Uranium Occurrences in Sedimentary Rocks of Pennsylvania

GEOLOGICAL SURVEY BULLETIN 1107-D

Prepared on behalf of the U.S. Atomic Energy Commission and published with the permission of the Commission

Uranium Occurrences in Sedimentary Rocks of Pennsylvania

By HARRY KLEMIC

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

GEOLOGICAL SURVEY BULLETIN 1107-D

Prepared on behalf of the U.S. Atomic Energy Commission and published with the permission of the Commission

---

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

CONTENTS

	Page
Abstract	243
Introduction	243
Acknowledgments	244
Investigations for uranium	245
Reconnaissance	247
Laboratory studies	248
Regional setting	248
Appalachian Plateaus province	249
Valley and Ridge province	249
Piedmont province	250
Uranium occurrences	251
Distribution	251
Stratigraphic relations	253
Devonian rocks	253
Mississippian rocks	255
Pennsylvanian rocks	256
Characteristics	257
Detailed descriptions of occurrences in the Valley and Ridge province	258
Composite description of occurrences in the Appalachian Plateaus province	262
Radioactive minerals	263
Composition of uraniferous rock	265
Origin	273
Economic potential	275
Localities	277
Appalachian Plateaus province	277
Valley and Ridge province	280
Piedmont province	283
References cited	284
Index	287

ILLUSTRATIONS

PLATE 2.	Map of Pennsylvania showing localities where uranium is known to occur	In pocket
FIGURE 30.	Map of drainage system of Lehighton quadrangle and adjoining areas	246
31.	Map of Pennsylvania showing stratigraphic positions of uranium occurrences in Paleozoic rocks	254

TABLES

		Page
TABLE 1.	Uranium minerals from uranium occurrences in sedimentary rocks of Pennsylvania	263
2.	Semiquantitative spectrographic analyses of uraniferous and nonuraniferous rock from Pennsylvania, New Jersey, West Virginia, and Tennessee, with radiometric and chemical analyses for uranium and selenium	266
3.	Chemical analyses for uranium and selenium in some rocks and minerals from Pennsylvania and New Jersey	272

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

URANIUM OCCURRENCES IN SEDIMENTARY ROCKS OF PENNSYLVANIA

By Harry Klemic

ABSTRACT

In Pennsylvania, uranium deposits occur in sedimentary rocks of Late Devonian to Late Triassic age in the Appalachian Plateaus, Ridge and Valley, and Piedmont provinces. As a result of searches made by prospectors and reconnaissance work by U.S. Geological Survey field parties, uranium occurrences have been discovered in three principal stratigraphic sequences: (1) Upper Devonian rocks, (2) Upper Mississippian and Lower Pennsylvanian rocks, and (3) Upper Triassic rocks.

The uranium occurrences in Upper Devonian rocks are commonly associated with gray sandstone or shale that contains copper minerals and carbonaceous plant fossils, but this association is not marked in the largest deposits with the greatest concentration of uranium. The occurrences in the Upper Mississippian and Lower Pennsylvanian beds are in rocks that commonly contain carbonaceous material but do not have megascopically noticeable copper minerals. Those in the Triassic rocks contain small amounts of carbonaceous material, traces of copper, and some pyrite.

Uraninite and possibly another black form of uranium oxide probably are primary minerals. Secondary uranium vanadates, phosphates, carbonates, silicates, and possibly arsenates are found in the various deposits.

Spectrographic and chemical analyses show that the abundance of uranium is independent of the abundance of any other element. The only relation noted is that lead, vanadium, and selenium are most abundant in rocks in which uranium is also abundant.

Some of the uranium occurrences probably formed by syngenetic deposition, others by early epigenetic concentration, and a few by relatively recent leaching and redeposition by ground water.

Of the many known uranium occurrences only two, both in Carbon County, seem to be deposits of potential economic value.

INTRODUCTION

Uranium occurs in sedimentary rocks at many localities in Pennsylvania. The rocks range in age from Late Devonian to Triassic. Many of the known occurrences were examined by the author during reconnaissance investigations for radioactive materials and studies of known uranium occurrences in Eastern United States. These studies were made by the U.S. Geological Survey on behalf of the U.S. Atomic Energy Commission. Reconnaissance was done by F. A. McKeown and the author, assisted by R. C. Baker, P. W. Choquette, F. J. Johnson, Jr., and A. R. Taylor. Separate studies were made by J. C. Ferm, E. D. Patterson, R. W. Schnabel, and R. C. Vickers. Some uranium occurrences were examined more recently by the author and J. C. Warman in conjunction with studies of uranium and geologic mapping in Pennsylvania.

This report describes the occurrence and distribution of concentrations of uranium in sedimentary rocks in Pennsylvania and some of the investigations for uranium carried out between 1953 and 1958. The areas discussed are shown in plate 2. The term "uranium occurrence," as used in this report, includes deposits in which only hand-sample amounts of uraniferous rock are exposed and others that are known to contain tens or hundreds of tons of uraniferous rock.

Uraniferous rock is used in a relative sense in this report. It includes rock with as little as a few thousandths of 1 percent uranium in some localities, and rock containing more than 1 percent in others.

At some of the occurrences secondary uranium minerals have been found, but much of the uraniferous rock is so similar in appearance to barren rock that the presence of uranium can only be detected by instruments for measuring radioactivity or by chemical tests. The uranium in some occurrences is in very fine grained material that is disseminated in the rock in association with dark interstitial material or plant fossils.

ACKNOWLEDGEMENTS

Many of the uranium occurrences were discovered by prospectors, and the cooperation of many prospectors in revealing the locations of their finds is gratefully acknowledged. Raymond Zimmerman, Charles S. Zimmerman, Harold F. Black, and John T. Barton were very helpful. Jack Kratchman and T. N. Walthier, geologists of the Raw Materials Office of the Atomic Energy Commission, provided information about the location of some of the occurrences.

Information furnished by Gordon Wood and Harold Arndt of the U.S. Geological Survey, Prof. J. L. Dyson of Lafayette College, and John Prizer, formerly of Jim Thorpe, Pa., is appreciated. The geologists of the Pennsylvania Turnpike Commission have been very cooperative.

The Lehigh Valley Railroad Co., the Lehigh Navigation and Coal Co., the Atlas Powder Co., and many private individuals permitted investigation of their property.

All spectrographic, mineralogic, and X-ray analytical determinations were made by members of the U.S. Geological Survey.

INVESTIGATIONS FOR URANIUM

Uranium minerals were found in northeastern Pennsylvania in 1874, as reported by Genth (1875). An occurrence of uranium near Jim Thorpe, formerly Mauch Chunk, Pa., was described at an early date by Wherry (1912). In 1948, F. A. McKeown found an occurrence of uranium in eastern Pennsylvania (unpublished data, 1949). Between 1951 and 1956, reconnaissance activity and prospecting continued in Pennsylvania. Schnabel and Vickers (1953) of the U.S. Geological Survey conducted reconnaissance investigations for radioactive material in the Clinton formation of New York, Pennsylvania, and New Jersey in 1951 with negative results. During 1953, Welch (1953) made a reconnaissance study of uranium in coal and related rocks in the anthracite fields of eastern Pennsylvania, also with negative results.

In 1953 and 1954 the U.S. Geological Survey undertook a program of road reconnaissance for uranium deposits in areas underlain by Paleozoic rocks in eastern Pennsylvania and areas underlain by Triassic rocks in eastern Pennsylvania and western New Jersey. As information about uranium occurrences in other areas of Pennsylvania became available from uranium prospectors, the reconnaissance was expanded to include these areas. The network of roads traversed with carborne equipment is shown in plate 2. McKeown (1953) made a detailed study of uranium occurrences in Bucks County, Pa., and Hunterdon County, N.J., and Klemic and Baker (1954) discovered additional uranium occurrences in eastern Pennsylvania and examined some that had been discovered by prospectors.

An intensive examination of the area around Jim Thorpe, Pa., was made by the author because this seemed to be most favorable with respect to the number of uranium occurrences and the quantity of radioactive rock exposed at the surface. A radiometric survey of much of the area adjoining the known uranium occurrences in Carbon County, Pa., was made with portable scintillation counters. Water samples were taken from 15 streams and springs in this area (fig. 30) and were analyzed for uranium.

An airborne scintillation-counter survey of parts of Carbon, Monroe, and Schuylkill Counties, Pa., was made by the U.S. Geological Survey in 1954. Flights were made along lines about one-quarter of a mile apart and trending east-northeast and west-southwest in the area between Tamaqua, Lehighton, Weatherly, and Bartonsville (see pl. 2).

Diamond-drill cores from test borings, and rocks exposed in excavations made along the northeast extension of the Pennsylvania Turnpike were examined. The results of test-mining operations and core drilling at the uranium occurrence on Mount Pisgah near Jim Thorpe in 1954 were studied during and after the operations. Some of the drill holes were probed to limited depths to measure variations in subsurface radioactivity.

Montgomery (1954) described the uranium minerals of the Jim Thorpe area, and Dyson (1954) described the relationship of stratigraphy and structure to uranium occurrences near Jim Thorpe. Pat-

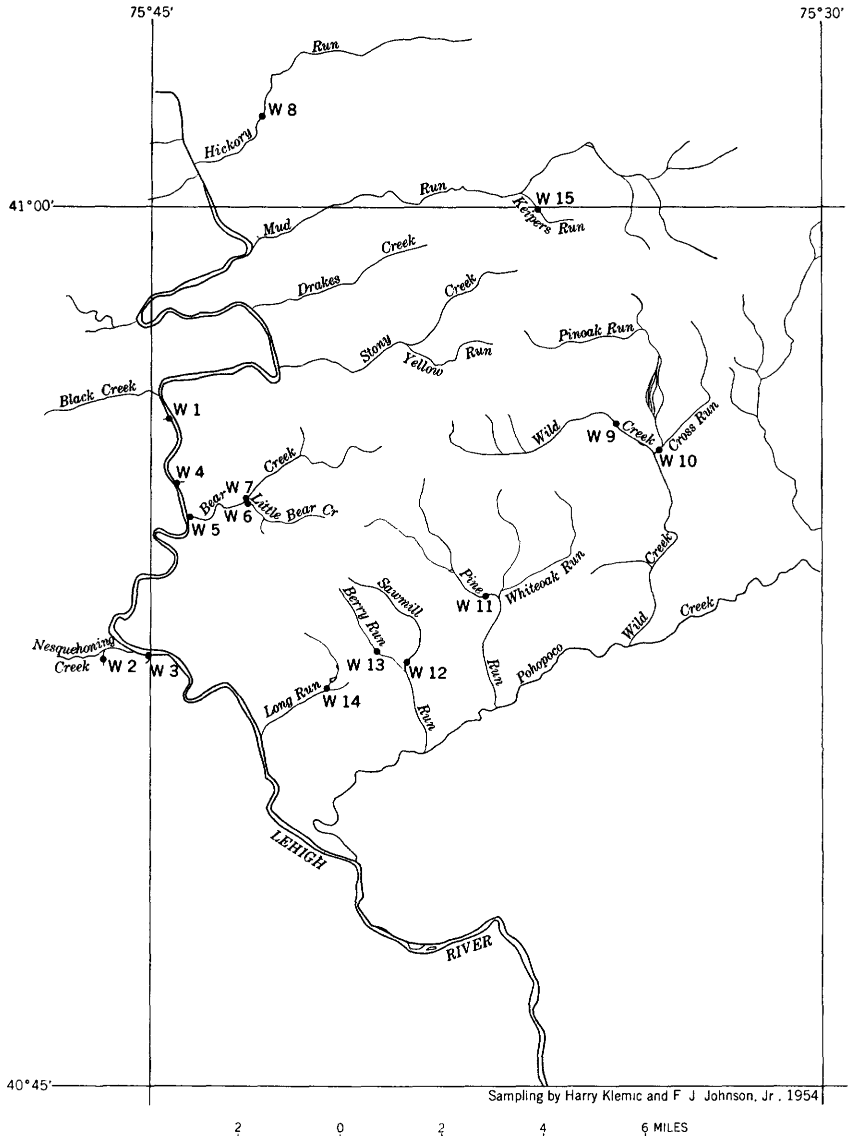

FIGURE 30.—Map of the drainage system of the Lehighton quadrangle and adjoining areas, Pennsylvania, showing water sampling sites. Sample W1 contains 0.2×10⁻⁷ percent uranium; all others contain less than 0.1×10⁻⁷ percent uranium.

terson (1954) and Ferm (1955) studied the radioactivity and uranium content of coal and related rocks in the bituminous coal regions of Pennsylvania. The distribution of uranium occurrences in Paleozoic rocks in Pennsylvania was discussed by the author (Klemic, 1955), and McCauley (1957) described sedimentary uranium occurrences in Pennsylvania. The geology and uranium occurrences of the northern part of the Lehighton (formerly Mauch Chunk) quadrangle and adjoining areas were mapped in 1955–58 by Harry Klemic, J. C. Warman, and A. R. Taylor (Klemic and others, 1962). From 1950–58 geologists of the U.S. Atomic Energy Commission, particularly T. N. Walthier in the early period and Jack Kratchman in the later few years, examined uranium occurrences in Pennsylvania and adjoining States.

Uranium has been mined at one locality in Pennsylvania (loc. 26, pl. 2): the Lehigh Navigation and Coal Co. has done a small amount of test mining at the Mount Pisgah uranium occurrence (Klemic and Baker, 1954) near Jim Thorpe. Several other occurrences have been tested by drilling, trenching, bulldozing, or by digging shallow pits or short drifts. Some occurrences are at old copper prospects which have shallow workings and small dumps. In 1960, no uranium ore was being mined in Pennsylvania.

RECONNAISSANCE

Much of the reconnaissance consisted of traversing roads with car-borne Geiger counters and scintillation counters. More detailed traverses with scintillation counters were made on foot in areas that were considered more likely to contain uranium deposits.

Reconnaissance investigations by field parties of the U.S. Geological Survey and the excellent work done by prospectors resulted in the discovery of many uranium occurrences in Pennsylvania. In addition, the background radioactivity was measured and variations in background radioactivity became better known. Background radioactivity over large areas in eastern Pennsylvania was found to range from 0.005 milliroentgens per hour (mr per hr) to 0.03 mr per hr. Readings of 0.01 to 0.02 mr per hr were most common, with occasional higher readings of 0.03 to 0.04 mr per hr in road cuts or along cliffs or steep hillsides. In some places where black or brown shale has been quarried the radioactivity near the face of the quarry ranges from 0.02 to 0.06 mr per hr.

Only one of the water samples taken from 15 springs and streams in the Lehighton quadrangle area (fig. 30) contained more than 0.1×10^{-7} percent uranium, the minimum measurable amount reported in the analyses. This sample, W 1, from a spring on the south side of the uranium occurrence at Penn Haven junction, contained 0.2×10^{-7} percent uranium. The spring, which flows from joints and fractures in slightly radioactive rock, was sampled for comparison with the other springs and streams in the area.

The airborne survey did not reveal any definite radioactivity anomalies except near the uranium occurrence on Mount Pisgah near Jim Thorpe. Some minor deviations in background radioactivity were noted and a few of the areas were checked on the ground, with negative results.

The road-traversing method was moderately successful and is a useful method of rapid reconnaissance in areas with suitable networks of roads. The airborne method is a useful rapid reconnaissance method not dependent upon the availability of roads. A low-level airborne traverse flown by a prospector in a private plane in a way that was almost equivalent to a road traverse resulted in the discovery of one uranium occurrence in northern Carbon County. Low-level airborne methods, however, are considered to be too dangerous to be practical over much of the terrain in Pennsylvania.

Water sampling was not tested adequately, but the rapid runoff and the replenishment of surface water by frequent rainfall seem to prevent the accumulation of measurable concentrations of uranium in most stream water in the mountainous areas. Testing of water from springs, wells and mine drainage might give more conclusive results.

Direct measurement of radioactivity in the field by using manually portable instruments is probably the best means of locating uranium. This method may be used alone in areas of rugged terrain, or as a supplement to airborne or carborne reconnaissance in other areas. Many of the uranium occurrences in Pennsylvania were found in this manner.

LABORATORY STUDIES

Mineralogic studies were made of samples of radioactive rock collected during the field work. Radiometric, chemical, and spectrographic analyses were made of selected samples of uraniferous rock. These studies show that the radioactivity of the rocks is due primarily to uranium and not to thorium. Results of sample analyses are given later in the report.

REGIONAL SETTING

Concentrations of uranium have been found in sedimentary rocks in 3 of the 7 geologic provinces in Pennsylvania: the Appalachian Plateaus, the Valley and Ridge, and the Piedmont (pl. 2). The uranium is in rocks of Late Devonian and Pennsylvanian ages in the Plateaus province, in rocks of Late Devonian, Mississippian, and Early Pennsylvanian ages in the Valley and Ridge province, and in rocks of Triassic age in the Piedmont. Uranium occurrences are also known in the Late Devonian rocks of southeastern New York and in Cambrian-Ordovician and Triassic rocks of west-central New Jersey.

Between the Piedmont and the Valley and Ridge provinces in eastern Pennsylvania, the metamorphic and igneous rocks of Precambrian age that constitute the Reading Prong of the New England province contain occurrences of uranium and thorium minerals (Montgomery, 1957). Uranium and thorium minerals also occur in crystalline rocks of the Piedmont province in southeastern Pennsylvania (Gordon, 1922).

Some of the geologic events that combined to produce the features distinctive to each physiographic province may also have influenced the concentration of uranium in the rocks. The geologic setting and distribution of uranium occurrences are therefore discussed by physiographic provinces.

APPALACHIAN PLATEAUS PROVINCE

The part of the Appalachian Plateaus province here considered extends from western to central and northeastern Pennsylvania. This is an upland area of gently folded and almost flat-lying rocks, dissected and drained by the Beaver, Allegheny, Susquehanna, Delaware, and Lehigh Rivers. Relief in the area is more than 1,600 feet—from stream valleys less than 800 feet above sea level in the western part of the State to highlands at altitudes of about 2,400 feet in the north-central part.

The area is underlain by sedimentary rocks of Middle and Late Devonian, Mississippian, and Pennsylvanian ages. Most of these rocks are graywackes or quartzites. The older beds of exposed Middle and Upper Devonian rocks are largely gray or tan sandstones and shales that contain marine fossils. In the eastern and central part of the State the younger Devonian rocks are composed of continental sediments; those in the western part were deposited in a marine environment. The continental sedimentary rocks thin to the west and north. Gray sandstone and conglomerate are the predominant rock types in the older Mississippian formations and red sandstone and shale make up the younger beds. The Mississippian formations thin to the west and north, and part of the series was removed by erosion prior to the deposition of the Pennsylvanian beds in the western part of the State (Leggette, 1936, p. 36–37). Pennsylvanian rocks in the province are largely gray sandstones, conglomerates, and shales, and they include some limestone members and several economically important bituminous coal beds.

VALLEY AND RIDGE PROVINCE

This province is a band of synclinal and anticlinal valleys and ridges that crosses from south-central to east-central Pennsylvania. It is arcuate in shape, convex to the northwest, and is about 65 miles wide in the central part of the State. The anthracite fields of northeastern Pennsylvania and the Broad Top coal field in the south-central part of the State are in this province. The Appalachian Plateaus province forms the western and northern boundaries of the Valley and Ridge province; the Blue Ridge and Piedmont provinces and the Reading Prong of the New England province form its southern and eastern boundaries.

The Susquehanna and Delaware Rivers cut across the province and, with the Schuylkill, Lehigh, and Juniata Rivers, form the major drainage system in the area. Relief in the province is about 2,100 feet—from about 2,600 feet above sea level near the Pennsylvania-Maryland border to about 500 feet where the major rivers leave the province.

Paleozoic sedimentary rocks ranging from Cambrian to Pennsylvanian in age are exposed in this province. The rocks are similar to those of the Appalachian Plateaus province—mostly graywackes and quartzites and chloritic shales—but are generally more indurated. In a few places in central Pennsylvania, mafic dikes, probably of Triassic age, intrude the Paleozoic rocks. No occurrences of uranium in areas adjacent to the intrusive rocks are known to the author.

PIEDMONT PROVINCE

This province is a dissected plain that in eastern Pennsylvania includes areas underlain by sedimentary and igneous rocks of Triassic age and areas underlain by older metamorphic rocks. In this report, descriptions of the rock units in the Piedmont cover only the Triassic rocks, because these contain the known uranium occurrences in sedimentary rocks. The Newark group comprises the Triassic sedimentary rocks of Bucks County. It includes the Stockton, Lockatong, and Brunswick formations, which have an aggregate thickness of about 11,000 feet (McLaughlin and Willard, 1949, p. 43). Diabase sills intrude the sedimentary rocks in the area.

The Stockton formation lithofacies of McLaughlin and Willard (1949, p. 43) is predominantly arkosic sandstone. It contains interbedded conglomerate and red shale. According to McKeown (unpublished data, 1954), specimens of the sandstone from uranium occurrences in the Stockton formation are composed of about 50 percent quartz, 20 percent microcline and plagioclase feldspars, and 20 percent clay matrix, with pyrite, muscovite, and zircon as accessory minerals. Much of the sandstone is speckled or stained with limonite. The sandstones are white, tan, brown or reddish brown, well indurated, and commonly medium grained, except in the upper part of the Stockton lithofacies where red fine-grained sandstone and red shale are common.

The Lockatong formation lithofacies in the Bucks County area is predominantly argillite, containing black or dark-gray beds and red beds with intervening brown transition zones that contain mud cracks and intraformational conglomerate (McLaughlin, 1944, p. 63). The argillite is dolomitic in places and contains argillaceous limestone in the lower part of the formation (McLaughlin, 1945, p. 107). An X-ray diffractometer analysis of a sample of dark-gray argillite from the uranium occurrence at Delaware quarry (loc. 36) showed the patterns of albite-oligoclase, sericite, dolomite, and possibly quartz. McKeown (unpublished data, 1954) has described an intraformational conglomerate or breccia of gray argillite and tan dolomite in the Lockatong. Pyrite occurs in some of the gray argillite in sparsely disseminated crystals. Traces of secondary copper minerals were noted on red argillite at locality 36. Plant fossils have been found at this locality, but although much of the argillite is black or dark gray, carbonaceous material constitutes only a minor amount of the rock (Duel, 1956, p. 20; Stevenson, 1948, p. 131–134).

The Brunswick formation lithofacies consists of red sandstone and shale and coarse conglomerate. It crops out about 5 miles north of Point Pleasant in Bucks County.

The Stockton, Lockatong, and Brunswick are considered to be contemporaneous facies in part. The sediments that formed the Stockton came from weathered crystalline rocks to the east, and those that formed the Lockatong and Brunswick were largely from weathered sedimentary rocks on the west of the basin (McLaughlin and Willard, 1949, p. 34–43).

Triassic rocks are cut by major faults to the north and south, but none were observed in areas with known uranium occurrences.

URANIUM OCCURRENCES

DISTRIBUTION

In Bradford, Columbia, Lycoming, Sullivan, and Wayne Counties, in the Appalachian Plateaus province of Pennsylvania, uranium occurs disseminated in thin beds, channels, or lenses of gray sandstone and shale in rocks of Late Devonian age. Most of these occurrences are in or near localities that have been prospected for copper (Weed, 1911), and the rocks may contain copper and iron sulfides, carbonate minerals, plant fossils, and coaly material. A composite description of these occurrences is given later in the report. In Clearfield and Beaver Counties uranium occurs in coal and underclay of Pennsylvanian age. The distribution of uranium occurrences in the Appalachian Plateaus province and in the Valley and Ridge and Piedmont provinces is shown in plate 2 and the localities are listed in a later section of the report.

No reconnaissance for uranium in northwestern or southwestern Pennsylvania has been done by the author, and no uranium occurrences in these areas have been reported by prospectors.

Uranium occurrences in the Valley and Ridge province in Pennsylvania are in Luzerne, Carbon, Schuylkill, Northumberland, Columbia, Montour, Dauphin, Huntingdon, Fulton, and Bedford Counties. In each of these counties, except Luzerne County, uranium has been found in rocks of Devonian age. In addition, uranium occurs in Mississippian-Pennsylvanian transition rocks in Carbon County, and in Mississippian rocks in Huntingdon and Luzerne Counties. Small amounts of uraniferous rock in the Pottsville formation of Pennsylvanian age have been found in Northumberland and Luzerne Counties.

Secondary copper minerals are found at most of the occurrences in the Devonian rocks, and the occurrence in Montour County is at an old copper prospect. Most of these uranium occurrences are like those in the Appalachian Plateaus province, but some, particularly those in Carbon County, have practically no trace of copper minerals. In the large and well-exposed deposits uranium occurs around roll-type structures as well as along beds. At two of the localities in Devonian rocks in Carbon County small amounts of lead minerals are present in the uraniferous rock. More detailed descriptions of two large and fairly well exposed uranium occurrences in Carbon County are given in a later section.

Uranium occurrences have been found in rocks of Triassic age in the Piedmont province in Bucks County, Pa., and adjoining parts of Hunterdon County, N.J. (McKeown, 1953). Most of these are in sandstone of the Stockton formation and argillite of the Lockatong formation of the Newark group within a radius of 5 miles from Point Pleasant, Pa. Uraniferous rock has also been found in sandstone of the Stockton near Newton, about 13 miles south of Point Pleasant; this locality has not been examined by the author. The uranium occurrences in the Stockton formation are commonly in thin zones parallel to bedding in limonite-stained or pyritiferous sandstone with mud pebbles or lenses. Torbernite and other secondary-type uranium minerals are present in minor amounts. The occurrences in argillite consist of uraniferous zones or beds of black argillite a few feet thick and extend discontinuously for a few hundred feet in places. The uranium is disseminated in an unidentified form.

STRATIGRAPHIC RELATIONS

DEVONIAN ROCKS

The uranium occurrences in the Catskill formation in the Valley and Ridge, and Appalachian Plateaus provinces are discussed together because they have many features in common.

The Catskill formation in Pennsylvania is a great body of continental sedimentary rocks of Late Devonian age. The sediments were derived from an eastern or southeastern source. The formation is thickest in Carbon County and it thins to the north and west. It apparently pinches out in Potter and Indiana Counties, but extends southwestward into Maryland. The thickness of sections of the uranium-bearing Paleozoic formations in several counties, and the approximate positions of the uranium occurrences within the formations are shown in figure 31. The stratigraphic positions of some of the occurrences, such as those in Carbon County, have been measured; others are estimated on the basis of their topographic position and the regional dip and approximate distance to an observed formational boundary or to a formational boundary as shown on a geologic map of the area. The positions of the uranium occurrences in north-central Pennsylvania as shown in figure 30 are in general agreement with those given by McCauley (1957, p. 7).

The base of the Catskill formation in Pennsylvania interfingers with, or is equivalent to, marine beds of a wide range in age; progressively younger marine beds occur at the base to the west and north of the Carbon County section. The top of the formation probably has a more limited range in age (Willard, 1939). In some areas gray beds of the lower part of the Pocono are very similar to gray beds in the Catskill formation. Because there is no pronounced intersystemic unconformity between the Pocono and the Catskill, the top of the Catskill is arbitrarily located at the top of the uppermost red bed that is below the typical gray beds of the Pocono.

The stratigraphic positions of the uranium occurrences in the Catskill formation seem worthy of more detailed examination. Willard (1939, p. 305 and fig. 72) describes thickness changes of units in the Catskill formation and presents a generalized geologic map of northeastern Pennsylvania. The units described by Willard are, from bottom to top: Damascus, Honesdale, Cherry Ridge, Elk Mountain, and Mount Pleasant members. The Cherry Ridge is equivalent to the Cattaraugus and the Elk Mountain is equivalent to the Oswayo. No similar differentiation of units within the Catskill formation has been made for south-central Pennsylvania, but the uranium occurrences in that area are in rock units that may correlate with the Honesdale or Damascus of the Carbon County area. Although the greatest number of known uranium occurrences in the

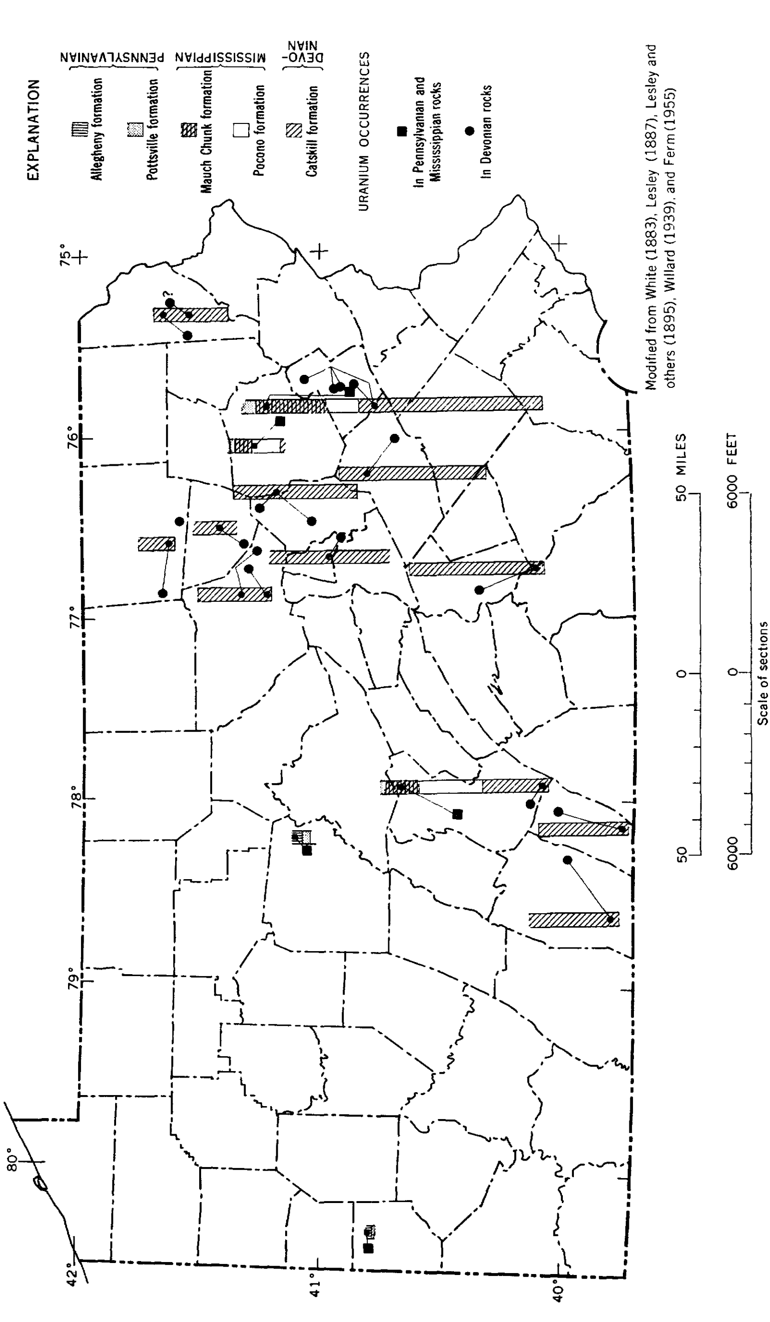

FIGURE 31.—Map of Pennsylvania showing stratigraphic positions of uranium occurrences in Paleozoic rocks. Length of bar indicates approximate thickness of stratigraphic section; closed bars indicate measured section.

Catskill formation are in the lower part of the Cherry Ridge or Cattaraugus member, uranium has been found in higher and lower units.

Uranium occurrences in Carbon County (locs. 21–25, pl. 2) are in the Cherry Ridge member of the Catskill, about 600 to 900 feet below the base of the Pocono formation. The occurrence at an old copper prospect in Wayne County is in rock mapped as Mount Pleasant shale and assigned a thickness of almost 600 feet by Willard (1939, p. 305, fig. 72). This occurrence is within 600 feet of the base of the Pocono if Willard's information is correct. In a quarry on the outskirts of Honesdale, in rock mapped as Honesdale sandstone by Willard (1939, fig. 72), a thin parting of gray shale in gray sandstone was found to contain secondary copper minerals and to be weakly radioactive. This locality and its stratigraphic position are shown with a question mark on figure 31 to indicate that cupriferous rock containing uranium may occur in beds more than 500 feet apart stratigraphically and less than 10 miles apart areally in separate lithologic units within the Catskill formation in Wayne County. Cupriferous rock has been reported in Wyoming County (White, 1883, p. 129) in gray sandstone below the Cherry Ridge member. The uranium occurrences in Bradford and Tioga Counties are near the base of the Cattaraugus, which Willard equates with the Cherry Ridge in this area. To the south in Columbia and Lycoming Counties the uranium occurrences, many of which are in old copper prospects, may also be in the Cattaraugus or Cherry Ridge member of the Catskill. These occurrences probably are distributed through a stratigraphic interval of more than 100 feet. This has not been measured precisely, but stratigraphic differences of several tens of feet between beds of uraniferous rock in limited areas are known.

MISSISSIPPIAN ROCKS

The stratigraphic positions of the three uranium occurrences in rocks assigned to the Mississippian system of Pennsylvania are about 500 or 600 feet below the base of the Pottsville formation. In the part of the Valley and Ridge province extending between south-central and northeastern Pennsylvania the Pocono and Mauch Chunk formations make up the Mississippian. Near Wilkes-Barre in Luzerne County (loc. 20, pl. 2), uranium occurs in gray sandstone at the top of the Pocono. In this area, the overlying Mauch Chunk formation is probably less than 600 feet thick and is composed principally of gray sandstone. The uraniferous rock more closely resembles the Pocono formation so it is considered by the author to be part of the Pocono, although no precise formational boundary between the Pocono and the Mauch Chunk is evident at this locality. At the Mount Pisgah locality near Jim Thorpe, in Carbon County (loc. 26, pl. 2), uranium occurs in gray sandstone and conglomerate in beds previously considered by the author to be part of the Pottsville formation, but considered by some (Wood and others, 1956, p. 2669–2688) to be a Pottsville facies of a Mauch Chunk-Pottsville transition zone, partly because the red beds that overlie the lower conglomerates represent the last period of deposition of red sediments of the Mauch Chunk type. Another consideration in placing the formational boundary at the top of the uppermost red bed is that such a contact can be mapped more precisely in the terrain of eastern Pennsylvania. It is likely, however, that the time boundary between the Pennsylvania and Mississippian in this area transects the formational boundaries as they are now defined.

In Carbon County, the Pocono and the Mauch Chunk, including the Mauch Chunk-Pottsville transition zone, are together more than 3,000 feet thick. In the Broad Top area in Huntingdon County, these same formations also total a little more than 3,000 feet and gray sandstones are intermixed with the red beds in the upper part. The uranium occurrences in the Broad Top area (locs. 32, 33, pl. 2) are also in the upper 600 feet of the Mauch Chunk formation, but the uranium is in both red and gray sandstone that is finer grained than most of the uraniferous rock at the other two localities.

PENNSYLVANIAN ROCKS

Uranium occurs in two stratigraphic positions in rocks of Pennsylvanian age. In northeastern and east-central Pennsylvania uranium has been found in the Pottsville formation in Luzerne and Northumberland Counties. The Pottsville formation is about 500 feet thick in Luzerne County and about 850 feet thick in Northumberland County (Lohman, 1937, p. 136, 195). The position of the uraniferous rock in the Pottsville formation in Luzerne County is not known to the author, but uranium is in the lower part of the Pottsville at the locality in Northumberland County.

In western Pennsylvania the uranium (locs. 18, 19, pl. 2) is associated with a coal bed in the upper part of the Allegheny formation, which is a little more than 300 feet thick (Sisler, 1932, p. 58).

A composite section of the Paleozoic rocks in which uranium occurs is given below for different parts of Pennsylvania.

Formation	*Uranium-bearing part of formation*	*Part of State*
Pennsylvanian:		
Allegheny formation	Upper	Western.
Pottsville formation	Lower; not determined.	East-central and northeastern.
Mississippian:		
Mauch Chunk formation	Upper	East-central and south-central.
Pocono formation	Upper	Northeastern.
Devonian:		
Catskill formation:		
Mt. Pleasant shale	Probably lower	Do.
Cherry Ridge and/or Cattaraugus.	Middle to lower	East-central, north-central, and south-central.
Honesdale?	Not determined	Northeastern and south-central.

In this section of continental sedimentary rocks, which is more than 1 mile thick, uranium occurs at localities that are relatively close to each other areally but about 4,000 feet apart stratigraphically, in both Carbon and Huntingdon Counties (fig. 31).

CHARACTERISTICS

Some features typical of many of the uranium occurrences discussed in this report are:

1. The uranium occurrences are in unmetamorphosed or slightly metamorphosed rocks composed of clastic sediments that were deposited in a continental environment.
2. Primary black uranium minerals occur in unweathered rock at some localities where secondary uranium minerals are found in weathered permeable rocks and along fracture surfaces, joints, and bedding planes.
3. The uraniferous rock does not contain any concentration of thorium.
4. Uranium may be concentrated in rocks with noticeable amounts of copper minerals, or carbonaceous material, or pyrite, but the abundance of uranium is independent of the abundance of these associated materials.
5. Uranium occurrences are most common in only 1 or 2 stratigraphic positions in any county.
6. The uranium at most localities is in layers of gray rock in formations that consist of both red and gray beds.
7. Primary sedimentary features such as layers, lenses, channels, minor variations in composition and grain size, concentrations of fossils, and curved or roll-type structures that may be

combinations of primary and diagenetic features, seem to have localized many of the concentrations of uranium.

8. Aside from minor coatings of secondary uranium minerals on fracture and joint surfaces, the uranium is concentrated interstitially as part of the rock and does not occur in veins or fissures.
9. The uranium occurrences do not seem to be related to faults; that is, faults are not the loci for deposition of the uranium and faults do not seem to have been channelways for movement of the uranium.
10. Although small folds may have influenced the concentration of uranium in a few localities, the influence of major geologic structures such as folds on the distribution of uranium is not readily apparent.
11. The concentration of uranium does not seem to be directly related to intrusive igneous rocks or hydrothermal activity, although the uranium occurrences in Triassic rocks in Bucks County are in an area where there has been igneous intrusion and hydrothermal activity.

Many of the deposits are small and exhibit only a few of these features. Others have not been examined in sufficient detail to determine whether or not they differ significantly from the remainder of the deposits. Most of the features of these occurrences have also been observed in uranium deposits on the Colorado Plateau or in other areas.

The following sections contain detailed descriptions of some uranium occurrences in the Valley and Ridge province, and a composite description of those in the Appalachian Plateaus province. For details of the uranium occurrences in the Piedmont province the reader is referred to reports by McKeown (1953, 1954) and to descriptions in the list of localities at the end of this report.

DETAILED DESCRIPTIONS OF OCCURRENCES IN THE VALLEY AND RIDGE PROVINCE

In Carbon County, Pa., some of the uranium occurrences in sandstone and conglomerate are large and well exposed, and distribution features of the primary uranium minerals may be studied. The rocks in this area are intensely folded, and joints and fractures are numerous. Bedding-plane slippage has been extensive as a compensation for the tight folding, and sets of grooves on some slickenside surfaces indicate more than one period and direction of movement.

Uranium occurs in two major stratigraphic positions—in Upper Devonian rocks and in a Mississippian-Pennsylvanian transition zone in which the uraniferous rocks resemble overlying rocks of Pennsylvanian age. The uranium is partly distributed in secondary minerals in natural outcrops of weathered rock, and the primary distribution of uranium is obscured. Fresh well-cemented uraniferous rock has been exposed in recent excavations in both sequences. The two most promising uranium deposits known in these stratigraphic units are described below.

Uraninite in Devonian rocks near Penn Haven Junction, Carbon County (loc. 23, pl. 2), is distributed in zones that follow bedding in part but also cut across bedding and other primary sedimentary features in the rocks. In addition, the distribution of clausthalite in some of the uraniferous rock closely parallels that of uraninite. The shape of the clausthalite particles indicates that they crystallized in their present position. The rock is fairly well sealed by matrix minerals and secondary uranium minerals are not very abundant. Uraniferous rock partly surrounding a roll-type structure is cut by a major joint in one place and the distribution of the uranium has been affected very little, if any, by the joint. Some of the joints are open and are encrusted with quartz crystals, indicating that there has been no further movement along the joints since the formation of the quartz crystals. These joints are part of a major regional joint system.

Chlorite and other matrix minerals practically seal the interstices of some of the uraniferous rock. In one thin section of rock from the uranium occurrence near Penn Haven Junction, the uraninite is in fine particles around the edges of clastic grains, and chlorite fills the interstices. Chlorite and a brown unidentified mineral fill thin cracks that cross the uraniferous rock. Uraninite in some thin sections is most abundant in narrow zones that are parallel to and include heavy-mineral layers. Narrow cracks that are parallel to bedding cross the clastic grains in the uraniferous zone and do not appear to contain uraninite. The narrow cracks are filled with a pale-brownish-yellow material that does not appear radioactive in autoradiograph sections. Some larger fractures contain radioactive secondary minerals. The interstitial matrix minerals interrupt the continuity of the narrow cracks that cross the clastic grains.

The rock is well cemented by matrix minerals, and the stress that fractured the grains caused little if any rotation of grains. The matrix minerals either absorbed the strains by plastic deformation, or fractured and later recrystallized. Uraninite seems to have been unaffected chemically and is not seen in the fractures. Chlorite has crystallized in the larger cracks. Chlorite also occurs in brecciated zones along bedding-plane fractures in the country rock. The concentration of uranium in a zone in which the clastic grains are fractured parallel to bedding has been seen only in thin sections. The fractured zone may be a very localized feature or part of a large incipient bedding-plane fracture, and the relation between the presence of uranium and the zone of fracturing may be merely coincidental.

The uraniferous rock near Penn Haven Junction is exposed in a minor fold or foldlike structure on the limb of a major anticlinal fold. About 1 mile to the south (loc. 24, pl. 2), across the strike, uranium occurs in a similar fold in what is probably the same stratigraphic position. About 6 miles south of Penn Haven Junction (loc. 25, pl. 2), and across the regional strike, uranium occurs in almost the same stratigraphic position, but facies changes and concealed intervals prevent exact correlations. About 6 miles north of Penn Haven Junction (locs. 21, 22, pl. 2), and about 20 miles southwest (loc. 27, pl. 2), uranium occurs in the same formation.

The uranium deposit in the Mississippian-Pennsylvanian transition zone on Mount Pisgah near Jim Thorpe in Carbon County (loc. 26, pl. 2) is exposed at the nose and along the north limb of a southwestward-trending and gently plunging syncline for about 2,000 feet. Uranium occurs in a well-defined stratigraphic unit consisting of coarse gray conglomerate and sandstone overlying the thick red-bed sequence of the Mauch Chunk formation; the unit is a basal conglomerate in a section of alternating gray and red beds about 500 feet thick. The basal unit, about 70 feet thick, is immediately overlain by thin beds of brown and red shale and siltstone. The predominant rock types are coarse conglomerate and conglomeratic sandstone with a dark-gray matrix, and gray sandstones in a heterogeneous mixture of lenses and bedded and crossbedded zones. Beneath this unit, brownish-gray sandstone grades into the underlying red beds. The basal conglomerate is massive in most places, and breaks into huge boulders or masses having irregular shapes that are influenced by the heterogeneity of the rock and its cementation. The sandstone is massive and well bedded, and locally contains roll-type structures that are ovoid bodies of sandstone elongate roughly parallel or at a small angle to the strike. The lenses of conglomerate wedge into the sandstone and have the appearance of lithified gravel bars or channel deposits. Bedding-plane fractures and some cross fractures are commonly quartz encrusted and slickensided.

Uranium occurs in two zones in the middle or upper part of the conglomerate unit. The lower uraniferous zone is the thicker and richer where the unit crops out and is the part of the deposit discussed below. The uranium occurs in a primary form probably as uraninite but possibly in another black primary mineral or amorphous material, and as secondary minerals. The secondary uranium minerals are probably of relatively recent origin, and this discussion will deal mainly with the distribution of the black primary minerals.

The primary form of uranium, referred to as uraninite in this discussion, occurs as very fine grained dark particles that are interstitial to clastic grains and in a form that is very similar to that of uraninite in the Devonian rocks near Penn Haven Junction. Concentrations of uraninite locally parallel bedding in sandstone, and elsewhere they are within lenses of sandstone or conglomerate. Uraninite also occurs in zones around roll-type structures in sandstone and in irregular diffusions in sandstone. The uraniferous zones have abrupt or gradational boundaries that have no apparent relation to any other features of the host rock. Some of the uraniferous rock is identical in megascopic appearance with rock that is barren of uranium and is only about 1 inch away along the same bed.

Much of the basal conglomerate unit is cemented by silica and micaceous matrix minerals, but the uraniferous rock is cemented by calcite. Illite is more abundant than chlorite and it fills the interstices of clastic grains in some of the uraniferous rock, but calcite is very abundant locally. The rock containing uraninite is very well cemented and may be almost completely impermeable because of the calcite cement. Calcite-filled fractures cut uranium-rich zones in the rock, indicating that the fracturing and precipitation or recrystallization of calcite have taken place since the deposition of uranium and without oxidation of the uraninite. Lenticular zones of porous and permeable conglomerate and sandstone with abundant secondary uranium minerals seem to be weathered bodies of uranium-rich rock in which the calcite cement has been dissolved, the primary uranium minerals oxidized, and the uranium combined into carnotite and tyuyamunite.

The distribution of uranium in the deposit and its relation to other features of the rocks is difficult to visualize. Radioactivity measurements are useful in studying the distribution of uranium, but results are confused by the abundance of secondary uranium minerals on fracture surfaces and in porous zones in weathered rock, by the commonly high background radioactivity, and by the abrupt variations in the uranium content of the rock and in distribution of uranium in a primary form. Concentrations of uranium are found in both sandstone and conglomerate that contain abundant black carbonaceous material, but rock that is equally dark with carbonaceous material and barren of uranium may be contiguous with uraniferous rock. The general impression of the deposit is that it consists of a concentration of uranium along channels or bars that trend southwestward. The apparent southwestward elongation of uraniferous zones that both parallel and cut across the bedding, and the orientation of fossil logs or roots in a southwestward direction, help to create this impression. The outcrop exposure may cut the deposit at a small angle. Not much information is available about the distribution of uranium downdip from the outcrop.

COMPOSITE DESCRIPTION OF OCCURRENCES IN THE APPALACHIAN PLATEAUS PROVINCE

A composite description of features observed at several of the localities shown in plate 2 is given for the uranium occurrences in the Appalachian Plateaus province because limited exposures of uraniferous rock at any one locality show only a few of their characteristics.

The deposits are generally in gray sandstone or shale interbedded with red beds of similar composition. The concentrations of uranium are in lenses, channels, or irregular zones, and are generally in rock that may contain one or more of the following materials: calcareous nodules, interstitial calcite, plant fossils (both carbonaceous fossils and imprints of plant stems with associated limonite-stained areas), fossil brachiopods, fossil fish scales(?), copper sulfides, iron sulfides, lead sulfide(?), and copper carbonates. Pyrite, chalcopyrite, chalcocite, bornite, a black material that may be tenorite, malachite, azurite, and chrysocolla have been identified megascopically by the author in samples from copper prospects at some of the localities. McCauley (1957, 1958) describes the metallic minerals from some of these deposits and adds digenite, covellite, marcasite, galena, and bornite to the list of associated minerals. Clausthalite has not been identified in these rocks, but it may be present and unrecognized because of its similarity to galena.

The zones of cupriferous rock are more extensive than the zones of uranium concentration. The concentration of copper and uranium in the same members of the Catskill formation is somewhat similar to that in the Pictou formation of Pennsylvanian age in Nova Scotia, as described by Brummer (1958, p. 309–324).

Uranium in the occurrences in the Appalachian Plateaus province is in a gray or black material interstitial to clastic grains and associated with carbonaceous material and limonite. Secondary uranium minerals occur along partings, on surfaces of the weathered rocks, and interstitially in weathered porous rock. The distribution of secondary uranium and copper minerals is continuously changing as weathering of the rocks and movement of ground water proceed. Not enough fresh rock is exposed at any of these occurrences to permit a satisfactory determination of the distribution of primary uranium and copper. At locality 15 (pl. 2), specimens rich in copper and iron sulfides found on the dump of a copper prospect pit were practically nonradioactive, but weakly radioactive rock that contains only minor amounts of copper minerals occurs a few tens of feet stratigraphically higher in the beds. At locality 11, however, gray sandstone with disseminated chalcocite is radioactive.

RADIOACTIVE MINERALS

The uranium minerals from uranium occurrences in sedimentary rocks of Pennsylvania are listed in table 1.

TABLE 1.—*Uranium minerals from uranium occurrences in sedimentary rocks in Pennsylvania*

[Mineral identifications by A. D. Weeks, D. D. Riska, R. B. Thompson, Jr., and Jerome Stone, U.S. Geological Survey, except as noted]

Minerals	Composition	Locality
Oxide:		
Uraninite	UO_2	21, 23, 26(?)
Arsenate:		
Metazeunerite(?) [1]	$Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$	34
Carbonate:		
Andersonite [2 3]	$Na_2Ca(UO_2)(CO_3)_3 \cdot 6H_2O$	26
Liebigite [3]	$Ca_2(UO_2)(CO_3)_3 \cdot 10\text{–}11H_2O$	26
Schroeckingerite [2 3]	$NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$	26
Phosphate:		
Autunite [3]	$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{–}12H_2O$	25
Meta-autunite [3]	$Ca(UO_2)_2(PO_4)_2 \cdot 0\text{–}6H_2O$	25
Dewindtite(?) [3]	$Pb_3(UO_2)_5(PO_4)_4(OH)_4 \cdot 10H_2O$	21(?)
Renardite(?)	$Pb(UO_2)_4(PO_4)_2(OH)_4 \cdot 7H_2O$	21(?)
Torbernite [1]	$Cu(UO_2)_2(PO_4)_2 \cdot 12H_2O$	36
Metatorbernite [1]	$Cu(UO_2)_2(PO_4)_2 \cdot nH_2O n=4$ to 8	25
Meta-uranocircite [2]	$Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$	25
Silicate:		
Kasolite	$Pb(UO_2)(SiO_3)(OH)_2$	23
Uranophane	$Ca(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$	23, 26
Beta-uranophane	$Ca(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$	26
Vanadate:		
Carnotite	$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$	26
Tyuyamunite	$Ca(UO_2)_2(VO_4)_2 \cdot 7\text{–}10.5H_2O$	26

[1] Minerals sometimes fluorescent; Palache and others (1957); and A. D. Weeks, U.S. Geological Survey (oral communication).
[2] Minerals identified by Arthur Montgomery (1954).
[3] Fluorescent minerals; Palache and others (1957) and A. D. Weeks, U.S. Geological Survey (oral communication).

Zircon, allanite, and sphene occur in minor amounts as detrital grains and contain some uranium but are not listed with the uranium minerals. Small amounts of unidentified minerals containing columbium and tantalum have been found in heavy-mineral layers in Devonian rocks at one locality (W. P. Williams, U.S. Geological Survey, oral communication) not shown in plate 2. These and other common detrital minerals that may contain uranium generally contain thorium. Thorium-bearing minerals are not concentrated in the uranium occurrences and are therefore considered as accessory minerals of the host rock.

In many of the occurrences, uraninite was probably the primary mineral from which the uranium in the secondary minerals was derived. In Carbon County (locs. 21, 23, pl. 2) uraninite occurs as very fine grained (−200 mesh) interstitial material. Black radioactive material that probably is uraninite has been found at locality 26.

Uraninite has also been found in the Stockton formation of Triassic age in a quarry (loc. 44) in New Jersey about 1 mile along the strike from uranium occurrences in the Stockton formation in Bucks County, Pa. (J. Kratchman, oral communication).

The uraniferous rock at some of the old copper prospects in Paleozoic rocks in Pennsylvania (locs. 1, 10, 17, pl. 2) is dark gray or black, and most of the uranium is in a megascopically unrecognizable form. It may be in uraninite or with carbonaceous material.

The types of secondary uranium minerals that form after weathering of uraninite reflect the availability of other elements to combine with uranium in the zone of oxidation around the uraninite. If only small amounts of suitable elements are available, or those that form relatively soluble secondary minerals, the uranium weathered from uraninite may be leached from the rock and deposited elsewhere.

Intermediate solid compounds may be required in the transformation from unoxidized ores to uranyl vanadates, phosphates, and arsenates (Garrels and Christ, *in* Garrels and Larsen, 1959, p. 81–89). If the uranium is combined into a relatively insoluble secondary mineral at or very near the site of the oxidizing primary uranium mineral there may be very little loss of uranium by leaching. Vanadium combines with uranium and other elements to form carnotite, which has a low solubility in normal ground water.

In some of the uranium occurrences there may be no low-valent (U^{+4}) uranium minerals, because of complete oxidation of the deposit, or because the uranium was transported in solution from another source and precipitated in the form of a high-valent (U^{+6}) mineral at its present site. The association of copper with uranium is common in the uranium occurrences in Paleozoic rocks of Pennsylvania. Torbernite is one of the secondary uranium minerals found in some of these deposits. Although traces of other copper-bearing minerals are rare at the uranium occurrences in the Bucks County area, Piedmont province, torbernite is the common secondary uranium mineral found there.

Vanadium is relatively abundant in locality 26 (pl. 2) near Jim Thorpe, Carbon County, where the uranium vanadates, carnotite and tyuyamunite, occur as secondary minerals. The uranium carbonates, andersonite, liebigite, and schroeckingerite (Montgomery, 1954, p. 105–106), have also been found at this locality. They occur as an efflorescence on fresh rock surfaces. Kasolite, a lead-uranium silicate, has been found at the uranium occurrence near Penn Haven Junction, Carbon County, where the lead selenide, clausthalite, occurs with uraninite in unweathered rock.

A yellow secondary mineral found in weathered rock at locality 21 (pl. 2) in northern Carbon County has an X-ray powder pattern similar to that of the rare lead-uranium phosphate minerals renardite and dewindtite. These minerals resemble in some respects the calcium uranium phosphate mineral phosphuranylite (Frondel and Cuttitta, 1954, p. 449–451). The mineral does not fluoresce under ultraviolet light; therefore it probably is not dewindtite, which fluoresces green in ultraviolet light (Palache and others, 1957, p. 875). According to A. D. Weeks (oral communication), phosphuranylite may fluoresce. It is likely, therefore, that the unknown mineral may be rendardite, but the small amounts of material available and the fine grain size and impurities make its identity difficult to determine.

COMPOSITION OF URANIFEROUS ROCK

Most of the uraniferous rock from the occurrences in Paleozoic formations fits into Krynine's (1948) low-rank graywacke group of detrital rocks, although Montgomery (1954, p.108) describes some of the rock as being arkosic. Ferm (1955) and Patterson (1954) describe occurrences of uranium in bituminous coal and underclay. The composition of the underclay is not stated. Two types of uraniferous rock in the Bucks County area have been described by McKeown (1953) as arkosic sandstone and argillite. As mentioned earlier in this report, some of the argillite is dolomitic.

The results of spectrographic analyses of uraniferous rock from some uranium occurrences in Pennsylvania and New Jersey, and of Chattanooga shale from Tennessee, are given in table 2. Some of these analyses were reported previously (Klemic and Baker, 1954) but are listed here for comparison with others not previously reported. The analyses of rock from New Jersey, West Virginia, and Tennessee are included for comparison with samples from Pennsylvania.

The percentage group in which many of the elements occur in "average" sandstone and shale, as reported by Green (1959), is indicated in the last two columns in table 2 for comparison of the composition of average rocks with that of the uraniferous rocks.

The samples listed in table 2 were analyzed spectrographically to ascertain any possible relation between the presence and abundance of uranium and other elements that could not be detected and measured by other means. Many factors must be considered in interpreting the differences and similarities in the composition of these samples. The samples were analyzed over a period of a few years, by more than one analyst and some of the analyses were more refined than others. In some analyses the elements are listed in their order of abundance within the percentage ranges with the most abundant element in the group listed first; in others the elements are grouped in percentage ranges but are not reported in order of abundance within the groups.

TABLE 2.—*Semiquantitative spectrographic analyses of uraniferous and nonuraniferous rocks from Pennsylvania, New Jersey, West Virginia, and Tennessee, with radiometric and chemical analyses for uranium and selenium, in percent* [1]

[Where groups of elements are partitioned by dashed line, those elements listed above line are in upper half of percentage range and those below are in lower half]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
XO	Si	Si	Al Si	Al Si	Si	Si	Al Si	Si	Si Fe Al	Si Al	Si Al Fe	Al Si	Al Si	Al Si	Al Si	Al Si	Si Al
X	Al Fe	Al Fe	Fe K	K Fe	Al Fe	Fe Al	K Fe Mg	Al Fe				Fe Cu K	K Mg Fe	K Fe Cu	Fe K	Ca Fe K	
									K Ti	Fe, K Ti	Ti	Mg Ca		Mg		Mg Na	Fe, K Mg, Na
0.X	K Mg Ca	Mg Ca Ti	Mg Ti Ca	Mg Ca Na	Mg Ca U	Mg	Ti Ba Ca	K Mg Ca				Na Ti	Na Ca	Na Ca	Mg Ca	Ti Mn	
	Ti U	Pb U	Na	Ti	Ti		Na	Ti	Mg Na Ca	Mg, Pb Na, U Ca, V	K, Ca U, Pb Mg		Ti Cu	Ti Pb	Na Ti	Cu	Cu, Ti Ca, Mn
0.0X	Pb Na Ba B Mn	Ba Mn V Na B	Ba Mn B Co Pb	Ba Pb B Mn V	Pb Mn Ba Na B	Ti Pb Na Mn B	Pb Sr B Cu Mn	Pb Na V Ba B				Mn Ba Co B Ni	Ba Mn Sr B Cr	Ba Mn Cr B Ni	Ba Mn B Co Ni	Ba Co Sr B Ni	Ba
	V	Co	Ni V	Co	V	Ba V	Co Cr V	Mn Cu	Ba Pb Cr Cu Zr	Ba B Cr Cu Zr	Na Ba Cr Cu V Zr	Cr Ag Sr V	Co Ni V	Sr Co V	Cr Sr	Cr Pb V	V, Sr B, Pb Co Ni
0.00X	Co Ni Ga Cr Cu Sr Y	Zr Ni Cu Y Cr Ga Sr	Ga Cr Sr Zr Cu Y Sc	Ga Cr Ni Sr Cu Y Sc	Co Cu Ni Cr Y Sr Ga	Cu Ni Zr Cr Sr Ga	Ni Ga Zr Y Sc	Ni Cr Sr Ga Y Zr				Pb Ga Zr Y Sc	Ga Pb Zr Y Sc Ag	Ga Zr Y Ag Sc	V Ga Zr Y Cu Pb Sc	Ga Zr Y Sc	Cr Zr Mo Ga Y La

									B, Mn Ga, Co Sc, Ni Sr, Sn Y, V	Mn, Sc Co, Sr Ga, Y Sn Ni	Mn, Sn B, Sr Co, Y Ga Ni Sc						Ag Sc
0.000X	Yb	Yb	Yb Be	Be Yb	Yb	Yb	Be Yb	Be Yb	------ Yb Be	------ Be Yb	------ Be Yb	Yb Be	Yb Be	Yb Be	Yb Be	Yb Be Ag	------ Yb Be
0.0000X																	
eU (percent)	0.23	0.32	0.017 0.016	0.026 0.027	0.25	0.063	0.017	0.10	0.015	0.14	0.31	0.004	0.004	0.008	0.004 Field esti- mate	0.004 Field esti- mate	0.004
U (percent)	0.22	0.30	0.026 0.025	0.022 0.022	0.22 0.24	0.060 0.055	0.011 0.012	0.13 0.13	0.014	0.16	0.30			0.003			0.004
Se (percent)		0.066				0.002		0.038	0.0005	0.0015	0.0082 0.0085						

See footnote at end of table.

TABLE 2.—*Semiquantitative spectrographic analyses of uraniferous and nonuraniferous rocks from Pennsylvania, New Jersey, West Virginia, and Tennessee, with radiometric and chemical analyses for uranium and selenium, in percent* [1]—Continued

[Where groups of elements are partitioned by dashed line, those elements listed above line are in upper half of percentage range and those below are in lower half]

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
XO	Fe Si	Si Al	Si	Si	Si	Si	Al Si	Al Si	Si Al	Si	Si	Si	Si Al	Si	- - - Si	Si
X		- - - K Ti Fe	Al Fe - - - U, Ca V, P	Al U - - - Ca, Fe Mg, Pb	Al Fe - - - V, Ca U, P	Al - - - Fe	Na Fe K Mg Ca	Na K Mg Ca Fe	- - - Na K Fe	Al - - - Fe	- - - Al Fe	Al Fe K	Fe K	Al Fe K	- - - Al Ca Fe K Mg	Al Ca - - - Fe K Mg
0.X	Al Ca As	Mg - - - Cu Na Ca	Mn Ba - - - Na, As Mg, Ti	Na - - - V	Ba Mn - - - Na Mg Ti	Mg K - - - Ca Ti	Ti	Ti	Ca	K - - - Mg Ca Na	Ti - - - Mg Ca Zr	Ca Na Mg Ti	Ca Na Mg Ti	Ca Na Mg Ti	- - - Na Ti	Mn Na - - - Ti
0.0X	Ni B Mn Ti	Ba Cr B - - - V Mn Zr Co Ni	Pb - - - B Li	Ba Ti Mn - - - Sr	Pb - - - B Li	Cu - - - Na B Ba Mn	Ba Mn Sr B Cr Co Ni	Ba Mn Sr B Co Cr Ni Cu	Ba Cu - - - Mn B Ti	Ti Ba - - - Zn, V Ni, Mn B, Mo Co Cu	Na Mn Ce Nd Ba - - - La, Ni Cr, Y Co B	Ba Ni Co B Mo V Zn Cr Cu Mn	Ba B Co Ni Cr Cu Mn Sr V	Ba B Ni Co Cr Cu Mo Mn V Sr	- - - Mn Zr Ba B	- - - Sr Ba Zr Cr B
0.00X	Cu Mg Pb Ga Zr Ba Cr Sr V	La Sr Pb - - - Ga Y Sc		Cr - - - Zr Cu		Pb Zr - - - Ga Y Sc Sr V	Cu Ga La Y Zn Zr Pb V Sc	Ga Pb Zn Y Zr V Sc	Zr Mg - - - Cr, Y Ga, Pb Sr V	Sr Cr Y - - - Pb Ga Zr Sc	V Sr Pb Cu Sn - - - Ga Er Yb Sc	Sr Y Zr Ga Sn Pb Sc	Zr Ga Y Sc Pb	Zr Y Ga Pb Sc	- - - Cr, Li Sr Cu V Ce	Zn - - - Ga, Ce Pb, Nd Y, Th Ni, Cu

															La Zn	Co La
0.000X	Yb	Ag - - - - Be Yb		Be		Cr - - - - Yb	Yb Be	Yb Be Ag	- - - - Yb Be	- - - - Yb		Yb Be	Yb Be	Yb Be	Pb, As Ga Ni - - - - Co, Y Se Be, Th	Sc As - - - - U, Er Be, Yb Sn
0.0000X						Be - - - - Ag				Be - - - -					Sc U Mo - - - - Ag	Ag Mo Se - - - -
eU (percent)			1.4			0.040	0.033	0.004	0.008	0.004	0.017 .015					
U (percent)	Probably 0.001	Probably 0.001	1.8			0.046	0.030	0.001	0.004		0.007 .008					
Se (percent)			0.040													

[1] Analysts.—Spectrographic: K. E. Valentine, Charles Annell, K. V. Hazell, H. W. Worthing.
Chemical: Marion Moeller, Roosevelt Moore, Carmen Johnson, Audrey Smith, Esma Campbell, Blanche Ingram, and Joseph Budinsky.
Radiometric: Percy Moore, B. A. McCall.

SAMPLE 1. Field No. HK3-45; Lab. No. 115036; Devonian sandstone (loc. 23).
2. Field No. HK3-50; Lab. No. 115037; Devonian sandstone (loc. 23).
3. Field No. HK3-61; Lab. No. 115047; Devonian sandstone (loc. 23).
4. Field No. HK3-41; Lab. No. 115031; Devonian sandstone (loc. 24).
5. Field No. HK3-43; Lab. No. 115034; Devonian sandstone (loc. 23).
6. Field No. HK3-49; Lab. No. 115033; Devonian sandstone (loc. 24).
7. Field No. HK3-36; Lab. No. 115027; Devonian sandstone (loc. 25).
8. Field No. HK3-37; Lab. No. 115028; Devonian sandstone (loc. 25).
9. Field No. HK6-53; Lab. No. 148823; Devonian clay and silty sandstone (loc. 22).
10. Field No. HK6-57; Lab. No. 148829; Devonian sandstone (loc. 21).
11. Field No. HK6-58A; Lab. No. 148831; Devonian sandstone (loc. 21).
12. Field No. HK3-62; Lab. No. 115216; Devonian shaly sandstone (loc. 2).
13. Field No. HK3-63; Lab. No. 115217; Devonian shale (loc. 2).
14. Field No. HK3-68; Lab. No. 115221; Devonian shale (loc. 1).
15. Field No. HK3-26; Lab. No. 115248; Devonian shaly siltstone (loc. 17).
16. Field No. HK3-28; Lab. No. 115250; Devonian shale (loc. 17).
17. Field No. A-8-1; Lab. No. 138361; Devonian sandstone (20 mi. northeast of loc. 17).
18. Field No. HK3-70; Lab. No. 115223; Mississippian conglomerate (near loc. 24).
19. Field No. MC-CU; Lab. No. 135376; Mississippian shale (near loc. 23).
20. Field No. MC-PVS; Lab. No. 125070+150414; Mississippian-Pennsylvanian sandstone.
21. Field No. MCPV-B; Lab. No. 135377; Mississippian-Pennsylvanian sandstone (loc. 26).
22. Field No. MC-PVL; Lab. No. 125071; Mississippian-Pennsylvanian sandstone (loc. 26).
23. Field No. HK5-3; Lab. No. 140762; Pennsylvanian sandstone (10 miles northwest of loc. 23).
24. Field No. FK3-82C; Lab. No. 113868; Triassic gray argillite (loc. 38).
25. Field No. FK3-83C; Lab. No. 113875; Triassic gray argillite (loc. 38).
26. Field No. HK3-116A; Lab. No. 129106; Triassic shale, New Jersey.
27. Field No. HK3-94; Lab. No. 127756; Devonian black shale, West Virginia.
28. Field No. HK3-97; Lab. No. 127759; Mississippian sandstone, West Virginia.
29. Field No. YB-28-A; Lab. No. 112842; Devonian black shale, Tennessee.
30. Field No. YB-28-B; Lab. No. 112844, Devonian black shale, Tennessee.
31. Field No. YB-28-C; Lab. No. 112850; Devonian black shale, Tennessee.
32. Abundance of elements in average sandstone (Green, 1959); not all elements are reported.
33. Abundance of elements in average shale (Green, 1959); not all elements are reported.

Included among the samples are conglomerate, sandstone, siltstone, shale, argillite, clay, and silty sandstone. The conglomerate is pyritiferous, the argillite is dolomitic, and the sandstones include quartzitic and friable rocks with a wide range in the relative amounts of granular detrital grains and micaceous and clayey matrix materials. Some are cemented by silica and the matrix materials, others by calcite. Samples of well-cemented and practically impermeable rock, of permeable rock obtained from recent excavations, and of weathered rock from natural exposures are included in those that were analyzed. These variations in the materials sampled and in the degree of weathering of the rocks contribute to the differences in composition that are shown in table 2.

The relatively impermeable rocks from recent excavations may have undergone practically no change in composition from the time of cementation to the time of analysis. They may have undergone great change in composition between the period of their original deposition and induration and the time of the cementation that sealed the rocks in their present state. The uranium and associated elements could have been introduced at any period from sediment deposition to final cementation, and they may have been combined into minerals that were altered diagenetically. Separation of uranium from elements originally associated with it may have occurred at any time up to the period when it was sealed in the rock by its final cementation. Thus, the analyses indicate the composition of the samples of rock as they are at present. Weathered samples differ in composition from their unweathered state. Because the addition or removal of one or more elements in the rock affects the relative abundance of all the other elements, it may bring them into or remove them from a detectable range of abundance, or it may shift them from one range of magnitude of abundance to another. Some variations in reported abundance of elements are readily explained and others that may be useful in deciphering the mode of origin of the uranium deposit are not understood. A discussion of the elements reported and their variations in abundance follows. Minerals in which the elements are known to occur in these and in other sedimentary rocks are mentioned. Most of these are common minerals in sedimentary rocks.

Silicon and aluminum are the most abundant elements in the samples, and iron is next in abundance. Quartz, siliceous rock fragments, and aluminum silicates contain almost all the silicon and aluminum. Iron is in detrital and chemically precipitated sedimentary iron oxides and in oxides resulting from weathering of pyrite and other iron minerals. Some of the iron is in pyrite and some in silicates. Calcium is in calcite or dolomite in some samples and may also be in silicates in others. Potassium, magnesium, sodium, and possibly barium may be almost entirely in silicates in most of the samples. Barite has been reported by McCauley (1957, p. 14) in some of the deposits. Chlorite, mica, and clay minerals are abundant in most of the samples. Phosphorus is abundant in two samples and is probably in apatite. Magnesium is in dolomite in a few samples. Ilmenite, leucoxene, sphene, and rutile account for most of the titanium. Manganese is likely to be in oxides, which stain some of the rocks. Copper is in sulfides, carbonates, silicates, and possibly in oxides in many of the samples. Lead is in clausthalite in a few samples, but may be in galena or secondary lead minerals in others. Tourmaline, an accessory mineral, may contain most of the boron and lithium, although some of the lithium may be in mica. Vanadium is in secondary uranium-vanadium minerals in some samples but is in an unidentified, probably black mineral in others. Zirconium is in accessory zircon, and yttrium, cerium, lanthanum, ytterbium, and beryllium may also be in zircon. Sphene and allanite may also contain some of these elements. Gallium, nickel, silver, and zinc may be in sulfides, or these elements as well as scandium, tin, and molybdenum may be minor elements in other more abundant minerals. Arsenic is reported in two samples, one of which is rich in pyrite and the other probably contains some sulfides. Selenium is in clausthalite in some samples and may also be in sulfides and unidentified minerals in others.

Thorium is not reported in any of these analyses, although uranium is abundant in some of the samples, and elements commonly found in heavy detrital minerals in sedimentary rocks are also fairly abundant. Many of these samples probably contain thorium, but in amounts below the limits of detectability by the methods used in analysis.

Results of chemical analyses for uranium and selenium in some rocks and minerals from Pennsylvania and New Jersey are given in table 3.

No regular increase in abundance of any element with an increase in the abundance of uranium is evident in the tables, but in some samples uranium is abundant and vanadium, lead, phosphorus, or selenium is also abundant. None of the samples with low uranium content is rich in selenium, vanadium, or phosphorus, and only one sample low in uranium is rich in lead. Some samples rich in uranium contain relatively small amounts of these elements. There is a negative correlation in that shales and argillites among these samples commonly contain more cobalt, nickel, strontium, and possibly chromium, and less uranium than the sandstone samples. However, no uranium-rich shales are represented in these analyses, although one of the argillite samples contains 0.033 percent uranium.

TABLE 3.—*Chemical analyses for uranium and selenium in some rocks and minerals from Pennsylvania and New Jersey* [1]

[Analyses in percent; analysts: Audrey Smith, Esma Campbell, Blanche Ingram, Roosevelt Moore, Maryse Delevaux, Joseph Budinsky, Rivers Powell]

Field No.	Laboratory No.	Age of rock from which sample was taken	Location	Locality (pl. 2)	Rock or mineral	Uranium (U)	Selenium (Se)
FK3-6	112381	Triassic	Hunterdon County, N.J.	44	Sandstone	0.031	0.0003
FK3-7	112382	do	do	44	Iron-stained sandstone containing clay pebbles.	.016	.0003
FK3-90	115254	do	do	44	Arkosic sandstone	.003	.0003
FK3-97	115261	do	Bucks County, Pa.	36	do	.021	.0005
FK3-99	115263	do	do	36	do	.035	.0004
FK3-106	115269	do	do	36	Dark-purple mudstone	.095	<.0003
FK3-115	115278	do	Hunterdon County, N.J.	45	Arkosic pyritiferous sandstone	.044	<.0003
MCPV-S	125070 and 150414	Pennsylvanian-Mississippian.	Carbon County, Pa.	26	Low-rank graywacke sandstone uranium ore cemented with calcite.	1.8	.04
PV20	149600	do	do	26	do	2.4	.023
HK3-37	115028	Upper Devonian	do	25	Low-rank graywacke sandstone	.13	.038
HK3-44	115035	do	do	23	do	.56	.02
HK3-49	115033	do	do	24	do	.060, .050	.022
HK3-50	115037	do	do	23	do	.30	.066
HK6-53	148823	do	do	22	Gray and black clay and silty sandstone.	.014	.0005
HK6-57	148829	do	do	21	Gray micaceous sandstone	.16	.0015
HK6-58A	148831	do	do	21	Brown sandstone containing yellow uranium minerals.	.30	.0082, .0085
HK6-80	149596	Devonian	Lycoming County, Pa.	11	Gray sandstone containing copper minerals.	.44	.004
HK6-82	149597	do	Sullivan County, Pa.	13	Micaceous gray sandstone containing copper minerals.	.24	.001
HK6-84	149598	do	Lycoming County, Pa.	7	Gray micaceous sandstone	.10	.0004, .0003
HK6-88	149599	do	Columbia County, Pa.	16	Gray shaly siltstone and very fine sandstone.	.40	.0003, .0003
HK6-109	150408	do	Schuylkill County, Pa.	27	Micaceous gray sandstone	.050	<.0003
HK6-111	150409	do	Huntingdon County, Pa.	32	Brown silty sandstone	.03	<.0003
HK6-114	150410	do	do	32	Red sandstone	.26	.0003
HK6-115	150411	do	do	32	Brown fine-grained sandstone	.024	<.0003
HK6-116	150412	do	do	33	Brown silty sandstone	.095	<.0003
HK6-117	150413	do	Bedford County, Pa.	35	Gray sandstone containing plant fossils.	.015	.0005
HK6-Se-2 [2]	TWC 5056	do	Carbon County, Pa.	23	Clausthalite from uraniferous sandstone.	------	13.7
HK6-Se-3 [2]	TWC 5056	Mississippian	do	(3)	Pyrite from conglomerate	[4] <.001	.0003
HK6-Se-5 [2]	TWC 5056	Pennsylvanian	do	(5)	Pyrite	[4] <.001	.025
HK6-Se-6 [2]	TWC 5056	do	Lackawanna County, Pa.	------	do	[4] <.001	.004
HK6-62B	148832	Devonian	Carbon County, Pa.	(6)	Galena	[4] <.001	<.01

[1] Triassic rocks sampled by McKeown (written communication, 1954).
[2] Sample lot 0-20.
[3] One mile northwest of locality 26.
[4] Probably less than 0.001.
[5] Three miles west-southwest of locality 26.
[6] Five miles east of locality 26.

On the basis of the analyses of samples from Pennsylvania, variations in abundance of elements other than uranium in the uraniferous rocks seem to reflect the composition of the host rock and not the composition of solutions that introduced uranium. Just as the uranium may have been deposited at any time during the deposition, lithification, and development of the rocks to their present composition so may other elements have been added or removed. Such changes may or may not have coincided with the deposition of uranium. Some of the lead is of radiogenic origin, and some of this radiogenic lead may have combined with selenium and sulfur to form authigenic clausthalite and galena in the zones where uranium is concentrated. Thus, part of the selenium and sulfur in the rock may have been concentrated in the uraniferous rock.

In some areas the ratio of enrichment of copper and uranium in the rocks over the normal concentration of the elements in average sedimentary rocks may be comparable, but in the Appalachian Plateaus deposits, the ratio of copper to uranium is much greater than the ratio of these elements in the deposits in Carbon County where uranium is relatively abundant.

ORIGIN

A consideration of the source of the uranium, and the methods by which it became concentrated, may furnish clues to where more and perhaps better deposits of uranium might be found. Possible sources of uranium in uranium deposits in sedimentary rocks are (a) hydrothermal solutions, (b) the material from which the sediments were derived, and (c) a combination of the first two.

The uranium may be deposited syngenetically as a mechanical concentration of detrital uranium-bearing minerals or as a chemical precipitate from solution during deposition of the sediments. Or, it may be deposited from solutions that permeate the sediments during or after their burial and lithification. The uranium occurrences from which the samples listed in table 2 were obtained include deposits that were formed in different ways, as will be described in the following paragraphs.

The deposit from which sample HK3–97 (table 2) was obtained is a placer or heavy-mineral-type deposit in sandstone of Devonian or Mississippian age in West Virginia. Zircon and monazite constitute more than 1 percent and possibly as much as 3 percent of some samples of this rock.

The argillite samples of Triassic age (loc. 5, table 2) and some shales of Devonian age (locs. 1, 2, 17, table 2) from Pennsylvania contain uranium that was probably deposited syngenetically by precipitation from solution. The trace-element content of these samples is somewhat similar and the rocks are comparable in other respects to the

Chattanooga shale, which contains uranium that is believed by Brown (1956, p. 461–462) to have been deposited syngenetically. McKeown (unpublished data, 1954) considers the uranium, pyrite, and and argillic alteration of the Triassic sandstones to be of epigenetic hydrothermal origin. The hydrothermal activity that occurred in the area, however, may have accompanied the intrusion of the dikes and sills during Triassic time in Pennsylvania and New Jersey, and if the uranium is of hydrothermal origin it may have been introduced penecontemporaneously with the Triassic sediments.

The uranium in Devonian rocks near Penn Haven Junction in Carbon County (loc. 23, table 2) was probably concentrated epigenetically. Uranium occurs in the same or correlative Devonian formations in many widespread localities and in different positions on major fold structures in Pennsylvania; these occurrences suggest that there may have been a syngenetic accumulation of uranium in the formation as a whole. The details of the distribution of uranium and the mineral and structural relations in the deposit near Penn Haven Junction, as described earlier, suggest an epigenetic concentration of the uranium in the formation before development of major joint systems that may have formed in post-Pennsylvanian time.

The widely separated uranium occurrences in the lower part of the Pottsville formation and in the upper part of the Mauch Chunk may also indicate that there was a widespread syngenetic deposition of uranium in sediments of this stratigraphic position. However, the uranium deposit in the Mauch Chunk-Pottsville transition zone on Mount Pisgah in Carbon County (loc. 26, pl. 2) was probably formed by an early epigenetic concentration of uranium, possibly in Pennsylvanian or Permian time. The uranium may have been leached from the source materials of the sedimentary rocks by the water involved in the weathering, transport, and deposition of the sediments, or it could also have been brought in by hydrothermal solutions. Carbonaceous material probably influenced the concentration of uranium, but local fracture zones may also have affected this. Major folding and fracturing took place later, and uplift and erosion exposed the rocks at the surface. Weathering of some of the near-surface rocks and oxidation of the primary uranium minerals resulted in the formation of secondary minerals, which were deposited in open fractures and porous zones and on outcrop surfaces.

Other geologists have studied the deposit on Mount Pisgah and discussed its possible origin. Wherry (1914, p. 147–151) considered the concentration of uranium minerals in a placer as its mode of origin. A placer deposit of radioactive minerals from pegmatites and igneous and metamorphic rocks in general would probably contain an appreciable amount of thorium with respect to uranium. This deposit is not known to contain any more thorium than might be found in rocks that are almost barren of uranium.

Montgomery (1954, p. 108–110) postulates that hydrothermal solutions may have brought in uranium or reworked uranium in minerals of detrital origin. He also describes evidence of shearing in uraniferous rock and interprets the mineral relations as evidence of uranium deposition by replacement of brecciated rock. No definite evidence of hydrothermal activity has been found in these rocks by the author.

Dyson (1954, p. 128–134) states that the concentration of uranium in the deposit on Mount Pisgah is definitely controlled by lenses with a high percentage of carbon, and to a lesser extent by fractures. His statements refer to both primary and secondary uranium minerals. He cites several features of the deposits that must be considered but does not select any single mode of origin as being the most likely.

Some of the uranium occurrences, such as those associated with the contacts of the Freeport coal in western Pennsylvania (locs. 18, 19) and a few of the occurrences in cupriferous Devonian rocks, may have formed by leaching of uranium from adjoining rocks and its precipitation in a secondary form, preferentially in weathered rocks at these localities in relatively recent time.

ECONOMIC POTENTIAL

A few deposits in eastern Pennsylvania may be comparable in size and grade with some deposits in Western United States that have been mined where facilities for milling the ore were available near the mines. However, the economic potential of the known uranium deposits in Pennsylvania for the near future does not seem to be favorable because of current marketing conditions.

A limited amount of test mining has been done at the uranium deposit on Mount Pisgah near Jim Thorpe, Carbon County (loc. 26, pl. 2), but the results of the testing have not been made public. This, however, is probably one of the largest of the known uranium deposits in Pennsylvania and only the near-surface parts of the deposit have been tested. There may be an extension of the ore zone down the dip of the beds.

The uranium occurrence near Penn Haven Junction, Carbon County (loc. 23, pl. 2), contains significant amounts of highly radioactive rock at surface exposures, and stratigraphic and structural features of the deposit suggest the existence of a deposit that may be of commercial value if the need arises for additional sources of uranium. The highly radioactive rock is exposed in two places a few hundred feet apart on a structure that has been breached by a river. This shows both structural and mineralogical continuity in the deposit, and it is reasonable to project extensions of the deposit both down the dip and into the hillsides along the strike of the beds.

The next largest known occurrence of uranium in the State is also in Carbon County. It is on Mauch Chunk ridge near Jim Thorpe (loc. 25, pl. 2). This occurrence, however, is spotty and there are no surface concentrations of uraniferous rock that are comparable in grade to those at the two deposits described above.

None of the other uranium occurrences in Pennsylvania that are known to the author have large outcrops of uranium-rich rock, and most of the occurrences do not have stratigraphic or structural features that suggest the possibility of significant increase in size or grade of the deposit with depth. Most of the occurrences are of interest merely as indications of the presence of uranium and of beds in which deposition of uranium from available sources was favored. A study of areas in which many of these small occurrences exist may lead to the discovery of larger deposits in places where the stratigraphic and structural features of the favorable beds made them more suitable hosts for the uranium that was available for concentration.

No reconnaissance comparable to that which has been done in the areas described in this report is known to have been done in western Pennsylvania and western Maryland. Their potential for uranium is unknown, but many of the rock units of Devonian to Pennsylvanian age in these areas may be as suitable host rocks for uranium as they are in eastern Pennsylvania. The two small uranium occurrences in Pennsylvanian rocks in Beaver and Clearfield Counties (pl. 2) indicate that some source of uranium and conditions under which it could be concentrated did exist in these areas, at least on a small scale.

In summary, most of the known uranium occurrences in Pennsylvania are not worthy of any development work. A few of the deposits—those in the Carbon County area in eastern Pennsylvania—may be of economic value if the need arises for additional sources of uranium.

Other deposits of potential economic value may be found in Pennsylvania. The available information shows that sources of uranium and features of the host rocks that were favorable for the formation of uranium deposits did exist in the State. Carbon County and adjoining areas, where the Catskill and Pottsville formations are thick and similar in composition and where there are similar structural features, may have the greatest potential for uranium in sedimentary rocks in the State. The large uranium occurrences in this area are evidence that sources, means of concentration, and favorable host rocks were available for the formation of uranium deposits. The areas of the favorable host rocks that are well exposed at the surface are only a minute fraction of the total area underlain by these beds, and there is no reason to believe that the concealed parts of these beds do not contain uranium in amounts at least equal to those in the exposed parts.

LOCALITIES

APPALACHIAN PLATEAUS PROVINCE

Locality [1]	*Description*
Bradford County:	
Monroeton quadrangle:	
1. On farm of A. E. Dibble 1 mile south of New Albany, about 1,000 ft west of Beaver Run near altitude of 1,340 ft in gorge of tributary of Beaver Run.	Copper prospect, short adit in gray shale of Catskill formation. Radioactive gray shale, no visible uranium minerals.
2. On farm of Carl Sherdel, about one-half a mile west of New Albany where road crosses Ladds Creek. Outcrop in streambed about 100 ft north of road; small adit on south side of Ladds Creek near stream level about 0.4 mile upstream from road.	Gray shale and sandstone of Catskill formation containing copper minerals and abundant plant fossils are radioactive. No visible uranium minerals.
3. On farm of Harold Messersmith 1 mile east of Overton and about 0.6 mile north of county line along Overton-Albany township boundary. Outcrop along road.	Outcrop of gray shale of Catskill formation containing secondary copper minerals and carbonaceous plant fossils is radioactive. No visible uranium minerals.
4. Loose boulders of radioactive rock near barn on farm of Charles Kinney west of Messersmith farm.	Gray sandstone and shale of Catskill formation are radioactive. No visible uranium minerals.
Canton quadrangle:	
5. On property of Harold Keltz, Canton, Pa. Outcrop along road in hollow on northwest side of Canton.	Greenish-gray sandstone and siltstone of Catskill formation containing carbonaceous plant fossils and calcareous nodules. Malachite stains and azurite on shaly partings. Slightly radioactive gray sandstone and shale. No visible uranium minerals. Beds almost flat-lying.
Lycoming County:	
Eagles Mere quadrangle:	
6. On north side of Big Run about 200 ft northwest of U.S. Highway 220 on north edge of Tivoli. Slump block at base of bluff along dirt road.	Dark-gray shale of Catskill formation stained by secondary copper minerals; carbonaceous plant fossils and gray shale containing brachiopod fossils. Weakly radioactive dark-gray shale. No visible uranium minerals.

[1] Locality numbers correspond to those shown on pl. 2.

Locality	*Description*
Lycoming County—Continued	
Eagles Mere quadrangle—Continued	
7. On farm of Leon Myers about 0.7 mile west of Beaver Lake and 0.7 mile south of Strawbridge. Outcrop in dirt road near crest of hill. Another outcrop of radioactive rock on the farm was not examined.	Radioactive greenish-gray micaceous sandstone of Catskill formation. No visible uranium minerals.
8. On Cunfer property on east side of Beaver Lake about ½ mile north of the lake outlet. Old copper mine adit about 15 ft above water level.	Gray sandstone of Catskill formation 15 ft or more thick, in which radioactivity is associated with plant fossils. No visible uranium minerals.
9. Outcrop in old road about 700 ft south of outlet of Beaver Lake at foot of bluff on west side of valley.	Reddish-gray sandstone of Catskill formation is spottily radioactive. No visible uranium minerals.
10. On west side of Beaver Run at foot of bluff about ½ mile south of Beaver Lake Hotel and about 250 ft north of where highway crosses creek.	A 20-ft adit extends into the hillside from a 4-ft joint in a 20-ft bed of gray sandstone of Catskill formation. Trashy gray silty and micaceous sandstone having spotty weak radioactivity. No visible uranium minerals.
11. About 1 mile south-southwest of south end of Beaver Lake on hillside facing south between branches of Beaver Run. Dirt road leads to prospect adit.	Gray and greenish-gray micaceous radioactive sandstone in lens or channel in red sandstone of Catskill formation. Rock contains carbonaceous plant material, malachite, azurite, chalcocite, and chalcopyrite. Radioactive zone appears to have been mined out in driving adit. There may be trace amounts of secondary uranium minerals on partings in gray shale and sandstone.
Sullivan County:	
Eagles Mere quadrangle:	
12. On farm of Willis Meyers about 2 miles north of hotel at Beaver Lake and about ¾ mile south-southeast of Beech Glen. Outcrop in field west of barn.	Weakly radioactive gray trashy sandstone and red silty sandstone of Catskill formation containing abundant fossil fish scales(?). Calcareous and silty zones are cupriferous. No visible uranium minerals.
13. Near Sonestown. About 2,000 ft east of U.S. Highway 220 on Sonestown-Nordmont road. Outcrop on north side of road	Radioactive gray and greenish-gray micaceous silty sandstone of Catskill formation containing secondary copper minerals

Locality	*Description*
near road level. Radioactive rocks in two beds 20 to 40 ft apart stratigraphically.	in lenses or channels. There may be trace amounts of secondary uranium minerals on partings in radioactive rock.
Columbia County:	
Laporte quadrangle:	
14. On Buttles property leased by J. R. Lauback about 7 miles north of Benton and 0.25 mile southwest of Brandem Church. Old copper prospect-outcrop and test pits about 30 ft above road level on northwest side of paved road.	Gray cupriferous sandstone and siltstone of Catskill formation containing plant fossils is weakly and spottily radioactive and has trace amounts of yellow or green radioactive minerals.
15. On farm of B. Fritz. Old copper prospect about 0.3 mile east of Sugarloaf School on road to Tri Mills. Small dump and flooded pit in field south of road and outcrop about 50 ft above road level on north side of road.	Gray sandstone of Catskill formation containing malachite, azurite, chalcocite, and bornite(?) is weakly radioactive. Some carbonaceous plant fossils. There may be trace amounts of green secondary minerals.
16. On farm of B. Fritz about 0.6 mile southeast of Sugarloaf School on east slope near top of hill. Site has been prospected for uranium.	Gray sandstone and siltstone of Catskill formation containing secondary copper minerals are interbedded with red sandstone. The gray rock is spottily radioactive. The strongest radioactive rock is a thin shaly layer containing secondary copper minerals. Trace amounts of green secondary uranium minerals.
Wayne County:	
Waymart quadrangle:	
17. On farm of Joseph Millen about 3.6 miles northwest of South Canaan at old copper prospect; 4 test pits in 2 groups about ½ mile apart along east slope of hill between Bronson and Robinson Ponds.	Gray sandstone and siltstone of Catskill formation containing secondary copper minerals and carbonaceous plant fossils are weakly radioactive. No visible uranium minerals.
Clearfield County:	
Clearfield quadrangle:	
18. In strip mine at LeContes Mills.	Upper 0.4 ft. of Lower Freeport coal bed in Allegheny formation contains small amounts of uranium in one area (Patterson, 1954). No uranium minerals reported.

Locality	*Description*
Beaver County:	
New Castle quadrangle:	
19. In road cut on State Route 51 about 1.5 miles south-southeast of Darlington.	Bottom 6 inches of Lower Freeport coal bed and top 3 inches of underclay in Allegheny formation contains small amounts of uranium at one locality in a prospect hole (Ferm, 1955). No uranium minerals reported.

VALLEY AND RIDGE PROVINCE

Locality	*Description*
Luzerne County:	
Wilkes-Barre East quadrangle:	
20. About 0.5 mile southwest of Laurel School along paved road at small quarry on south side of road and north of Lehigh Valley Railroad about 0.7 mile southeast of Laurel Run.	Radioactive rock is iron-stained sandstone near top of Pocono formation. Disseminated nodules of pyrite in sandstone. Mauch Chunk formation is thin or absent at this locality, so the uranium occurrence is only slightly below the Pennsylvanian-Mississippian contact. No visible uranium minerals.
Carbon County:	
Stoddartsville quadrangle:	
21. About 1.8 miles southeast of State Route 940 in road cut along northeast extension of Pennsylvania Turnpike.	In Catskill formation, primary(?) black uranium mineral in radioactive gray sandstone. Yellow secondary uranium minerals including renardite(?) in limonite-stained weathered zones along fractures. Pyrite nodules in gray sandstone.
22. About 3.1 miles southeast of State Route 940 near south end of road cut along northeast extension of Pennsylvania Turnpike.	In Catskill formation. Uranium in weathered silty gray sandstone and weathered black carbonaceous shale. No visible uranium minerals.
Lehighton quadrangle:	
23. About 0.4 mile south of Penn Haven Junction in outcrop near railroad-track level on both sides of Lehigh River. Described in text as the Penn Haven Junction occurrence.	In Catskill formation. Uraninite in sandstone containing small amounts of clausthalite (PbSe) and minor amounts of secondary minerals, such as uranophane and kasolite. The occurrence is in a minor anticlinal fold on a limb of a large anticline. Uraninite from this occurrence may be useful for age-determination studies.

Locality	*Description*
24. About 1.1 miles south of Penn Haven Junction. Outcrop on west side of river near railroad-track level, and talus on east side of river near same altitude and extending down to foot of steep slope.	Uranium in sandstone and siltstone in a minor anticlinal fold in Catskill formation. Traces of yellow secondary uranium minerals.
25. Along U.S. Highway 309 about 0.3 mile southeast of Jim Thorpe and along south side of tracks of Central Railroad of New Jersey in places from 0.3 mile southeast of Jim Thorpe to about 0.8 mile east of Jim Thorpe.	Uraniferous rock is sandstone and siltstone of the Cherry Ridge member of the Catskill formation on the south limb of the Panther Valley syncline. Small amounts of yellow and green secondary uranium minerals, including autunite, metatorbernite, metauranocircite, and probably uranophane.
26. On south side of U.S. Highway 309 about 0.4 mile northwest of bridge across Lehigh River at junction of U.S. Highway 309 and State Route 903. Small adits in cliff along highway at foot of Mount Pisgah near Jim Thorpe.	Uraniferous rock is basal conglomerate and sandstone, similar to overlying Pottsville formation, in transition zone of Pottsville and Mauch Chunk formations on north limb near nose of Panther Valley syncline. Some of uraniferous rock is sandstone or conglomerate with black matrix. Secondary uranium minerals are abundant as yellow or green films or coatings on surfaces and in weathered zones. These secondary minerals are described in table 1. Black uranium-rich sandstone from this deposit may be suitable for age-determination studies.
Schuylkill County:	
Orwigsburg quadrangle:	
27. About 1 mile northwest of Hecla on east side of saddle in ridge between Cold and Brushy Runs. Radioactive rock crops out about 60 ft below crest of ridge and near stream level along Brushy Run.	Uraniferous rock is gray sandstone of Cherry Ridge member of Catskill formation. Trace amounts of yellow secondary uranium minerals.
Columbia County:	
Bloomsburg quadrangle:	
28. About 2.4 miles north along State Route 339 from center of Light Street. Outcrop on south side of road where road turns to east.	Uranium is in sandstone lenses or channels in thin beds of gray sandstone in the Catskill formation. Trace amounts of green secondary uranium minerals.

Locality	*Description*
Montour County:	
Shamokin quadrangle:	
29. About 1.25 miles south of junction of Roaring Creek and Susquehanna River and about 5 miles south-southeast of Danville. Old copper prospect adit about 170–200 ft above stream level at sharp west bend in stream.	Small amounts of uranium associated with plant fossils in gray sandstone of Catskill formation. Trace amounts of yellow secondary uranium minerals on partings in radioactive rock.
Dauphin County:	
Harrisburg East quadrangle:	
30. Outcrop on north side of State Route 443 about 3.8 miles northwest of Linglestown and about 0.75 mile northeast along State Route 443 from Albright Church.	See description for locality 29 above.
Huntingdon County:	
Orbisonia quadrangle:	
31. About 9.5 miles southwest of Orbisonia along gravel road on Sideling Hill Creek about 1.2 miles north of Huntingdon-Fulton County line.	Uranium in small amounts associated with plant fossils in gray and tan sandstone of Catskill formation. Trace amounts of green secondary uranium minerals.
Broad Top quadrangle:	
32. About 2.5 miles north-northeast of Robertsdale, outcrop near road level on northeast side of State Route 994 about 0.7 mile northwest of point where Route 994 crosses East Broad Top Railroad.	Uranium in gray and red sandstone of Mauch Chunk formation. Trace amounts of yellow secondary uranium minerals.
33. About 2.4 miles north-northeast of Robertsdale, and about 0.2 mile northwest of East Broad Top Railroad crossing along State Route 994. Outcrop near barn on farm of G. P. Territa.	Uranium in gray sandstone of Mauch Chunk formation. No visible uranium minerals.
Fulton County:	
Broad Top quadrangle:	
34. About 1 mile west of Hustontown along State Route 76, outcrop on south side of road near northwest end of road cut.	Small amounts of uranium in sandstone and siltstone associated with plant fossils in Catskill formation. Trace amounts of green secondary uranium minerals.

Locality	*Description*
Bedford County:	
Clearville quadrangle:	
35. At north edge of Clearville quadrangle about 5 miles east of Everett and 0.8 mile northwest of Juniata Crossing, where U.S. Highway 30 crosses Raystown Branch of Juniata River. Outcrop along steep bluff on west side of river tangent to the apex of the westward loop in the river.	Small amounts of uranium in sandstone associated with plant fossils in Catskill formation. May be trace amounts of yellow or green secondary uranium minerals.

PIEDMONT PROVINCE

Locality	*Remarks*
Bucks County:	
Point Pleasant quadrangle:	
36. About 1.9 miles east of Lumberville, in a quarry about 0.3 mile south of State Route 32, on property of C. M. Kieffer.	Uraniferous rock is sandstone, containing disseminated pyrite and limonite, in Stockton formation. Can be located by radioactivity. Only trace amounts of yellow and green uranium minerals.
37. On south side of State Route 32 about 1.7 miles east of Lumberville, in a quarry owned by Harry Lipman.	Uranium is in sandstone of Stockton formation containing disseminated trace amounts of yellow or green secondary uranium minerals.
38. Along State Route 32 about 2 miles north of Point Pleasant in Delaware quarry, owned by Joseph Busick.	Uraniferous rock is black argillite of the Lockatong formation. No visible uranium minerals.
39. Outcrops along a dirt road about 1.5 miles northeast of Pipersville and 0.3 mile northeast of Tohickon Creek.	Uraniferous rock is gray argillite of the Lockatong formation. No visible uranium minerals.
Doylestown quadrangle:	
40. About 0.25 mile northwest of Pipersville in a road cut along U.S. Highway 611.	Uraniferous rock is dark-gray to black argillite of the Lockatong formation. No visible uranium minerals.

Radioactive gray and black argillite was found about 1.3 miles north, 2.7 miles north, 2.7 miles northwest, and about 2 miles north-northeast, of Point Pleasant, Pa. (locs. 41, 42, 43 in Pennsylvania, and loc. 47 in New Jersey, pl. 2). Radioactive sandstone in the Stockton formation in New Jersey about 2 to 4 miles east and east-southeast of Point Pleasant, Pa. (locs. 44, 45, 46) has been examined by McKeown (unpublished data, 1954). No visible uranium minerals are reported in the argillite. Torbernite and uranophane(?) have been found in the radioactive sandstone, and uraninite has been found at locality 44 (pl. 2) in the Stockton formation (J. Kratchman, oral communication). This material may be suitable for lead-uranium age-determination studies. Most of the uraniferous sandstone at these localities contains disseminated pyrite or is limonite stained in weathered zones.

REFERENCES CITED

Brown, Andrew, 1956, Uranium in the Chattanooga shale of eastern Tennessee, *in* Page, L. R., Stocking, H. E., and Smith, H. B., Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 457–462.

Brummer, J. J., 1958, Supergene copper-uranium deposits in northern Nova Scotia: Econ. Geology, v. 53, no. 3, p. 309–324.

Deul, Maurice, 1956, Colloidal method for concentration of carbonaceous matter from rocks: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 5, p. 909–917.

Dyson, J. L., 1954, Relation of stratigraphy and structure to uranium occurrences near Mauch Chunk, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Inf. Circ. 5, p. 124–134.

Ferm, J. C., 1955, Radioactivity of coals and associated rocks in Beaver, Clearfield, and Jefferson Counties, Pennsylvania: U.S. Geol. Survey TEI–468, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Frondel, Clifford and Cuttitta, Frank, 1954, Studies of uranium minerals (pt. 14): renardite: Am. Mineralogist, v. 39, nos. 5 and 6, p. 448–451.

Garrels, R. M., and Larsen, E. S., Jr., 1959. Geochemistry, mineralogy of Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, 236 p.

Genth, F. A., 1875, Preliminary report on the mineralogy of Pennsylvania: Pennsylvania 2d Geol. Survey Rept. B, 1874, p. 144.

Gordon, S. G., 1922, The mineralogy of Pennsylvania: Acad. Nat. Sci., [Philadelphia] Spec. Pub. no. 1.

Green, Jack, 1959, Geochemical table of the elements for 1959: Geol. Soc. America Bull., v. 70, table 2.

Klemic, Harry, 1955, Occurrences of uranium in Paleozoic rocks of Pennsylvania, *in* Geologic investigations of radioactive deposits—Semiannual progress report, June 1 to November 30, 1955: U.S. Geol. Survey TEI–390, p. 196–198, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Klemic, Harry, and Baker, R. C., 1954, Occurrences of uranium in Carbon County, Pennsylvania: U.S. Geol. Survey Circ. 350, 8 p.

Klemic, Harry, Warman, J. C., and Taylor, A. R., 1962, Geology and uranium occurrences of the northern half of the Lehighton, Pennsylvania quadrangle and adjoining areas: U.S. Geol. Survey Bull. 1138, in press.

Krynine, P. D., 1948, The megascopic study and field classification of sedimentary rocks: Pennsylvania State Coll. Mineral Industries Expt. Sta., Tech. Paper 130, 165 p.

Legette, R. M., 1936, Ground water in northwestern Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. W3., 215 p.

Lesley, J. P., 1887, Annual report of the Geological Survey of Pennsylvania for 1886: Pennsylvania 2d Geol. Survey, 1636 p.

Lesley, J. P., and others, 1895, A summary description of the geology of Pennsylvania: Pennsylvania Geol. Survey Final Rept., 3 v., 2588 p., illus., atlas (1892–5).

Lohman, S. W., 1937, Ground water in northeastern Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. W4, 300 p.

McCauley, J. F., 1957, Preliminary report on the sedimentary uranium occurrences in the State of Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Prog. Rept. 152, 22 p.

——— 1958, Discussion of supergene copper-uranium deposits, Nova Scotia Econ. Geology, v. 53, no. 8, p. 1038–1042.

McKeown, F. A., 1953, Uranium in Triassic rocks, Bucks County, Pa., and Hunterdon County, N.J., *in* Geologic investigations of radioactive deposits—Semi-annual progress report, June 1 to November 30, 1953: U.S. Geol. Survey TEI–390, p. 197, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1954, Uranium occurrences in Bucks County, Pa., and Hunterdon County, N.J., *in* Geologic investigations of radioactive deposits—Semi-annual progress report, December 1, 1953 to May 31, 1954: U.S. Geol. Survey TEI–440, p. 167, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

McLaughlin, D. B., 1944, Triassic stratigraphy in the Point Pleasant district, Pennsylvania: Pennsylvania Acad. Sci. Proc., v. 18, p. 62–69.

——— 1945, Type sections of the Stockton and Lockatong formations: Pennsylvania Acad. Sci. Proc., v. 19, p. 102–113.

McLaughlin, D. B., and Willard, Bradford, 1949, Triassic facies in the Delaware Valley: Pennsylvania Acad. Sci. Proc., v. 23, p. 34–44.

Montgomery, Arthur, 1954, Uranium minerals of the Mauch Chunk area, Pennsylvania: Pennsylvania Acad. Sci. Proc., v. 28, p. 102–110.

——— 1957, Three occurrences of high-thorian uraninite near Easton, Pennsylvania: Am. Mineralogist, v. 42, nos. 11 and 12, p. 804–820.

Palache, Charles, Berman, Harry, and Frondel, Clifford, 1957, The system of mineralogy of James Dwight Dana and Edward Salisbury Dana: 7th ed., v. 2, New York, John Wiley & Sons.

Patterson, E. D., 1954, Radioactivity of part of the bituminous coal region of Pennsylvania: U.S. Geol. Survey TEI–479, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Schnabel, R. W., and Vickers, R. C., 1953, Reconnaissance of the Clinton formation in New York, Pennsylvania, Maryland, and New Jersey: U.S. Geol. Survey TEM–434, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Sisler, J. D., 1932, Bituminous coal fields of Pennsylvania, Part 2: Pennsylvania Geol. Survey, 4th ser., Bull. M6.

Stevenson, R. E., 1948, Pigmentation of the black Triassic argillite of Bucks County, Pennsylvania: Pennsylvania Acad. Sci. Proc., v. 22, p. 131–134.

Weed, W. H., 1911, Copper deposits of the Appalachian States: U.S. Geol. Survey Bull. 455, p. 59–61.

Welch, S. W., 1953, Radioactivity of coal and associated rocks in the anthracite fields of eastern Pennsylvania: U.S. Geol. Survey TEI-348, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Wherry, E. T., 1912, A new occurrence of carnotite: Am. Jour. Sci., v. 33, p. 574–580.

——— 1914, Carnotite near Mauch Chunk, Pennsylvania: U.S. Geol. Survey Bull. 580.

White, I. C., 1883, Geology of the Susquehanna River region: Pennsylvania 2d Geol. Survey, Progress Rept. G7.

Willard, Bradford, 1939, The Devonian of Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. G19.

Wood, G. H., Trexler, J. P., Arndt, H. H., Yelenosky, Andy, and Soren, Julian, 1956, Subdivision of the Pottsville formation in southern anthracite field, Pennsylvania: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 11, p. 2669–2688.

INDEX

	Page
Abstract	243
Acknowledgments	243
Allanite	263
Allegheny formation	256, 257
Andersonite	263, 264
Applachian Plateaus province	249, 250, 252, 253, 258, 262
Background radioactivity	247, 248
Barite	271
Bloomsburg quadrangle	281
Broad Top area	256
coal field	250
quadrangle	282
Brunswick formations	250, 251
Calcite	270
Cambrian-Ordovician rocks	248
Canton quadrangle	277
Carbon County, uranium occurrence in	248
Carnotite	264
Catskill formation	253, 257, 262, 276
Cattaraugus formation as used by Willard	253, 255, 257
Cerium	271
Chattanooga shale	265
Chemical analyses	272
Cherry Ridge formation	253, 255, 257
Chlorite	259
Clausthalite	259, 264, 271
Clearfield quadrangle	279
Clearville quadrangle	283
Clinton formation	245
Coal, uranium content	247, 251
Copper	251, 252, 255, 257, 271
Damascus formation	253
Devonian rocks	248, 249, 254, 257
Dolomite	270
Doylestown quadrangle	283
Eagles Mere quadrangle	277, 278
Economic potential	275
Elk Mountain formation	253
Fossils	251, 262
Freeport coal	275
Galena	271
Gallium	271
Geiger counter, use of	247
Harrisburg East quadrangle	282
Honesdale formation	253, 255, 257
Illite	261
Ilmenite	271
Jim Thorpe area	245, 264, 275, 276
Kasolite	264
Lanthanum	271
Laporte quadrangle	279
Lehighton quadrangle	246, 247, 280; pl. 2
uranium in	247
water samples	247
Leucoxene	271
Liebigite	264
Limonite	284
Localities of favorable host rocks	277
Lockatong formation	250, 251, 252
Manganese	271
Mauch Chunk. *See* Lehighton quadrangle.	
Mauch Chunk formation	255, 257, 260, 274
Methods of reconnaissance	248
Minerals, radioactive	263
Mississippian rocks	248, 249, 254, 257
Monazite	273
Monroeton quadrangle	277
Mount Pisgah	245, 247, 248, 256, 260, 274, 275
shale	253, 257
New Castle quadrangle	280
Orbisonia quadrangle	282
Ore production, uranium	247
Orwigsburg quadrangle	281
Oswayo formation	253
Penn Haven junction	247, 260, 274, 275
Pennsylvanian rocks	248, 249, 254, 257, 276
Phosphuranylite	265
Piedmont province	249, 250
Pocono formation	253, 255, 257
Point Pleasant quadrangle	283
Pottsville formation	252, 255, 257, 274, 276
Pyrite	257
Reading Prong	250
Reconnaissance, airborne method	248
carborne	248
road traverse method	248
References	248–286
Rutile	271
Schroeckingerite	264
Scintillation counter, use of	247
Secondary uranium minerals	244
Sedimentary rocks, age	249
uranium in	244, 263

Page

Selenium, chemical analyses for ... 272
Shale, radioactivity in ... 247
Shamokin quadrangle ... 282
Source of uranium ... 273
Sphene ... 263, 271
Stockton formation ... 250, 252, 283, 284
Stoddartsville quadrangle ... 280

Thorium ... 249, 257, 263, 271, 274, 275
Titanium ... 271
Torbernite ... 252, 264, 284
Tourmaline ... 271
Triassic rocks ... 248, 252, 258
Tyuyamunite ... 264

Uraniferous rock, composition of ... 265
  spectrographic analyses of ... 265, 266, 267, 268, 269
Uraninite ... 259, 263, 264
Uranium occurrence in Appalachian Plateaus province ... 249, 250, 251, 252, 253, 262, 273
  Brunswick formation ... 250, 251
  Carbon County ... 248, 255, 280, 281
  Catskill formation ... 253, 257, 280, 281, 282, 283
  Cattaraugus formation as used by Willard ... 255, 257
  Cherry Ridge member of the Catskill formation ... 255, 257, 281
  Damascus member of the Catskill formation ... 253
  Honesdale member of Catskill formation ... 253, 255
  Jim Thorpe area ... 245, 246
  Late Devonian sedimentary rocks ... 249
  Lehighton quadrangle ... 246, 247, 280, 281
  Lockatong formation ... 250, 251, 252
  Mauch Chunk formation ... 255
  Mount Pisgah area ... 245, 247, 248, 256, 260, 274, 275, 281
  Penn Haven junction ... 247, 259, 280, 281
  Pennsylvanian sedimentary rocks ... 249
  Pottsville formation ... 252, 255
  sedimentary rocks ... 263
  Stockton formation ... 250, 252, 264, 283
  Triassic rocks ... 252
  Valley and Ridge province ... 253
  water samples ... 245, 247
Uranophane(?) ... 263, 284

Valley and Ridge province ... 249, 250, 252, 258, 280
Vanadium ... 264, 271

Water samples ... 245, 246, 247, 248
Waymart quadrangle ... 279
Wilkes-Barre East quadrangle ... 280

Yttrium ... 271

Zircon ... 263, 273
Zirconium ... 271

O