BULLETIN 47

Geologic Series

CONTINUITY OF THE HARDYSTON FORMATION IN THE VICINITY OF PHILLIPSBURG, NEW JERSEY

by

JOHN C. LUDLUM

DEPARTMENT OF

CONSERVATION AND DEVELOPMENT

STATE OF NEW JERSEY

CHARLES P. WILBER, *Director and Chief of the Division of Forests and Parks*

MEREDITH E. JOHNSON, *Chief of the Division of Geology and Topography*

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LETTER OF TRANSMITTAL

April 1, 1940.

Mr. Charles P. Wilber, Director,
Department of Conservation and Development,
Trenton, N. J.

SIR:

I have the honor to transmit and to recommend for publication as Bulletin 47 of the Geologic Series of our reports the accompanying manuscript dealing with the *Continuity of the Hardyston Formation in the Vicinity of Phillipsburg, New Jersey,* by John C. Ludlum. Although this study was restricted to a relatively small area the conclusions reached apply to a much larger region, and for this reason I believe that Mr. Ludlum's field evidence and the results of his petrographic study of carefully selected samples of the Hardyston formation should be published. I might add that prior to the writing of this report Mr. Ludlum discussed with me at various times the problem which it attacks, and that I have verified the field evidence which he cites.

Yours very truly,

MEREDITH E. JOHNSON,
Chief of the Division of Geology and Topography.

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ILLUSTRATIONS

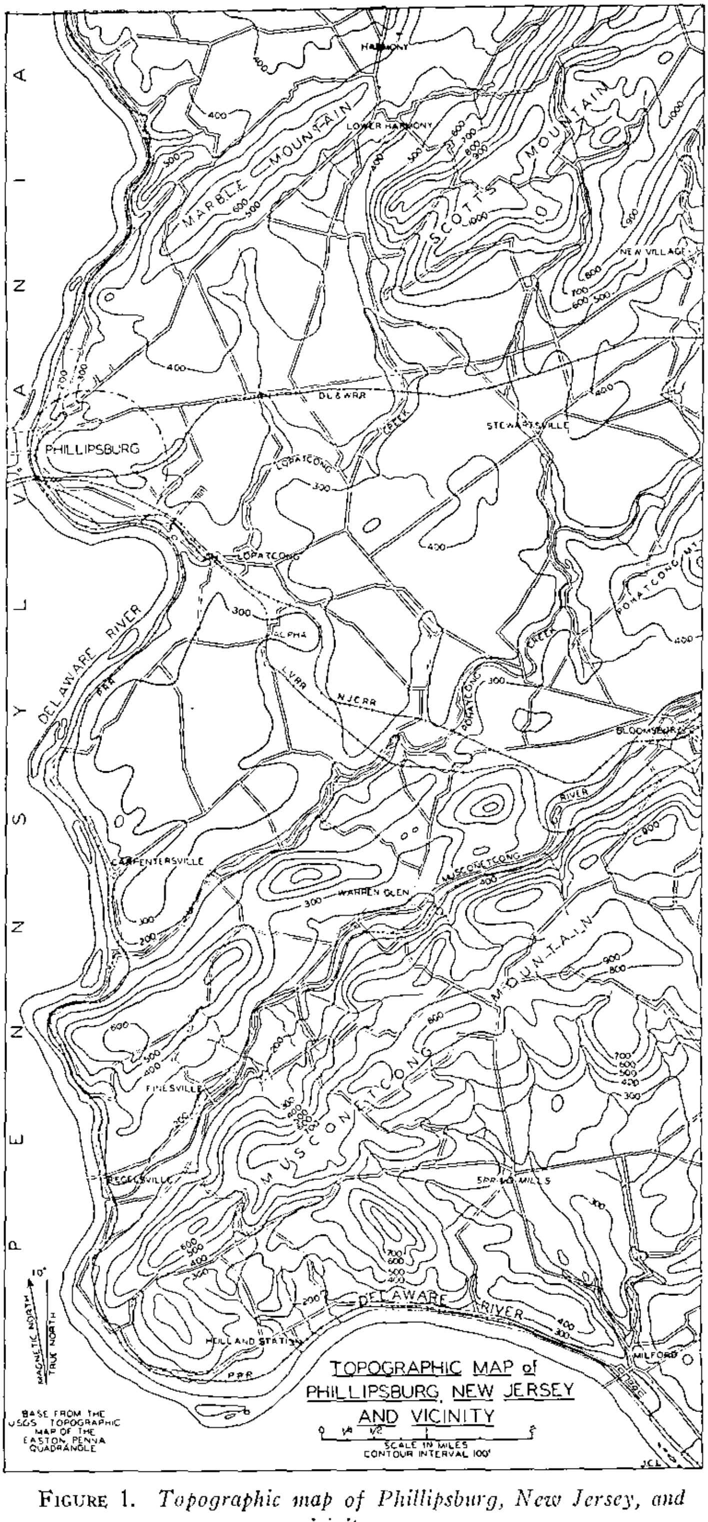

FIGURE 1. *Topographic map of Phillipsburg, New Jersey, and vicinity.*

CONTINUITY OF THE HARDYSTON FORMATION IN THE VICINITY OF PHILLIPSBURG, NEW JERSEY

By JOHN C. LUDLUM

INTRODUCTION

PURPOSE

The major geologic facts about this region have been known for many years. For the most part, this knowledge is a result of investigations made under the direction of the New Jersey State Geologist and published in the Bulletins and Annual Reports of the Geological Survey of New Jersey. Publications of the Topographic and Geologic Survey of Pennsylvania and various scientific journals also contain information which relates directly or indirectly to the geology of the region. The emphasis in these publications has been on those geologic formations which are surficially extensive and of economic importance.

The Hardyston formation is limited both in economic importance and surface expression, yet it is of decided value in delineating the geology of the region. A great deal of uncertainty has existed for some time regarding the extent of this formation, the reasons for its lack of surface expression in places, and local variations in its lithology. The purpose of this paper is to further explain and present the solutions to these problems in the region of Phillipsburg, New Jersey. The conclusions reached are the result of six weeks of field study of the region during the summer of 1938 and several later visits.

By the very nature of the problems involved, there are several possible interpretations other than those of the writer. It is hoped that this paper will stimulate other workers toward similar investigations so that the common goal of scientific truth may eventually be reached.

ACKNOWLEDGMENTS

The writer wishes to express his sincere thanks to Professor C. M. Nevin and Mr. G. W. Berry of Cornell University, Professor Freeman Ward of Lafayette College, Professor B. L. Miller of Lehigh University, Mr. M. E. Johnson, State Geologist of New Jersey, and Dr. J. M. Hills of the Amerada Petroleum Corporation, Midland, Texas, for their help and encouragement in the work. Thanks are expressed also to Dr. S. A. Berthiaume of Cornell University and Mr.

W. L. Stothoff of Flemington, New Jersey, for their co-operation. It should also be recognized that much of the basic information has been drawn from the publications of previous workers in the region to which references are made where possible.

REGIONAL SETTING

The area studied is a roughly rectangular strip located in the northwestern part of New Jersey and including parts of Warren and Hunterdon Counties. The strip extends from north to south for twelve miles along Delaware River which forms its western and southern boundaries. The eastern limit of the area lies six miles to the east of the Delaware and is determined by a line extending through the towns of Milford, Bloomsbury and New Village (Fig. 1).

The land forms of the area consist primarily of parallel ridges trending northeast-southwest and are separated by even-floored valleys of the same general trend. The Great (Kittatinny or Appalachian) Valley bounds the ridges on the north. Musconetcong Mountain, the southernmost ridge, is flanked on the south by the Triassic Lowlands.

The ridges rise rather abruptly to heights averaging five hundred feet above the valley floors and eight hundred and fifty feet above sea level. They are known locally as the New Jersey Highlands and the term is often used to include the parallel valleys as well. A more useful term, "valley fingers", has been applied to the valleys of the region by Ward[1]. He uses this term to indicate their tributary nature to the Great Valley, since similar formations are exposed in both the Great Valley and the valley fingers. The whole area is a part of the southern extension of the New England Upland known as the Reading Prong.

Drainage of the area is controlled by the superposed Delaware River which cuts through the ridges almost at right angles to their structural trend. The main tributary drainage, however, is well adjusted to the underlying structure.

[1] Ward, Freeman, Recent geological history of the Delaware Valley: Pennsylvania Topog. and Geol. Survey, Bull. G10, p. 8, 1938.

DESCRIPTIVE GEOLOGY

PRE-CAMBRIAN

The high ridges of the area are composed, without exception, of strongly metamorphosed pre-Cambrian formations. The oldest formation is thought to be the white, coarsely crystalline Franklin Limestone, which is well exposed at Lower Harmony on the southeast flank of Marble Mountain. Outcrops of the Franklin Limestone are very limited, however, and the ridges consist primarily of gneiss with lesser occurrences of schist. Both the gneiss and the schist are intruded by granite which may assume the characteristics of a pegmatite. The more common occurrence of the granite is as thin but extensive lit-par-lit injections.

The age relationships of these pre-Cambrian rocks present a difficult problem which has not been completely solved. From numerous published studies of similar sections in other parts of New Jersey, some of the gneisses and schists are of igneous origin and intrude the Franklin Limestone. However, some of the metamorphics, in addition to the Franklin, are unmistakably of sedimentary origin.

HARDYSTON

The pre-Cambrian formations are overlain unconcormably by the relatively thin Hardyston quartzite of Lower Cambrian age. The Hardyston outcrops along the flanks of the pre-Cambrian ridges. It is considered in detail later in this paper.

KITTATINNY

The Hardyston grades upward, without evident unconformity, into a characteristically massive, blue-gray dolomite known as the Kittatinny. This formation reaches a thickness of three thousand feet and is usually unfossiliferous. It is commonly divided into three members in Pennsylvania, but such a separation has not been published for the New Jersey occurrences. In eastern Pennsylvania, the lower two members, Tomstown (Leithsville) and Allentown, are considered to be of Cambrian age. The upped member, Beekmantown, is of Ordovician age.

Continuous outcrops of the Kittatinny are few in number, largely because of its occurrence in the valley fingers. While no attempt is made in this paper to make the difficult separation of the Kittatinny, yet those characteristics whereby it is separated in Pennsylvania were used in determining the general structure of the area.

JACKSONBURG

The upper member of the Kittatinny, which consists in part of beds of true limestone, is separated from the overlying Jacksonburg formation by a slight unconformity (Fig. 2). The Jacksonburg consists of very thin bedded limestone in its lower part, grading upward into a thin bedded, buff colored limy shale known locally as "cement rock". Abundant fossils of Trenton age[2] occur locally in the Jacksonburg. Although the total thickness is not measurable in the area, it is estimated not to exceed four hundred feet. The Jacksonburg outcrops mainly as a sinous strip in Pohatcong Valley, extending from Carpentersville to New Village.

NEWARK

South of Musconetcong Mountain, the eroded surfaces of the pre-Cambrian, Hardyston, and Kittatinny formations are separated from the overlying Newark Group of Triassic age by a major unconformity. The Newark Group is represented here by the Brunswick formation which consists of interbedded, very massive red conglomerates and thinner beds of red sandstone and shale. The sediments of this formation are continental in origin and may reach a thickness of six thousand feet or more.

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[2] Miller, R. L., Stratigraphy of the Jacksonburg Limestone: Geol. Soc. America Bull., vol. 48, No. 11, p. 1703, 1937.

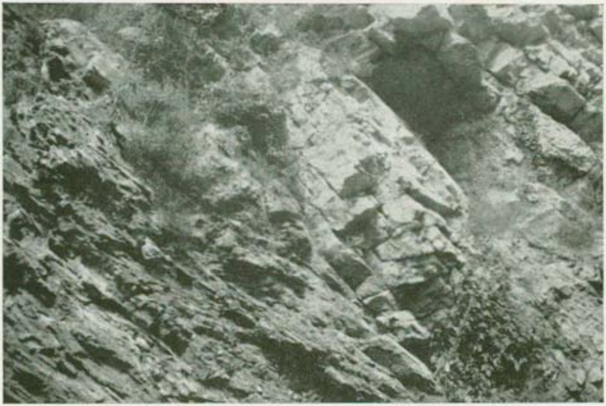

FIGURE 2. *Contact of Kittatinny (on right) and underlying, overturned Jacksonburg. Exposure in abandoned quarry of Edison Cement Corporation east of Stewartsville.*

A. *Mount Parnassus. Photograph taken from the Pennsylvania side of Delaware River.*

B. *Dolomite exposed on the west side of cut through Mount Parnassus. Dark rock in background is pre-Cambrian.*

FIGURE 4.

STRUCTURE

GENERAL

All the formations of the area, with the exception of the Brunswick, have been folded and faulted during one or more periods. It has long been recognized that the pre-Cambrian ridges are anticlines while the Paleozoic belts of the valley fingers are broad synclines. The Hardyston and Kittatinny dip away from the ridges except where faulting interrupts this normal relationship. The major folds are asymmetrical and somewhat overturned so that their axial planes dip to the southeast. The general position of Pohatcong Creek and Musconetcong River, near the southeast side of their valleys, may well be a result of migration down the gentle northwest limbs of the synclines in which they flow. The limbs of the major folds are complicated by minor folds and longitudinal thrust faults of usually small displacement. Normal strike faults are absent in the area except perhaps bordering and in the Triassic. Dip faults are few in number. Faulting in the Kittatinny is certainly more common, in this area, than the map (Fig. 3) indicates. Without separation of the Kittatinny, and in consequence of the difficulty in recognizing key beds in this formation, however, it is impossible to trace these faults and determine their displacement with any degree of certainty.

It has been shown by Miller and Behre[3] that folding affected the Ordovician Martinsburg shales and slates both at the close of the Ordovician (Taconic disturbance) and at the close of the Paleozoic (Appalachian revolution). Since much of their study was made in the Great Valley adjacent to this Highland area, both periods of deformation should be effective here also, although positive evidence of two periods of deformation was not found.

The Triassic sediments of the southern part of the area were gently folded, block faulted on a large scale, and tilted at the end of the Triassic (Palisade disturbance). Although the effects of this period of deformation without doubt extended at least into the Highland region, yet local evidence is again largely lacking. This may be explained by the magnitude of the Triassic fault blocks, and the restricted area of this study.

MOUNT PARNASSUS AND ASSOCIATED FAULTS

South of Marble Mountain, a broad synclinal valley is formed by the coalescence of the Pohatcong and Lopatcong Valleys, which is

[3] Miller, B. L., Taconic folding in Pennsylvania, Behre, C. H., Jr., Taconic folding in the Martinsburg shales: Geol. Soc. America Bull., vol. 36, No. 1, 1925.

made possible by the southwest plunge of the Scotts Mountain anticline beneath the valley sediments.

In the railroad yards south of the old Delaware River traffic bridge, a small knobby hill rises sixty-five feet above the valley floor. This hill was early known as Mount Parnassus (Fig. 4A). The greater part of the hill consists of pre-Cambrian crystalline rocks, which occupy an anomolous position on either side of a core of Kittatinny dolomite (Fig. 4B). These relationships were first noted by Finch[4] in 1824, before the railroad cut was made, but he offered no explanation. Peck[5] described it as the result of shortening of the crust at right angles to the general strike, by movement along two thrust faults dipping to the east.

The faults which Peck identified, delimit the dolomite within the hill to a strip seventy-five feet wide extending completely through the hill in a general north-south direction. Although Peck described these faults as thrusts, they are almost vertical, and the main movement seems to have been that of a strike slip with a stress acting from the south. The greatest amount of movement took place along the western fault where the dolomite and gneiss are in direct contact. Along the eastern fault a small amount of the Hardyston is present on the upthrown side and is in contact with the dolomite. The rocks show such strong fracturing and brecciation that no reliable evidence of the position of the dolomite in the Kittatinny formation could be recognized. The faults bounding the strip of dolomite represent tear faults of an overthrust block from the south, which has brought the pre-Cambrian to its present high position. The narrow slice carrying the dolomite lagged behind in the overthrust movement so that erosion has not as yet exposed the underlying formations.

Along the tracks of the Delaware, Lackawanna and Western Railroad, five-eighths of a mile almost due east of Mount Parnassus, there is a small exposure of lower Jacksonburg limestone. It extends for four hundred yards along the north side of the tracks, dipping 24 degrees, S 10 E. It is somewhat discontinuous, since the cut has exposed the underlying dolomite in places (Fig. 5A). The width of the exposed Jacksonburg is but little more than that of the cut itself, since it has been truncated by a fault along the south side of the tracks (Fig. 5B). The movement has been a thrust from the south which has carried the almost flat-lying Kittatinny over the Jacksonburg at this point. The fault is in direct strike line with Mount Par-

[4] Finch, J., Geology of the country near Easton, Pennsylvania: Am. Jour. Sci., vol. 8, p. 237, 1824.

[5] Peck, F. B., Preliminary notes on the occurrence of serpentine and talc at Easton, Pennsylvania: New York Acad. Sci. Annals, vol. 13, No. 6, p. 427, 1901.

A. *Kittatinny-Jacksonburg contact five-eighths of a mile east of Mount Parnassus. Hammer rests on Kittatinny; thin overlying beds are Jacksonburg.*

B. *Jacksonburg-Kittatinny fault contact five-eighths of a mile east of Mount Parnassus. Hammer rests on Jacksonburg; overlain by Kittatinny.*

FIGURE 5.

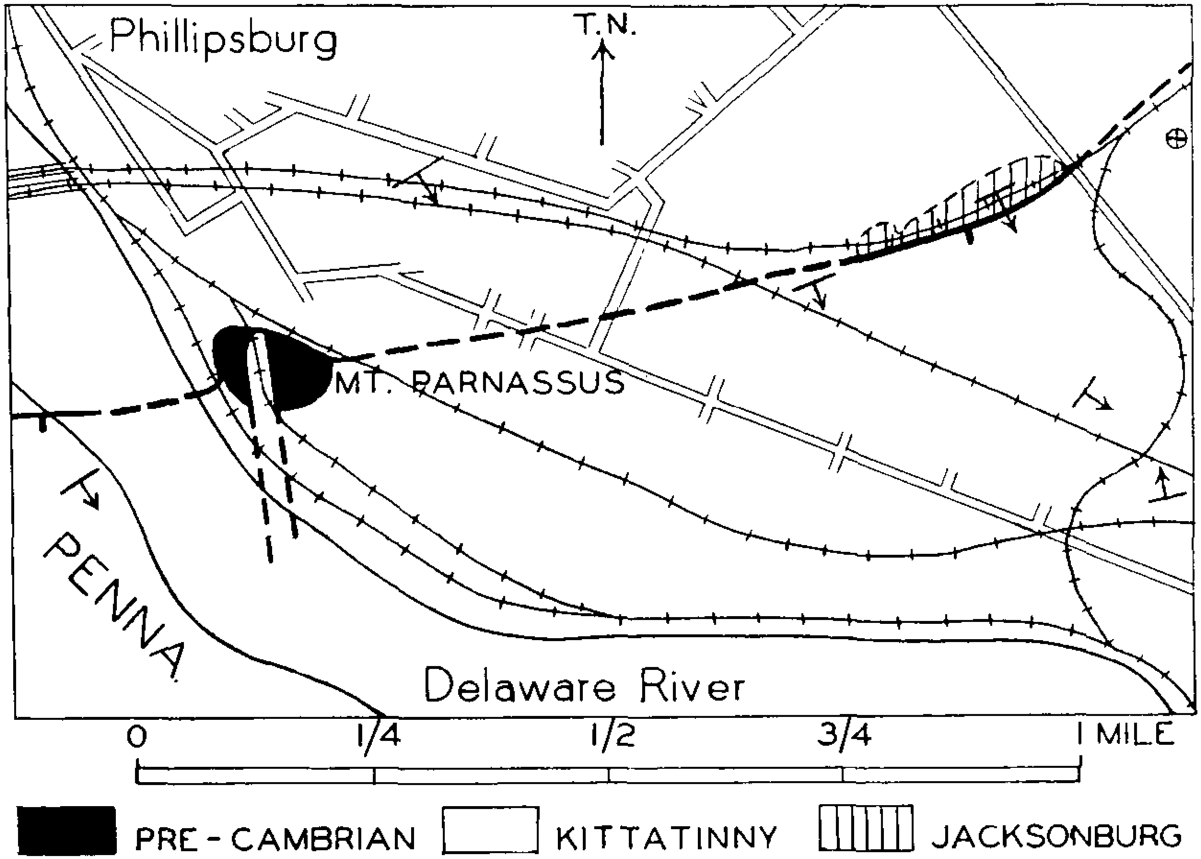

FIGURE 6. *Geologic map of Mount Parnassus fault area.*

A. *Fault of very small displacement in Jacksonburg. Exposure in railroad cut near Alpha.*

B. *Fracture cleavage in Jacksonburg dipping southeast. Exposure in railroad cut near Alpha.*

FIGURE 7.

nassus, and it is probable that it is an extension of the same fault which underlies that hill (Fig. 6).

JACKSONBURG

The thin bedded Jacksonburg limestone is the most incompetent formation in the area and has been more strongly folded and faulted (Fig. 7). With the exception of the one exposure mentioned above, it occurs in the area only in the Pohatcong Valley syncline, where it has been closely folded and overturned to the northwest. Evidence indicates that the overturning to the northwest prevails from Carpentersville to the abandoned Edison Cement Corporation quarry, one and a quarter miles northeast of Stewartsville. All dips obtained on the Jacksonburg are to the southeast. The southeast contact of the Jacksonburg with the Kittatinny, in the above quarry, dips to the southeast (Fig. 2). A possibility remains that the southeast limb of the syncline may be truncated by a fault along part of its length. Evidence for this may be seen near Stewartsville, where the Kittatinny, adjacent to the estimated contact with the Jacksonburg, shows gentle northwest dips. Actual outcrops are largely lacking from Alpha to Stewartsville.

Close to the tracks of the Central Railroad of New Jersey, almost midway between Alpha and Lopatcong, numerous fragments of a thin bedded limestone occur along the axis of a minor synclinal fold. It is possible that these fragments are residual from underlying Jacksonburg but the area of occurrence is very limited and fossils are absent. It seems likely from the nature of the fold that the immediately subjacent formation is of upper Beekmantown age and the fragments are residual from the limy phases therein.

TRIASSIC CONTACT

The Triassic Brunswick sediments, which bound Musconetcong Mountain on the south, have an average dip to the northwest of about fifteen degrees. The contact of the Brunswick with the older formations follows a narrow valley from the Delaware northeast, passing to the north of Spring Mills and Little York. Near the Delaware, the contact is with the Kittatinny dolomite, which dips to the southeast at about forty degrees. To the east, the contact is in some places with the pre-Cambrian, in other places with the Hardyston, and in still other places with the Kittatinny. The northwestern limit of the Triassic sediments, in much of New Jersey, is a fault contact. The contact in this area, though concealed, could be determined within twenty feet at places. No definite evidence of faulting could be observed and the contact seems to be one of normal overlap.

It is difficult to imagine the great thickness of Triassic sediments accumulating in a narrow basin without downfaulting taking place along the borders. Traces of such faulting might be covered by later Triassic sediments. This theory is postulated in explanation of the Triassic contact in this area. Local departures from the usual fifteen degree dip to the northwest are a result of local block faulting and folding at the end of the Triassic.

An interesting formation is exposed in several places where the Triassic is in contact with the pre-Cambrian, notably one and five-eighths miles east of the Delaware and again one-half mile north of the Spring Mills-Little York road, west of Little York. The formation is undoubtedly of sedimentary origin and consists of a very fine-grained dark gray phyllite. Well developed slaty cleavage which is crumpled and broken is shown in some specimens while the cleavage is fairly consistent in others. Mineralizing solutions from the pre-Cambrian crystallines have been injected into the latter type, west of Little York, giving the rock a schistose appearance. Thus there is a definite gradation from the sedimentary phases, through the injected phases, into the crystallines. The stage of metamorphism and this gradation establish a pre-Cambrian age for the formation. A tentative correlation perhaps may be made with the pre-Cambrian Moravian Heights formation of Pennsylvania.[6]

[6] Fraser, D. M., Stratigraphy and petrography of the pre-Cambrian rocks and Paleozoic igneous rocks of Northampton County, Pennsylvania: Pennsylvania Topog. and Geol. Survey, Bull. C48, p. 170, 1939.

HISTORICAL GEOLOGY

Following the formation of the complex group of pre-Cambrian rocks of both igneous and sedimentary origin, a great erosion period beveled their surface to a more or less even plain. This period was brought to a close by a rapid submergence and deposition of the marine Hardyston quartzite and Kittatinny limestone followed in Cambrian and early Ordovician time. This was followed by uplift, erosion, and another submergence. The Jacksonburg limestone was then deposited, and in somewhat shallower seas the mud and sand now constituting the Martinsburg formation.

At the close of the Ordovician, there was a period of uplift and folding, followed by submergence and deposition of a great thickness of Paleozoic sediments which are not now represented in this area. This period of sedimentation was brought to a close, at the end of the Permian, by the Appalachian revolution.

There ensued a long erosion interval, during which time the folded mountains were continually being reduced. During Triassic time the Brunswick sediments were deposited in a broad elongate basin under continental conditions. Since almost all the rock fragments which make up the Brunswick conglomerate are of Paleozoic sediments, the present widespread exposure of the pre-Cambrian rocks in the Highlands must have been accomplished during and since the Triassic.

Erosion finally resulted in the formation of the Schooley peneplain. Renewed uplift has brought about the rough dissection of the peneplain, of which the ridges in the area are reduced remnants. The Delaware River, formerly a consequent stream on the Schooley peneplain, was superposed across the general structure. The continuity of the valley finger levels and that of the ridge levels is a result of differential resistance to erosion of the pre-Cambrian and Cambro-Ordovician formations.

The ice of the Pleistocene covered much of the area during its Illinoian advance; and scattered remnants of glacial and glaciofluvial deposits have survived stream erosion. A later, Wisconsin, advance of the ice pushed a tongue down the Delaware at least as far as Carpentersville,[7] but these deposits are limited to the immediate valley of the Delaware in this area.

[7] Footnote by the State Geologist: This opinion is not shared by the State Geologist.

HARDYSTON QUARTZITE

HISTORY

In 1840, Rogers[8] first mentioned the occurrence, in New Jersey, of "a white quartzose sandstone, somewhat coarse and friable" overlying the Primary (pre-Cambrian) rocks and of restricted surface exposure. This was his Formation I of the Lower Secondary (Paleozoic) rocks. Later, and until 1890, geologists held that this formation could be correlated with the Upper Cambrian Potsdam of New York. In 1865 Lesley[9] indicated some doubt as to the correctness of that correlation, but nevertheless used it in 1885.[10]

Nason,[11] in 1890, described an Olenellus fauna from this formation near Franklin Furnace, New Jersey, which made it Lower Cambrian. In 1896, Walcott[12] made a similar age determination for the Chickies (Chiques) and Hellam formations in Pennsylvania. In his paper, a summary is given of the important literature concerning this formation.

Wolf and Brooks[13] named this formation Hardistonville from good exposures near the town of that name in the vicinity of Franklin Furnace. The name was shortened to Hardiston by Kummel and Weller,[14] and its spelling changed to Hardyston by the United States Board on Geographic Names. The term Hardyston has also been adopted for occurrences in eastern Pennsylvania.

On the basis of the Olenellus fauna[15] there is complete correlation between the Hardyston, Chickies, Hellam, and Reading quartzites of Pennsylvania, New Jersey and Maryland; the Chilhowee quartzite of Alabama, Tennessee and Virginia; and the Bennington quartzite of New York and Vermont.

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[8] Rogers, H. D., Final report on the geology of New Jersey, p. 11, Philadelphia, 1840.

[9] Lesley, J. P., Note on the geological age of the New Jersey Highlands as held by Professor H. D. Rogers: Am. Jour. Science, 2nd ser., vol. 39, p. 223, 1865.

[10] Leslie, J. P., A geological hand atlas of the sixty-seven counties of Pennsylvania: 2nd Geol. Survey of Pennsylvania, Rept. of Progress 10, pp. 16-17, 1885.

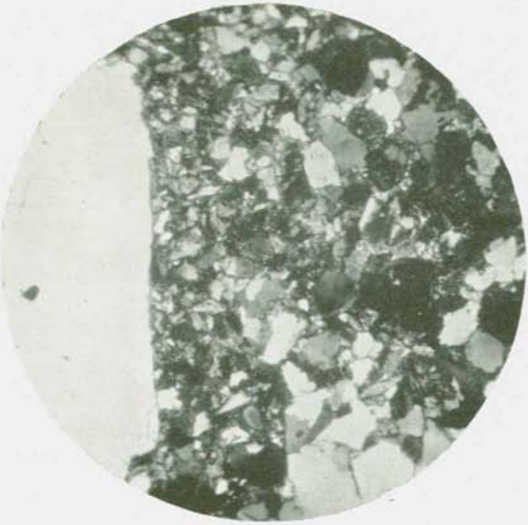
[11] Nason, F. L., The post-Archean age of the white limestone of Sussex County, New Jersey: Am. Rept. Geol. Survey of New Jersey for 1890, pp. 31-49, 1891.

[12] Walcott, C. D., The Cambrian rocks of Pennsylvania: U. S. Geol. Survey Bull. 134, pp. 3-43, 1896.

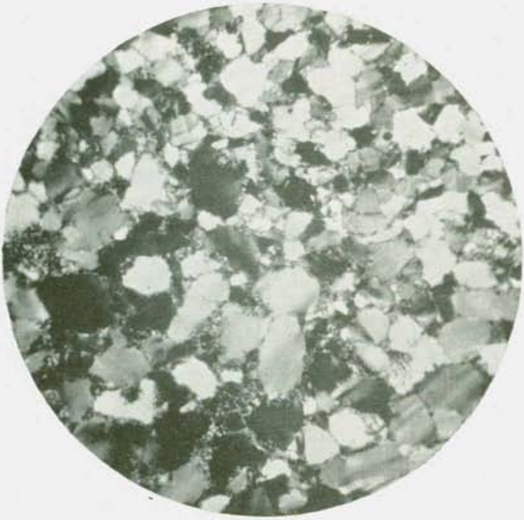
[13] Wolf, J. E., and Brooks, A. H., The age of the Franklin White Limestone of Sussex County, New Jersey: U. S. Geol. Survey 18th Ann. Rept., pt. 2, 443, 1898.

[14] Kummel, H. B., and Weller, Stuart, Paleozoic limestones of Kittatinny Valley, New Jersey: Geol. Soc. America Bull., vol. 12, p. 149, 1901.

[15] Walcott, C. D., op. cit., p. 33.



A. *Thin section, crossed nicols,* X 18. *Hardyston specimen from northwest side of Musconetcong Valley near Warren Glen. Angularity of grains characteristic of lower Hardyston.*



B. *Thin section, crossed nicols,* X 18. *Hardyston specimen from exposure three-quarters of a mile north of Riegelsville. Shows preponderance of quartz characteristic of such finer phases, better rounding of grains and quartz cement.*

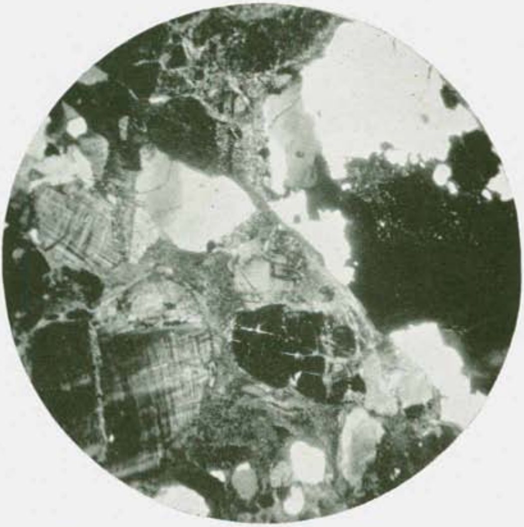
FIGURE 8.

A. *Outcrop of Hardyston three miles southeast of Alpha.*

B. *Same formation and locality, view just west of exposure shown in "A".*

FIGURE 9.

A. *Thin section, crossed nicols, X 50. Specimen from point near Pohatcong Creek, one and a half miles northeast of Bloomsbury. Dolomite replacing quartz grains in Lower Kittatinny near contact with Hardyston.*



B. *Thin section, crossed nicols, X 18. Hardyston specimen from southwest nose of Scotts Mountain, showing quartz and microcline grains cemented by iron oxide.*

FIGURE 10.

The character of the Hardyston varies to such a degree from outcrop, even in the restricted area considered in this paper, that an inclusive description would be of little value. In addition, no continuous vertical section of the formation is exposed in the area. Several phases may be recognized, however, and used for correlation purposes.

Close to the contact with the pre-Cambrian, the Hardyston is arkosic and has much the appearance of a crystalline rock. This is because of the angularity of the fragments of quartz and feldspar, the smallest amount of sorting, and the great degree of induration (Fig. 8A). Good examples of this type may be seen in residual blocks along the southwest slope of Pohatcong Mountain. However, the clastic nature of the mineral grains is easily recognized in thin sections.

Some local lenses are developed at the base of the Hardyston which are distinctly conglomeratic and the well rounded quartz pebbles may reach an inch in diameter. The pebbles are well scattered and separated by fine angular grains of quartz and feldspar.

The greater part of the Hardyston is a fine-grained, very compact silicified sandstone (quartzite) and occurs in beds from a few inches to several feet in thickness (Fig. 8B). Although there is some feldspar in this phase, the proportion is decidedly less than that in the lower and coarser phases. The color, when unweathered, is usually light buff, but may vary through several shades to a deep purple. Good exposures occur along the Lehigh Valley Railroad tracks, three miles southeast of Alpha (Fig. 9). The quartzite grades upward into a thin, buff colored sandy shale, which is exposed as residual material one mile east of Bloomsbury on State Highway 28. This sandy shale in turn grades into the typical Kittatinny dolomite (Fig. 10A).

Although the Hardyston is called a quartzite, the term does not imply a great amount of dynamic metamorphism. The component grains are seldom distorted. The compact nature and vitreous appearance is a result of cementation by a very fine-grained quartz and secondary enlargement of the original quartz grains. In some of the darker phases the cementing material is iron oxide (Fig. 10B). Outcrops of this type occur along the road which skirts the southwest nose of Scotts Mountain. In still another type, the quartz grains have been almost completely replaced by chalcedony. This has produced a rock similar to the jasper described by Fraser[16] as present in

[16] Fraser, D. M., Contributions to the Geology of the Reading Hills, Pennsylvania: Geol. Soc. America Bull., vol. 49, No. 8, p. 1202, 1938.

the Hardyston in parts of Pennsylvania. The best examples of this type occur adjacent to the Delaware along the northwest end of the extension of Pohatcong Mountain. Bayley,[17] in describing several abandoned limonite workings at this place, said that the Hardyston was absent. Its presence, however, is indicated by the jasper and by typical Hardyston fragments in the excavations.

The arkosic phases weather readily to bleached and milky colored fragments, which surficially assume the characteristics of a sandstone. Where the rock is composed entirely of quartz grains, it is very resistant to weathering. In the types where the cement is iron oxide or where iron bearing minerals are present, the rock weathers to shades of red and brown.

The thickness of the Hardyston shows great variation. In New Jersey and eastern Pennsylvania, it has been recorded as 5-200 feet (Lewis and Kummel), 20-300 feet (Hills), almost zero to 200 feet (Stose), few feet or less to 200 feet or more (Kummel), thirty feet to a foot or less (Wolf and Brooks), and a few feet to three hundred or four hundred feet (Peck). In this area the maximum thickness is two hundred and fifty feet and in places it seems to be entirely absent.

In general, the Hardyston grades upward from coarse to fine material. The percentage of feldspar decreases upward through the formation. Considering a vertical section, massive bedding is best developed near the center.

CONDITIONS OF DEPOSITION

The apparent poor sorting of the basal Hardyston and the limited thickness of the formation as a whole, indicate rapidly changing conditions of deposition. Furthermore, the variation in thickness is such that its deposition must have been greatly controlled throughout by the original topography of the floor of the body of water in which it was deposited. No large pebbles are found in the formation in this area. There are relatively few pebbles present, and these are well separated. The contact with the Kittatinny is gradational lithologically, but there is little interfingering of sandstone and dolomite.

The pre-Cambrian land surface must have been one of gentle relief just prior to submergence. Its submergence at the beginning of the Cambrian period was sudden and yet not to great depths. This resulted in the apparent poor sorting near the base of the Hardyston. Furthermore, the land mass supplying the sediments had little relief

[17] Bayley, W. S., Iron mines and mining in New Jersey: Final Rept. Series of the New Jersey State Geologist, vol. 7, p. 21, 1910.

A. *Exposure of Hardyston three-quarters of a mile north of Riegelsville.*

B. *Same formation and locality, but a different view.*

FIGURE 11.

so that deposition of coarse material was limited and probably localized. The amount of deposition was restricted to little more than filling the irregularities of the shallow sea floor. This would account for the great variation in thickness in New Jersey. With a further small increase in depth, the sea flooded a much broader area so that the source of sediments, presumably predominantly to the southeast, became rapidly distant. Consequently, without much increase in depth of water, proper conditions were quickly attained for the deposition of the massive Kittatinny dolomite.

MAPPING

Mapping of the Hardyston formation in the Highland Region of New Jersey is difficult because of the scarcity of outcrops. In the area considered in this paper, only six localities were found where unquestionable outcrops of the Hardyston were exposed. Three of these have already been mentioned. There are good exposures three-quarters of a mile north of Riegelsville (Fig. 11) and also near the crest of the extension of Pohatcong Mountain north of Warren Glen. A small exposure is located on the northwest flank of Musconetcong Mountain, between Riegelsville and Finesville.

The resistance of the pre-Cambrian rocks to erosion and weathering, following the stripping of the Hardyston from the tops of the anticlinal ridges, concentrated a destructive attack on the Hardyston which led to its present reduction. While much of the Hardyston is compact and resistant, its weak basal and upper beds reduce the resistance of the formation as a whole. Furthermore, the accumulation of thick deposits of talus material along the lower parts of the ridges has served to conceal the Hardyston. The very limited thickness of the formation in some localities effectively reduces the number of outcrops. Its absence in some places is explainable by faulting and subsequent erosion.

The writer was therefore largely dependent on residual material in mapping the formation. Such a method introduces sources of error which were eliminated as much as possible. Some glacial deposits are found in the area, but most of them are glacio-fluvial in origin, and contain well rounded quartzite fragments. Ward[18] has described the characteristics of Illinoian till deposits of the area as follows: "When broken open, the fragments always show zones of color and alteration, commonly an outer yellow-brown zone merging into a duller zone within, this in turn giving way to a core of unaltered material". No rock fragments showing such zoning were admitted as evidence and rounded fragments were never used in the mapping.

[18] Ward, Freeman, op. cit., p. 43.

The necessity of being able to recognize residual Hardyston was of particular importance along the northwest flank of Marble Mountain. The ground surface of the Great Valley, at this point, is covered with great numbers of rounded quartzite pebbles and boulders. The majority of these are of glacio-fluvial origin and indefinite source. Near the base of Marble Mountain, however, fresh angular fragments occur in greater abundance. In this same linear zone, large angular blocks of typical Hardyston weighing several tons apiece are also present. Their position associated with the smaller fragments, furnishes substantial evidence of the near-surface presence of the Hardyston.

It was found to be generally true throughout the area that, when glacial, glacio-fluvial, and fluvial materials were eliminated from consideration, the occurrence of fresh, good sized, angular fragments of quartzite, typical of the Hardyston observed in outcrops of the area, was limited to very definite linear zones. These were in general along the bases of the ridges and continuity between the zones and actual outcrops was traceable.

Where the noses of the anticlinal ridges are low and plunge under the Paleozoic sediments, relatively large areas of residual Hardyston occur. Such areas are at the southwest end of Scotts Mountain and in the saddle between Pohatcong Mountain proper and its southeastern extension. These represent areas of gentle dip in contrast with the exposures along the flanks of the ridges where dips are steep and the zones of residual Hardyston are consequently narrow.

CONTINUITY

An examination of the geologic map (Fig. 3) will show that the Hardyston has not been mapped as a completely continuous formation. The gaps represent areas where residual Hardyston is absent. Conditions at these places seem no less favorable for the appearance of residual material, than where it is now found.

The failure of the Hardyston to appear even residually in certain places along the flanks of the pre-Cambrian ridges may be explained by: 1. It was not deposited; 2. It was deposited in such limited thickness that its appearance would not be expected; 3. It has been faulted out.

Where the Hardyston is not mapped, there is no evidence, even topographically, that faulting has occurred. Exceptions should be made of the northwest flank of Marble Mountain immediately adjacent to the Delaware River, where an established fault on the Pennsylvania side may be properly extended and also near Little York where the Kittatinny is in direct contact with the pre-Cambrian along a pre-Triassic or Triassic shear zone. Some geologists, however, have favored faulting as an explanation of every absence of the Hardyston, an opinion which has been stated by Bayley[19] as follows:

> "The underlying quartzite grades upward into shales and these into limestones. The limestones and shales are folded and faulted. In many places they lie immediately upon the Algonkian rocks. In these cases the junction is supposed to be along a fault plane, the quartzite being beneath the limestone, many feet below the surface."

The writer believes that this assumption is not reasonable without definite evidence of faulting. When the recognized thickness of the Hardyston is so variable, even within limited areas, absence because of non-deposition should be considered. The nature of the Hardyston sediments, and their very limited thickness in some places, makes probable the existence of local unsubmerged areas (areas of non-deposition) in the Cambrian sea. The later submergence of these areas would allow the deposition of the dolomite sediments upon the pre-Cambrian surface with little if any Hardyston.

In many published geologic maps showing the Highlands of New Jersey, the ridges are often bounded by high angle faults of both normal and reverse types. Their planes usually dip to the southeast. Such faults have sometimes caused local omission of the Hardyston, as well as parts of the Kittatinny.

The continuity of the Hardyston in the area considered obviated the necessity of such faults. Two faults do occur, however, which have cut out the Hardyston locally along the southeast flank of the extension of Pohatcong Mountain. When the separation of the Kittatinny dolomite into definite members has been accomplished, it may be found that other ridge-marginal faults occur in the Kittatinny itself, or at its contact with the Hardyston.

If one assumed that the Hardyston was deposited as a continuous blanket over the pre-Cambrian formations, its absence or presence along the flanks of a Highlands ridge would then indicate whether or not faulting had occurred. It is believed, however, that the evidence cited in this report is sufficient to show that the lack of continuity of the Hardyston is in part to be explained by non-deposition. Hence, though it still remains a key to the larger structures of the Highlands, its absence should be interpreted as indicative of faulting only where there is definite supporting evidence.

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[19] Bayley, W. S., op. cit., p. 21.