STRATIGRAPHY AND STRUCTURE
OF THE SILURIAN AND LOWER DEVONIAN ROCKS
AT HIGHLAND MILLS AND CORNWALL, NEW YORK

by

JOHN B. SOUTHARD

Submitted in Partial Fulfillment
of the Requirements for the
Degree of Bachelor of Science
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June, 1960

Signature of Author . . . .
Department of Geology, May 21, 1960

Certified by . . . .
Thesis supervisor

Accepted by .
Chairman, Departmental Committee on Theses

MIT Document Services

Room 14-0551
77 Massachusetts Avenue
Cambridge, MA 02139
ph: 617/253-5668 | fx: 617/253-1690
email: docs@mit.edu
http://libraries.mit.edu/docs

DISCLAIMER OF QUALITY

Due to the extreme size (28" × 42") of figure maps 2 and 3, we are unable to include these pullouts with the rest of the provided thesis.

CONTENTS

ILLUSTRATIONS

ABSTRACT

The Silurian and Lower Devonian rocks in two small areas in Orange County, New York, in the northern part of the Green Pond - Skunnemunk Mountain Paleozoic Outlier, were subdivided into lithologic units on a finer scale than in the past and were mapped at a scale of 1" to 200'. In addition, reconnaissance work was done in two other small areas in the northern part of the outlier.

The stratigraphic succession at Highland Mills in (in ascending order): the conglomerate unit (new name) of the Green Pond formation, the quartzite unit (new name) of the Green Pond, the red sandstone unit (new name) of the Green Pond, the cross-bedded sandstone unit (new name) of the Green Pond, the evenly bedded sandstone unit (new name) of the Green Pond, the Longwood formation, the sandy claystone unit (new name), the carbonate unit (new name), an unexposed interval, the Central Valley sandstone, the Connelly conglomerate, the Mountainville member (new name) of the Esopus formation, the lower black mudstone member (new name) of the Esopus, the Highland Mills member (restricted) of the Esopus, the upper black mudstone member (revised name) of the Esopus, the Woodbury Creek member of the Esopus, the Kanouse sandstone, and the Cornwall shale.

The stratigraphic succession at Cornwall is (in ascending order): the conglomerate unit (new name) of the Green Pond formation, the Longwood formation, the sandy claystone unit,

(new name), the black shale unit (new name), the laminated limestone unit (new name), the crystalline linestone unit (new name), the calcareous shale unit (new name), an unexposed interval, the Connelly conglomerate, the Mountainville member (new name) of the Esopus formation, the lower black mudstone member (new name) of the Esopus, the Highland Mills member (restricted) of the Esopus, the upper black mudstone member (revised) of the Esopus, the Woodbury Creek member of the Esopus, the Kanouse sandstone, and an unexposed interval.

The lower part of the calcareous shale unit is of Coeymans age, the upper part of the calcareous shale unit is of New Scotland age, the Central Valley sandstone is of late Helderberg or Oriskany age, the Connelly conglomerate is of Oriskany age, the Highland Mills member of the Esopus formation is of post-Oriskany and pre-Woodbury Creek age, the Woodbury Creek member of the Esopus is of post-Highland Mills and pre-Onondaga age, and the Kanouse sandstone is of pre-Onondaga age. Some of the other units are fossiliferous, but their collections have not been studied; the rest are unfossiliferous.

The Green Pond formation was divided into five lithologic units at Highland Mills, but only the lowest of these units is present at Cornwall. There is a disconformity at the top of the Green Pond formation both in Highland Mills and in Cornwall.

The part of the section above the Longwood shale and below the unexposed interval below the Central Valley sandstone at

Highland Mills was divided into two lithologic units, the sandy claystone below and the carbonate unit above. At Cornwall the part of the section above the Longwood shale and below the unexposed interval below the Connelly conglomerate was divided into four lithologic units, the sandy claystone unit, the black shale unit, the laminated limestone unit, the crystalline limestone unit, and the calcareous shale unit (in ascending order). Only the sandy claystone unit is common to both the Highland Mills area and the Cornwall area.

The Central Valley sandstone was recognized at Monroe, as was the Connelly conglomerate. The Connelly was also recognized at Cornwall.

The Highland Mills member of the Esopus formation was restricted, and two new members of the Esopus below the Highland Mills member were established. The five members of the Esopus were recognized at Cornwall; their outcrops there had previously been thought to be Cornwall shale. The Mountainville member was recognized at Monroe, and the lowest three members were recognized at a locality midway between Highland Mills and Monroe.

The Kanouse sandstone was recognized for the first time in Cornwall.

ACKNOWLEDGEMENTS

I wish to express my thanks to all those who gave me advice, assistance and encouragement in this project: to Prof. William F. Brace and Prof. Ely Mencher of the Massachusetts Institute of Technology, Prof. Raymond Siever and Prof. Bernard Kummel, Jr., of Harvard University, Dr. Donald W. Fisher, State Paleontologist of New York, and Dr. Lawrence V. Rickard, Assistant State Paleontologist of New York for field inspection and suggestions; to Mr. Kenneth Kothe, a graduate student at Cornell University, for pointing out to me the outcrops of the Esopus formation at Monroe and at Bakertown road; and to Mr. Robert Southard for assistance in mapping. Above all I wish to thank Prof. Arthur J. Boucot, of the Massachusetts Institute of Technology, for his unflagging assistance, advice and inspiration.

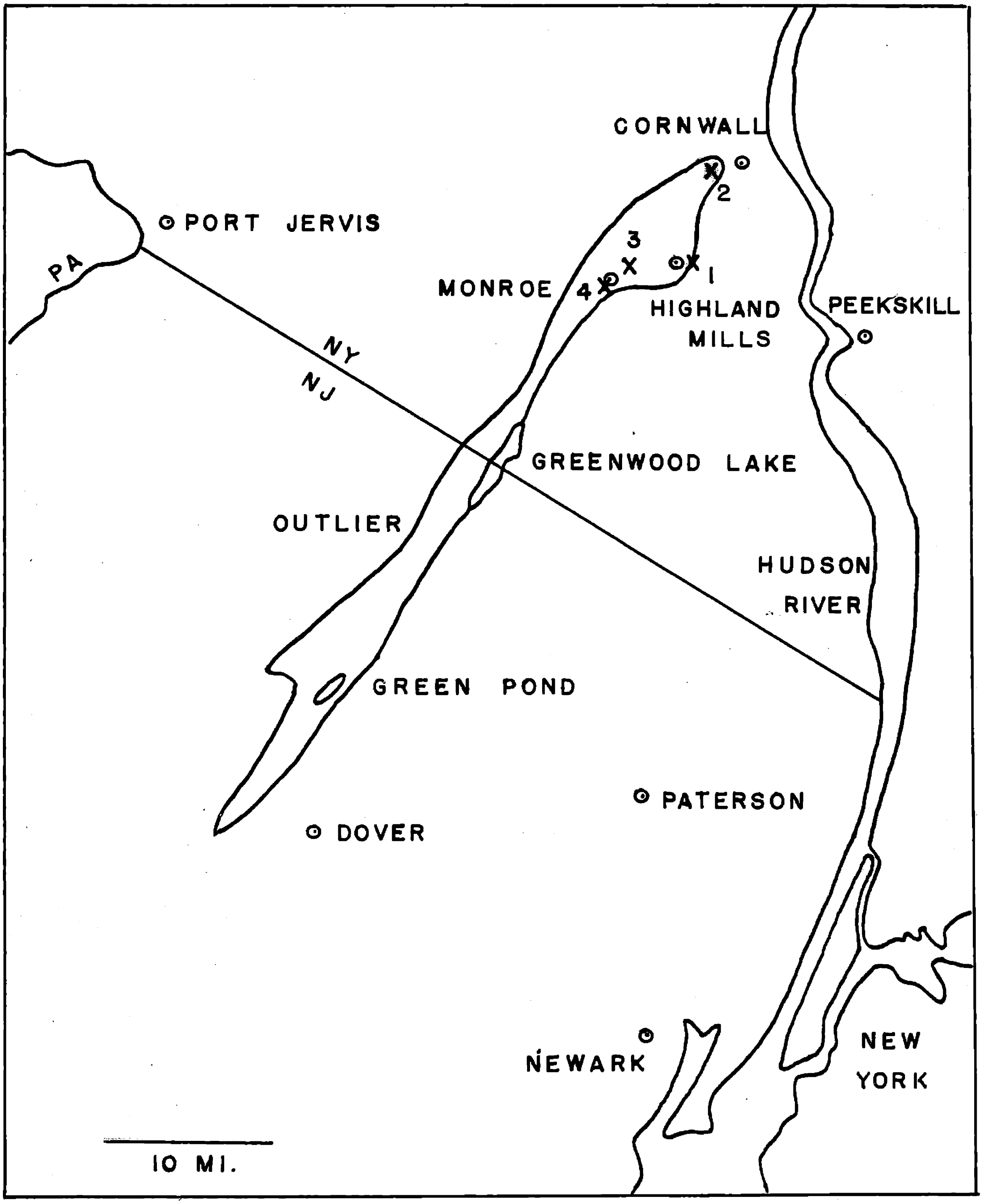

FIG. I
INDEX MAP

OUTCROP AREAS (X'S)
1 HIGHLAND MILLS
2 CORNWALL
3 BAKERTOWN ROAD
4 MONROE

INTRODUCTION

The purpose of this paper is the amplification of what is known about the stratigraphic relations of rocks of Silurian and Lower Devonian age in the northern part of the Green Pond - Skunnemunk Mountain Paleozoic Outlier by recognition and detailed mapping of lithologic units and by zonation of the rocks by means of the brachipod faunas contained in them. The Green Pond - Skunnemunk Mountain Outlier is an area of Silurian and Devonian rocks surrounded by rocks of Precambrian, Cambrian and Ordovician age. It stretches from Cornwall, Orange County, New York, to Dover, New Jersey, a distance of almost 50 miles; it is never more than five miles wide. (See index map, fig. 1). Its location about 30 miles to the southeast of the main Silurian-Devonian outcrop belt makes it important in interpretation of regional stratigraphic relations.

Two outcrop areas were chosen for study: the area around Pine Hill, just east of the village of Highland Mills, Orange County, New York, and the area around Pea Hill, a few miles west of the village of Cornwall, Orange County, New York. (see the maps, figs. 2 and 3). From scrutiny of the work of Ries (1896), Darton (1894) and Boucot (1959), these two areas seemed to be the best places to begin studying the stratigraphy of the northern part of the Outlier. The area around Highland Mills was studied first because the structure there is simpler than at Cornwall. The section was divided into lithologic units on as fine a scale as seemed meaningful, and these units were mapped on a scale of two hundred feet to the inch. Then the area west of Cornwall was investigated to determine whether the units set up at Highland Mills could be recognized. Whenever this was possible, they were mapped and their features were compared with those at Highland Mills. In both cases new units were recognized and mapped at Cornwall.

In addition to detailed work at Highland Mills and Cornwall, reconnaissance work was done in two areas pointed out by Kothe (oral communication): a cut for a bowling alley in Monroe and an outcrop area near Bakertown road just north of New York Route 208, midway between Monroe and Highland Mills. (See the index map, fig. 1).

STRUCTURE

The structure in the Highland Mills and Cornwall areas was studied to aid in the interpretation of the stratigraphy.

The structure of the Highland Mills area is much simpler than that of the Cornwall area. The Silurian and Devonian rocks exposed at Highland Mills lie on the east limb of a syncline; rocks of Silurian and Lower Devonian age are not exposed on the west limb. At the north end of Pine Hill outcrops of Silurian and Devonian rocks end abruptly; the rocks strike into a mass of Precambrian gneiss situated several hundred yards to the north. Either the Silurian and Devonian rocks are tightly folded around the Precambrian rocks, or faulting has taken place; considering the constancy of attitude of the rocks all along Pine Hill, faulting is the most likely explanation. At the south end of the Pine Hill outcrop area, there is a minor flexure; dips are gentler and strikes are closer to north-south. Although there is evidence of minor faulting (with slips less than a foot), there are no faults with large enough slip to be mapped.

At Cornwall the Silurian and Devonian rocks have been more highly deformed than at Highland Mills. The structural situation in the northern part of the outcrop area west of Cornwall is clear, as is the structural situation in the southern part of the area; however, the structural relations between the northern and southern parts are not clear. The northern part consists of outcrops in two ridges. The east ridge (called Pleasant Hill) lies just west of the New York Thruway and is parallel to it. The strike of the ridge is about N 10 E. Its northern end lies just south of the abandoned New York Ontario and Western Railroad. It extends southward about 3/4 mile. The strike of the west ridge is about N 40 E, and it is situated so that its north end lies only a few hundred yards west of the north end of the east ridge. The ridges diverge to the south. They are of about the same length. The east ridge consists of rocks on the east limb of a syncline, and the west limb consists of rocks on the west limb of the same syncline. The rocks of the east limb are nearly vertical, and the rocks of the west limb dip 50-60 degrees south. The syncline pitches gently to the south, and its axial plane dips steeply to the south. There is more structural disturbance in the east limb than in the west limb.

The southern part of the Cornwall outcrop area consists of outcrops on Pea Hill, which is situated slightly south of midway between the southern ends of the two ridges discussed above. Its rocks are folded to form a syncline in the eastern part of the Hill and an anticline in the western part. These folds pitch to the south (more steeply than the fold discussed above) and their axial planes dip steeply to the south. The traces of their axial planes strike a little west of north. The syncline in Pea Hill seems to be continuous with the syncline to the north, but there must be bending or faulting in between their exposures because of their difference in orientation.

STRATIGRAPHY

The stratigraphic succession at Highland Mills, arranged in stratigraphic position, is as follows:

Cornwall shale
Kanouse sandstone

Esopus Formation	Woodbury Creek member upper black mudstone member Highland Mills member lower black mudstone member Mountainville member

Connelly conglomerate
Central Valley sandstone

(unexposed interval)

carbonate unit
sandy claystone unit
Longwood formation

Green Pond Formation	evenly bedded sandstone unit crossbedded sandstone unit red sandstone unit quartzite unit conglomerate unit

The stratigraphic succession at Cornwall, arranged in stratigraphic position, is as follows:

(unexposed interval)

Kanouse sandstone

Esopus Formation	Woodbury Creek member upper black mudstone member Highland Mills member lower black mudstone member Mountainville member

Connelly conglomerate

(unexposed interval)

calcareous shale unit
crystalline limestone unit
laminated limestone unit
black shale unit
sandy claystone unit
Longwood formation

Green Pond Formation	quartzite unit conglomerate unit

GREEN POND FORMATION

The Green Pond formation consists of coarse quartz pebble conglomerate of probable Upper Silurian age widely distributed in the Outlier, especially in the southern part in New Jersey. In the upper part of the formation there is a variable thickness of quartzite. For discussions of the formation, see Darton (1894) and Ries (1896). The formation is referred to in this paper as the Green Pond formation and not as the Green Pond conglomerate, as it has been called in the past, because of the presence of quartzite in its upper part. The Green Pond is stratigraphically equivalent to the Shawangunk conglomerate to the west. Since the Green Pond is unfossiliferous, its age is uncertain. It is situated above the Taconic unconformity and below rocks of known Devonian age.

An attempt was made to recognize lithologic units in the Green Pond formation (particularly in the quartzites) and trace them along the length of Pine Hill, not only to describe the lateral and vertical variations in lithology of the Green Pond in this area, but also to try to discover, on the basis of well exposed and easily traceable strata, any structural complexities which might affect the tracing of lithologic units in the overlying strata (no such structural complexities were found). The Green Pond formation was subdivided into five lithologic units, four of which are in the quartzite.

These units were established using two criteria: that they represent constant conditions of sedimentation throughout, and that they are set off from each other by changes in conditions of sedimentation which, however slight, are greater than any changes within the units themselves. They are thus genetic units, but whether they will be of value in interpreting the depositional history of the formation depends on their lateral persistence relative to the spacing of the outcrops of the formation. The outcrop area of the Green Pond nearest to the one at Highland Mills is in Cornwall, seven miles to the north of Pine Hill; there, almost all the quartzites are missing. All other outcrop areas of the formation are much farther away from Pine Hill than the outcrop area at Cornwall is, and they have not been examined with a view toward recognition of the units set up at Pine Hill.

The lithologic units recognized at Pine Hill are (in ascending order): the conglomerate unit, the quartzite unit, the red sandstone unit, the crossbedded sandstone unit, and the evenly bedded sandstone unit. Descriptions of these units follow.

conglomerate unit

Exposure - The lower part of the conglomerate unit is excellently exposed all along the lower part of the east slope of Pine Hill at Highland Mills. The upper part of the unit is exposed on the upper part of the slope; outcrops of this part of the unit are mostly restricted to the southern part of the hill, and are not as continuous as those of the lower part. At Cornwall the conglomerate unit is well exposed on both the east and west limbs of the syncline.

Lithology - The dominant rock type of the unit is quartz pebble conglomerate. A small amount of sandstone is interbedded with it. The coarseness of the conglomerate decreases toward the top of the unit, and the proportion of the total thickness made up by sandstone beds increases. The sandstone beds comprise about a quarter of the thickness of the unit in the lower part, and about a third in the upper part. Besides these changes, the character of the unit remains the same throughout its thickness.

The concentration of pebbles with respect to the matrix in the conglomerate beds varies. In some beds the pebbles appear to be closely packed, while in others they appear to be floating in the matrix. Moreover, many of the sandstone beds contain isolated pebbles. The distinction between sandstone beds and conglomerate beds is nevertheless real, because most of the conglomerate beds contain a large number of pebbles, and most of the sandstone beds contain only a few pebbles. Transitional cases are not often seen.

The maximum pebble size is four and one-half inches. Pebbles of this size occur in only a few beds, and only in the lower part of the unit. Their distribution is sparse even in the beds in which they occur. In most of the beds the pebbles are no larger than one or two inches. The maximum pebble size in the uppermost part of the unit is one-half inch. Pebbles which are not equidimensional tend to lie with their largest cross sections parallel to the bedding. Larger pebbles are well-rounded, but smaller ones are not so well-rounded. All but less than one percent of the pebbles consist of milky quartz. They all have a reddish surface stain. The matrix of the conglomerate consists of coarse or very coarse quartz sand, and is red and yellow in color.

The conglomerate beds range in thickness from six inches up to ten or fifteen feet. They, as well as the sandstone beds, tend to become thinner upward. Within the thicker conglomerate beds there are usually irregular variations in coarseness vertically. The sandstone layers range in thickness from a few inches to three feet. They thicken and thin irregularly along strike and generally pinch out within several tens of feet laterally. The conglomerate beds seem to show a greater lateral persistence than the sandstone beds. The color of the sandstone beds is the same as the conglomerate beds except that yellow is predominant. The sandstone beds are usually crossbedded to some degree; sometimes entire beds are single sets of cross-laminations. The sand is usually coarse or very coarse.

Thickness - At Highland Mills 285 feet of the conglomerate unit are exposed. Probably the thickness of the unexposed part at the base is not great. At Cornwall, 115 feet are exposed.

Lower contact - The lower contact of the unit is nowhere exposed along the base of Pine Hill. The ledges of coarse conglomerate along the base of the hill end abruptly, apparently at about the same stratigraphic level. The presence of pre-Silurian limestone about one-half mile south of the southern end of Pine Hill and striking roughly toward the lowland east of the hill points toward the coarse conglomerate being the basal beds of the Green Pond and resting unconformably on the limestone, but there is no evidence to prove this interpretation. The outcrops of the coarse conglomerate beds of the Green Pond formation west of Cornwall are in the same geomorphologic situation as at Highland Mills (steep ledges ending abruptly at a gentle slope down to low land); there, black shale more highly metamorphosed than would be expected if it were post-Taconic in age, and resembling the Ordovician black shale exposed elsewhere in the area, underlies the slope down to low land, pointing strongly toward an unconformity just below the lowest outcrops of the conglomerate. This might also be the situation at Highland Mills.

Lateral variation - The conglomerate unit retains its character and thickness for the entire extent of its exposure, both at Pine Hill and in the two ridges formed by the limbs of the syncline at Cornwall.

quartzite unit

Exposure - The quartzite unit crops out along the crest or just east of the crest of Pine Hill, almost continuously in the southern two-thirds of the hill, but only occasionally in the northern third. A few beds similar to the quartzite unit are present at Cornwall at the top of the Green Pond formation on the west limb of the syncline.

Lithology - The quartzite unit consists entirely of medium to thickly bedded quartzite. Major parting planes divide the rock into beds six inches to three feet thick. The color of the rock varies from light red and pink almost to white. On a scale of a few inches, the rock is vaguely mottled pink and white. Hammer fractures pass mostly through the grains in the more quartzitic beds, but partly around the grains in less quartzitic beds. The less quartzitic beds stand out less prominently than the quartzitic ones. They tend also to be darker in color. Bedding surfaces exposed to weathering are irregular on a scale of a few inches, displaying low knobs and bumps of all shapes. On a large scale, however, the bedding surfaces are close to being planar. Laminations show up well where the rock is not highly quartzitic, but they are partly or wholly obscured in quartzitic beds. Some of the laminated beds show crossbedding, but many show straight and even lamination unaccompanied by crossbedding. On the bottom surfaces of some beds, there are concentric circles of thin purple markings. On surfaces perpendicular to the stratification these markings appear as arches and domes. Boucot (oral communication) thinks these are Liesegang rings.

Thickness and lateral variation - At Highland Mills the thickness of the unit, as measured at several places along Pine Hill, is 55 feet. It varies no more than a few feet along the entire length of the Hill. The unit is constant in character all along the Hill. On the west limb of the syncline at Cornwall, there are a few beds of quartzite one or two feet thick interbedded with the conglomerate unit at its top, just below the disconformity with the overlying Longwood formation. These beds can be traced along the west limb, but they are absent from the east limb; there the Green Pond formation consists of conglomerate throughout its entire thickness. The quartzite beds on the west limb have exactly the same character as the beds of the quartzite unit at Highland Mills.

Lower contact - At Pine Hill there is everywhere an unexposed interval of at least two feet and usually three or four feet between the conglomerate unit and the quartzite unit. The contact was unearthed in two places where it seemed close to the surface. It is gradational; the sandstone or conglomerate of the conglomerate unit grades rapidly into several inches of red very fine sandstone or coarse siltstone and then into the quartzite of the quartzite member. This rapid change in lithology occurs all along the area of good outcrop on Pine Hill. There is no interbedding of conglomerate with quartzite. On the west limb of the syncline at Cornwall each of the quartzite beds at the top of the conglomerate unit is sharply set off above and below from the conglomerate with which it is interbedded.

red sandstone unit

Exposure - The red sandstone unit is best exposed in the southern part of Pine Hill, along or near the crest, where it crops out semi-continuously. In the northern part of the Hill it is exposed only in a few places. It is more poorly exposed than the other units of the Green Pond formation. It is missing at Cornwall.

Lithology - The unit consists mainly of red sandstone, with some red mudstone shale between the sandstone beds. The sandstone consists entirely of well-rounded quartz sand cemented by silica and stained with hematite. Hammer fractures pass mainly around the grains. No laminations are visible on fresh surfaces, but they show up vaguely on weathered surfaces. No crossbedding is present. The shale shows no small-scale stratification features. Cleavage is imperfectly developed in it. Changes between the two rock types are gradational; no sharp contacts between beds are seen. Beds of both rock types are usually a few inches thick. The shale beds disintegrate on exposure to weathering without changing color; The sandstone beds either weather to pink or light purple or remain red.

Thickness and lateral variation - In the extreme southern part of Pine Hill there are a few feet of red shale at the top of the unit which are not present farther north. The unit thins progressively from 5 feet at the south end of Pine Hill to 2 feet near the north end. The unit becomes more sandy to the north.

Lower contact - The quartzite of the underlying unit grades upward into the red sandstone over a thickness of less than a foot. The character of the contact is the same all along Pine Hill.

crossbedded sandstone unit

Exposure - The crossbedded sandstone unit is exposed along or just to the west of the crest of Pine Hill for most of its length. As with the other units of the Green Pond formation, it is best exposed in the southern part of the hill. It is missing in Cornwall.

Lithology and lateral variation - The unit consists mostly of strongly crossbedded red and purple sandstone, with variable amounts of siltstone and mudstone interbedded with it. The sandstone is composed of well-rounded coarse quartz sand cemented by silica. Hammer fractures pass partly through and partly around the grains. The color of the fresh surface is red or reddish purple. The reddish purple beds generally weather to a lighter shade, but the red beds do not change their color appreciably. The crossbedding laminae vary in thickness and prominence. They are more noticeable on weathered surfaces than on fresh surfaces. The sandstone tends to part along crossbedding laminae. The lowest part of the unit contains numerous red shale fragments; these are probably derived from the underlying red sandstone unit. They are particularly numerous in the lowest few inches. They vary in size from a few mm. to three cm., are tabular or irregular in shape, and lie roughly parallel to the stratification. The purplish red sandstone occurs below the red sandstone and grades up into it. In places the red sandstone grades up into several feet of evenly bedded siltstone with one or more thin partings of fine red mudstone showing well developed ripple marks about two cm. in length and several mm. high. In other places the red sandstone grades upward into only a few beds of siltstone without any mudstone partings. The lowest three or four feet of the unit is everywhere purplish red crossbedded sandstone; this grades up into red sandstone and then into a variable thickness of siltstone and mudstone. In places, crossbedded sandstone overlies the siltstone in addition to underlying it.

The succession of beds in the unit varies a great deal laterally. It is the most variable unit of the Green Pond formation.

Thickness - The unit is about 8 feet thick along Pine Hill. The thickness varies within a few feet.

Lower contact - Because the underlying unit weathers easily, the contact with it tends to be covered. The contact was unearthed in a few places for several inches. The crossbedded sandstone of the unit rests on the underlying red sandstone unit with sharp contact. The contact appears to be slightly undulating over the several inches it was exposed.

evenly bedded sandstone unit

Exposure - The evenly bedded sandstone unit is well exposed along or near the crest of the southern part of Pine Hill. It is missing in the northern part of Pine Hill and at Cornwall.

Lithology - The sandstone is composed of medium to coarse quartz sand cemented by silica. The grains are rounded. Hammer fractures pass mostly around the grains but partly through them. Major parting planes divide the rock into beds three to six inches thick. Laminations one to two mm. thick are present in almost all beds. They are less distinctive in beds with more quartzitic character. They stand out conspicuously on weathered surfaces because of accentuation of color differences. Although on a small scale they undulate slightly, on a large scale the bedding is extremely even. This evenness of the bedding is a prominent feature of the unit. Crossbedding is present in some beds; such beds are usually single crossbedded units. On a scale of several inches there is a distinctive mottling of purple with purplish white in the rock. Purple predominates, with the purplish white occurring either as irregular layers fairly sharply set off from the purple or as irregular patches less distinctly set off.

Thickness and lateral variation - Individual beds can be traced for a few hundred yards before they change their character or pinch out. The unit is thickest in the southern part of Pine Hill; it is 13 feet thick there. It thins to the north and disappears altogether about midway along the hill. There is evidence that this thinning and pinching out is caused by erosional truncation of the unit by the overlying Longwood formation. First, as described in the section on the Longwood, there is a widespread erosional disconformity at the base of the Longwood; certainly some of the evenly bedded sandstone was eroded before deposition of the Longwood, and it is possible that the erosion accounts for the thinning of the sandstone. Second, in the unit there is a two foot zone of distinctly redder and softer beds which can be traced for several hundred yards along the southern part of the hill in semi-continuous outcrop. This zone is of constant thickness, and the distance from the base of the unit to the base of this red zone is constant to within a few inches. The distance from the top of the red zone to the disconformity at the top of the unit becomes progressively smaller toward the north. Past a certain point, the unit becomes less well exposed because it changes its position relative to the crest of the hill. At the next good exposure north of this point (a few hundred yards from it), the disconformity rests on the unit only 4 feet from its base, and the red zone is missing. A few hundred yards north of this exposure the evenly bedded sandstone unit is missing altogether; the disconformity rests on the underlying crossbedded sandstone unit. The progressive thinning of the unit in spite of the lateral persistence of the bedding sequence and thickness relations within the unit suggests erosional truncation.

Lower contact - The contact with the underlying crossbedded sandstone unit is sharp and straight. No truncation of crossbedded units is seen; however, the unit seems to rest everywhere on an evenly bedded top layer of the underlying unit.

LONGWOOD FORMATION

Name - Darton (1894) suggested the term Longwood shale for red shale overlying the quartzites of the Green Pond formation in the Outlier. Because much of the formation is not shaly, the Longwood is here referred to as the Longwood formation.

Exposure - The Longwood formation is excellently exposed in the gravel quarry at the south end of Pine Hill and on the slope above it. It crops out semi-continuously to the north along the west slope of the Hill. At Cornwall the Longwood is well exposed on the east limb of the syncline, but on the west limb only its lowest beds are exposed, and only in a few places.

Lithology - The Longwood formation is a gradational sequence from conglomeratic sandstone at its base, through sandstone and siltstone, to mudstone at the top. It was not divided into lithologic units because no meaningful ones could be distinguished. The basal beds are interbedded purplish red quartzitic sandstone and red sandstone, both strongly crossbedded into lenticular units, and containing fine quartz pebbles and tabular red shale fragments up to two inches in size lying parallel to the laminations. The sandstone parts into even slabs about one-half inch thick. The purplish red quartzitic sandstone is restricted to the lowest few feet of the formation. The pebbles cease to occur at about the same level as the quartzitic sandstone. The red sandstone grades upward into red coarse siltstone bedded in the same way as the sandstone. Thin partings of mudstone appear in the siltstone and become thicker and more numerous upward. The flaggy beds of siltstone are sharply set off from the mudstone. The mudstone shows well developed cleavage, and it is distinctly brighter red than the siltstone. No small scale stratification features are present in the mudstone. The highest siltstone beds occur about halfway up through the formation; mudstone is the sole constituent above. Under the influence of incipient cleavage the mudstone in the uppermost part of the formation disintegrates into small flattened chunks when it weathers naturally; in the quarry, where the mudstone has been blasted and has not had time to disintegrate by natural weathering processes, it parts into beds generally two to six inches thick but sometimes up to a few feet thick. The mudstone consists of two components, fine mud and coarse mud. The fine mud is brighter red than the coarse mud. The two sediment types appear to have been regularly interbedded initially; in the present state of the rock there are all gradations between regular interlayering of the two components and a complex mixture of contorted and irregular fragments of the fine mud in the coarse mud. Thin mudcracked layers of the fine mud surrounded and filled by the coarse mud are common. The only sign of chemical weathering in the mudstone is the presence of dendrites of manganese oxide on cleavage cracks. The Longwood formation at Cornwall differs only in the absence of the purplish red quartzitic sandstone at the base of the formation.

Thickness - The Longwood formation is 260 feet thick at Highland Mills and 145 feet thick at Cornwall.

Lower contact - The Longwood formation overlies older rocks with erosional disconformity. The contact is exposed in many places in the southern part of Pine Hill and in a few places in the northern parts of the ridges formed by the east and west limbs of the syncline. The nature of the contact is the same in all of its exposures. Although the contact is straight in some places, it usually shows relief of up to a few inches. Immediately overlying the contact is a thin discontinuous (but persistent) bed of quartz pebble conglomerate consisting of sand and fine pebbles. The pebbles tend to be concentrated in areas of depression along the contact. In the southern part of Pine Hill the Longwood rests on the evenly bedded sandstone unit of the Green Pond formation; in the northern part of the hill, it rests on the crossbedded sandstone unit of the Green Pond; at Cornwall, it rests on the conglomerate unit of the Green Pond.

SANDY CLAYSTONE UNIT

<u>Exposure</u> - At Highland Mills the upper part of the unit is exposed at the north end of the quarry at the south end of Pine Hill. The lowest part is exposed in a small cut into the west side of Pine Hill a few hundred yards north of the quarry; here, the rock is deeply weathered but is in place. At Cornwall the unit is exposed only in the steep east bank of the old limonite pit at the south end of the ridge formed by the east limb of the syncline.

<u>Lithology</u> - The unit consists mainly of gray and greenish gray finely laminated slightly calcareous claystone. Interbedded with the claystone are beds of sandstone one to six inches

thick consisting of clear subrounded to rounded quartz sand medium to coarse in size. Their contacts with the claystone are either sharp or gradational above or below. In many layers of the claystone there are large or small concentrations of the same kind of sand as in the sandstone beds. At Highland Mills the amount of sand decreases upward in the unit but, even though the sandstone beds disappear about halfway up through the unit, sand is present in the claystone even at the top. At several horizons claystone with a high concentration of sand rests with erosional disconformity on claystone devoid of sand. The sandy claystone above the disconformities often contains fragments of the underlying sand-free claystone. At Cornwall, possibly because of its thinness, the unit does not change its character vertically. In the top layers of the unit at Highland Mills mudcracked layers are common. Irregular polygons three to four inches in size are formed by the cracking. The cracks usually extend several inches into the underlying layers. In a zone of variable thickness inward from exposed surfaces the claystone weathers to tan color and loses its coherence.

Thickness - At Highland Mills the unit is 75 feet thick. The lowest 6 feet and the highest 42 feet are exposed; the rest lies buried under a talus slope of Longwood shale fragments near the quarry. At Cornwall the unit is only 6 feet thick.

Age - Because it is unfossiliferous, the age of the sandy claystone is uncertain. Its position in the section indicates that it is pre-Helderberg in age. Rickard (oral communication) likened the lithology of the unit to the Decker Ferry formation.

CARBONATE UNIT

Name - The term carbonate unit is given to rocks at Highland Mills overlying the sandy claystone unit and lying below the unexposed interval up to the Central Valley sandstone.
Exposure - At Highland Mills the unit is exposed only in the small outcrop area at the north end of the red shale quarry at the south end of Pine Hill. The unit is absent at Cornwall.
Lithology - The lowest foot of the unit is tightly cemented dark gray sandstone consisting of medium to coarse subangular to subrounded quartz sand. Although sand is the dominant constituent of the rock, the matrix material appears to be in excess of what would be present in a normally packed sandstone. The matrix is siliceous and rich in clay. Tabular or irregular fragments of greenish gray laminated claystone float in the sandstone. They tend to lie parallel to the stratification. They range in size from a few mm. to two cm. in size.

The basal conglomerate bed grades upward within several inches into fine grained shaly dolomite which splits very irregularly along the stratification into disc-shaped fragments. The rock consists of interlocking grains of dolomite which are of uniform size except for occasional clots of larger grains. The color of the fresh surface is dark gray, but all the rock within a few feet of the surface shows an anastomosing network of brown rock. This brown rock has the same texture as the rest of the rock. The brown color is apparently due to staining. Subrounded quartz sand of fine to medium size floats in the rock; it comprises a few percent of the rock. A few unidentifiable brachiopods were found in the shale.

The shale grades upward within a few inches into a rock type which, although it is coarser, has approximately the same composition and mineralogy as the underlying shale. It consists mainly of grains of dolomite up to one-half mm. in size. Irregular wisps and bands of hematite, both granular and finely divided, occur throughout the rock on a fine scale. Fine quartz sand grains occur scattered through the rock. They tend to be concentrated in the hematite wisps. The color of the freshest surface which could be found in the outcrop is yellowish gray. The rock shows no influence of cleavage. It splits along the bedding only slightly. The rock weathers to fine grained soft dark green material or to finely divided limonite. These weathering products occur mainly in fine closely spaced irregular parallel cracks perpendicular to the bedding. The top two feet of this rock type become finer grained, and the rock parts more easily along the bedding planes. It appears to lose its iron content at the same time.

Resting on the shale with sharp contact is a three foot bed of coarse limestone, the highest rock exposed in the

Highland Mills area below the Central Valley Sandstone. It consists of coarsely crystalline calcite with hematite, (both as grains and in finely divided form), abundant. The hematite tends to be concentrated in bands or lenses. Occasional quartz sand grains are seen. Crinoid columnals and bryozoan fragments are abundant. Both kinds of fossil are partly replaced by hematite; the bryozoan fragments, consisting of finely crystalline calcite, show replacement in certain zones controlled by the internal structure, and the crinoid columnals, composed of optically continuous calcite, show gross replacement from the outer surface of the fossil inward. In the upper part of the dolomite below, there is an 8 inch bed of coarse limestone identical with the limestone at the top of the unit except that the hematite layers are more regular. Crossbedding, with the hematite stringers as crossbed laminae, is displayed. The presence of this bed, separated from an identical bed above by the dolomite, is evidence that no important time break is involved in the sharp change in rock type from fine dolomite to the coarse limestone bed at the top of the unit. The general textural and compositional similarity is further evidence of genetic relation.

Thickness - The unit is 19½ feet thick. The thickness of the conglomeratic rock and shaly dolomite at the base is 3 feet; the thickness of the coarser grained dolomite above is 20 feet (including the 8 inch limestone bed); the thickness of the coarse conglomerate at the top of the unit is 1½ feet.

Lower contact - The conglomeratic sandstone at the base of the unit rests with erosional disconformity on the sandy claystone unit. There is slight relief to the contact, and partly torn up claystone is observed just below the contact. Fragments of the sandy claystone are present in the lowest bed of the carbonate unit. Nothing is known about the time significance of the disconformity.

Age - Because the unit is unfossiliferous its age is not known. The age of none of the rocks underlying it is known, and above it there is a covered interval of 145 feet up to the lowest exposure of the Central Valley sandstone. Fossils were collected from the top limestone bed of the unit (fossil locality no. 1 on the map, fig. 3), but they have not yet been prepared.

BLACK SHALE UNIT

Name - The term black shale unit is given to rocks exposed at Cornwall overlying the sandy claystone unit and underlying the laminated limestone unit. Hartnagel (1907) considered these rocks (as well as the rocks of the underlying sandy claystone unit) to be the Decker Ferry limestone. The unit is not exposed at Highland Mills.

Exposure - The unit is poorly exposed in the old limonite pit at the south end of the ridge formed by the east limb of the syncline and is well exposed at the north end of the ridge, in the cut for the abandoned railroad. In the limonite pit, the lowest 6 feet are exposed; in the railroad cut, the highest 8 feet are exposed.

Lithology - The rocks exposed at the limonite pit are dark gray non-calcareous mudstone shale which splits along well developed cleavage. No stratification features, either on a large or a small scale, can be seen. The rock weathers to dull brown. The rocks in the railroad cut have slightly different lithology; they are calcareous black mudstone shale with well developed cleavage, and are interbedded with coarser less shaly black calcareous siltstone. A striking feature of the rock is the presence of silicified tentaculites lying parallel to the bedding. These weather to light gray, whereas the rest of the rock does not change its shade appreciably.

Thickness - The thickness cannot be determined exactly, but it lies somewhere between 6 feet (the minimum thickness actually exposed) and 30 feet (the maximum thickness which is consonant with the mapping of units above and below). Whether the rocks exposed at the two ends of the ridge overlap stratigraphically or are separated by a covered interval of a few feet is not known. Hartnagel (1907) reported that Longwood shale was exposed in the railroad cut 35 feet below the laminated limestone unit (his Rondout limestone), and that the lowest few feet were rocks which seem similar to the sandy claystone unit established in this paper. (These outcrops have since been covered). He reported the rest to be black shale. If this is the case, then the thickness of the black shale unit is about 30 feet.

Age - The age of the unit is not known.

LAMINATED LIMESTONE UNIT

Name - The term laminated limestone unit is applied to rocks at Cornwall overlying the black shale unit and underlying the crystalline limestone unit. Hartnagel (1907) called these rocks the Rondout limestone. They are not referred to as Rondout limestone in this paper because the writer has not investigated the stratigraphic relation of the unit to the north, toward the type locality of the Rondout. The unit is not exposed at Highland Mills.

Exposure - The unit is well exposed in two places along the ridge formed by the east limb of the syncline: just east of an old limestone pit about a hundred yards south of Orr's Mills Road, and in the cut for the abandoned railroad at the north end of the ridge. It is poorly exposed in a few places on the west limb of the syncline.

Lithology - The unit consists entirely of light gray to dark gray finely laminated fine grained limestone. The rock is composed almost entirely of interlocking calcite crystals, mostly very small. Subangular silt-sized quartz grains comprise about one percent of the rock. The laminations stand out as fine ridges on weathered surfaces, and differ in color on fresh surfaces. The color differences are probably due to varying amounts of fine detritus or organic material. The rock splits into beds three inches to one foot thick. Between the major parting planes there is subsidiary parting along some of the laminations. The stratification is very close to being planar. The rock weathers to a tan color.

Thickness - The unit is 19 feet thick at the north end of the east ridge. It is 44 feet thick at the limestone digging midway along the ridge. This difference appears to be real, because both the upper and lower contacts of the unit are exposed at both places.

Lower contact - The black shale unit becomes interbedded with beds resembling those of the laminated limestone unit except that their stratification is less regular and their laminations are less distinct. Within 5 feet of the first appearance of the crystalline limestone beds the transition is complete.

Age - The age of the unit is not known; it contains no fossils. It immediately underlies rocks thought by Hartnagel (1907) to be Manlius in age. The age of none of the rocks underlying it is known.

CRYSTALLINE LIMESTONE UNIT

Name - The term crystalline limestone unit is here applied to dark gray crystalline limestone overlying the laminated limestone unit and underlying the calcareous shale unit.

Hartnagel (1907) called these rocks Manlius limestone. Apparently the boundaries of the rock unit he called Manlius and the boundaries of the crystalline limestone unit coincide. The writer hesitates to use the term Manlius limestone for the unit because Rickard (oral communication) considered its lithology to be different from the typical Manlius lithology.

Exposure - The unit is exposed only at Cornwall; if it is present at Highland Mills it lies in the covered interval between the carbonate unit and the Central Valley sandstone. At Cornwall it is exposed in the ridge formed by the east limb of the syncline both in an old limestone pit about a hundred yards south of Orr's Mills Road and in the cut for the abandoned railroad at the north end of the ridge. It is poorly exposed in the west limb of the syncline.

Lithology - The rock consists mostly of interlocking grains of calcite. The rock is more coarsely crystalline in the lowest two feet of the unit than above; in the lowest two feet, the calcite grains reach three mm. in size, while in the beds above their maximum size is one mm. There are irregular lenses and wisps of hematite in the rock which are not noticeable in the hand specimen. The color of the rock is dark gray on fresh surfaces; the rock weathers conspicuously to brownish orange. The rock splits irregularly along the stratification into beds three to six inches thick. Silicified brachiopods and crinoid columnals made up of optically continuous calcite are common in the unit.

Lower contact - The contact with the underlying laminated limestone is sharp. It shows relief of three to four inches along the few feet for which it is exposed in the limestone pit and in the railroad cut.

Age - Fossil collections were made from the unit (fossil locality no. 4 on the map, fig. 2), but they have not yet been prepared and studied. Hartnagel (1907) considered the unit to be of Manlius age.

CALCAREOUS SHALE UNIT

Name - The informal designation calcareous shale unit is here applied to rocks overlying the crystalline limestone unit and separated from the Connelly conglomerate by an unexposed interval. Hartnagel (1907) called the lower cherty part of the unit Coeymans limestone and the upper non-cherty part New Scotland limestone. His usage is not followed in this paper because the writer has not examined their lithologic similarity to the Coeymans and the New Scotland in their type locality, and because the unit does not seem divisible into two distinct lithologic units.

Exposure - The calcareous shale unit is exposed best on the west slope of the ridge formed by the east limb of the syncline, from Orr's Mills Road northward for a few hundred yards. It is exposed in the limonite pit at the south end of the ridge formed by the east limb of the syncline, and is poorly exposed in the west limb of the syncline for a few hundred yards south of the abandoned railroad. If the unit is present at Highland Mills, it lies in the unexposed interval between the carbonate unit and the Central Valley sandstone.

Lithology - The lower part of the unit is dark gray to black impure cherty limestone. From the fresh surface the rock appears to be a finely crystalline mass of calcite, but when the rock is dissolved in hydrochloric acid, a porous mass of fine grained clay-sized material remains. Calcite comprises 1/2 to 2/3 of the rock. Some layers are more calcareous than others. Cherty layers occur every few feet in the lower part of the unit; the chert is dark gray to black, and it weathers to light gray. Brachiopods and crinoid columnals are included in it, and are often observed to be partly in the chert and partly in the surrounding rock. The fossils in the surrounding rock are also silicified. The chert occurs either as unconnected nodules or as a partly connected two-dimensional network.

Upward the rock becomes less cherty and the fossils contained in the rock become less silicified. At the same time the rock becomes finer grained, more shaly, and less calcareous. No chert is found more than halfway up through the unit. The upper part of the unit consists of fine grained black mudstone shale which splits persistently but roughly along a well developed cleavage direction. It splits only occasionally along the stratification. No laminations are observed; the stratification is displayed only by the occurrence of richly fossiliferous lenses and layers a few cm. thick and by the attitudes of brachiopods and crinoid columnals. All of the rock in the unit weathers to light gray; no iron oxide staining on weathered surfaces is observed. The change from dark gray impure cherty limestone below to black mudstone shale above is imperceptible. At no horizon can a dividing line be drawn for a separation of rock types.

Thickness - One hundred and ten feet of the unit is exposed. The upper contact is not exposed. Above the unit there is an unexposed interval of indeterminate thickness up to the Connelly conglomerate.

Lower contact - The contact with the underlying crystalline limestone unit is exposed in only one place, in the east limb of the syncline a few hundred feet north of Orr's Mills road. It is abrupt, and it shows no relief.

Age - Fossils were collected from the lowest beds of the unit (fossil locality no. 1 on the map, fig. 2), from the beds about midway up through the unit (fossil locality no. 2 on the map, fig. 2), and from the highest beds exposed in the unit (fossil locality no. 3 on the map, fig. 2). Boucot (oral communication) identified the following brachiopods from the highest beds:

Leptostrophia sp.

Schuchertella sp.

Howellella cyclopterus

Coelospira sp.

Rhipidomella sp.

Leptaenisca sp.

Schizophoria sp.

Kozlowskiellina perlamellosa

Eospirifer macropleura

Leptaena rhomboidalis

Levenea subcarinata

Meristella sp.

Eatonia sp.

Costellirostra sp.

Nucleospira sp.

and unsorted dalmanellids, platyorthids, orthids, and rynchonellids.

The following brachiopods were identified by Boucot (oral communication) from the beds in the middle of the unit:

Rhipidomelloides oblata

Meristella cf. *M. arcuata*

Strophonella hadleyana

Spinulosa gaspensis

Anoplia sp.

Schuchertella sp.

Levenea sp.

Leptostrophia becki

Kozlowskiellina perlamellosa

Coelospira sp.

"*Camarotoechia*" *nobilis*

Leptaena rhomboidalis

<u>Chonostrophia</u> <u>helderbergia</u>

and unsorted orthids.

On the basis of these brachiopod faunas, Boucot (oral communication) considers the middle and upper part of the unit to be New Scotland in age. Preparation of fossils was not completed for the collection from the lowest beds of the unit, but Boucot, on the basis of preliminary examination, considers them to be Coeymans in age.

CENTRAL VALLEY SANDSTONE

<u>Name</u> - Boucot (1955) established the Central Valley sandstone on the basis of its occurrence below the Connelly conglomerate on the west side of the Thruway cut at Highland Mills. It had not previously been recognized in the Outlier. No detailed work was done on it for this paper because of the difficulty in gaining access to the Thruway cut.

<u>Exposure</u> - There are only two known exposures of the Central Valley sandstone: on the Thruway at Highland Mills and in the bowling alley cut at Monroe. It is not exposed in the Cornwall area.

<u>Lithology</u> - The unit consists of angular, poorly sorted, medium quartz sand. The sandstone is mottled violet and white, and it weathers to white. Weathering takes place very rapidly; in the several years since the Thruway cut was made, the sandstone has weathered to such a degree that no solid rock can be found in the cut without digging.

Thickness - Boucot (1959) reported that Fisher and Kriedler measured a thickness of 25 feet plus for the formation.

Lower contact - The lower contact of the unit is not exposed. There is a covered interval between the top of the carbonate unit exposed in the red shale quarry at the southern end of Pine Hill and the lowest exposure of the Central Valley sandstone. Mapping revealed that this unexposed interval is about 145 feet thick.

Age - Boucot (1959) considered the Central Valley sandstone to be of Becraft to Orikany age, with a suggestion that it may prove to be closer to the Oriskany than to the Becraft. He identified the following fossils in the unit:

Platyorthis planoconvexa

Camarotoechia? sp.

Hysterolites sp.

Meristella? sp.

Cyrtina rostrata

Leptostrophia sp.

Chonetes sp.

Nanothyris cf. *N. subglobosa*

pterineoid pelecypod

cf. *Dipleura* sp

Odontochile sp.

proetid

unidentified coral

CONNELLY CONGLOMERATE

Name - Chadwick (1908) used the term Connelly conglomerate for quartz pebble conglomerate underlying the Glenerie limestone of Oriskany age and overlying the Port Ewen limestone of either Oriskany or late Helderberg age near Connelly Post Office in the Rhinebeck quadrangle, N.Y. Although neither the Glenerie nor the Port Ewen is known in the Outlier, quartz pebble conglomerate equivalent in age to Chadwick's Connelly conglomerate is present at Highland Mills, and Boucot (1959) considered it to be a lithologic equivalent of the Connelly.

Exposure - The Connelly conglomerate is well exposed in the west side of the Thruway cut at Highland Mills. It was recognized also at Cornwall on the north slope of Pea Hill and at the bowling alley cut in Monroe.

Lithology - The Connelly conglomerate consists entirely of quartz pebbles, mostly fine or very fine, normally packed, with some sand in the interstices. The rock is cemented by silica. The fresh rock is pinkish white to white; upon weathering it becomes stained with limonite and disintegrates to gravel. At Highland Mills the grain size decrease upward; the top few feet are quartzose sandstone almost devoid of pebbles. At Cornwall all of the formation exposed is massive and shows no stratification features (the attitude of the stratification could not be determined).

Thickness - Boucot (1959) reported that Fisher and Kreidler measured a thickness of 45½ feet for the formation at Highland Mills. The thickness was not measured precisely at Monroe; it is roughly 15 feet. The thickness could not be measured at Cornwall because of the absence of stratification features.

Lower contact - The contact with the underlying Central Valley sandstone is exposed both at Highland Mills and at Monroe. At Highland Mills the contact is abrupt; at Monroe the Central Valley seems to grade into the Connelly. The contact was not examined closely at Monroe, however.

Age - Boucot (1959) concluded that the Connelly conglomerate is most probably of Oriskany age (the fossils used for dating the unit, although of Oriskany age, are broken and abraded, and so they might be reworked fossils from rocks older than the conglomerate). He identified the following fossils from the unit:

Costispirifer cf. *C. arenosa*

Meristella? sp.

Hypparionyx cf. *H. proximus*

Rensselaeria cf. *R. elongata*

Beachia sp.

ESOPUS FORMATION

The term Esopus shale was given to black *Taonurus*-bearing mudstone of pre-Onondaga and post-Oriskany age in eastern New York. Ries (1896) and Darton (1894) believed that the Esopus was missing from the outlier, but Clarke (1909) later noted the presence of the Esopus shale and Schoharie grit in the newly made Erie railroad cut at Highland Mills.

Boucot (1959), dropping Clarke's use of the term Schoharie grit for the upper part of the section exposed in the railroad cut, considered all the rocks in the cut to be Esopus.

Boucot (1959) subdivided the Esopus formation at Highland Mills, on the basis of outcrops both in the railroad cut and in the newly made cut for the New York State Thruway a few hundred yards to the east, into three members: the Highland Mills member, the middle member, and the Woodbury Creek member. The Highland Mills member consists of gray sandstone and siltstone with no Taonurus markings; the middle member consists of black mudstone with Taonurus on almost all the bedding planes; the Woodbury Creek member consists of gray sandstone with no Taonurus.

Two additional members were recognized underlying Boucot's Highland Mills member. The lower, here named the Mountainville member, consists of light gray siltstone with Taonurus on the majority of bedding planes, and the upper, here called the lower black mudstone member, consists of black mudstone shale with no Taonurus at all. Boucot did not recognize these units because he incorrectly correlated the Mountainville member in the Thruway cut with the Highland Mills member in the railroad cut, and the lower black mudstone member in the Thruway cut with the middle member (in this paper referred to as the upper black mudstone member) in the railroad cut.

In the area west of Cornwall the Esopus formation is well exposed both in the syncline and in the anticline which together form Pea Hill. It is not exposed elsewhere in the Cornwall area. Each of the members recognized at Highland Mills is present at Cornwall, and differences in each member between the two areas are minor. Structural differences between the two areas tend to obscure the similarities; at Cornwall the Esopus is fairly strongly cleaved, whereas at Highland Mills it is only weakly cleaved. Textural changes caused by the development of the cleavage also tend to obscure the similarities. Darton (1894) and Hartnagel (1907) considered these exposures to be Cornwall shale. Field work for this paper has shown that the exposures belong in reality to the Esopus formation (see p. 67 for a discussion of this mistake).

Mountainville Member

Name - The name Mountainville member is here given to the *Taonurus*-bearing strata of the Esopus formation which overlie the Connelly conglomerate and grade up into the lower black mudstone member of the Esopus. The name is taken from the village of Mountainville, a few miles to the north.

Exposure - At Highland Mills the Mountainville member is well exposed on both sides of the Thruway cut in its southernmost part. The lower contact of the member is exposed only in the west side of the cut. The type section of the Mountainville member is in the west side of the Thruway cut. The member is not exposed elsewhere in the vicinity of Highland Mills. At Pea Hill in Cornwall the Mountainville member is exposed in both the anticline and in the syncline. It is particularly well exposed on the east limb of the syncline on the northeast side of the hill. The member has also been recognized in two other localities: in a cut for a new bowling alley in Monroe and near Bakertown road, just north of N.Y. Route 208, midway between Highland Mills and Monroe. The member was not studied in detail at either of the last two localities.

Lithology - The member consists entirely of light to dark gray medium siltstone. At Highland Mills, cleavage in it is only weakly developed. The rock splits partly along this incipient cleavage and partly along the stratification; in either case the parting is irregular. At Cornwall the rock is well cleaved, and splits very little along the bedding. Taonurus cauda-galli occurs on the majority of bedding surfaces. Its presence is one of the prominent features of the member. It causes the bedding surfaces to display series of steplike curving ridges a few mm. apart and with a relief of less than one mm. On planes perpendicular to the stratification the Taonurus takes the form of series of steplike marks, with each mark set between the branches of the next. The rock shows no lamination; beds in which Taonurus does not occur show a vague mottling of darker and lighter gray on a scale of a few mm.

At Highland Mills the rock generally weathers to lighter gray without noticeable alteration of the texture. In some places it weathers to pinkish white or almost to white. This light color of the weathered rock is a prominent feature of the unit. There is some orange and brown staining, but it is not conspicuous and is restricted to joint surfaces. At Cornwall the weathering is less conspicuous but shows the same features.

Except that Taonurus is absent from the lowest several feet of the member and the lowest two or three feet consist of bluish gray siltstone which parts thinly along bedding surfaces, the member is constant in character throughout its thickness.

Thickness - At Highland Mills the member is 210 feet thick. At Cornwall the thickness seems to be about the same, but it is difficult to estimate it closely; the lower part is not exposed, and there are structural complications.

Age - Fossil collections were made from the member(locality no. 1 on the map, fig. 2), but for lack of time they were not prepared. The member must remain undated until the fossils it contains have been studied. It overlies the Connelly conglomerate, which is of Oriskany age, and it is older than the Highland Mills member of the Esopus.

Lower contact - The contact between the basal shale of the Mountainville member and the underlying Connelly conglomerate is sharp and straight, with no relief apparent. It is exposed both at Highland Mills, in the west side of the Thruway cut, and at Monroe.

lower black mudstone member

Name - The strata between the Mountainville member and Boucot's (revised) Highland Mills member are here called the lower black mudstone member.

<u>Exposure</u> - The entire thickness of the member is exposed in the east side of the Thruway cut. In the west side of the cut all of the member except the top several feet is exposed. Besides the good exposures on the Thruway, there are poor exposures on the wooded slope between the Thruway and the railroad. These outcrops take the form of several parallel gentle ridges extending from the Thruway almost to the railroad. The type section of the member is the east side of the Thruway cut. At Pea Hill the member is well exposed on the west limb of the syncline near the southwest side of the hill, and less well exposed at the nose of the syncline and on its east limb in the north and east sides of the hill. It has been recognized at the Bakertown Road locality.

<u>Lithology</u> - The member consists of very dark gray to black mudstone or fine siltstone. There are no laminations or other small-scale features indicative of stratification. Cleavage is partly developed, causing the rock to break into tabular chunks of all sizes. The rock parts mainly along the cleavage and only slightly along the bedding. Where they can be seen, bedding surfaces are planar. At Highland Mills exposed bedding planes often show a network of fine cracks caused by cleavage; such bedding planes show various stages of disintegration into cleavage fragments. At Pea Hill, well developed cleavage in the member has almost obliterated stratification features. Weathering produces prominent brown and olive-colored stains on most exposed surfaces.

In contrast to the underlying member, _Taonurus_ does not occur at all.

Thickness - The member is 165 feet thick at Highland Mills and about 135 feet thick at Cornwall.

Lower contact - The contact with the underlying Mountainville member is gradational through a thickness of several feet. The rocks gradually lose the characteristics of the Mountainville member and take on those of the lower black mudstone member.

Age - The lower black mudstone member is unfossiliferous, and so it cannot be dated precisely. It is post-Oriskany in age but is older than the Highland Mills member of the Esopus.

Highland Mills member

Name - The name Highland Mills member was given by Boucot to rocks underlying his middle member of the Esopus formation and overlying the Connelly conglomerate. Because of his error in correlation between the railroad cut and the Thruway cut, the rocks which he considered to comprise the Highland Mills member in reality overlie the lower black mudstone member of the Esopus instead of the Connelly conglomerate. The rocks in the railroad cut which he considered to be the Highland Mills member are actually the Highland Mills member, but the beds in the Thruway cut which he considered to be the Highland Mills member are in reality the Mountainville member. His lithologic description of the lowest part of the member is mistakenly based on outcrops of the Mountainville member in the Thruway cut. He made the west side of the Thruway cut the type section for the member, but actually the member is not exposed there; the type section for the member must be reassigned to the east side of the Thruway cut.

Exposure - The member is exposed in its entirety in the east side of the Thruway cut, but it is not exposed at all in the west side of the cut. All of it except the lowest several feet is exposed in the railroad cut. On the wooded slope between the railroad and the Thruway there is fresh float which is identical in lithology to the rocks of the Highland Mills member. (Boucot mistakenly considered this float to be the Woodbury Creek member). At Pea Hill the lower part of the member is exposed on the east limb of the syncline on the south slope of the hill but nowhere else; the upper part of the member is exposed on the west limb of the anticline on the north slope of Moodna Creek.

Lithology - Most of the unit is composed of light bluish gray very fine sandstone and coarse siltstone. Part of the sandstone shows no laminations, while part of it shows vague laminations one to two mm. thick, which stand out as vague ridges. The rock parts along bedding planes to form beds one-half to two inches thick. This parting, along with numerous joints perpendicular to the bedding, produces tabular plates and blocks of sandstone a few inches to a foot in size. Although on a small scale the stratification is planar, the large bedding surfaces (a few tens of feet in width) exposed in the railroad cut are curved to form irregular domes and basins. This is reflected in irregular thickening and thinning along the bedding. The sandstone beds usually occur in series grading upward into siltstone which splits easily along the bedding surfaces into layers about one-half mm. thick. Overlying each siltstone phase with sharp contact is another series of sandstone beds. The thickness between siltstone phases is six inches to a few feet. The siltstone comprises less than a tenth of the total thickness of the member.

A very prominent feature of the unit is the presence of tube-like bodies in many beds. These bodies are cylindrical, 1/4 to 3/8 inches in diameter, with circular cross section. They are composed of the same material as the rest of the rock, but are set off by a surface of division. This surface of division is barely noticeable in fresh rock, but it is accentuated by weathering. The bodies assume all attitudes with respect to the bedding surfaces: some are normal to the bedding, some are oblique to it, and others lie parallel to it. On weathered bedding planes they appear as knobs or pits when they are roughly perpendicular to the bedding, and as grooves or ridges when they are roughly parallel to it. Although on some of the bedding surfaces on which they occur they are only sparsely scattered, on most they are very numerous.

There are several richly fossiliferous lenses about midway through the thickness of the member. These weather deeply to bright orange friable material. Fossils are only sparingly scattered through the rest of the member. Fossil lenses with the same character and in the same position in the member occur at the Bakertown Road locality.

Joint planes in the sandstone are stained brownish orange and in places bright red. Often on bedding planes along which parting has taken place the brownish orange stains are arranged in wavy arcs a few tenths of a mm. wide. A prominent feature of many joints is a dark brown zone extending into the rock about one-half inch from the joint surface. The texture of this zone seems to be the same as that of the fresh rock. The transition from weathered to unweathered rock is sharp and usually straight.

About two-thirds of the way up through the member there are a few tens of feet of strata with a slightly different lithology; these rocks are medium siltstone, medium to dark gray in color. Cleavage is present but is poorly developed; it causes the rock to break into small rough tabular fragments. The tube-like bodies described above are present in these beds also, but they are not as prominent. The rock weathers to a rusty shade. The transition from these rocks to the dominant rock type of the member is gradational over a thickness of several inches both above and below.

The features of the member at Pea Hill and at the Bakertown Road locality are exactly the same as at Highland Mills.

Thickness - At Highland Mills the member is 155 feet thick. At Cornwall its thickness is roughly the same; it is difficult to estimate because the upper and lower parts of the unit are not exposed together on the same limb of either of the folds.

Lower contact - The upper part of the lower black mudstone member becomes interbedded with sharply bounded sandstone and siltstone beds of the Highland Mills member, and several feet above the first appearance of such beds the transition to the Highland Mills member is complete. The contact is well exposed in the east side of the Thruway cut at Highland Mills. The interbedding is partly exposed on the east limb of the syncline at Pea Hill.

Age - Boucot (1959) considered the Highland Mills member to be of post-Oriskany and pre-Woodbury Creek age on the basis of its brachiopod fauna. The faunal list below differs from his list by the presence of *Amphigenia preparva*; he found this fossil in the series of outcrops in the woods just west of the Thruway at Highland Mills. He considered these outcrops to be in the lower part of the Woodbury Creek member, whereas they are in reality in the Highland Mills member. This error does not affect his conclusion that the Highland Mills member is pre-Woodbury Creek and post-Oriskany in age, but it places the zone of *Amphigenia preparva* in the Highland Mills member. The following fossils were found in the unit.

Platyorthis planoconvexa

Camarotoechia? sp.

Leptocoelia flabellites

Hysterolites perimele

Cyrtina rostrata

"Schuchertella" sp.

Eodevonaria cf. E. gaspensis

"Chonetes" cf. "C". nectus

Etymothyris sp.

Prionothyris diobolarus

Meganterella finksi

Amphigenia preparva

upper black mudstone member

Name - The term middle member was applied by Boucot to Taonurus-bearing strata underlying the Woodbury Creek member and overlying the Highland Mills member. These strata are similar in lithology to the Esopus formation in its type locality. Because of the recognition of two members of the Esopus formation lower than the Highland Mills member, this "middle" member can no longer be considered either to be in the central part of the Esopus formation or to be the second of three members. It is here given the name upper black mudstone member.

Exposure - The entire thickness of the member is well exposed both in the railroad cut and in the Thruway cut at Highland Mills. It does not crop out elsewhere in the Highland Mills area. Its exposure in the east side of the Thruway cut is here assigned as its type section. At Pea Hill it is exposed only on the north slope of Moodna Creek on the west limb of the anticline near its nose. It is not exposed at the Bakertown road locality.

Lithology - The member is composed entirely of black and dark bluish gray mudstone, with the black appearing to be slightly finer grained. The most striking feature of the unit is the presence of Taonurus cauda-galli. In the lowest several feet of the member it occurs only sporadically, but above a certain horizon it appears on virtually all the bedding surfaces. Since the rock does not split as evenly along the stratification as the Mountainville member does, the ridges formed by the intersection of the Taonurus with the bedding planes is rougher and more irregular than in the Mountainville member. The only indication of stratification on a fine scale is the Taonurus; no laminations are present. The rock breaks sharply along the bedding planes into beds one to three feet thick. On a scale of a few tens of feet the bedding surfaces are perfectly planar. At Highland Mills the member shows no influence of cleavage; only in certain layers is the cleavage developed to a slight degree, producing a slight fissility. At Cornwall the member is slightly cleaved. At Highland Mills, a few feet above the contact with the Highland Mills member, there is a $1\frac{1}{2}$ foot bed similar to all the other beds in the lower Taonurus-poor part of the member except that its color is dark purplish red. It is exposed both in the railroad cut and in the Thruway cut.

Surfaces of the rock which have been exposed to weathering for a relatively short time change their color to light olive green. Under the influence of more prolonged weathering, the rock becomes stained rusty brown or orange and in places red.

Thickness - At Highland Mills the unit is 80 feet thick. At Cornwall it is about 55 feet thick.

Lower contact - The upper beds of the Highland Mills member grade upward within a few feet into the beds of the upper black mudstone member. There is no sign of a sudden change. Two choices arose for the placing of the contact: first, as described above, at the gradation between rocks with lithology and bedding character of the Highland Mills member and of the upper black mudstone member; second, at that bedding plane where Taonurus abruptly becomes the dominant feature of the rock (below this bedding plane only traces of Taonurus are observed.) At Highland Mills this bedding plane is 15 feet above the change in lithology from the Highland Mills member. The first choice seems to be the most significant one, and so it was chosen as the contact. Boucot (1959) did not specify on such a fine scale where the contact should be placed. The contact is best exposed at Highland Mills in the railroad and Thruway cuts. It is also exposed on the north slope of Moodna Creek in Cornwall.

Age - The unit contains no diagnostic fossils. It is intermediate in age between the Highland Mills member and the Woodbury Creek member.

Woodbury Creek member

Name - The name Woodbury Creek member was applied by Boucot (1959) to strata underlying the Kanouse sandstone and overlying the upper black mudstone member (Boucot's middle member) of the Esopus formation.

Exposure - At Highland Mills the entire thickness of the member is exposed in the east side of the Thruway cut. Approximately the lowest third of the unit is exposed in the railroad cut. At Pea Hill in Cornwall it is exposed only on the north slope of Moodna Creek.

Lithology - At Highland Mills the member is composed almost entirely of light gray coarse siltstone or very fine sandstone. The rock splits along the bedding in a rough and irregular way. Partings divide the rock into beds six inches to a foot thick. The lowest few feet are darker gray than the rest, and their lithology resembles that of the underlying member more than does the rest of the member. At Cornwall some of the beds are dark gray and are slightly calcareous. The rock is more highly cleaved in Cornwall than in Highland Mills.

The most prominent feature of the member, both at Highland Mills and at Cornwall, is the occurrence of black markings on most of the bedding surfaces. When viewed in the bedding surfaces these markings appear as contorted wormlike bodies about 1/8 inch wide and up to a few inches long, flattened in a direction normal to the bedding. When viewed normal to the bedding they appear as strips or lenses a little less than a mm. thick lying parallel to the bedding. They occur in profusion throughout the unit, although they are smaller and less conspicuous in the lowest few feet. The tock shows no lamination at all; except for the attitudes of shells, the wormlike markings are the only guide to the stratification on a small scale.

At Highland Mills the weathering of the unit is distinctive: some beds weather into small roughly tabular fragments, while other beds disintegrate into large blacks only. In the lower part of the unit in the railroad cut at Highland Mills, spheroidal weathering of certain beds is taking place. These beds are disintegrating into small chips in a network of zones on the bedding surfaces, leaving spheroidal bulges of unweathered rock between the zones. The spheroids are one to two feet in size. These weathering phenomena provide a conspicuous contrast, on a large scale, with the underlying upper black mudstone member; under the same conditions of weathering, beds of the upper black mudstone member retain their planar character. At Pea Hill the Woodbury Creek member shows no distinctive weathering features.

Lower contact - The lower contact of the Woodbury Creek member is placed at the transition zone between rocks containing *Taonurus* and those containing the wormlike markings described above. This transition is complete within about a foot. It coincides with the beginning of the transition from the more thickly bedded darker gray rock of the upper black mudstone member to the slightly more thinly bedded lighter gray rock of the Woodbury Creek member. This transition is complete in a few feet.

Thickness - The thickness of the unit at Highland Mills is 125 feet. At Cornwall the lowest 20 feet of the unit is exposed. Above the highest exposure of the unit there is a covered interval of about 55 feet up to the lowest exposure of Kanouse sandstone.

Age - Boucot (1959) concluded that the upper half of the Woodbury Creek member is Onondaga in age because of the presence of "*Spirifer*" *macrus*, *Eodevonaria arcuata*, *Pentagonia unisulcata*, and *Amphigenia elongata*. He considered the lower half of the member to be intermediate in age between the Highland Mills member and the upper half of the Woodbury Creek member (Onondaga in age) because of the occurrence of *Amphigenia preparva* and *Etymothyris* sp. The outcrops in which he found these two fossils (the outcrops in the woods just west of the Thruway at Highland Mills) have proved to belong to the Highland Mills member and not to the Woodbury Creek member. The effect of this correction is to ally the lower part of the Woodbury Creek member more closely to the upper part. All of the Woodbury Creek member must be considered of Onondaga age.

The revised list of brachiopods from the Woodbury Creek member is as follows:

"Spirifer" macrus

Hysterolites? sp.

Elytha fimbriata

Pentagonia unisulcata

Cyrtina rostrata

Leptaena "rhomboidalis"

Schuchertella sp.

Eodevonaria cf. E. arcuata

Chonostrophia sp.

Anoplia nucleata

Amphigenia cf. A. elongata

KANOUSE SANDSTONE

Name - The term Kanouse sandstone was applied by Kümmel (1908) to sandstone and quartz pebble conglomerate of Onondaga age in the outlier. Its presence at Highland Mills was first noted by Kindle and Eidman (1955). Earlier Clarke (1909) had considered its exposures at Highland Mills to be the highest part of an Esopus-Schoharie sequence exposed in the railroad cut. Kindle and Eidman (1955) and Boucot (1959) dated the formation as Onondaga in age on the basis of the brachiopod fauna it contains.

Exposure - The lowest ten or fifteen feet of the Kanouse sandstone is exposed in the northernmost part of the east side of the Thruway cut at Highland Mills. Higher beds are exposed on the steep slope leading down to the railroad cut from the west side of the Thruway. In the area west of Cornwall there are a few poor exposures of the Kanouse in the steep north bank of Moodna Creek.

Lithology - The Kanouse sandstone consists of two rock types: hard gray medium sandstone composed mostly of quartz sand, and hard conglomerate composed of rounded very fine to fine quartz pebbles tightly cemented by silica. The sandstone displays no stratification features on a small scale either on fresh or on weathered surfaces. A few fine pebbles float in it. It weathers deeply to brown without changing its strength characteristics; at the surface, weathering produces a thin zone of porous crumbly rock. The conglomerate weathers deeply to brown without a change in its strength, just as the sandstone does. Stratification is revealed in the conglomerate by vague vertical variations in maximum and average size of the pebbles and in frequency of the larger pebbles. The sandstone and conglomerate are interbedded in beds a few inches to a few feet thick. The upper contacts of the sandstone beds are sharp and slightly undulating, whereas the conglomerate beds grade upward into the overlying sandstone beds.

Several feet above the lowest beds exposed on the west side of the Thruway (that is, about two thirds of the way through the thickness of the formation exposed at Highland Mills), the conglomerate beds cease and the sandstone changes its character slightly. The sandstone becomes lighter gray, softer and more easily disintegrated by weathering. Roughly ten feet of this type of sandstone are exposed on the slope. At Cornwall the outcrops are all sandstone. Its lithology is very similar to the sandstone at Highland Mills. Although no conglomerate is exposed in place, angular chunks of it lie at the base of the slope on which the outcrops are situated. Its character is exactly the same as at Highland Mills.

Thickness - At Highland Mills 25 feet of the Kanouse sandstone is exposed. At Cornwall, only a few feet are exposed. There is a covered interval of a few tens of feet between the highest exposure of the Woodbury Creek member of the Esopus formation and the lowest exposure of the Kanouse.

Lower contact - Sandstone beds of the Kanouse sandstone are interbedded with beds of the Woodbury Creek member of the Esopus formation. The transition from one to the other is complete over a thickness of a few feet. The contact is exposed in the east side of the Thruway cut at Highland Mills.

It is covered in Cornwall.

Age - Boucot (1959) considered the Kanouse sandstone to be unquestionably of Onandaga age.* He identified the following brachiopods in it:

Rhipidomella musculosa var. solaris
Platyorthis planoconvexa
Camarotoechia? sp.
Atrypa reticularis
Acrospirifer macrothyris
"Spirifer" macrus
Elytha fimbriata
Meristella nasuta
Protoleptostrophia sp.
Leptaena "rhomboidalis"
Stropheodonta demissa
Megastrophia hemispherica
Schuchertella sp.
Eodevonaria arcuata
Amphigenia elongata
"Prionothyris" sp.
Centronella sp.

CORNWALL SHALE

Name - Darton (1894) applied the term Monroe shale to exposures of dark gray shale bearing a Hamilton fauna in several localities around Monroe. He considered these outcrops and

* Now (oral communication) Boucot considers it of pre-Onondaga age.

the outcrops in Cornwall, on Pea Hill, to be the best exposures of the Monroe shale in the northern part of the Outlier. Hartnagel (1907) reported a ruling of the Committee on Stratigraphic Names of the United States Geological Survey that the use of the term Monroe be restricted to certain strata in Michigan. He therefore proposed the name Cornwall shale as an alternative to Darton's Monroe shale because he, like Darton, believed that the rocks on Pea Hill belong to the same formation as the rocks of Hamilton age around Monroe (such rocks actually exist).

It is shown in this paper that the Pea Hill outcrops belong to the Esopus formation and not to the Cornwall shale, so that the assignation of the outcrops as the type locality for the Cornwall shale is in error. The rocks Darton conceived to be the Cornwall shale are present at Highland Mills and Monroe, but they are not exposed around Cornwall (if the Cornwall shale is present at Cornwall it lies unexposed in the north bank of Moodna Creek stratigraphically above the outcrops of the Kanouse sandstone). The outcrop area around Pea Hill cannot remain the type locality for the Cornwall shale; a new type locality must be assigned. Not enough work has been done in the Outlier to permit a choice.

Exposure - At Highland Mills the Cornwall shale is exposed in the bed and west bank of Woodbury Creek just west of the outcrop area of the Kanouse sandstone.

Lithology - The Cornwall shale consists of black shale which parts easily along the cleavage. There is some parting along the stratification, but the cleavage obscures this parting. In a few places thin laminations are seen on weathered surfaces. Wormlike markings lying parallel to the stratification are the only sign of organic remains. In some layers the shale is calcareous. Irregular patches of fine pyrite are scattered through the rock.

Thickness and contacts - At Highland Mills 80 feet of the unit is exposed. Neither its upper contact nor its lower contact is exposed. There is a covered interval of 250 feet between the highest exposure of Kanouse sandstone and the lowest exposure of the Cornwall.

Age - The age of the Cornwall shale at Highland Mills is uncertain. It is probably lower Hamilton in age, because it is situated stratigraphically between the Kanouse sandstone (an Onondage equivalent) and the Bellvale sandstone (a Hamilton equivalent), exposed farther north along Woodbury Creek.

BELLVALE SANDSTONE

Farther north along Woodbury Creek from the outcrops of the Cornwall shale the Bellvale sandstone is exposed. It consists of dark gray flaggy sandstone probably of graywacke composition. Specimens of _Mucrospirifer_ were found in it. It was not studied in detail.

REFERENCES

Boucot, A.J., 1959, Brachiopods of the Lower Devonian rocks at Highland Mills, New York: Jour. Paleontology, v. 33, no. 5, p. 727-769.

Chadwick, G.H., 1908, Revision of "The New York series": Science, new ser., v. 28, p. 346-348.

Clarke, J.M., 1909, Early Devonic History of New York and Eastern North America, pt. 2: N.Y. State Mus., Mem. 9, 250 p.

Darton, N.H., 1886, On the area of Upper Silurian rocks near Cornwall Station, eastern-central Orange County, New York: Amer. Jour. Science, 3rd ser., v. 131, p. 204-216.

———, 1894, Geologic relations from Green Pond, New Jersey, to Skunnemunk Mountain, New York: Geol. Soc. America, Bull., v. 5, p. 367-394.

Hartnagel, C.A., 1907, Upper Silurian and Lower Devonian formations of the Skunnemunk Mountain region: N.Y. State Mus. Bull. no. 107, p. 39-54.

Kindle, C.H., & Eidman, S.H., 1955, Fauna of the Kanouse sandstone at Highland Mills, New York: Jour. Paleontology, v. 29, no. 1, p. 183-185.

Kümmel, H.B., 1908, Description of the Franklin Furnace quadrangle, New Jersey: U.S. Geol. Survey Folio no. 161, 27 p.

Ries, H., 1896, The geology of Orange County, New York: 15th Ann. Rpt., N.Y. State Geol. Surv., p. 395-476.