many uses for this flat rock. As the towns in the area grew in size a demand for paving stone led to the quarrying of flagstone as a commercial activity, first as a part-time occupation, and later on a full-time basis. This was under way before the Civil War and by the end of the nineteenth century the quarry industry was a major facet in the region's economy.

R. W. Stone reported that at the peak of the industry's activity in 1906, 35 flagstone quarries were in operation in Pike County. (Bulletin 72, Pa. Geol. Survey, 1923) Only a few of these were in the area of this report.

By 1920 the bulk of these quarries lay idle. The use of Portland cement for sidewalks, curbs, and gutters, was not the only factor in this decline. High freight rates, high wages, and lack of trained quarry help, all contributed to the industry's distress.

The bulk of the flagstone operations lay north of Port Jervis. As there is no railroad south of that point, the flagstone quarries of the lower Minisink country were opened largely for local markets. Operations were centered in a small area behind Dingman's Ferry and another behind Milford. Grey Towers, the home of the late Gifford Pinchot, is built of sandstone taken from old stone fences that undoubtedly came from the Milford quarries.

In recent years there has been a revival of the flagstone industry. A market has appeared in the popularity of patios, private swimming pools, attractive garden walks, etc. A number of quarries that had been idle are reactivated, but none of these are in the lower Minisink region. That this demand may lead to the revival of the industry there is not impossible but improbable.

SAND AND GRAVEL

Although the area is abundantly supplied with sand and gravel which was unloaded on its surface by the Pleistocene glaciers, and their melt water, practically no commercial utilization of this material is being undertaken today. Nevertheless it offers a wonderful supply of aggregates for any major construction project, and will undoubtedly be so used. It has been used in the past on a purely local basis.

In general this material is found in two areas, first; the alluvial filled valley of the river itself, and second; the glacial veneer on the highlands. The former is the only potential supply in the lower Minisink country, as it is readily accessible, close to the highways, and roughly sorted.

In many places boulders left by the ice have been used in the construction of houses, barns, and fences. Some of these boulders have been dug from sand and gravel beds. Their use, because of their size, has been purely local.

SOILS

The only large area of productive soil in the lower Minisink country is found on the flood plains and alluvial flats of the Delaware River. This soil is young, fertile, and extensively farmed. It provides the area with its only significant farm lands today. It was utilized by the Indians in their crude agricultural activities and it furnished the early settlers with the basis for their frontier agrarian economy.

Much glacial material is mixed with river wash in this soil, and in places cobbles and even small boulders interfere with plowing, but on the whole the alluvial soil is well suited to cultivation. Flooding has renewed the soil from time to time and thus aided in maintaining its high productivity.

Behind the escarpment of the Pocono Plateau on the Pennsylvania side of the river the Lordstown soil lends itself to forest growth but not to agriculture. In this soil the natural forest cover was lush. The Lordstown furnished the basis of the early lumbering activities in the area. It is derived from glacial material which in turn was derived from shales and sandstones, is an acid soil, somewhat immature, and can be classed best as stony loam.

In the belt of low ridges, chiefly on the New Jersey side north of Walpack Bend in the valleys of Mill Creek and Flat Brook Creek, Devonian limestones have produced small areas of limestone soil. This is farmed in limited areas. The presence of numerous sinks has greatly reduced the land best suited for crops by rendering it unsuited for plowing and cultivation.

All in all, the best soil, and the soil on which most of the area's farming is done, lies in the alluvial flats of the river.

SCENERY

Undoubtedly one of the most valuable natural resources of the Minisink country is its scenery. Scenery attracts visitors, and the more spectacular it is, the more visitors will come to enjoy it. In the early days scenery as a natural resource was not too important. Not until access to the area became easy, did its scenic beauty and wonders attract visitors in large numbers, yet even prior to the days of the automobile folk "rode the steam cars" from New York to Stroudsburg or Port Jervis, and then traveled by horse drawn vehicles to view the wonders of the Minisink country.

Chief among these wonders were a series of magnificent waterfalls which drop from the Pocono escarpment into the Delaware Valley below. At the time the Delaware Valley was freed from ice at the end of the last ice age, these streams tumbled over the very edge of the plateau. They have now cut their way back into the plateau to form picturesque gorges down which they cascade in a series of one fall after another. Around these falls summer hotels were built in the last century, many of which survive today. One state park has been created which includes several of these falls. A number of others are open to visitors on payment of a nominal admission charge. In this way the falls are preserved and protected from despoilation, the common fate of far too many natural beauty spots in America.

The falls, beginning at the site of the proposed Tock's Island Dam, and situated in a line running northeast parallel to the Delaware River, are as follows:

<u>BUSHKILL FALLS</u> On the Little Bushkill Creek just north of the village of Bushkill. Known as the "Niagara of Pennsylvania", these falls tumble 100 feet into a deep gorge. Below the main falls there is a second drop to a lower level. The gorge is rimmed with improved pathways from which excellent views of the falls may be enjoyed. According to one authority Bushkill Falls have the longest single drop in the area, but R. W. Stone sites another Pike County waterfall as having an equal drop. Admission charged.

<u>WINONA FALLS</u> On Saw Creek, also near the village of Bushkill. Quoted in a guidebook as being the "most advertised waterfalls of the Poconos." Admission charged.

THE CHILD'S PARK FALLS Dingman's Creek flows through the George W. Childs State Park to reach the Delaware at Dingman's Ferry. About 3½ miles from the Delaware is Fulmer Falls where the stream drops from 890 to 850 feet and then pours from a sandstone ledge to 800 feet. At 750 feet the stream falls 40 feet to form Deer Leap Falls which cascades into a deep pool. From there, in two cascades, the creek reaches a drop of 100 more feet known as High Falls. These are about one mile from the village. These triple falls are the main attraction of the park, and being a state park, admission is free.

DINGMAN'S FALLS West of the village of Dingman's Ferry, also on Dingman's Creek, these falls are famous for their beautiful setting amid ferns, spray drenched moss, and high trees. They drop 177 feet. Admission charged.

SILVER THREAD FALLS Another waterfall also on Dingman's Creek and located near the village of Dingman's Ferry is the sparkling, well-named cataract Silver Thread Falls. Admission charged.

NOTE: Dingman's Creek in a seven mile course drops almost 1000 feet. Thus we have the five falls just described, as a series of steps down which this torrent plunges to create seven miles of what may well be described as some of the most spectacular scenery of Pennsylvania.

RAYMOND KILL FALLS Raymond Kill flows into the Delaware River three miles below Milford. In its last 1¼ miles it drops 310 feet. The chief fall is 125 feet and is made in two jumps. To quote from the Second Geological Survey of Pennsylvania, 1881 Report G-6 by I. C. White on "The Geology of Pike and Monroe Counties", the stream "excavates a beautiful glen, overhung with vertical walls of pine clad rock 200 feet high, into whose depths the sun never shines." This beauty has been preserved and the falls are a popular spot for summer visitors. Admission charged.

SAW KILL FALLS This is one of the finest waterfalls in the area. It is located on the estate of the late Gifford Pinchot near Milford. The water of Saw Kill drops in two steps into a deep gorge. At the foot of the first fall the water fans out over a shelf of rock composed of fossil coral and shells. Recently this fall has been renamed Pinchot Falls in honor of Pennsylvania's conservationist governor. It is free to the public.

Before leaving the subject of the Minisink countrys' waterfalls in Pike County, it is of interest to note the frequent occurrence of the term "kill" in the stream toponomy. This is of course indicative of the early Dutch presence in the valley. "Kill" is the Dutch word for stream.

Waterfalls are generally absent from the New Jersey side of the Delaware River, at least spectacular cataracts such as Pike County has to offer are missing, but near Walpack Center there is one waterfall. This drops 50 feet to fall on a water wheel which in turn generates electricity for a private home!

If it is short on waterfalls, New Jersey makes up this deficiency with one of the finest views of the Minisink country that can be found the length of its valley. This is the vista obtainable from High Point, the highest spot in New Jersey, 1800 feet above tide and 1500 feet above the Delaware River at Port Jervis. The exact elevation of High Point as given in Bulletin 50 of the New Jersey Geological Survey, 1940, is 1804 feet. The four feet are explained by stating that this measurement was made on top of a large glacial boulder! High Point is located on top of the Kittatinny Mountain.

A state park was established at High Point in 1922. From there the view of the Minisink country well over one thousand feet below is indeed rewarding. Thousands of people visit this overlook every year and return time after time.

Included in the general category of scenery, but more on the picturesque rather than the spectacular side, is the drive on the New Jersey side of the river along the trace of the original Old Mine Road. The present highway passes through a region replete with rural beauty and history. It is the oldest settled region of the Minisink country. Descendants of the original families are still living in this remote region. Between Flatbrookville and the Delaware Water Gap the road traverses more rugged terrain clinging to the lower slopes of the Kittatinny Mountain and passing the site of the old copper mine. This road and mine site may conceivably be developed as a tourist attraction. There is a trend today in restoration projects and the Old Mine Road could well come under this heading.

WATER

GROUND WATER Two sources of ground water have been utilized in the Minisink country. These are:

Glacial valley fill, consisting of clay, sand, gravel, and "quicksand." Found on the flood plains and islands of the Delaware River this material has yielded small supplies from wells and a few springs. Water is found in lenses of water-bearing gravels at various depths. Two wells near Milford show a total thickness of the valley fill to 300 feet.

Sandstones outcropping on the escarpment. These yield moderate to good supplies of water from both springs and wells. The sandstones are all Devonian in age. Interbedded shales are of no value as aquifiers.

The ground water from these sources is all soft. Judged by quantity there seems to be no large industrial supply in the area. There has been sufficient water in the past to meet the demands of local residents and summer visitors.

Three public water supplies in the valley depend upon ground water. Matamoras secures its water from drilled wells. Milford and Bushkill obtain their water from springs. Practically all the domestic or farm water supplies are secured from private wells or springs.

SURFACE WATER Surface water presents no particular problem, but it is somewhat seasonal. The waterfalls tend to run low by autumn. The Delaware River maintains a relatively good flow, but is in no sense a navigable stream save perhaps when in flood. In the past lumber rafts were floated down this river to markets below the water gap. This however was one way traffic, highly seasonal, and ceased as the industry retreated from the area and the railroad gave the upper valley direct access to New York via Port Jervis.

The tributaries of the Delaware, chiefly those tumbling down from the plateau, furnished water power for mill sites. Saw mills were more significant in the development of the area than grist mills. This of course was due to the early importance of the lumbering industry. It is reflected today in the toponomy by the name Sawkill at Milford. Milford, an early lumbering center, takes its name from mill ford, or, the ford at the mill.

POSITION AND CORRIDOR VALUE OF THE LOWER MINISINK COUNTRY

Although the resources of any area are vital factors in its economic development, they are not the whole story by any means. The location of an area may render its resources utterly useless save on a very local basis. Remoteness due to inaccessibility can quickly and effectively doom a region to marginal economies.

In some respects this is the story of the lower Minisink country. Although situated within easy distance of three great centers of population, it possesses considerable isolation today. No railroad follows the Delaware River between Port Jervis and the Delaware Water Gap, and the construction of a railroad would not have been a very difficult engineering task. No canal was ever projected through this segment of the valley, yet that too would have been an easy construction job. A highway does follow it on the Pennsylvania side today, but in New Jersey only secondary unnumbered roads supply limited service to the area.

For a short time the river itself serviced the lumbering industry as a route to markets, but today, in spite of the fact that the lower Minisink country is an ideal passageway for man, it is a bypassed corridor. Why?

The answer lies in the fact that it is not a through corridor, that is, it does not connect two regions between which there can be a large profitable exchange of goods. Moreover, it also fails as a penetration corridor. In other words, it does not tap any great natural resource and furnish it with a route to market. The nearest it came to serving in that capacity was the time the Dutch built their road from the Hudson River to the copper mine on the northern slopes of the Kittatinny Mountain in the Minisink country. The closest it came to serving as a through corridor was the period the river was used to float lumber rafts to tidewater. Both these periods of utilization were short and left no permanent mark on the economy of the region.

It might be well to note that at no time was anthracite coal moved through the valley below Port Jervis. The Delaware and Hudson Canal and later the Erie Railroad conveyed coal from the northern coal fields around Carbondale south to Port Jervis, but from that point moved it directly to the Hudson River, turning away from the Delaware to reach New York City.

The only through corridor use of the lower Minisink country today is found in highway 209 between East Stroudsburg and Port Jervis. Beyond Port Jervis it serves to connect the Delaware Valley with the Hudson Valley by way of the valley originally followed by the old Mine Road and later the Delaware and Hudson Canal.

Although the Delaware River in the lower Minisink country may not be the river to follow (except by canoe) it has certainly been a river to be crossed. This is in part due to the longitudinal divide the river created which separates the region into two parts, one on each side of the river and each in a different state. Yet in no sense has the river been a barrier to movement between Pennsylvania and New Jersey. This was due to the ease with which it could be crossed. For this reason a number of ferries have seen service from time to time and from place to place. Each catered essentially to local traffic. In all, between the Delaware Water Gap and Port Jervis, eight ferry crossings had been in business. This gave the river one ferry crossing for every five miles. These ferries operated under various names as owners changed. None are in operation today, for bridges have eliminated the need for a ferry.

The ferries were small craft, best described as flatboats, but some of the earliest were only canoes for foot passengers. The flatboat type were poled across the river. Some were attached to lines which served to hold them in their courses. They operated on call, being summoned by the ringing of a bell placed at the ferry landings. Although records are fragmentary for some of the ferries, the following list serves as a roster of the eight ferries listed above, with some data pertaining to each.

1. TRANSUE'S FERRY. Operated somewhere between the Delaware Water Gap and Shawnee around 1880. Named for David Transue, its owner.

2. SHAWNEE FERRY. Crossed the river between Shawnee and Depue islands. Established around 1760. Also known as Old Shoemaker's Ferry and later Brotzman's Ferry.

3. SHOEMAKER'S FERRY. Also called Lutz's Ferry. Operated early in the last century and was in business in 1927. It crossed the river near Tock's Island.

4. DIMMICK'S FERRY. Also known as Fisher's Ferry. Crossed below Poxono Island. Was in business well into the present century. Operated on an overhead steel wire. Last ferry capable of carrying two automobiles.

5. DECKER'S FERRY. Also known as Walpeck, or Walpeck's Ferry. Located at Walpeck Bend. This ferry serviced Fratbrookville. It was operated as early as 1744 and ran until 1898.

6. ROSENKRAN'S FERRY. Located one mile above Bushkill this ferry was a successor to Decker's Ferry.

7. DINGMAN'S FERRY. This service operated from the present town bearing its name from 1735 until 1834. It was then replaced by a toll bridge. This was a three span covered wooden bridge, 541 feet in length. It was swept away in a flood, rebuilt, and then blown down in a storm. A third bridge broke down in 1869, and ferry service was resumed until 1900 when the fourth bridge was built.

8. WELL'S FERRY. This ferry crossed the river just below Milford. It was established around the American Revolution by three brothers named Wells. In 1836 it too was replaced by a wooden toll bridge, also covered, of four spans with a total length of 654 feet. Almost immediately the two spans on the New Jersey side were swept out in a flood, but they were rebuilt at once, and this bridge served until 1903, when it too was carried down the river on a flood crest. It was rebuilt of steel construction and placed in service the same year.

Both of these bridges lead to the highway (U.S.206) that follows the old Minisink Path of the Indians through Culver's Gap in the Kittatinny Mountain. Over this route Indians carried their furs to Perth Amboy to barter with the white man.

Minisink Island (half way between the two bridges) was the headquarters of the Minsi tribe. It was an important fur trading center. From their the Minisink Path started to the coast.

THE ISLANDS IN THE RIVER

There are about two dozen islands in the Delaware River between the water gap and Port Jervis. Ten of these are large enough to bear names and be so marked on the topographic maps of the U. S. Geological Survey. Seven of these named islands are in New Jersey and three lie on the Pennsylvania side of the line. All are flat, alluvial, and subject to flooding. Most of them, at one time or another, have been farmed. Several have evidence of Indian occupancy of interest to archaeologists. Of these, possibly Minisink Island is the best known. Today they are utilized in various ways. Some are under cultivation, but not of a permanent nature. One has an emergency air strip. Another has a golf course. All those above the proposed dam will of course go under water when the dam is built and the reservoir filled. Those so affected will be, reading up river from Tock's Island, Poxono, Depew, (not to be confused with Depue Island down stream from Tock's), Shapnack, Namanock, Minisink, and Mashipacong islands.

BOROUGHS

Only two communities in the lower Minisink country have over 1000 population. These form the only two boroughs in the area. They are Matamoras and Milford in Pike County. Matamoras is situated across the Delaware River from Port Jervis and in a sense a part of the Port Jervis geographic community. It shares in the economic position of its New York neighbor. From a population of 1761 in 1950 it has grown to a population of 2087 in 1960.

Milford, a few miles down the river, is the county seat of Pike County. A one-time lumbering center, its chief function today is political. It has grown from a population of 1111 in 1950 to 1198 in 1960.

MANUFACTURING

By no stretch of the imagination can one call the lower Minisink country industrial. However, several small manufacturing plants are located in Matamoras and Milford. The total number of people employed in these plants is under fifty. Textile and metal working with some wood working constitute their activities. They are essentially overflow from the industrial area of Port Jervis which lies just outside the limits of this report. Port Jervis was originally serviced by the Delaware and Hudson Canal and later the Erie Railroad, thus having access to anthracite coal and New York markets. Neither of these transportation facilities penetrated further south along the river, thus helping to maintain the isolation of the Minisink flats.

VACATION LAND

Although manufacturing may not be a major cog in the economy of the lower Minisink country, one human activity can be considered the area's major business. This is the so-called vacation or tourist "industry." It began in the early decades of the last century when New Yorkers and Philadelphians "discovered" the Delaware Water Gap and a summer resort was developed there. Within coaching distance of this resort were the waterfalls of the Minisink country, and in time summer hotels and boarding houses were in business at Bushkill and Dingmans. At mid-century the railroad reached the water gap and Stroudsburg. This added impetus to the summer visitor trade. Whole families would migrate from the city to the large establishments built to house them during July and August. Commonly father would run up (by train, of course) for long weekends, while mother and the children stayed for the season.

With the advent of the automobile this picture began to change. Families no longer flocked to the lower Minisink country to spend the whole summer. Two week and weekend stays became more and more common. The mobility of the automobile changed the vacation habits of many Americans.

Augmenting the hotels and boarding houses, the summer camp appeared on the scene. This in turn was followed by the motel. All are presently important parts of the holiday business in the lower Minisink country.

The area developed several specialties in its offerings to holiday seekers. It caters to sportsmen with its excellent hunting and fishing close at hand. The famous Shawnee golf course attracts the nation's best golfers. Summer theatre and workshops of varied nature interest others. The tourist trade, whether seasonal or transient, is there to stay.

ENGINEERING PROBLEMS

The intent of this section is to call attention to possible problems arising from the geological environments in which facilities for recreational use may be developed. In doing so, the obvious "problems" that will be dealt with in normal procedures are omitted or simply stated.

For example, it is assumed that the Corps of Engineers will retain responsibility for making the detailed geologic investigations that are prerequisite to successful construction and future integrity of the Tocks Island Dam. Suffice it here to note that much of the dam will be underlain by glacial material resting on Bossardsville (and probably predominantly the Poxono member) shale. There are questions of whether or not the contemplated leakage through the glacial material will reach magnitude to cause piping, or whether there will be problems of slippage in the shale. In addition, the northwest abutment of the dam will be developed on Keyser-Helderberg limestones, and there are questions pertaining to the properties of these members. In each case, it is assumed that the Corps of Engineers will undertake full investigations.

In similar fashion, it is apparent that each development that provides facilities for concentrations of people will include water supply and sanitary systems. Each such site, as it is brought into consideration, will require thorough study of geologic conditions pertaining to safe and sufficient water supplies and to safe and economic sanitary disposal. There is no point in trying to forecast the problems to be encountered in each of many developments that will be individually unique and whose location is now unknown.

A specific problem that can be noted is the occurrence of veneers of glacial materials on steep bedrock slopes. These occur principally on the northwest side of the valley, notably southwest of the Milford Cliffs. It is certain that a number of these deposits will be readily eroded at the shoreline level of the reservoir and probably will slump or slide into the reservoir. This will scar the banks and of course might be a hazard to those in boats in the vicinity at the time of a major dump. In many cases, it may be that the problem will be eliminated during development by the stripping of the materials for use in construction and fill. This does not appear to be a major difficulty but deserves further investigation as per item A in Chapter VII.

A related question is the probable behavior of bedrock in steep bank occurrences. There is no clear evidence of a serious problem of slaking, although the occurrence of soft powdery to clayey weathering products of the shaley members is a common characteristic of residual soils. Therefore, the consideration of these rocks is included in item A of Chapter VII.

The exposures of Silurian-Devonian limestones especially in the Montagu area, give no evidence of having solution openings. Indirect

evidence of solution is found in reports of very hard water in wells that presumably have reached these formations. Moreover, it should be noted that much of the area in which limestone is the bedrock carries a mantle of glacial cover that might well obscure solution phenomena. A detailed examination and perhaps some drilling is recommended if this is not already scheduled as part of the engineering study of the reservoir.

It is probable that boating facilities will be located on the Recent and Pleistocene glacio-fluvial deposits at the confluence of tributaries with the main valley, since the areas of steep and high banks are hardly suitable for such development. Thus much development will occur on unconsolidated materials. In general, being glacio-fluvial, these have a good mixture of sizes of materials, are reasonably well-drained, and are well-compacted. Each such site, however, will require thorough investigation to determine probably stability under the conditions of expected loading and of aperiodic inundation.

In summary, no geologic situations are apparent that would indicate any problems of such magnitude as to suggest that the contemplated development is unsound or will encounter unusual expenses. Such an assessment, once applied to the Tocks Island dam site by the Army Engineers in 1934,* has been withdrawn as a result of the later investigations. The integrity of the dam site is not considered pertinent to these remarks. The geologic conditions in the rest of the development area certainly pose no problems of similar magnitude.

* House Doc. 179, 73d Cong., 2d Sers., Govt. Prtg. Off., 1934.

CHAPTER VII

REMARKS

Introduction

This section of the survey report is concerned with a brief comprehensive consideration of topics for which further investigation is desirable. It also suggests several ways in which it appears likely that the mutual interests of the academic scientific community and the administration of the National Recreation Area may be promoted. For convenience, the sequence follows the preceding report topics in the first two sections, i.e., geology and biology. The third portion is concerned with considerations involving both.

A. Geological Research

1. Study of Shoreline and Bank Conditions.

In the reconnaissance survey there was insufficient time and authorization to carry out an investigation that obviously should be completed before dam construction. Actually, it may well be that the Corps of Engineers will include such a study among the preliminary engineering investigations. If so, it would be desirable to insure that the study include considerations of interest to the National Recreation Area as well as examination of immediate shoreline conditions for the purposes of the engineering investigation.

In brief, the study should include a thorough field examination of every portion of the zone that will comprise the "banks" of the reservoir. The apparent subdivisions of the study are as follows:

a. Field examination of the surface configuration, regolith, and probable bedrock of the zone lying between the 410 and 428 foot contours.

b. Field examination and characterization of bank conditions above 428 feet.

c. Collection of samples of all significant rock types occurring in the banks for purposes of obtaining weathering rates on selected ones by some properly equipped laboratory.

2. Pleistocene Geology

The reconnaissance survey indicates that there are considerable needs for further research in the geology of the National Recreation Area. Most of these will be amenable to long-term programming as indicated in item A 3 and C below. However, there is one very important period of geologic time, the Pleistocene, which deserves detailed investigation. This should be undertaken as early as feasible for two obvious reasons: 1) Much of the Pleistocene material will be inundated by the reservoir; 2) Important facilities most certainly will be located on sites underlain by Pleistocene deposits. On more general

basis, the interpretive services of the National Recreation Area will have considerable interest in the Pleistocene.

3. Long-range Geologic Studies

As noted in Chapter III, the Delaware Valley in the National Recreation Area may be characterized as comprising the thinnest part of the Folded Appalachians and lying between the so-called "Plates" of the Pocono Plateau and the New Jersey Highlands. This is a unique geologic province, the detailed investigation of which will contribute to understanding of a variety of fundamental problems. As a manifestation of its significance, the area is visited regularly by field parties from at least a dozen institutions. The continued research program would proceed along two broad lines:

a. Regional studies: refinement of the geologic map; detailed investigations of structural geology, stratigraphy, and paleontology.

b. Processes: investigations of weathering, siltation, and geophysics, particularly crustal stability.

B. Biological Research

1. Reptiles

A small-scale investigation should be conducted in the spring and summer of 1963, to identify as early as possible the locations of any dens of rattlesnakes and copperheads. For each, there are brief critical periods in which the dens must be observed. Moreover, it will be a matter of considerable efficiency to enlist the aid of local residents who are known to Professor Trembley and may be induced to cooperate, although reluctantly.

Otherwise, the survey of reptiles is considered to be reasonably comprehensive and further studies will be likely to develop in due time as a part of continuous interest perhaps in the framework of the discussion in part C below.

2. Amphibians

Information on this group of the biota as presented in Chapter VI is recognized to be incomplete. Consequently, long range research plans should include further study.

3. Aquatic Biology

There are three distinct aquatic environments in the National Recreation Area that will deserve a high level of research interest.

a. Most obvious will be a continuous study of the reservoir itself. Innumerable aspects concerned with the quality of water in all of the various parameters, food chains, fishery management, and the like immediately come to mind.

b. Depending upon the final boundaries chosen for the Area, there will be at least a half dozen and perhaps several tens of upland

lakes in and near the Area. These are known to have wide diversity of initial conditions and an equally wide variation in potential usefulness. Each will deserve study in its own right, and it will be highly significant to consider them in combination for some logical program of preservation of singularities and management for maximum contribution to the functions of the Area.

c. There is also wide diversity in the physical characteristics and environments in the streams that are now tributary to the Delaware and will be tributary to the reservoir. Again, there will be sound reasons for studying each and determining a program of management for them individually and collectively.

4. Birds

The checklist of birds given in Chapter VI is considered to be very good. However, as is normal to the study of birds, continuous revision is to be expected. It is recommended that the list be printed and distributed to ornithological groups, principally the amateurs. It can be anticipated that the reporting will be excellent.

Along with the efforts of these observers, systematic studies should be undertaken to establish more firmly the facts on migration, especially with respect to gross numbers, species, and times. It is believed that information supplied in Chapter VI is reasonably comprehensive for residents.

5. Insects

The treatment of insects in Chapter VI is clearly partial. It is to be hoped that systematic studies may be pursued in the future, and that the specialists at Rutgers University will be the nearest and most competent to handle these investigations.

6. Mammals

The materials in Chapter VI should be thoroughly extended. As noted, there appears to be a subspecies boundary for at least thirty species and subspecies that seemingly occurs through the middle of the Recreation Area. The reality of this boundary should be firmly established or refuted. There are now no ecological reasons that can be advanced to explain it. If it is as significant as it appears in the survey findings, it should be thoroughly investigated.

7. Plants

The extraordinarily valuable work of collecting that has been carried out over many years at the University of Pennsylvania should be continued and encouraged. As a result of this fine collection, the plant list of Chapter VI is considered to be reasonably complete for the Pennsylvania portion. The New Jersey side is apparently virtually unworked and deserves attention.

8. Plant Communities and Vegetative Successions

The identification of major plant communities in Chapter IV is considered to be valid. The mapping of the communities is clearly

reconnaissance in quality, limited to the obvious conclusions that may be drawn from inspection of the composite aerial photomap. It is recommended that detailed mapping be undertaken as early as feasible as a basis for future studies of natural and managed successions that are possible in wide variety in the Recreation Area, and to serve most effectively in the planning of land use in the Area.

C. Long Range Scientific Interests

The National Park Service of necessity has had to direct its resources primarily to the extraordinary problems of providing the facilities and serving the "floods" of visitors to the Parks. Nevertheless, it is implicit in the interpretive services and in the maintenance of the natural or managed bases of "attractions" in the Parks that fundamental understanding of the environment must be achieved. Therefore, the Service has been scientifically and research oriented and has contributed in these directions to the degree feasible. It is to be hoped that this tradition will be sustained in the "Loch Tock" National Recreation Area. The scientific and academic community can be relied upon to support the tradition.

The exact procedure is not easily stated. As indicated in sections A and B above, there are many topics of research interest. These can be pursued in several ways. Some will be in varied degree of direct concern to particular Federal and State agencies that will cooperate with the Park Service in the management of the total resource. For example, the fishery, which must be based upon comprehensive knowledge of the aquatic biology and quality of the water bodies, comes immediately to mind. Thus there will be the basis for research grant and similar procedures without any other formal arrangements. The existence of the problems will stimulate the research efforts. However, experience indicates that the operating agencies probably will have budget problems and in some cases restrictions on the use of funds for research so that a continuation of present practices will not clearly produce the desirable degree of cooperation.

Aside from the research interests, there will be educational objectives to be pursued. These may range from the elementary level to collegiate graduate studies. Thus there may be involved such agencies as public and parochial school administrations, a variety of public and private agencies that have interests in education in the natural sciences, Scout groups, for instance. Some of these have their own facilities but may be interested in having access to a better situation. Others may be considering how to establish facilities for education in a field situation.

In general, educational and research objectives tend to be consistent with each other although there are some glaring exceptions. The casually involved Boy Scouts or School Nature Camp children with "Gee Whiz" type of supervisors will not be desirable associates, taking the time and disturbing the schedules and facilities, of serious research personnel. While the mixture may be beneficial to a few of the children and to a very few of the supervisors, it is doubtful that the end result

will be beneficial on balance. Similarly, the objectives of preserving and protecting "natural areas" are not compatible with mass visitations to the areas.

Thus it appears that more than one kind of facility will be required. For some research purposes, a comparatively simple "camp" that will provide shelters for camp-type living and for bad weather shelter will be sufficient. For other research, laboratory facilities will have to be more elaborate. The same kinds of facilities can accommodate field-trip visitors for short periods, and with little addition can handle groups for longer periods such as school term classes (probably 6- to 12-week summer, although occupance during other seasons is conceivable). In all of the foregoing uses, collegiate levels of interest are assumed and on this basis the needs are compatible. It is likely that most of the institutions in northern New Jersey, southern New York, and eastern Pennsylvania will be interested in participating in such activity.

It does not seem appropriate for one small group to undertake to lay out in detail a plan for a venture of this magnitude. Rather, it is recommended that the Park Service sponsor, or endorse a proposal to some other source of sponsorship, a meeting of representatives of the various institutions to establish an "Association of Delaware Valley Colleges and Universities" or some other more suitable title. The consortium would explore the purposes, ways and means of achieving cooperation in the scientific services to and higher educational use of the Recreation Area.

Once this pattern is established, it is believed that the people concerned will be able to provide leadership and guidance in the conduct of primary and secondary school level of education and similar activities of other groups.

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