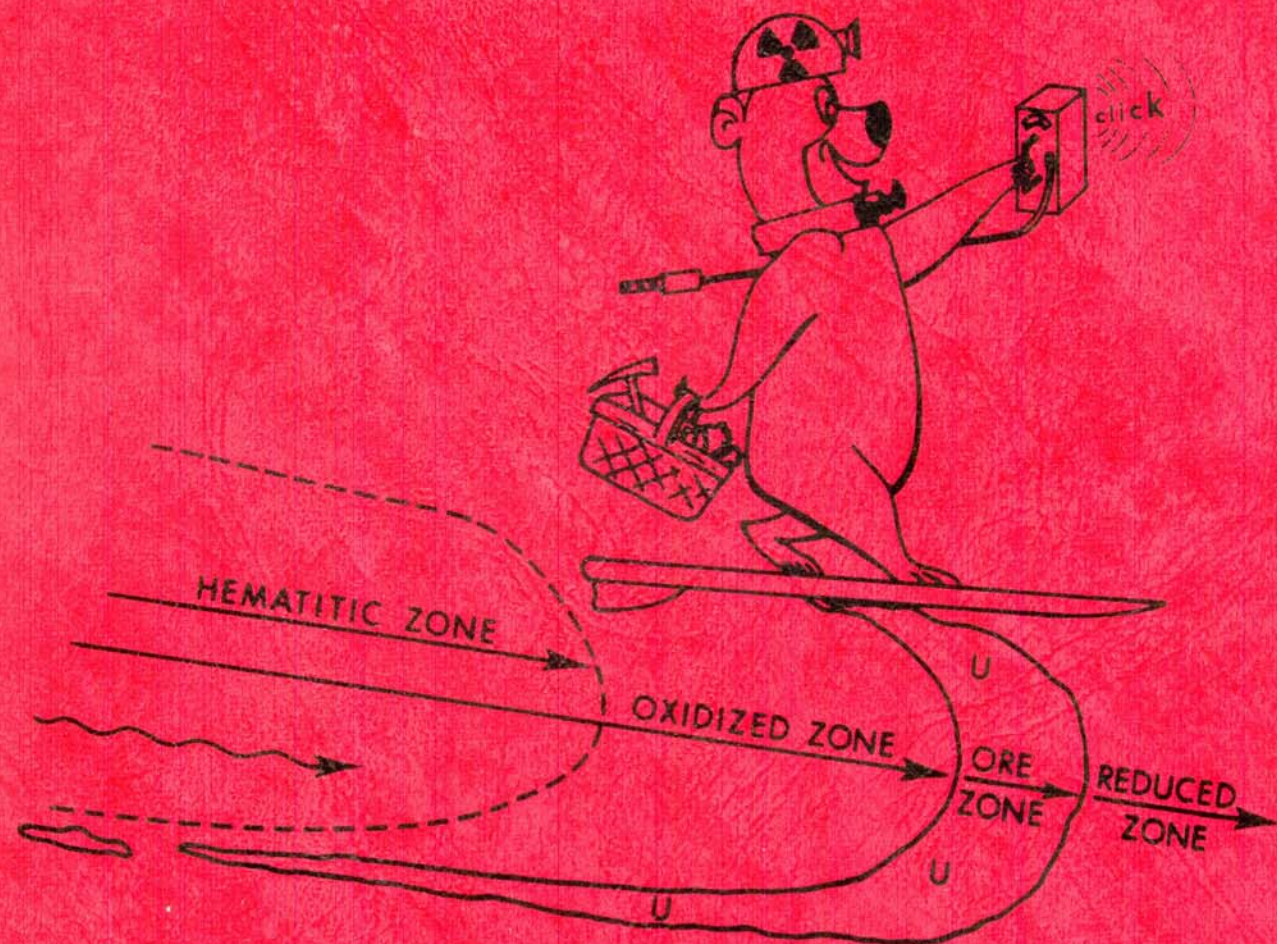


43th. Annual Field Conference Of Pennsylvania Geologists



Uranium in Carbon, Lycoming, Sullivan and Columbia Counties, Pennsylvania

October 6 and 7, 1978
Hazleton, Pa.

Host: Pa. Geological Survey

Guidebook for the
43rd ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

URANIUM IN CARBON, LYCOMING, SULLIVAN,
AND COLUMBIA COUNTIES, PENNSYLVANIA

Leaders: W. D. Sevon, Pennsylvania Geological Survey
A. W. Rose, The Pennsylvania State University
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D. T. Hoff, Pennsylvania Historical and Museum Commission

October 6 and 7, 1978

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- ii Figure 36. Outcrop at SE adit of McCauley Prospect 22...
 1 Paragraph 1, line 5: "dectors" should be : "detectors"
 2 Carbon County, paragraph 1, line 7: insert; east in the Pocono...
 28 Paragraph 3, line 6: "(Stop 1)" should be relocated; Taminae (Stop 1) from...
 28 Paragraph 4, line 1: insert; best described uranium occurrence...
 28 Paragraph 4, line 7: insert; Formation (Pennsylvanian) or...
 30 Paragraph 1, line 6: insert; plant fragments, but...
 30 Paragraph 2, line 1: insert; "the" and delete); include the copper
 sulfides chalcocite...
 31 Line 2; insert; length of up to...
 31 Line 5: insert; retain the cell...
 31 Geochemistry of Uranium, paragraph 1, line 4: insert; conditions).
 However,...
 32 Paragraph 2, line 4: delete "to"; to the deposits...
 35 Paragraph 2, line 9: insert; Apparently, the...
 46 Gaucher: insert; copper-uranium...
 47 McCauley, 1957b: insert; copper-uranium...
 60 Paragraph 2, line 6: delete hyphen; freshly broken...
 61 Paragraph 1, lines 6, 7, 8: lines should read; "uranium phosphates
 phosphuranylite, renardite(?) autunite, meta-autunite, and rare torbernite(?)
 as well as chervetite(?), francevillite(?), and clausthalite were observed
 in a tan to gray, coarse-grained sandstone with quartz pebbles and shale
 chips. The minerals were noted 5m NW of the"
 62 Line 3: insert the following sentence after "yellow coatings."; "Some of the
 meta-uranocircite occurs in carbonaceous plant fragments."
 69 Line 2: "10 m" should be "150 m"
 70 Line 2 of Petrology: "pebble" should be "pebbles"
 72 Paragraph 2, line 3: "these" should be "the"
 73 Paragraph 4, line 4: "333±35x10⁶" should be "335±35x10⁶"
 74 Line 1: "are in progress" should be "contain 1.34% V₂O₅ and 2.58% U₃O₈."
 74 Paragraph 4, line 2: insert "in"; "Mauch Chunk in"
 75 Line 4; "matrix to conglomerate." should be "matrix in conglomerate."
 75 Table 5, Eastern Channel, Radioactivity: "5±" should be "5±1"
 79 Paragraph 3, line 7: "0.3 mR/hr" should be "0.6 mR/hr"
 86 Line 4: "was located: should be "is located"
 86 Line 11: "was located" should be "is located"
 87 Paragraph 2, line 4: "5.7 m deep" should be "5.7 m long"

LAST-MINUTE ANALYSES*

p.61, paragraph 2, line 11-13

The uraninite laminae contains: 10 ppm Ag, >10,000 As, 10 B, 700 Ba,
5 Be, 30 Bi, 300 Cd, 50 Co, 50 Cr, 50 Cu, <10 Ga, 2000 Ge, 200 La, 100 Mn,
<2 Mo, <10 Ni, <20 Nb, 7,000 Pb, <100 Sb, <10 Sc, <100 Sr, <10 Sn, 7,000 Ti,
1,000 V, <50 W, 100 Y, 200 Zr, and <200 Zn.

p.62, paragraph 2, lines 5-6

The chromium muscovite contains: 200 ppm B, 500 Ba, >10,000 Cr, 100 Cu, 500 Pb,
3,000 Ti, 1,000 V, and <200 Zn.

*These analyses were performed by Gordon Van Sickle of Skyline Laboratories, Inc.,
Wheat Ridge, Colorado, on 10/3/78 on a rush basis (at no extra charge) for the 43th
Annual Field Conference of Pennsylvania Geologists.

URANIUM IN CARBON, LYCOMING, SULLIVAN AND COLUMBIA COUNTIES, PENNSYLVANIA

by: W. D. Sevon, Pennsylvania Geological Survey
A. W. Rose, The Pennsylvania State University
R. C. Smith, II, Pennsylvania Geological Survey
D. T. Hoff, Pennsylvania Historical and Museum Commission

INTRODUCTION

Uranium minerals in Pennsylvania have been known since at least 1875 (Genth, 1875; Wherry, 1912; 1914), but concerted interest in the occurrence of these minerals in Pennsylvania did not occur until the 1950's. During the uranium "boom" of the early 1950's, Pennsylvania was prospected by numerous people using radiation detectors, many previously unknown uranium mineral occurrences were located, and a literature on Pennsylvania uranium began to accumulate (McKeown, 1949; Dyson, 1954; Klemic and Baker, 1954; Montgomery, 1954; McCauley, 1957a & b; Gaucher, 1959; and Klemic, 1962). This literature "boom" culminated with the work of McCauley in 1961 and Klemic and others in 1963. In addition, the Atomic Energy Commission conducted aerial radiometric surveys of the Carbon County area (Klemic and Cooper, 1975) and a small amount of material was mined at the Mt. Pisgah occurrence near Jim Thorpe (Stop 4). Following the initial flurry, interest in Pennsylvania uranium waned until the early 1970's when uranium's increasing demand, scarcity and projected price rejuvenated that interest. Since 1972 several energy-related organizations have been actively searching for new uranium occurrences, evaluating the potential of known occurrences and attempting to develop a model of occurrence suitable for exploration.

The existing literature of Pennsylvania uranium is basically descriptive with regard to geographical, stratigraphic and mineralogic occurrence of known Pennsylvania uranium deposits. In this guidebook we will attempt to go beyond this and create sedimentological and geochemical models which will account for the primary distribution of the uranium minerals and their enclosing rocks and a post-depositional model which will explain the present localizations of those minerals. Briefly, the model postulates that uranium in the form of minerals and ions was liberated by weathering and erosion from a southeastern source area in the ancestral Piedmont, carried into the Appalachian basin through a specific distributary system, deposited within fluvial channels and later concentrated by ground water circulation. Development of this hypothesis will concentrate on the Upper Devonian uranium occurrences.

Although this guidebook is the product of four writers and all have reviewed and commented upon the writings and ideas of their co-writers, each part is almost exclusively the product of a specific individual. Sevon wrote: Introduction, Acknowledgements, Sedimentary Framework, Geologic Setting, Environmental Concerns, the Road Log and some of the Stop Descriptions. Rose wrote: Uranium Occurrences, Formation of Uranium Deposits and

Uranium Exploration Methods. Smith wrote: most of the Stop Descriptions and prepared the maps of known occurrences. Hoff located and described stops, especially their mineralogy, and prepared the mineral exhibits for the conference.

ACKNOWLEDGEMENTS

The writers would first like to thank Arthur A. Socolow, Pennsylvania Geologic Survey, for conceiving this trip and selecting the areas to be covered. We also thank those exploration geologists involved in Pennsylvania uranium who have shared both ideas and information.

GEOLOGIC SETTING

CARBON COUNTY

The part of Carbon County with known uranium occurrences is in the eastern part of the Appalachian Mountain Section of the Valley and Ridge Province. The area comprises a thick sequence of Paleozoic rocks which have been deformed into a variety of asymmetric and concentric second-order folds (wavelengths of up to 3.2 km) (Nickelson, 1963, p. 16) with an average N70E axial trend. These folds are intensified to the west in the Southern and Middle Anthracite Fields and become less significant to the east in Pocono Plateau Section of the Appalachian Plateaus Province. In addition to the broad folds, numerous small third-order folds (wavelengths from a few hundred meters to 0.8 km) occur. Bedding dips are commonly steep. Evidence of major faulting in the area is generally lacking, but the existence of a folded fault, the Pottchunk fault, within the Mauch Chunk-Pottsville transition zone has been suggested by Wood (Wood and others, 1969, p. 95-100; and Wood, 1974) and projected into the Lehighton quadrangle on the basis of his work (Epstein and others, 1974, Plate 1). Cleavage is common in shales of the area and a system of fractures is so well developed that bedding-parting is sometimes obscured.

The entire sequence of Devonian and Mississippian rocks is magnificently exposed along the Lehigh River in the Jim Thorpe area and several type localities have been established in these exposures. Table 1 gives a generalized summary of the various mapped stratigraphic units shown in Figure 1. Details of the depositional history of the area and specifics about the rocks important to the uranium occurrences are given in following sections. Detailed descriptions of stratigraphic sections and full discussions of the geology of the area are presented by Epstein and others (1974) and Sevon (1975a & b).

Subsequent to Alleghanian orogenesis (see later section) the area was subjected to erosion, presumably from early Triassic to the present. Wilson and Fairbridge (1971) suggest that three major cycles of peneplanation came to an end around 200, 130, and 60 x 10⁶ years ago respectively. The final of these cycles is preserved today as the upland concordance commonly called "Schooley."

The current cycle of erosion has produced a landscape of ridges and valleys related to hard and soft rocks, respectively, and some plateau areas

Table 1. Stratigraphic sequence in part of Jim Thorpe area, Carbon County, Pennsylvania. Abstracted from Epstein and others, 1974.

Pennsylvanian

POTTSVILLE FORMATION: White sandstones and conglomerates; braided rivers; 251 m.

Mississippian

MAUCH CHUNK FORMATION: Well-bedded, grayish-red siltstones and sandstones; nodular limestones; upper 152 m a transition zone of red siltstones interbedded with gray sandstones and conglomerates; meandering rivers; 684 m.

POCONO FORMATION: Gray conglomerates and crossbedded sandstones; few gray siltstones; quartzitic texture; braided rivers; 250 m.

Mississippian-Devonian

SPECHTY KOPF FORMATION: Basal diamictite, pebbly mudstone, gray planar bedded and crossbedded sandstones; glaciation(?) and braided rivers; 167 m.

Upper Devonian

CATSKILL FORMATION

DUNCANNON MEMBER: Red conglomerates, sandstones, siltstones and shales arranged in fining-upward cycles; crossbedded; meandering rivers; 295 m.

CLARK'S FERRY MEMBER: Gray sandstones and conglomeratic sandstones; planar and trough crossbeds in large bed sets; braided rivers; 276 m.

BERRY RUN MEMBER: Gray sandstones and minor conglomeratic sandstones; crossbedded; red siltstones at top; braided rivers; 300 m.

SAWMILL RUN MEMBER: Gray sandstones; crossbedded; red siltstones and shales at base and top; braided and meandering rivers; 129 m.

PACKERTON MEMBER: Gray sandstones; minor conglomeratic sandstones, siltstones and shales; crossbedded and planar bedded; braided rivers; 127 m.

LONG RUN MEMBER: Alternating gray and red sandstone and red siltstone and shale in fining-upward cycles; meandering rivers on delta plain; 720 m.

BEAVERDAM RUN MEMBER: Olive gray siltstones and very fine-grained sandstones with thin shales; alternating massive and fissile beds; crinoid columnals and load casts; prodelta on shelf; 293 m.

WALCKSVILLE MEMBER: Alternating greenish gray sandstone and red siltstone and shale in fining-upward cycles; abrupt lateral color and grain size changes; meandering streams on lower delta plain; 197 to 640 m.

TOWAMENSING MEMBER: Gray sandstones and siltstones; shale clast conglomerates; carbonaceous debris; pelecypod molds and burrows; delta front; 60 m.

TRIMMERS ROCK FORMATION: Dark gray, massive to thin-bedded and fissile siltstones; turbidites; slump structures and load casts; brachiopods; prodelta; 322 m.

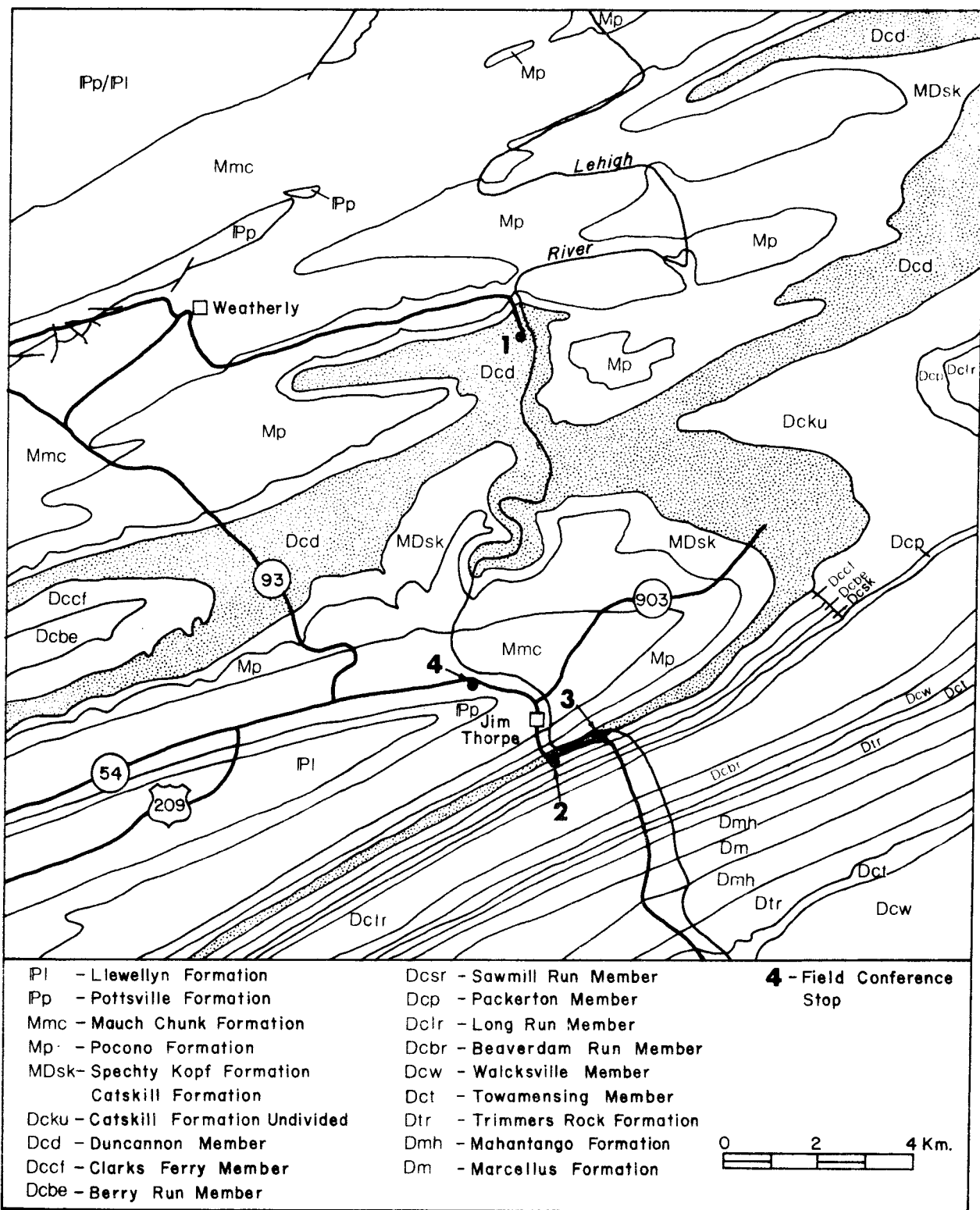


Figure 1. Geologic map of part of Carbon County, Pennsylvania. From open file state geologic map compilation data, Pa. Geol. Survey, Harrisburg.

where rocks are hard and bedding dips are low. Carbon County is transected by the Lehigh River that has cut a narrow, steep-walled gorge up to 300 m below the adjacent uplands. The course of the river is mainly normal to the trend of fold axes and, except for local reaches where the course parallels bedding strike, is probably related to the regional fracture system.

LYCOMING-SULLIVAN-COLUMBIA COUNTIES

The area of Lycoming, Sullivan and Columbia Counties to be visited on this field conference is at the northern margin of the Appalachian Mountain Section of the Valley and Ridge Province. The area comprises a sequence of mainly red Upper Devonian Catskill Formation overlying dark gray marine siltstones and shales of the Lock Haven Formation (stratigraphic equivalent of the Trimmers Rock Formation) and underlying the mainly gray sandstones of a Mississippian-Upper Devonian transition zone (unnamed as yet) (Figure 2). The general nature of the Catskill sequence is indicated in Table 2.



Figure 2. Crossbedded sandstones of the Mississippian-Upper Devonian transition zone in Sullivan County, Pennsylvania. Outcrop is located on the west side of U. S. Route 220 about 4 km SW of Laporte in the Eagles Mere quadrangle (approx. $41^{\circ}23'12''\text{N}/76^{\circ}30'33''\text{W}$). Scale divided into feet.

Table 2. Stratigraphic sequence of the Catskill Formation in the Sonestown area, Sullivan County, Pennsylvania. Section description abstracted from Geolog of No. 1, A. Bennett drilled by The California Company in 1951 at 41°21'00"N/76°30'58"W, about 3.3 km E of Sonestown, Sonestown quadrangle. Top of section is about 200 m below the top of the Catskill. Total Catskill Formation thickness in area about 1070 m. Standard Geolog abbreviations used.

Formation	Major Units	Description	Thickness (m)
Catskill Formation	F	Sandstone, rd, vfg-fg, mic, calc; w/ rd sh intbd.	21.3
		Siltstone, lgt gy, arg, mic; w/ lgt gy sh strgs.	4.6
		Sandstone, rd, vfg-fg, mic, calc; w/ calc nod, slst & sh strgs.	41.1
		Sandstone, v lgt gy, vfg, mic, sl calc.	6.1
		Sandstone, rd, vfg-fg, arg, mic, calc; w/ rd sh intbd.	56.4
		Shale, rd, mic, calc; w/ rd slst strgs.	19.8
		Sandstone, rd, vfg, arg, mic, calc.	15.2
	E	Siltstone, rd, arg, mic, calc; w/ rd sh intbd.	42.7
		Siltstone, rd, arg, mic, calc; w/ gn gy & rd ss & sh strgs.	12.2
		Siltstone, rd, sdy, mic, calc; w/ rd sh strgs.	131.1
	D	Shale, gn, slty, mic; w/ gy gn, mic, calc, slst intbd.	12.2
		Siltstone & sandstone intbd, gy gn, calc, sl mic; w/ rd, calc, sh intbd.	39.6
	C	Siltstone, rd, arg, mic, calc; w/ rd sh strgs & intbd.	79.2
	B	Siltstone & shale intbd, gy gn & rd.	30.5
		Sandstone, gy gn, vfg, slty, calc; w/ slst strgs.	9.1
		Shale, rd, slty, mic; w/ rd, arg, mic, calc, slst strgs.	12.2
		Siltstone, gy, arg, mic, sl calc; w/ gy, sl mic, calc, ss intbd.	51.8
	A	Shale, rd, slty, mic, sl calc.	12.2
		Shale, gn, slty, mic; w/ gy gn, ss & slst strgs.	9.1
		Shale, rd, slty, mic, sl calc; w/ ss & slst strgs.	21.3
		Shale, gn, slty, mic; w/ gn slst & rd ss intbd.	12.2
		Shale, rd, slty, mic, intbd w/ siltstone, rd, arg, mic, sl calc.	30.5
		Siltstone, gy gn, sl arg, sl mic, calc.	9.1
		Sandstone, rd, vfg, slty, sl calc, intbd w/ rd slst; w/ sh strgs.	16.8
		Sandstone, gy gn, vfg, sl mic, calc.	6.1
		Sandstone, rd, vfg, mic.	3.0
		Shale, gn, slty, mic; w/ gy gn, mic, calc ss & slst strgs.	7.6
		Sandstone, gy gn, slty, sl mic, calc; w/ gn sh strgs & rd slst & sh intbd. (Total Catskill, 874.5 m)	21.3
Lock Haven Formation	B	Sandstone, gy/gy gn, vfg, slty, sl mic, sl calc; w/ gn sh strgs.	57.9
		Shale, gn gy, slty.	6.1
		Sandstone, gn gy, vfg, slty, sl mic, calc; w/ gn sh strgs & intbd ss, slst & sh at base	70.1
	A	Siltstone & shale intbd, gn gy; several hundred meters	

No other well logs in the area have been studied and the areal extent of the subdivisions is not known. The mappability of these subdivisions is not known, but at least part of Unit A of the Catskill Formation was mapped by Mahar (1978) and showed moderate lateral persistence. The rocks in the area have low dips, generally less than 10° and folds are broad. Cleavage has not been reported, but a fracture system is well developed. Figure 3 is a geologic map of the area.

The landscape is composed of the steep slopes of the Allegheny Front and North Mountain to the north which rise 300 m or more above the lower-lying, dendritically dissected, hilly surface to the south. This lower dissected landscape generally has relief of 60-120 m and mainly south-oriented drainage.

SEDIMENTARY FRAMEWORK

Essential to understanding the important uranium occurrences in Pennsylvania is the development of a workable sedimentological model. In this section we shall present a model which seems to best account for the source area, the sediment-input system and the deposition of the sediment which today is rock locally containing uraniferous minerals. The model presented initially is restricted to the Upper Devonian, but the relevance of the model to other parts of the Paleozoic will be suggested later.

Barrell (1913; 1914a & b) was the first to envisage the nature of Upper Devonian basin filling and his view is still valid although not specific as to many details.

"The margins of the gravel plain may therefore be estimated at perhaps from 25 to 35 miles to the southeast of the Greene Pond syncline, making the original limits of the Upper Devonian deposits from 45 to 60 miles south-east of the present outcrops in Pennsylvania. Considering all the lines of evidence, especially the distance to an available source for the quartzite and the shortening of this distance due to later folding, the larger figure seems more probable than the smaller." (Barrell, 1914b, p. 239)

"The uniformity in the character of the delta from northeast to southwest, its development marginal to the uplands, and the somewhat rapid gradation from gravel to sand and clay on leaving the mountains suggests the presence of a number of comparatively short streams which built flat coalescing fans rather than the debouchement of one or two great continental rivers. The form of the plain was somewhat similar to that plain of Tertiary alluvium which faces the Rocky Mountains, and was built by overloaded rivers in a region of semi-arid climate." (Barrell, 1913, p. 466)

Neither the work of Willard (Willard and others, 1939, p. 270-273), who proposed three delta lobes, nor that of Walker (1971), who argued progradation

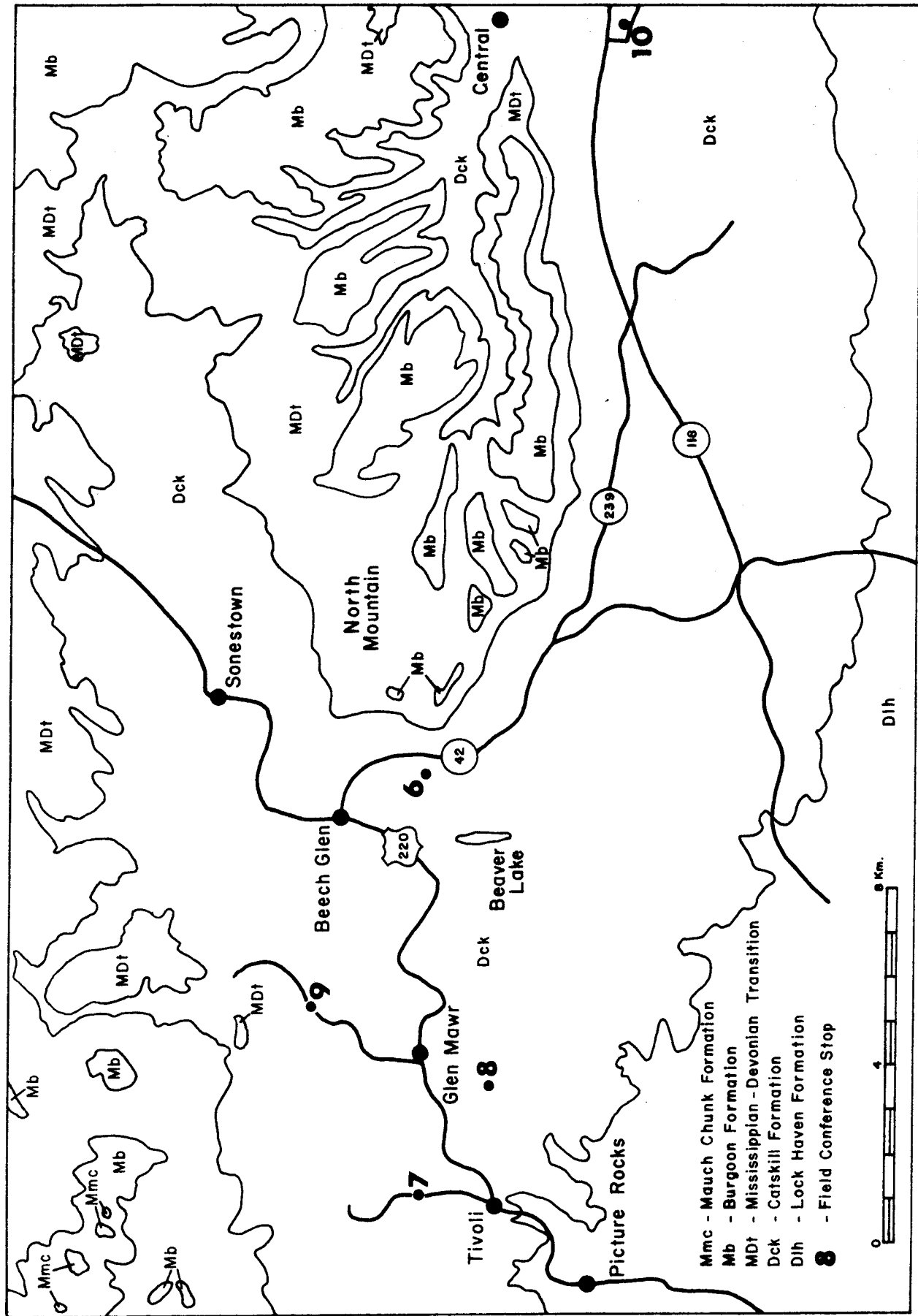


Figure 3. Geologic map of part of Lycoming, Sullivan, and Columbia Counties, Pennsylvania. From open file state geologic map compilation data, Pa. Geol. Survey, Harrisburg.

by a quiet muddy shoreline, has significantly altered the basic concept of Barrell. Willard did initiate the practice of identifying specific sediment-input systems within Pennsylvania. The thesis which will be developed here is that at least eight specific distributary systems originated in ancestral Piedmont rocks to the southeast and fed sediment northwest into the Pennsylvania part of the Appalachian basin. The centers of these input systems can be accurately defined along the southern margin of Devonian rock outcrop, but specific distributary systems become increasingly difficult to distinguish farther north and northwest.

SOURCE AREA

Although the Paleozoic existence of an eastern landmass, Appalachia, has long been recognized as a necessity, an adequate account of this landmass has only recently been possible with the development of plate tectonic models for the eastern margin of North America (Bird and Dewey, 1970; Schenk, 1971; Dietz, 1972; Hatcher, 1972; Odom and Fullagar, 1973; Graham and others, 1975; Rankin, 1975; and Van Houten, 1976). Bird and Dewey briefly discussed the general similarity of aspects of Pennsylvania geology to their New England and Newfoundland model (1970, p. 1046-47) and Dietz (1972) developed a general model for the central Appalachians. Root (1973) developed an evolutionary model for the folded Appalachians of Pennsylvania (Fig. 9, p. 357), but did not tie the model into plate tectonics.

In general, the developmental model is as follows: Following separation of the North American and African plates in the Late Precambrian (Figure 4, A & B), a western sediment source gradually diminished until only carbonates were deposited on a quiet shelf along the eastern margin of the North American plate. Sometime during the Late Precambrian an island arc system developed seaward of the present continental margin of North America and began to serve as an eastern sediment source (Figure 4, C). The establishment of these volcanic islands probably marks the formation of a trench-subduction zone (Hatcher, 1972, p. 2749) and thus the initiation of movement which would eventually result in the collision of two plates. As plate movement continued, the eastern tectonic landmass (Appalachia) grew larger through gradual uplift and was subjected to deformation, metamorphism and intrusion. This landmass contributed more and more clastics to the Appalachian basin and, as a result of plate convergence, was deformed westward toward the basin (Figure 4, D). Following a period of active convergence of the northeastern North American and northwestern South American plates that culminated in the Upper Devonian (McKerrow and Ziegler, 1972; Smith and others, 1973), the North American and South American plates separated and, following a period of moderate uplift and continued lowering of Appalachia by erosion, a final convergence of the North American and African plates produced the Alleghanian tectonism (Figure 4, E) which left the eastern Appalachian basin deformed and Appalachia emplaced as the present Piedmont. During the Triassic, tensional separation of the two plates resulted in normal faulting, igneous activity, erosion and gradual change to sedimentation from a western source (Figure 4, F & G).

The reality of the ancestral parts of the present Piedmont being the source of sediment for the Appalachian basin can be evaluated through study of clast lithology within the basin sediments. Clasts from a conglomerate within the Duncannon Member of the Catskill Formation, exposed at the Bear

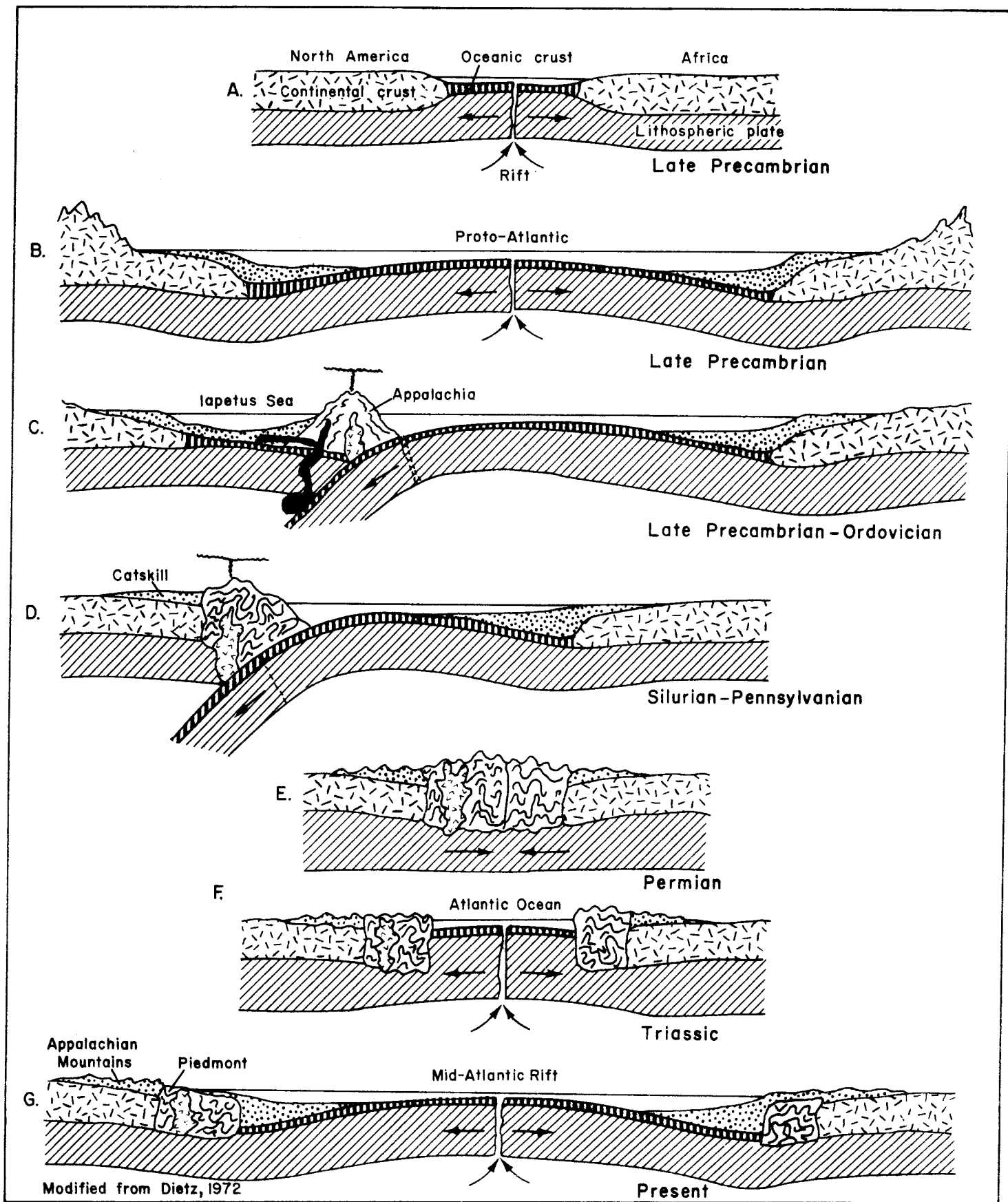


Figure 4. Diagrammatic model of the plate tectonic history of central Appalachian basin. Model modified from Dietz, 1972.

Mountain fire tower, about 1.5 km east of Jim Thorpe, have been identified as follows (quantities by estimation): massive, white, vein quartz (90% +), white quartzite (2% ±) ≥ red quartzite > fibrous vein quartz ≥ chert ≥ conglomerate > gneiss > black quartzite > basalt(?) (trace). All of the clasts are subrounded to well-rounded. Pebble counts of subrounded to rounded clasts in the basal polymictic diamictite of the Spechty Kopf Formation at Penn Haven Junction (Sevon, 1969a, p. 10) give the following: white, clear and smoky quartz (51%), red quartzite (11%), gray and green siltstone (11%), slate (9%), red and gray shale (7%), gray and green sandstone (3%), chert (3%), and conglomerate (2%). Clasts of gneiss have been observed in this unit. In addition, phyllite grains are common in the sand-size fraction of both of these units. Although direct comparisons have not been made as yet, all of the above mentioned clasts could have been derived from currently exposed rock in the Piedmont (Gray and Shepps, 1960). Barrell (1913, p. 239) earlier noted the similarity between the quartzite clasts of the Skunnemunk conglomerate (Upper Devonian, Green Pond outlier in New York and New Jersey) and Cambrian quartzites.

The absence of two materials in Upper Devonian rocks in the Jim Thorpe area is problematical. Identification of clasts mentioned above and thin-section data (Sevon, unpublished analyses) indicate a total absence of limestone clasts and a paucity of feldspar. Both of these items are sufficiently abundant in the Piedmont to warrant expectation of their presence in Upper Devonian sediments. The possibility exists that neither limestone nor feldspar bearing rock was exposed in Appalachia during the Upper Devonian. Two additional factors may have combined to eliminate these materials. (1) The distance of transport from Appalachia to presently exposed sites may have been sufficient to partly destroy the weaker limestone and feldspar particles while more resistant species survived. Barrell (1914b, p. 239; see earlier quote) argued for a transport distance of 96 km for Upper Devonian materials now present in Pennsylvania. Pelletier (1958, p. 1056) calculated the distance to the fall line for the overlying Mississippian Pocono Formation to be about 204 km southeast of present outcrop and Meckel (1967, p. 238) placed the fall line near Philadelphia during deposition of the Pennsylvanian Pottsville Formation. (2) Climate in both Appalachia and the depositional plain may have encouraged destruction of limestone and feldspar. Barrell (1913, p. 470-472) presented early climatic discussions and more recently Woodrow and others (1973) gave a comprehensive evaluation of the subject. The latter concluded, "The coastal plains of the continent existed in tropical wet and dry (savanna) climates while parts of the hinterland may have experienced tropical wet climates." (Woodrow and others, 1973, p. 3058). The combination of temperature, rainfall and distance of transport may have been adequate to destroy limestone and feldspar clasts while allowing their decay products to contribute to Catskill sedimentation. Calcium carbonate was certainly in the depositional system as reflected by carbonate paleosols within the red beds, and calcareous nodules and cement in calcareous breccias. Many Catskill sandstones and siltstones in the more distal parts of the former basin contain small to moderate quantities of calcite. Clay minerals and sericite are abundant, both in the matrix of sandstones and in the abundant siltstones and claystones of the Catskill. Much of this clay could represent the products of decayed potassium feldspar.

Of additional importance to this report is the fact that Piedmont rocks today contain uraniferous minerals. Gordon (1922, p. 140) reports several

localities for uraninite. Smith (1978, p. 131, 187-191, 267-269) describes the occurrence of several secondary uranium minerals, such as phosphuranylite, fourmarierite, vandendriesscheite, meta-autunite and metatorbernite which have apparently been derived from primary uraninite formed during Piedmont pegmatite emplacement.

SEDIMENT-INPUT SYSTEMS

Sometime during the growth of Appalachia, a drainage system developed which carried sediment northwestward from the highlands into the Appalachian basin. Our contention is that, once established, these input systems were relatively fixed in position and that the centers of these systems can be identified along the southern margin of Devonian rock outcrop. Eight centers of sediment input have been identified in Pennsylvania (Figure 5) and others are known in adjacent states. Recognition of these centers is based upon interpretation of the physical attributes of lithologic units in the following ways:

(1) Thickness: where units have a limited area of maximum thickness and an areal pattern of pronounced lateral decrease in thickness away from the maximum, the area of maximum thickness is interpreted as the sediment-input center.

(2) Facies variation: where changes in lithology in laterally equivalent units are best explained by derivation of sediment from different input systems, the areal center of a particular facies is interpreted as the sediment-input center.

(3) Sedimentary structures: where the occurrence of specific sedimentary structures is best explained by relationship to a sediment-input center, the center is positioned relative to those structures.

Since our primary interest here is the Carbon and Lycoming-Sullivan-Columbia County areas, we will discuss in detail the evidence for a sediment-input system relevant to those areas and then make only brief mention of evidence for other sediment-input systems.

The Lehigh River sediment-input system (Figure 5), named for the Lehigh River along which the Devonian rock system is almost totally exposed, had its center in the approximate position of the present Lehigh Water Gap at Palmerton and influenced the immediate area laterally normal to depositional strike for probably no more than 19 to 24 km either side of the center. Interpretation of the Lehigh River sediment-input system is based on the following evidence (arranged in ascending stratigraphic sequence):

(1) Palmerton Formation (Sevon, 1968a; Epstein and others, 1974, p. 119-127). Unimodal, basically structureless, rarely fossiliferous, quartz sandstone achieves its greatest thickness in the Lehigh River area and laterally thins to nothing within 40 km.

(2) Hazard paint ore member of the Buttermilk Falls Limestone (Miller, 1911, p. 48-68; Epstein and others, 1974, p. 122, 127-131). Hard, fossiliferous, clay ironstone attains its greatest thickness just east of the Lehigh River, thins to nothing laterally within a short distance and represents unique depositional conditions.

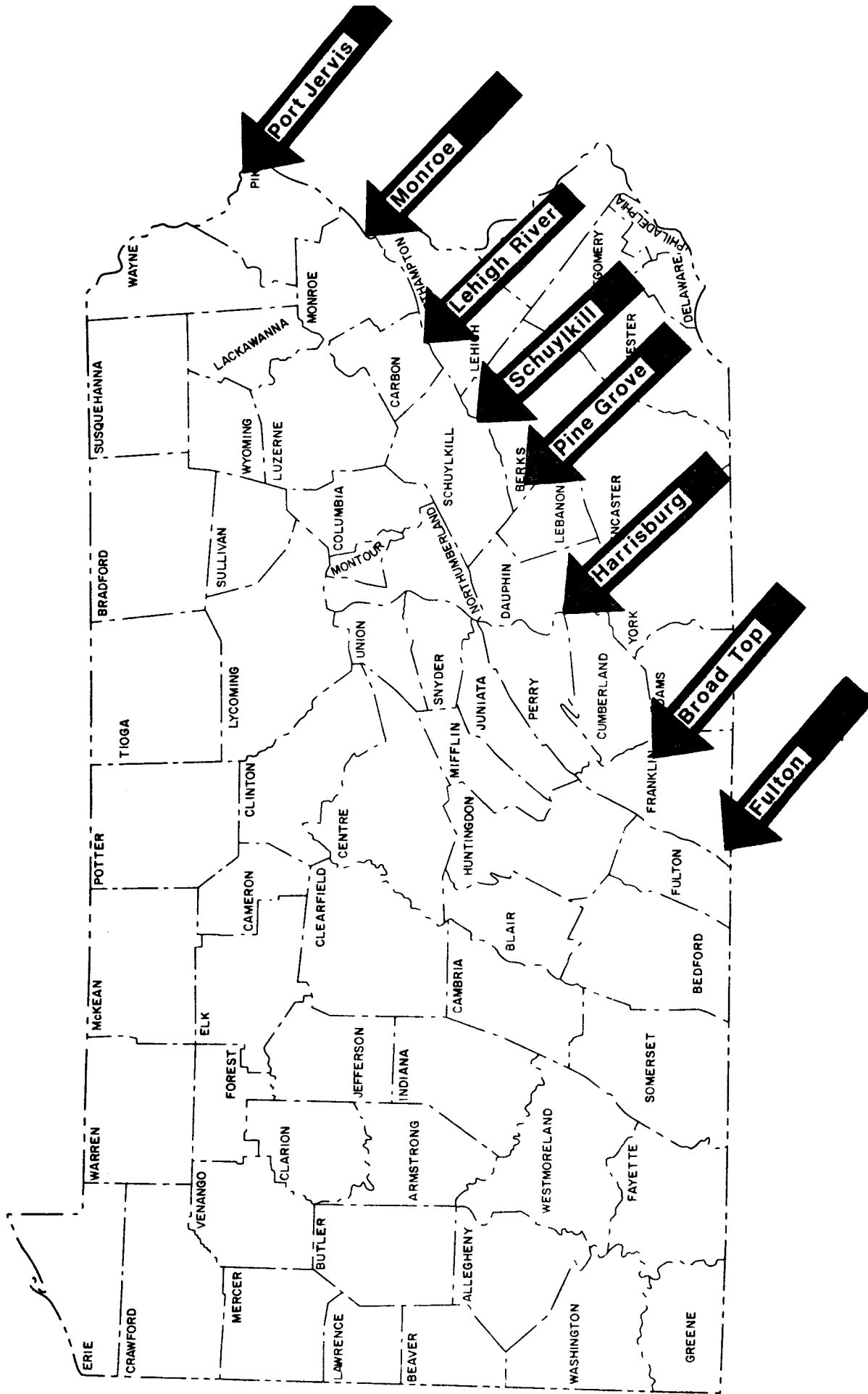


Figure 5. Interpreted centers of sediment-input systems entering the central Appalachian basin during the Devonian.

(3) Nis Hollow siltstone of the Mahantango Formation (Epstein and others, 1974, p. 140-141). Thin sequence of siltstones and very fine-grained sandstones within a thick sequence of shale is thickest at the Lehigh River and thins rapidly both parallel and normal to depositional strike.

(4) Trimmers Rock Formation (Epstein and others, 1974, p. 146-152; Sevon, 1975a). Sequence of marine siltstones and shales of turbidite origin has slump structures and an upward increase in bed thickness and grain size of greater dimension in the Lehigh River area than that present in laterally equivalent rocks 19 to 24 km to the northeast and southwest along depositional strike.

(5) Towamensing Member of the Catskill Formation (Epstein and others, 1974, p. 158-162; Berg, 1975, p. 11-14). Sequence of planar-bedded to cross-bedded sandstones with some shales shows local thickening near the Lehigh River and lateral thinning along depositional strike. Sparsely fossiliferous in the Lehigh River, the unit contains coquinas in areas believed removed from centers of input (Sevon, 1975a).

(6) Long Run Member of the Catskill Formation (Epstein and others, 1974, p. 171-175; Berg, 1975, p. 21-24, Berg and others, 1977, p. 19-23). Sequence of fining-upward cycles is dominated in the Lehigh River area by siltstone and claystone, red color and low angle crossbedding in sandstones. Within 19 to 24 km along depositional strike, gray, trough crossbedded sandstones appear within the unit and increase in quantity as distance from the Lehigh River increases.

(7) Packerton, Sawmill Run, Berry Run and Clark's Ferry Members of the Catskill Formation (Epstein and others, 1974, p. 175-190); Sevon 1975a; Berg, 1975, p. 24-26; Berg and others, 1977, p. 23-28). Thick sequence of gray, crossbedded sandstones with some conglomeratic sandstone is subdivisible in Lehigh River area because of red shale marker beds. Laterally in all directions these marker beds are lost as more red bed units intervene throughout the sequence. The total thickness of each interval decreases away from the Lehigh River. The Packerton Member, which forms the front edge of the Pocono Plateau, changes northeast along depositional strike from sandstone to conglomeratic sandstone and conglomerate in the basal part of the unit. The main facies change occurs about 24 km east of the Lehigh River.

(8) Duncannon Member of the Catskill Formation (Epstein and others, 1974, p. 190-192; Sevon, 1975a & b). Sequence of red fining-upward cycles decreases in coarseness in all directions away from the Jim Thorpe area. Areal pattern of maximum clast size and quantity of conglomerate in lower part of unit indicates a narrow linear belt of coarse clasts oriented north from Bear Mountain fire tower 1.6 km east of Jim Thorpe.

(9) Spechty Kopf Formation (Epstein and others, 1974, p. 192-198; Sevon, 1968b, 1969a & b, 1973). This complex unit has a variety of lithologies, but particularly an areally restricted polymictic diamictite. The diamictite was apparently deposited in a north to northwest oriented channel cut into the underlying Duncannon and is areally restricted to the vicinity of the Lehigh River between Jim Thorpe and Penn Haven Junction.

The other proposed centers of the sediment-input are based generally on less detailed work on the whole Devonian rock system, but in some cases more detailed work on particular parts of the rock system. The information is summarized as follows for each named sediment-input center (Figure 5): (1) Port Jervis: Burtner (1964); work in progress by W. D. Sevon and T. M. Berg in Pike County, Pennsylvania. (2) Monroe: interpretation of the work of Berg (1975) and Berg and others (1977); unpublished observations by Sevon. (3) Schuylkill: unpublished observations by Sevon. (4) Pine Grove and Harrisburg: Kaiser (1972). (5) Broad Top: unpublished observations by Sevon. (6) Fulton: Dennison and deWitt (1972). In addition, other sediment-input centers have been defined by McCave (1968) and Burtner (1964) in New York and by Dennison and deWitt (1972) in Maryland.

The several sediment-input systems apparently operated independently and fluctuated in degree of sediment input. For example, the Harrisburg and Pine Grove systems were very active during deposition of the Middle Devonian Montebello Member of the Mahantango Formation (Kaiser, 1972) while the other systems were relatively quiescent. Similar fluctuations account for facies relationships which define the sediment-input systems.

The individual sediment-input systems apparently also supplied different mineralogical suites as different terrane was exposed and eroded in the headwaters of the system. For example, atomic absorption analyses indicate that sandstones and shales from the Clark's Ferry and Duncannon Members along the Lehigh River contain only about 0.2% Na₂O, compared to approximately 1% Na₂O in the stratigraphically lower Long Run Member (Simon Pirc, The Pennsylvania State University, pers. com.). Similar high amounts occur in the Duncannon and Clark's Ferry sediments along the Susquehanna River north of Harrisburg at Peters Mountain. The U and Th contents of the Duncannon and Clark's Ferry along the Lehigh River also appear to be slightly higher than in the Long Run (Simon Pirc, pers. com.).

Insufficient work has been done to date to allow exact correlation of a specific sediment-input system for more than a few miles northwest of the present southern margin of outcrop. However, we believe that specific systems maintained their integrity for a considerable distance as the alluvial plain prograded northwestward into the basin. A hypothetical progradation for two instances in the Devonian is presented in Figure 6. The presence of uranium minerals in the Lycoming-Sullivan-Columbia Counties area may indicate a relationship between that area and the Lehigh River sediment-input system.

There is evidence that some of these sediment-input systems were active in the same general (perhaps even specific) locations for longer than the Devonian. The work of Epstein and Epstein (1972) on the Shawangunk Formation in eastern Pennsylvania indicates that the Monroe and Lehigh River systems were active during at least the Lower Silurian. The various isopach maps of Colton (1970) suggest major input activities as follows: Lower Cambrian, Fulton; Upper Ordovician, Monroe and Harrisburg; Silurian, Schuylkill; Mississippian, Harrisburg; and Pennsylvanian, Schuylkill. Additional support is suggested by the work of Yeakel (1962), Meckel (1967), and Hoque (1968).

DEPOSITIONAL ENVIRONMENTS

Although deposition of the Catskill has long been considered deltaic in origin and certainly fits the definition provided by Barrell (1912, p. 381),

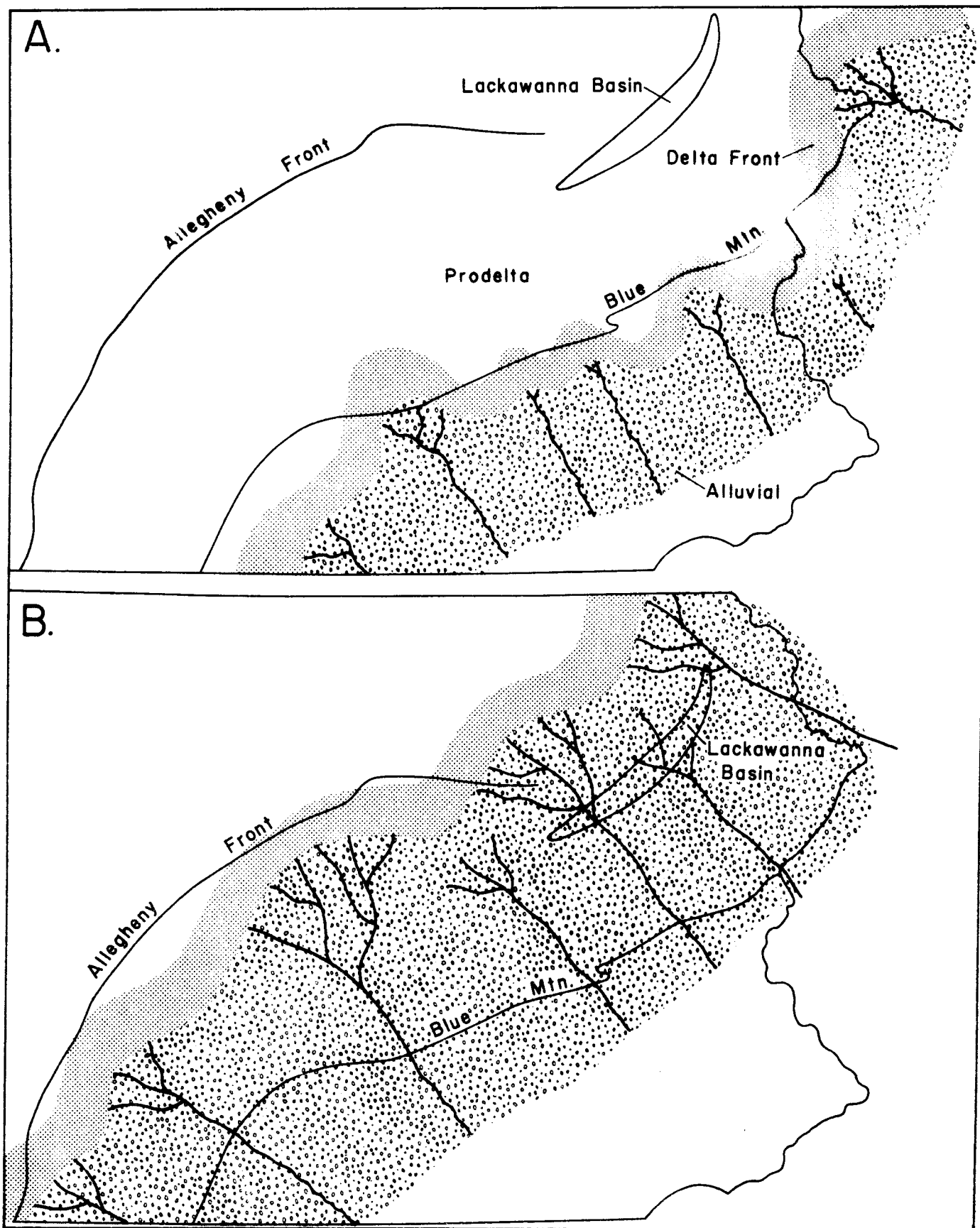


Figure 6. Hypothetical progradation of Devonian sediment-input systems into the central Appalachian basin. A: Late Middle Devonian. B: Middle Upper Devonian.

"A delta may be defined as a deposit partly subaerial built by a river into or against a body of permanent water," specific environments of deposition have only recently been identified for various Catskill rocks. Allen (Allen, 1965; Allen and Friend, 1968) was among the first to delineate specific environments in northeastern Pennsylvania with the recognition of meandering river deposits. Specific environments of the Upper Devonian marine-nonmarine transition in central Pennsylvania were interpreted by Walker (1971; 1972) and Walker and Harms (1971). Epstein and others (1974) described the environments of deposition for the various mapped units in the Lehigh-Palmerton-Jim Thorpe area and Glaeser (1974, p. 14-15) outlines the outcrop criteria for recognizing five different environments - prodelta, delta front, delta plain, braided and meandering rivers - found in Upper Devonian rocks of northeastern Pennsylvania. Humphreys and Friedman (1975) described three different depositional environments - tidal flats, meandering and braided rivers - which they recognized in the Sullivan-Lycoming-Columbia County area. In addition, environments of deposition of lower and higher stratigraphic units have been interpreted by McIver (1961) and Meckel (1967). Meckel (1970) also discussed alluvial environments for the various similar sequences involved in the filling of the central Appalachian geosyncline.

The sequence of Upper Devonian rocks in northeastern Pennsylvania, when studied vertically and horizontally, logically follows Walther's (1894) law of facies and represents a vertical transition from marine to nonmarine depositional environments and a lateral progradation of these environments northwestward into the former central Appalachian basin. Although numerous depositional environments have been identified, we shall briefly discuss only the main environments for those rocks associated with the uranium occurrences in the two areas of interest.

Carbon County

Two fluvial environments dominated sedimentation during the latter part of Catskill deposition: braided and meandering rivers. The character of sediments produced by these environments is admirably displayed along the south side of U. S. Route 209 between Packerton and Jim Thorpe.

The braided river deposits, represented by rocks of the Packerton, Sawmill Run, Berry Run and Clark's Ferry Members of the Catskill Formation, are characterized by: (1) sand domination with an almost total lack of silts and clays, (2) basal contacts of depositional sets are scoured with low relief (generally less than 1 m), (3) sets of strata are sand on sand, (4) sets of strata generally range from 1/2 to 2 m thick, (5) tabular and trough crossbeds are abundant and planar beds are common, (6) some lag gravels occur, (7) lithology is dominantly fine- to very coarse-grained sand with some conglomeratic sandstone, (8) parting lineations and current crescents occur but are not abundant, (9) carbonaceous material and ripple bedding are generally absent, (10) individual beds have poor lateral continuity, (11) there is no definite vertical sequence and (12) gray color predominates. Figure 7 shows typical braided-river sediments of the Clark's Ferry Member. Braided-river sedimentation occurs principally on longitudinal bars that parallel stream flow and in migrating transverse bars or sand waves oriented normal to stream flow (Figure 8). These sediments represent deposition in high-gradient streams with low but flashy discharge and high sediment bed load.



Figure 7. Planar bedded and crossbedded braided river sandstones of the Clark's Ferry Member of the Catskill Formation. Outcrop occurs on the southwest side of U. S. Route 209 approximately 0.9 km S of the center of Jim Thorpe (approx. $40^{\circ}51'32''\text{N}/75^{\circ}44'00''\text{W}$). Scale divided into feet.

The meandering river deposits, represented by rocks of the Duncannon Member of the Catskill Formation, are characterized by: (1) mixed proportions of gravel, sand, silt and clay with sand and gravel comprising about half the member, (2) repeated sequences (cycles) of fining-upward grain sizes, (3) scoured basal contacts of cycles cut into underlying fine-grained beds with relief generally less than 2 m but up to 8 m observed (Sevon, 1975a, Section 5, Unit 11), (4) cycles up to 30 m or more thick, (5) conglomerate or conglomeratic sandstone sometimes occurs at base of cycle, particularly near the base of the member, (6) multidirectional festoon crossbeds, large scale trough crossbeds and some small scale trough and tabular crossbeds in the sandstones, (7) crossbeds replaced upwards with planar beds, (8) siltstones generally thinly laminated, (9) claystones frequently burrowed, contain rootlet structures, rarely mudcracked and sometimes contain race (small calcium carbonate concretions), (10) poor lateral continuity of specific cycle normal to flow direction but some continuity parallel with flow direction (Figure 9), (11) consistent vertical sequence, (12) ripple bedding

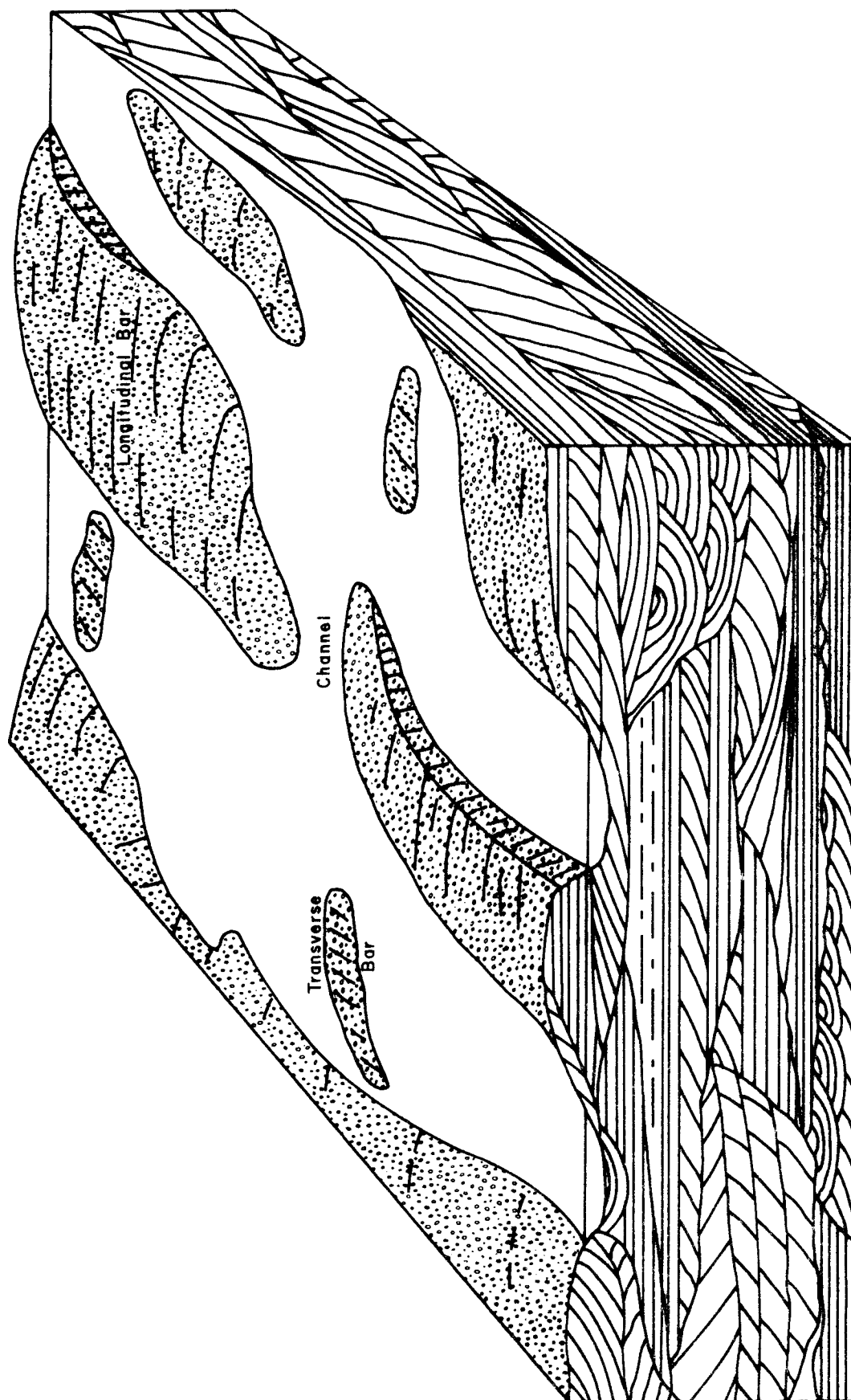


Figure 8. Depositional model of an idealized braided fluvial system. After Brown and others (1973, p. 14).

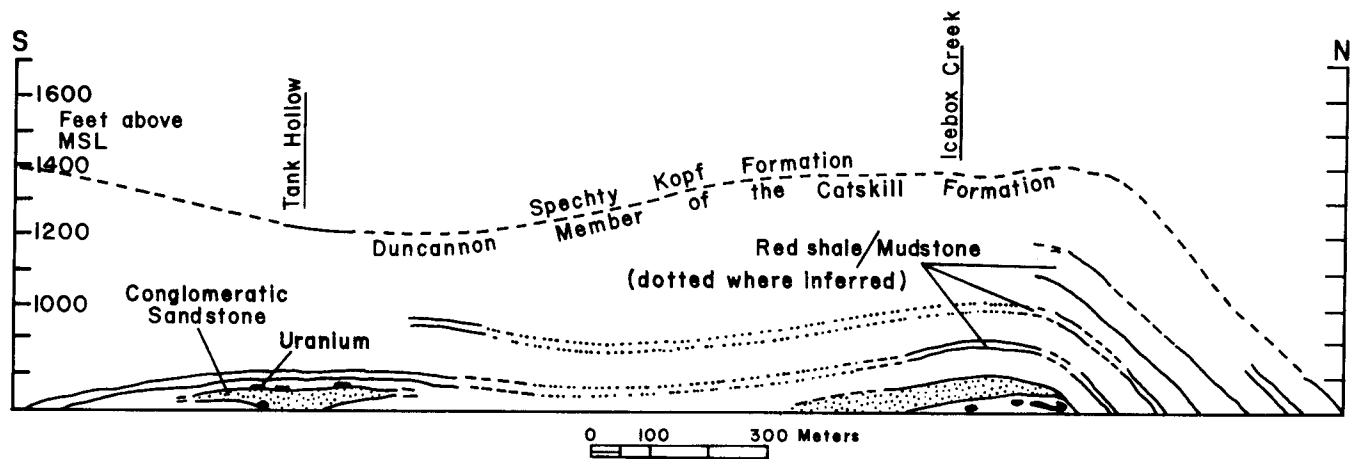


Figure 9. Cross section of the rocks exposed on the west side of the Lehigh River south of Penn Haven Junction. From Schmiermund, 1977, Figure 3, p. 7.

common and (13) dominantly red color. Figure 10 shows a typical fining-upward cycle of the Duncannon Member. Meandering river deposits result from sedimentation under low gradients, moderately high and relatively uniform flow and large suspended load. Erosion occurs at the base and along the cut-bank; deposition, on point bars, levees and flood plains (Figure 11). In

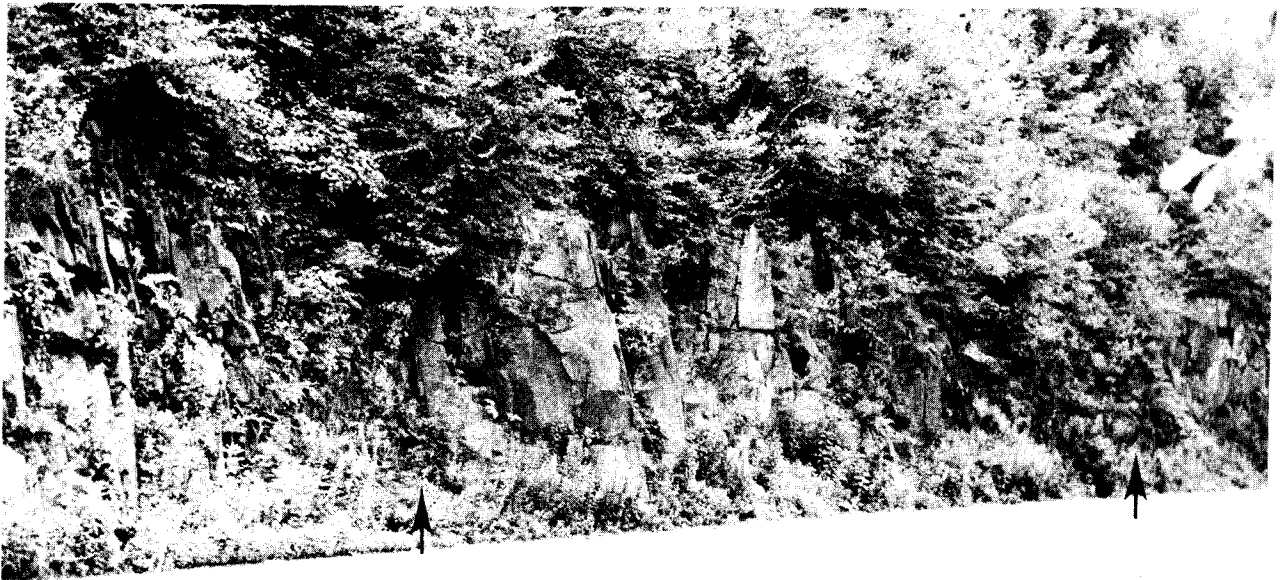


Figure 10. Fining-upward cycles in meandering river sediments of the Duncannon Member of the Catskill Formation. Exposed on the southwest side of U. S. Route 209 approximately 0.6 km S of the center of Jim Thorpe (approx. $40^{\circ}51'32''\text{N}/75^{\circ}44'12''\text{W}$). Rock face in center 2-3 m high. Arrows point to bases of cycles.

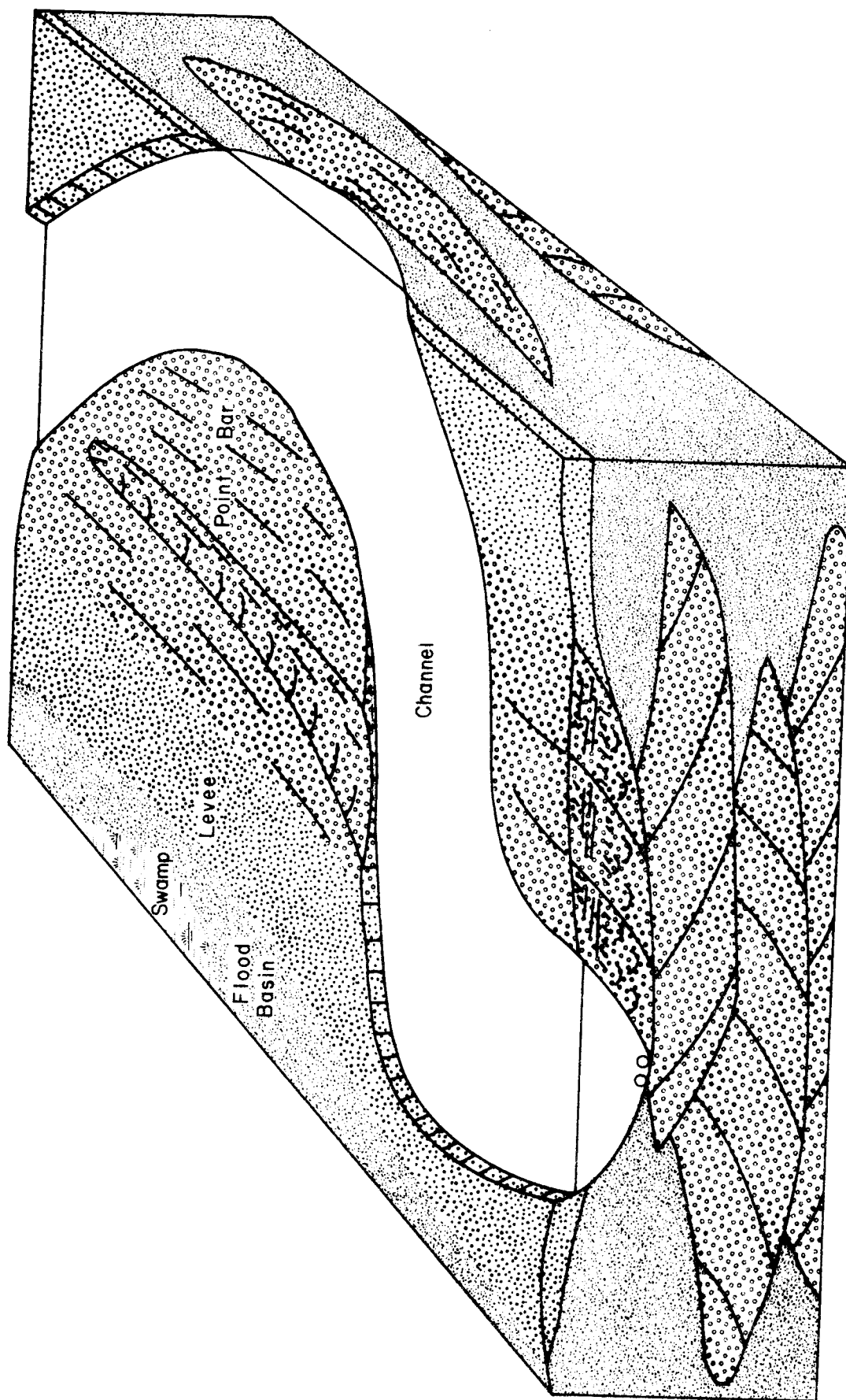


Figure 11. Depositional model of an idealized fine-grained-meanderbelt fluvial system. After Brown and others (1973, p. 17).

the depositional model used here, the fine-grained meanderbelt model of Brown and others (1973), lateral variability is pronounced because of the vertical stacking of the channel deposits within a somewhat restricted zone relative to the size of the flood basin.

Rocks of the basal part of the Mauch Chunk-Pottsville transition zone, which contains the Mt. Pisgah uranium occurrence, comprise a fining-upward sequence and presumably also represent meandering river sediments, probably deposited in a coarse-grained-meanderbelt (Brown and others, 1973, p. 13-16). Meckel (1970) also ascribes a fluvial origin to these rocks. The sequence exposed along U. S. Route 209 has been previously described (Dyson, 1954; Epstein and others, 1974, p. 456-457). The whole transition zone has been described by Gault and others (1957).

Lycoming-Sullivan-Columbia Counties

Catskill sedimentation in this area contrasted considerably with that in Carbon County because of (1) increased distance from the source area and (2) lower depositional gradient. The increased distance from source resulted in only finer-grained sediment being brought into the area and the lower gradient resulted in smaller-scale deposits. Although numerous depositional environments are recognized in the Catskill of this tri-county area (e.g., tidal flat, tidal channel, braided stream, delta plain, meandering river) the meandering river environment dominates most of the Catskill.

The meandering river deposits are characterized by: (1) lenticularity of the sandstone bodies, (2) scoured basal contacts cut into underlying finer-grained deposits generally with relief less than 30 cm, (3) basal sandstone frequently with a calcareous breccia comprising red or gray shale clasts, plant fragments, calcareous nodules (reworked caliche(?)) and calcite cement, (4) basal sandstones with trough crossbeds, (5) basal sandstones may be red or gray, (6) upward decrease in grain size and magnitude of cross-bedding followed by change to planar bedding, (7) upward change to red color, (8) red siltstones and claystones may contain trace, burrows and rootlets, (9) repeated cycles with predominance of fine-grained sediments, (10) siltstones and claystones may show some interbedding and contain interbedded sandstones, (11) sandstones generally very fine- to fine-grained with minimum of coarser sand sizes and (12) cycles seldom more than a few meters thick. These fining-upward cycles are the same in origin as those in Carbon County (Figure 11), but represent deposition under the different control factors mentioned above. Figure 12 shows a typical meandering stream deposit in the Catskill of the field conference area. Lateral variability is pronounced in this area and the finer-grained flood basin deposits (Figure 13) appear more abundant than channel deposits.

The general relationship of the depositional environments to the source area, the alluvial plain and the ocean basin is shown in Figure 14. As sedimentation continued through time the various environments prograded away from the fall line generally overstepping more shoreward environments (Figure 6).

URANIUM OCCURRENCES

About 50 prospects and occurrences of uranium in Paleozoic rocks of Pennsylvania have been mentioned in the literature (Rose, 1970), and another

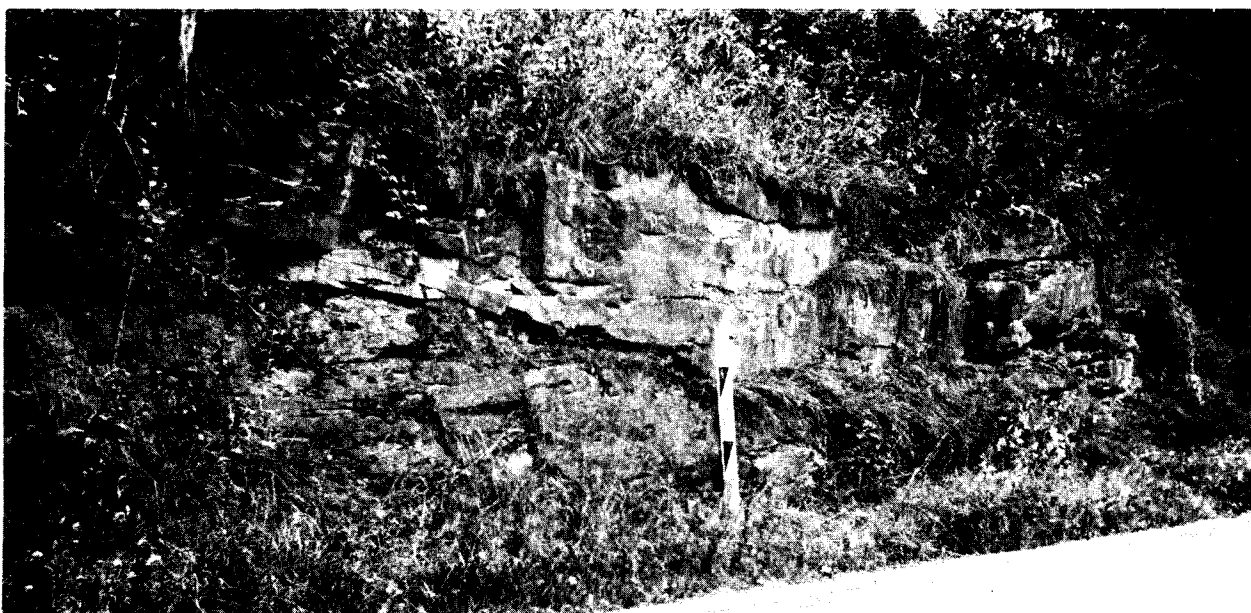


Figure 12. Red channel-fill sandstone in basal part of fining upward cycle in the Catskill Formation, Lycoming County, Pennsylvania. Outcrop occurs on west side of road in Lick Run valley about 2.3 km NNW of Glen Mawr ($41^{\circ}19'56''\text{N}/76^{\circ}40'03''\text{W}$, Picture Rocks quadrangle). Scale divided into feet. Erosional base channel cut into red siltstones and claystones.

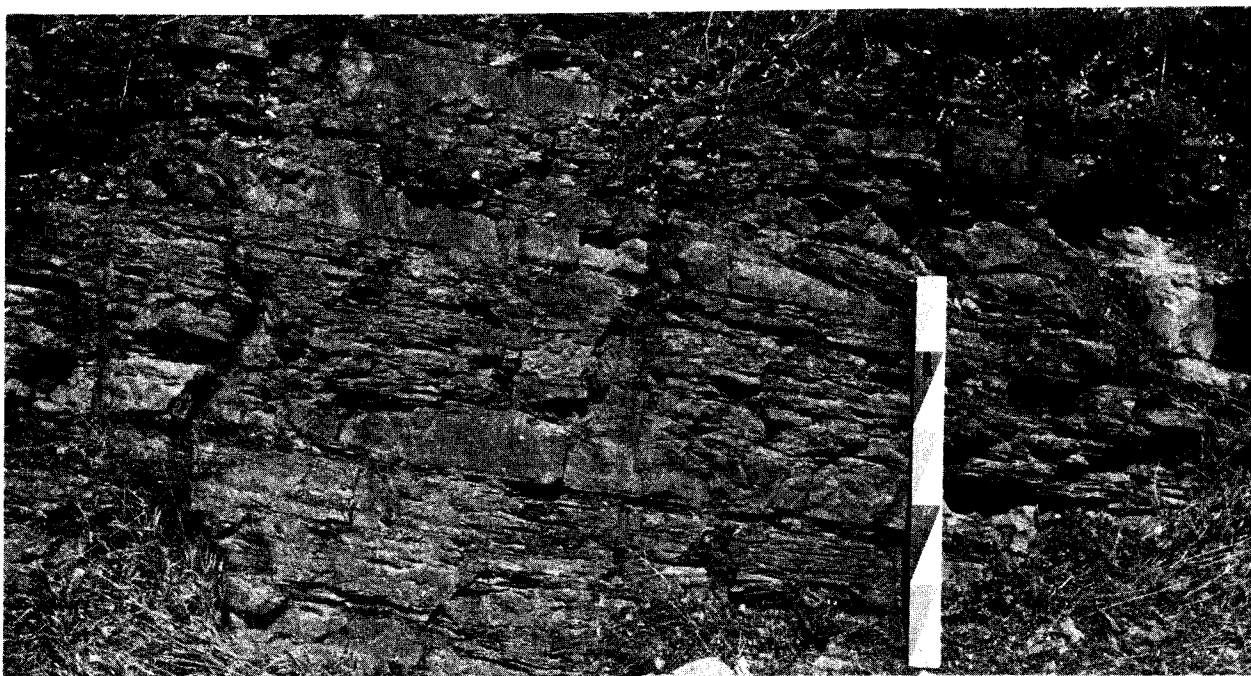


Figure 13. Red flood-basin siltstones, claystones and thin sandstones in Catskill Formation, Lycoming County, Pennsylvania. Outcrop occurs on the west side of U. S. Route 220, 1.2 km NE of Tivoli ($41^{\circ}18'10''\text{N}/76^{\circ}40'52''\text{W}$, Picture Rocks quadrangle). Scale is divided in feet.

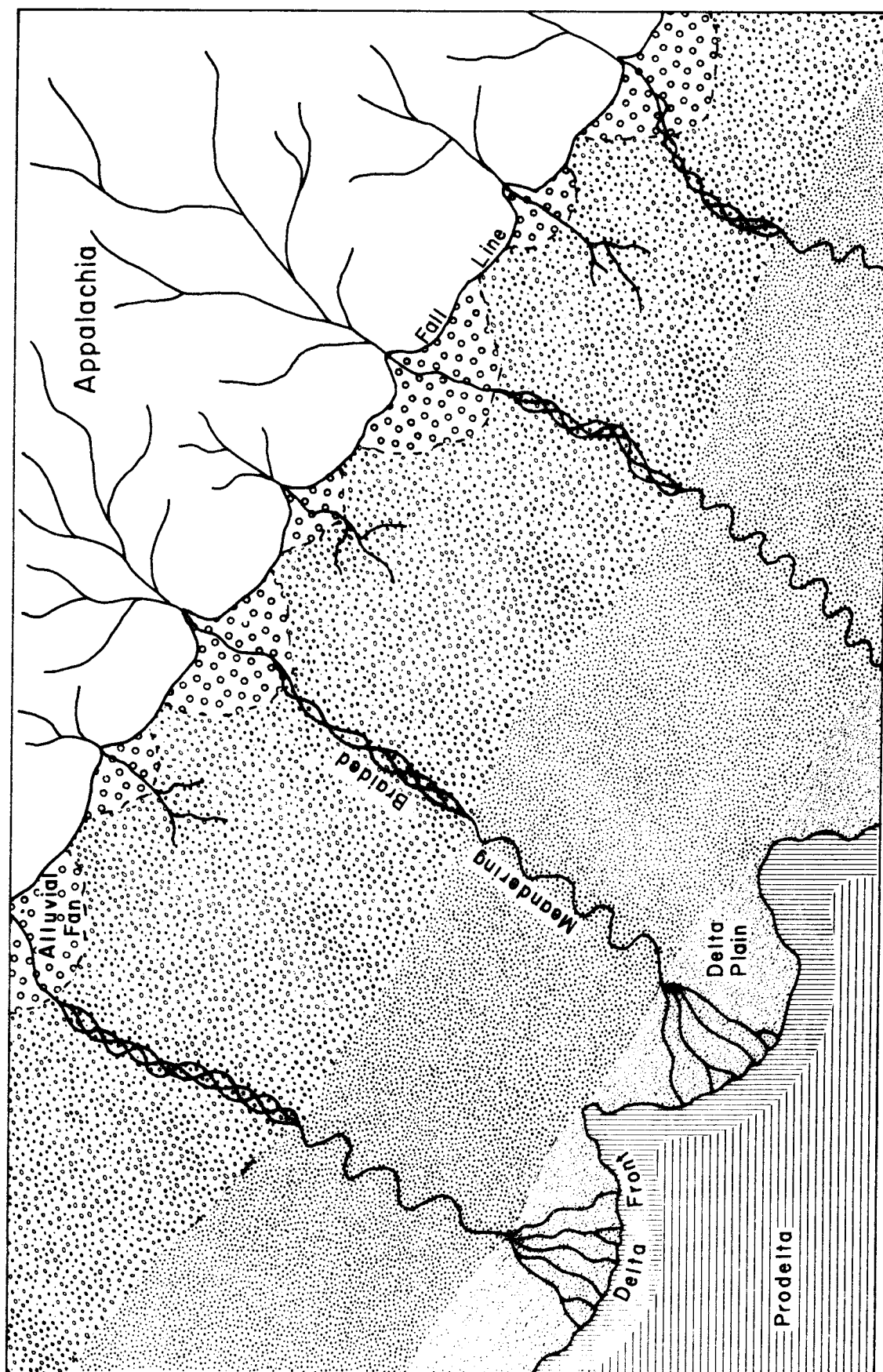


Figure 14. General distribution of environments of clastic sedimentation during Catskill time.

score are known to the writers. These occurrences can be grouped into three general types, based on their geological relations:

1. U occurrences in the Upper Devonian Catskill Formation along the Lehigh River near Jim Thorpe.

2. U-V occurrences in the upper part of the Mississippian Mauch Chunk Formation near Jim Thorpe, Wilkes-Barre, and in south-central Pennsylvania.

3. Red-bed Cu-U occurrences in the Upper Devonian Catskill Formation, scattered throughout the State but with a concentration in north-central Pennsylvania.

Examples of these three types of occurrences will be visited on this conference. The Penn Haven Junction prospect is the best-described example of the first type, the Mt. Pisgah prospect at Jim Thorpe is the best example of the second type, and the several occurrences in Lycoming, Sullivan, and Columbia Counties fall in the third group.

TYPES OF URANIUM OCCURRENCES

Type 1: Penn Haven Junction Type

Two geographic clusters of uranium occurrences are known in the Catskill Formation near Jim Thorpe. One cluster is near Penn Haven Junction along the Lehigh River about 6.5 km north of Jim Thorpe, and the other is along the Lehigh River about 0.8 km southeast of Jim Thorpe. Essentially all known occurrences are in rock cuts excavated for the railroads and highways that parallel the Lehigh River.

The occurrences near Penn Haven Junction have been described by Klemic and others (1963) and Schmiernund (1977). Stratigraphically, they are either in the lowermost part of the Duncannon Member or the topmost part of the Clark's Ferry Member. All the known occurrences in this cluster are either just below, within, or just above a single horizon of conglomeratic and relatively quartzitic sandstone (Figure 9).

The uranium occurs sporadically in thin lenses subparallel to bedding in the finer-grained and less quartzitic sandstone underlying and overlying the conglomeratic sandstone. However, the most continuous and highest grade mineralization occurs just south of Penn Haven Junction as curving roll-like bodies about a meter thick that cut across the bedding (Figures 15 and 16). Some of the lens-shaped bodies are localized by some concentrations of carbonaceous plant fragments, but the roll-shaped portions do not contain visible organic matter. The conglomeratic sandstone and immediately underlying, less-quartzitic sandstone within the U-bearing zone exhibit hematitic staining of the matrix and grain surfaces, but the sandstones outside the U zone are gray-green with no staining. The greenish color is caused by a member of the chlorite group.

Mineralogically, uraninite is the main primary uranium mineral. Brannerite (theoretically $(U,Ca,Ce)(Ti,Fe)_2O_6$) has been reported (Finkelman and Klemic, 1976), but its natural occurrence is questioned by one of the writers (Smith, 1978, p. 228). Uranium contents up to 0.56% have

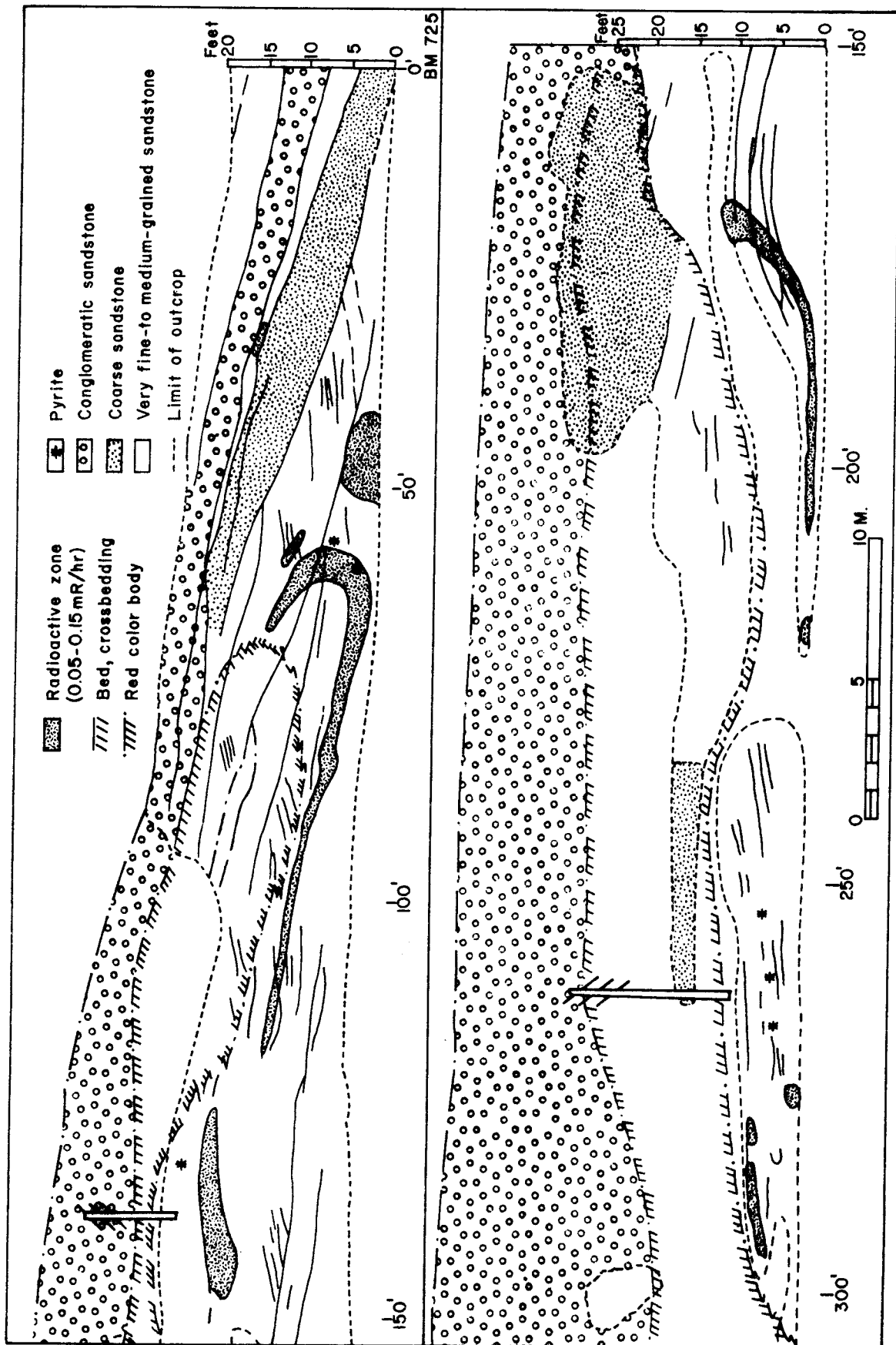


Figure 15. Sketch of important features of the uranium bearing beds of the Catskill Formation on the east side of the Lehigh River south of Penn Haven Junction, Carbon County, Pennsylvania. Right end of lower section attaches to left end of upper section. Outcrop trends approximately NNW-SSE. From Schmiermund, 1977, Plate 3.

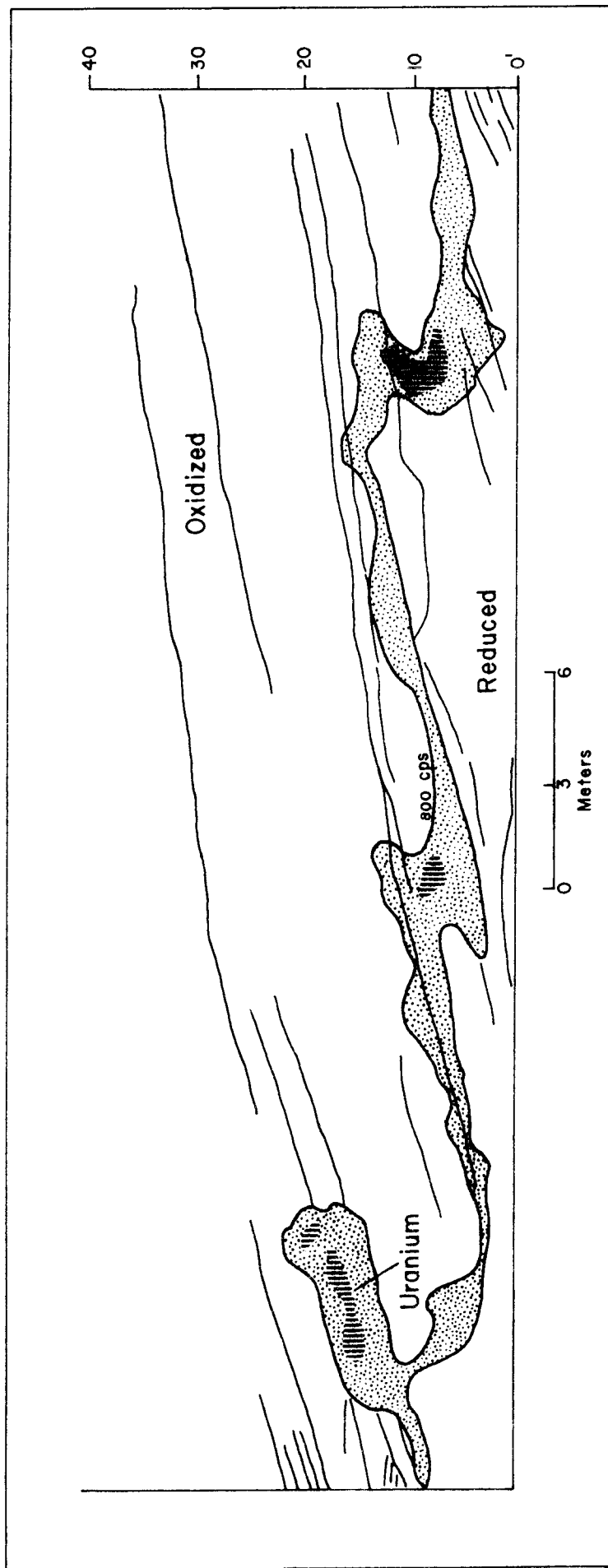


Figure 16. Sketch of the en echelon "C rolls" in the uranium bearing beds of the Catskill Formation on the east side of the Lehigh River south of Penn Haven Junction, Carbon County, Pennsylvania. Modified from Klemic and others, 1963, Plate 2.

been recorded in the roll-shaped zone, but values of 0.1% are more typical. Associated, introduced primary minerals include clausthalite (PbSe) and traces of pyrite. Except for one small lens (Stop 1, "Tank Hollow") copper minerals are sparse, although a slight enrichment of Cu (70 ppm) can be detected in the roll, along with a minor concentration of arsenic. Uranium is most abundant in rock containing relatively abundant heavy minerals, including ilmenite, magnetite, leucoxene (an ill-defined mixture of TiO₂ polymorphs), zircon, and, possibly, allanite. However, the occurrence of uraninite in zones cutting across the bedding and the reported occurrence of brannerite(?) within leucoxene that has apparently formed by in situ alteration of ilmenite indicates that the uranium has been introduced or remobilized and is not detrital.

The prospects south of Jim Thorpe are at the top of the Clark's Ferry Member and in the base of the Duncannon Member on both sides of the Lehigh River and in the U. S. Route 209 highway cut above the river. The zone of occurrences extends for over 1 km along the strike. The rocks are steeply dipping and the distribution of uranium is not known in detail. Klemic and others (1963) suggested two zones about 7.6 m apart on the west side of the river, but Smith and Hoff (Stop 3) describe a more complex situation. Some of the radioactivity is localized by limonite staining and is evidently secondary, but some occurs in gray sandstones lacking obvious organic fragments in most places. Traces of secondary copper-uranium minerals have been noted with the uranium. The highest reported U contents are 0.13% U.

Lead-uranium dates on the Penn Haven Junction occurrence are discordant, ranging from 220 to 438 m.y. (Stern and others, 1960). Because of the range of values and the difficulty of separating and correcting for the common lead in the clausthalite (PbSe), these ages are clearly only approximate, but a Paleozoic age for emplacement of the uranium seems likely. Smith and Hoff (Stop 1) have discovered a clausthalite-free uraninite laminae from which better dates are anticipated.

Type 2: Mt. Pisgah Type

The largest known and best described occurrence in Mississippian rocks is the Mt. Pisgah prospect exposed in road cuts on U. S. Route 209 just northwest of Jim Thorpe (Klemic and others, 1963; McCauley, 1961). Other smaller occurrences in Mississippian rocks are in the Broad Top area of south-central Pennsylvania and near Wilkes-Barre. All of these are within the red and gray sandstone and shale sequence of the Mauch Chunk Formation, or in the immediately overlying Pottsville Formation or immediately underlying Pocono Formation.

The uranium-bearing zone at Mt. Pisgah is in dark gray conglomerate and sandstone at the base of a transition zone between the Mississippian Mauch Chunk Formation and the Pennsylvanian Pottsville Formation (Dyson, 1954; McCauley, 1961). The rocks in the vicinity of the occurrence dip at angles of 25 to 55° to the south and are a few hundred meters north of the axis of the Mt. Pisgah syncline (eastern end of the Minersville Synclinorium of Wood, 1974). The stratigraphic zone in which the deposits lie also contains considerable slickensiding and bedding movement of undetermined magnitude.

The primary uranium mineral occurs as tiny black specks in the matrix of the sandstone and has been identified as coffinite (USiO₄) in one specimen

by Smith (1978). Secondary uranium minerals reported from the exposures include carnotite(?) ($K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$), tyuyamunite ($Ca(UO_2)_2(VO_4)_2 \cdot 5-8H_2O$), uranophane and beta-uranophane ($Ca(UO_2)_2SiO_7 \cdot 6H_2O$), andersonite ($Na_2Ca(UO_2)(CO_3)_3 \cdot 6H_2O$), liebigite ($Ca_2U(CO_3)_4 \cdot 10H_2O$), and schroëckingerite ($NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$). Vanadium is considerably enriched in the ore, in contrast to Penn Haven Junction, and P, Ba, Cu, As, Mn, and Pb are slightly to moderately enriched (Klemic and others, 1963; Rose and others, 1976). No primary vanadium minerals have been identified. The mineralized rock occurs as scattered pods and lenses within the conglomerate unit for all of the 610 m of strike length exposed in the highway cut. Three adits, recently back-filled to prevent entry, were excavated in the 1950's to distances of 15 m into the mineralized zones, and a small amount of ore was mined. Unfortunately, the adits were put in horizontal and did not test the down-dip extent of the mineralization. The zone has also been explored by a number of drill holes, but the results have not been made public. Samples grading up to 1.8% U have been collected from the occurrence. Near the westernmost adit, the rock is continuously mineralized in a zone about 46 m long and about 1.5 m thick. Other pods and lenses extend for up to several meters and have more irregular shapes (McCauley, 1961). Fossil logs and plant fragments localize some of the ore and are elongated in a southwesterly direction, perhaps suggesting the orientation of channels in which the sediments were deposited (Klemic and others, 1963, p. 84).

Isotopic U-Pb ages of specimens from Mt. Pisgah give somewhat discordant ages ranging from 314 to 413 m.y. A similar age is reported by Smith (1978) for a coffinite specimen, based on microprobe analyses for U and Pb. These ages are approximately the same as the age of the host sediment and suggest that the uranium was emplaced during or shortly after sedimentation. The very impermeable nature of much of the sandstone and quartzite suggests that the uranium must have arrived at essentially its present location prior to or during final lithification.

Type 3: Beaver Lake Type

Most of the known uranium occurrences in Pennsylvania occur within the Catskill Formation as copper occurrences with trace to minor associated uranium. A cluster of almost 40 such deposits occurs in the area around Beaver Lake in Lycoming and Sullivan Counties (Sonestown and Picture Rocks quadrangles). Another cluster is located about 19 km to the east, near Central and Grassmere, in Columbia County (Red Rock and Elk Grove quadrangles), and a third cluster occurs about 32 km to the north near New Albany in Bradford County. Other Cu-U occurrences are scattered within the Catskill Formation throughout the northeastern, north-central, central and south-central parts of the state.

Distinguishing features of this type are the association of Cu and U, and localization by accumulations of carbonaceous plant fragments in the base of channels filled by fine-grained sandstone with calcareous breccia lenses. The presently known occurrences are all relatively small and low grade, the size being limited mainly by the extent of reducing zones in the Catskill. The known Cu-U occurrences are mainly in the lower half of the formation, scattered from the transitional marine-nonmarine zones at the base up through the red fluvial sandstones and mudstones in the middle of the formation. A few occurrences are known in the upper part of the Catskill in larger bodies of sandstone.

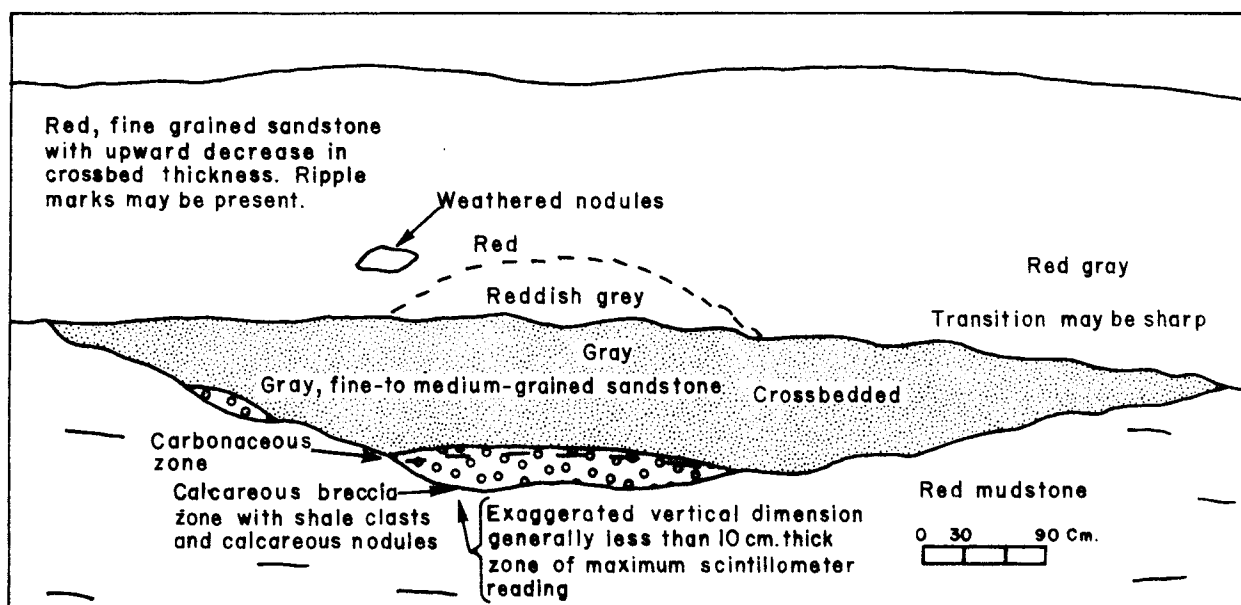


Figure 17. Idealized sedimentologic character of a Lycoming-Sullivan-Columbia Counties copper-uranium occurrence. From Mahar, 1978, Figure 4, p. 19.

At a typical occurrence, a paleostream channel less than a meter deep has been cut into underlying sediments (Figure 17). The basal part of this channel is frequently filled with a calcareous breccia comprising a fine sandy matrix, mudstone chips, carbonate fragments, and carbonaceous plant fragments. Overlying the calcareous breccia is a zone of fine-grained sandstone containing plant fragments but with few or none of the larger clastic fragments found in the carbonate breccia. The sandstone grades upward into gray crossbedded sandstone and at some occurrences to siltstone. The channel-filling calcareous breccia and carbonaceous zone, as well as some of the overlying sandstone and in places some of the rock underlying the channel have a gray color derived from organic matter and the presence of Fe in reduced form (chlorite). A sharp boundary with hematitic red sediment usually occurs just below the channel, and a more gradational boundary into red sandstone and siltstone is typical above the channel.

Primary copper minerals include copper sulfides (chalcocite, digenite, djurleite and/or anilite (Cu_7S_4), chalcopyrite, and minor bornite. Pyrite is present at some localities. The sulfides partly replace plant fragments and partly are disseminated through the fine sandstones. Uranium appears to be largely in the carbonaceous matter, possibly adsorbed or as an organic complex, but uraninite has been identified at one locality by Hoff and Smith. Quartz and traces of galena and barite are present locally. Malachite is the most abundant secondary product, along with smaller amounts of azurite, chrysocolla, uranophane ($\text{Ca}(\text{UO}_2)_2\text{Si}_2\text{O}_7 \cdot 6\text{H}_2\text{O}$), metazeunerite ($\text{Cu}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$), kasolite ($\text{Pb}(\text{UO}_2)\text{SiO}_4 \cdot \text{H}_2\text{O}$), metatorbernite ($\text{Cu}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$), and other species (see stop descriptions). The primary minerals are generally most abundant with the organic matter above the calcareous breccia zone, but some radioactivity typically occurs in the calcareous breccia as well.

At most localities the sulfides and uranium are restricted to lenses and pods several centimeters in lateral dimension, and a few centimeters in

thickness. At several localities, a series of such lenses is found within a single gray channel-filling sandstone over a length up to many tens of meters.

The age of this type of occurrence is uncertain. The copper sulfides retain cell structure of the replaced plant fragments in some instances, so the replacement probably occurred before deep burial. However, McCauley (1961) points out that sulfides are localized along joints and cleats in the organic matter, suggesting mineralization after sedimentation, lithification and the formation of joints. Because most of the uranium is in an unidentified form in the organic matter, it could have arrived at its present location even in Recent time, but earlier deposition seems more likely. No compelling evidence exists for contemporaneous deposition of the copper and uranium, although the almost universal association suggests that they were deposited as part of the same process.

FORMATION OF URANIUM DEPOSITS

GEOCHEMISTRY OF URANIUM

The behavior of uranium in low-temperature environments is well-depicted by its relations on an Eh-pH diagram (Figure 18). Under reducing conditions, uraninite is very insoluble under both acid conditions (to pH 0.3 and relatively alkaline conditions. However, under oxidizing conditions, uranium is very soluble at all pH values, either as uranyl ion (UO_2^{2+}) or as one of the several uranyl carbonate complex ions. Figure 18 shows relations for a CO_2 pressure of 10^{-2} atm, which is typical of many groundwaters, but higher CO_2 pressures are possible and would increase the solubility of uranium by increasing the stability of the uranyl carbonate complexes. Because uraninite is non-stoichiometric (i.e., indefinite proportions of U and O) and usually contains more oxygen than UO_2 , a field for U_4O_9 ($\text{UO}_{2.25}$) is shown on the diagram, but in natural minerals there is probably a single non-stoichiometric solid with approximately the stability of the combined UO_2 and U_4O_9 phases. In the presence of quartz, coffinite has approximately the same stability as uraninite, but is probably favored by strongly reducing conditions (Langmuir, 1978).

As can be seen on the diagram, uranium is quite soluble in surface waters and in some ground waters, but is insoluble in the more reducing subsurface waters. Thus, uranium can be leached from rocks during weathering and move with surface and ground waters until it encounters a reducing environment such as a concentration of organic matter, sulfides, H_2S , methane or similar reduced substances.

A second factor controlling the mobility of uranium is adsorption by Fe-oxides and organic matter, both of which strongly adsorb uranyl ions in the pH range of most natural waters. In alkaline waters, strong complexing by CO_3^{2-} limits the degree of adsorption. The net result of the solubility and adsorption relations is that U can migrate in solution until it encounters: (1) a reducing environment or (2) an accumulation of Fe-oxides or (3) organic matter, except in relatively, alkaline carbonate-rich waters, in which case it may remain in solution until strongly reducing conditions are encountered. Organic matter can initially adsorb uranium, and later act as a reductant to uraninite.

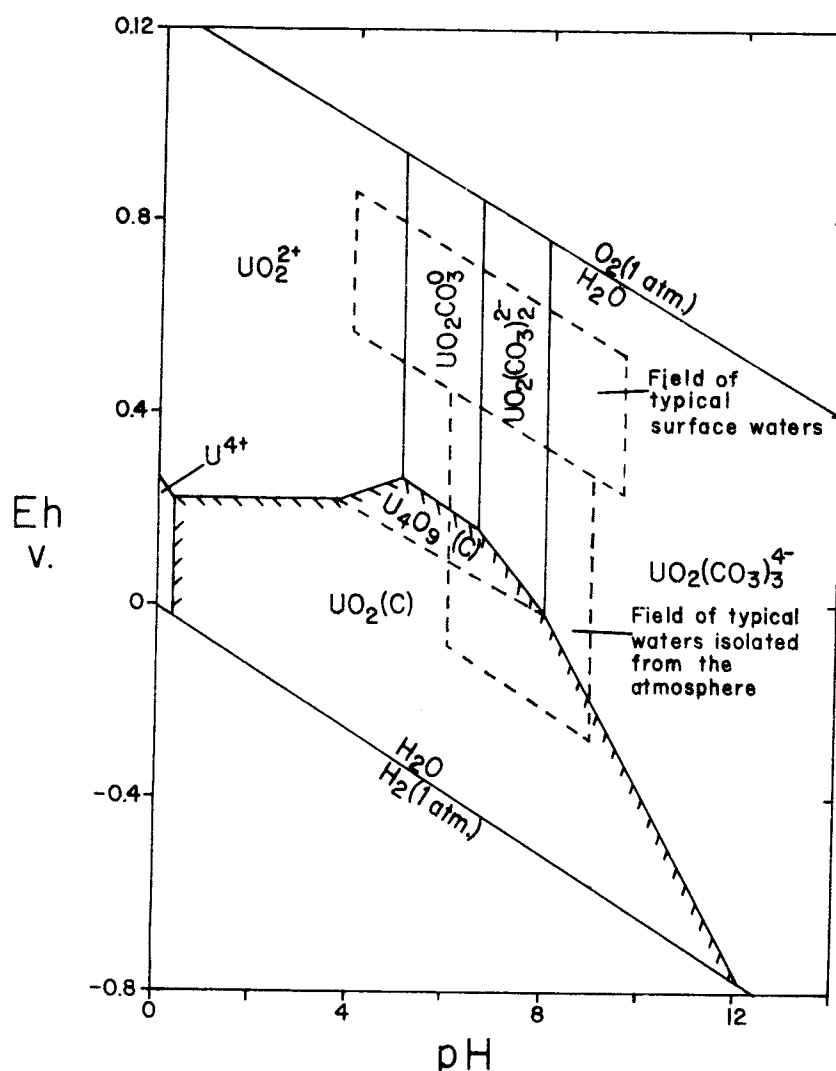


Figure 18. Geochemistry of uranium at 25°C, 1 atm, and 10^{-2} atm of CO_2 . Within the fields of $\text{U}_4\text{O}_9(\text{C})$ and $\text{UO}_2(\text{C})$, solubility is less than 10^{-6} moles/liter; C in these fields means crystalline. Uranium is soluble under other Eh-pH conditions. The U_4O_9 field indicates diagrammatically the effect of non-stoichiometry in uraninite.

A third limit to mobility of uranium is dissolved vanadium. If appreciable vanadium is present, uranium may be immobile under even oxidizing conditions.

ORIGIN OF TYPE 1 DEPOSITS

At Penn Haven Junction, uranium is concentrated in the form of uraninite near the margins of a zone of hematite-stained sandstone centered on a conglomeratic sandstone unit (Figure 15). This geometry is strikingly similar to the deposits in the Gas Hills of Wyoming (Fischer, 1970). In this district uranium occurs as roll-like bodies at a redox boundary between iron-stained oxidized sandstone and reduced pyritic sandstone (Figure 19). The ores are believed to have formed by flow of oxidizing uranium-rich ground

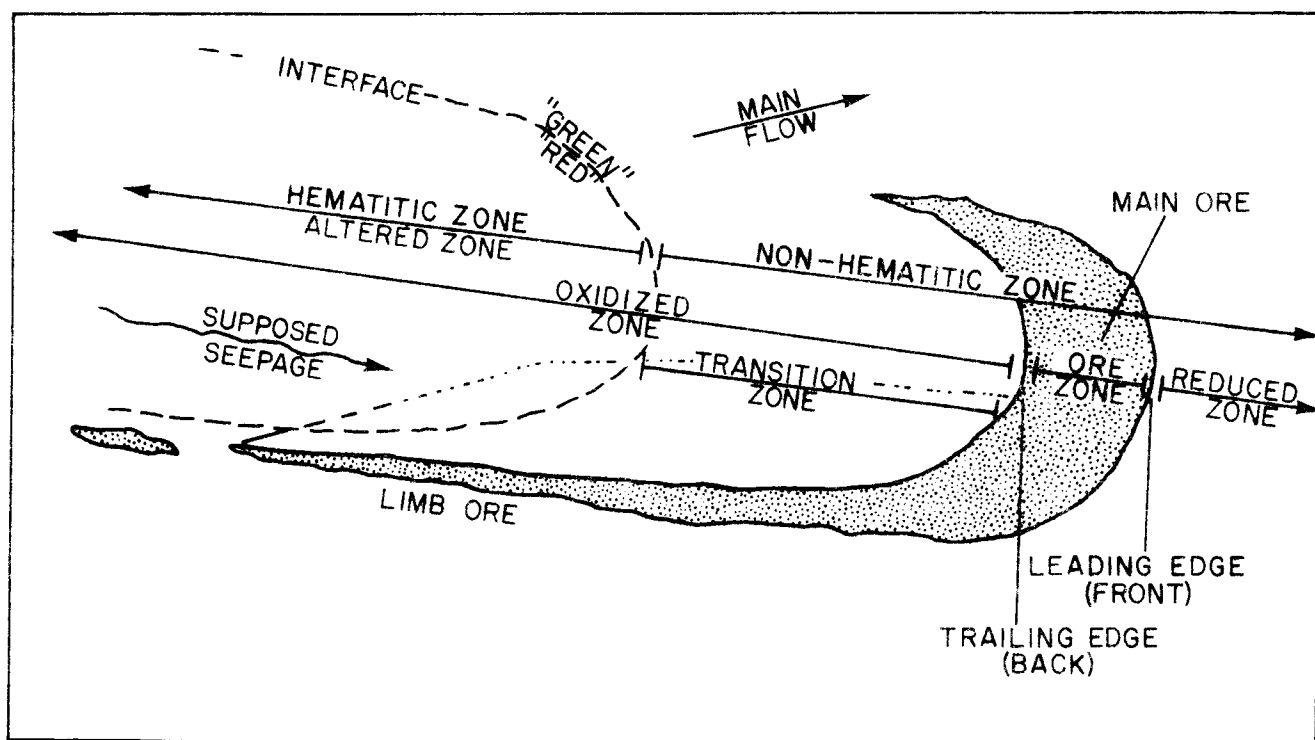


Figure 19. Idealized "C-roll" with nomenclature. From Schmiermund, 1977, Figure 4, p. 17.

water through the permeable, poorly consolidated sandstone units until they encountered a reducing environment. At this point, the ground water was reduced by pyrite and traces of organic matter, probably with the catalytic aid of bacteria, and uranium was deposited. Conversely, the most upflow portions of the previously deposited ore and associated pyrite were oxidized by reaction with the ground water and moved downflow via solutions from which they were reprecipitated.

At Penn Haven Junction, the conglomeratic sandstone and adjacent low rank graywacke contain hematite coatings on quartz and other grains, and ilmenite (FeTiO_3) is partly oxidized to hematite (Fe_2O_3) and leucoxene. In a transition zone up to a meter or so in width between the hematitic zone and the ore zone, the abundance of hematite decreases and the abundance of chlorite increases. In addition, leucoxene coatings on ilmenite grains increase in thickness until clumps of leucoxene the size of ilmenite grains are all that remain. These alteration effects apparently result from dissolution of Fe^{2+} from ilmenite, leaving behind insoluble TiO_2 mixtures. Some Fe may enter chlorite, and some is evidently removed from the ore zone. Ahead (downflow) of the ore zone, no hematite is present, and the rock has a greenish to gray color caused by small amounts of chlorite containing ferrous iron.

Results of a study of the trace element distribution across the ore zone are illustrated in Figure 20. U, Pb, and Se are enriched in the ore zone along with smaller amounts of As, Cu and possibly Mo; Mg and Fe are distinctly

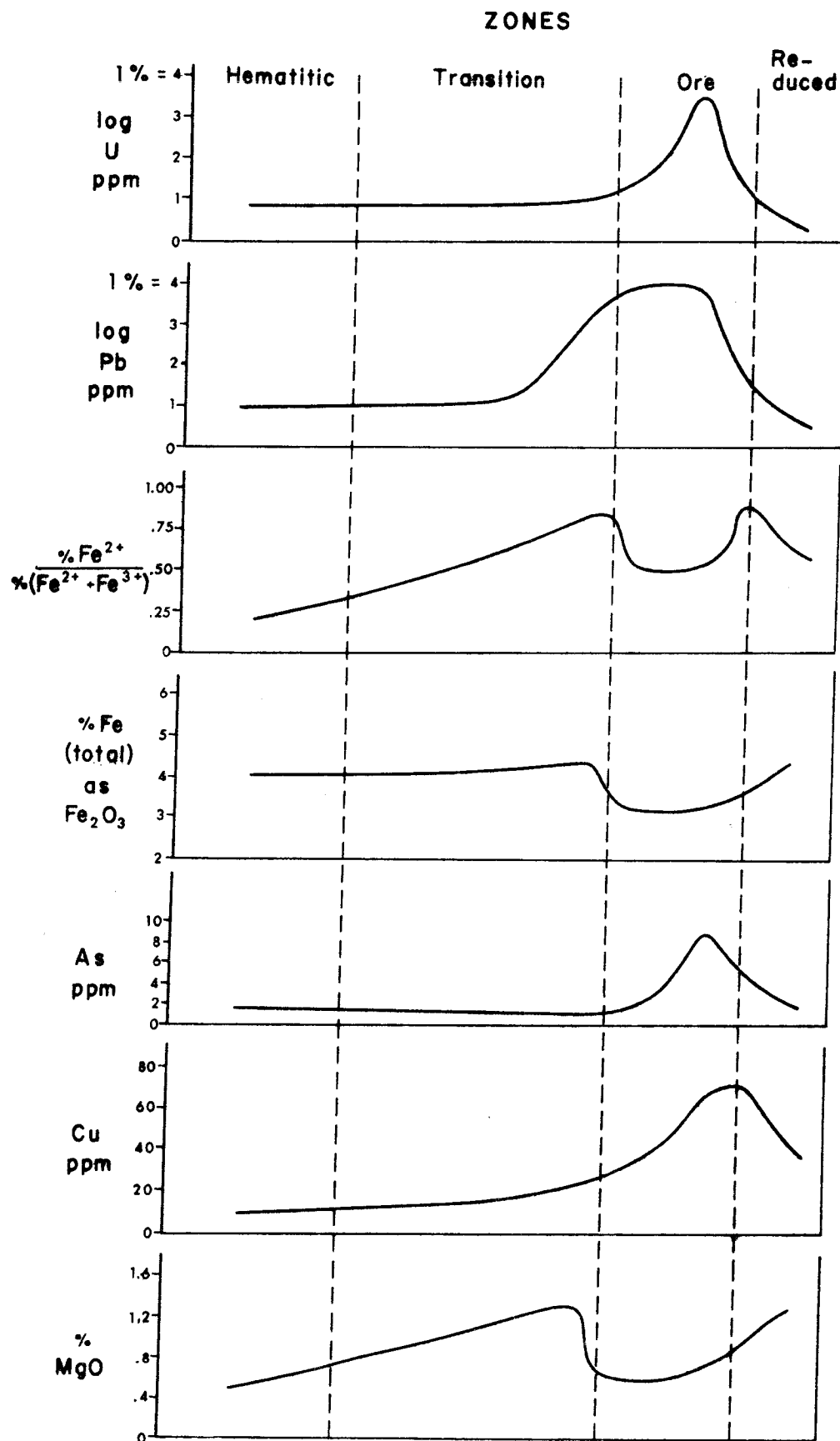


Figure 20. Idealized distribution of selected elements across the "C-roll" in the Catskill Formation south of Penn Haven Junction, Carbon County, Pennsylvania. Note the enrichment of U and Pb and the depletion of Fe in the ore zone. From Schmiermund, 1977, p. 78.

depleted. The trace element patterns are similar to those observed by Harshman (1974) in the roll-type ores of Wyoming.

Based on the above observations, an origin by an oxidizing groundwater seems reasonable for the Penn Haven Junction deposit. The groundwater is inferred to have flowed predominantly in the conglomeratic sandstone unit, which is better sorted than other sandstones of the area and was probably more permeable until deep burial, deformation and recrystallization. This oxidizing groundwater could have transported U, Pb, Se, and As and other elements, perhaps for many kilometers, until the water leaked out of the aquifer into surrounding units, or until the grain size or permeability of the aquifer decreased. In some places the uranium is clearly localized by concentrations of organic matter, but in others, such as the roll-shaped zone nearest Penn Haven Junction, interaction with a reducing water may have contributed to precipitation.

The precipitation of uranium evidently occurred after deposition of at least some of the sediments overlying the conglomeratic sandstone, because uranium occurrences are found above the top of this unit as well as below it. Analysis of a suite of samples from the conglomeratic hematite-stained sandstone exposed near Penn Haven Junction shows that most of this body is distinctly anomalous in uranium content over an exposed width of about two kilometers, containing several times the background content of uranium in sandstones (Simon Pirc, The Pennsylvania State Univ., personal comm.). Apparently the uranium was not leached from the ground water conduit of this area, but was brought in with the ground water. Although some uranium might have been initially deposited in local plant trash zones by underflow in the river system occupying the channel, apparently at least some of the precipitation process occurred at a later date, and probably almost all of it did. The question then arises, did major precipitation occur (1) within the remainder of the Upper Devonian or (2) much later.

Regarding (1), the source of the uranium and the conditions that lead to flow of oxidizing ground water remain speculative. In modern environments, uranium is much more abundant in surface and ground waters of arid and semi-arid regions than in humid regions. This difference results from concentration of dissolved solutes by evaporation and transpiration, and by the lesser degree of leaching of rocks in such arid areas, leaving more uranium and other solutes available. The tropical wet and dry climate suggested by Woodrow and others (1973) for the Upper Devonian may have been conducive to the development of several periods of relatively U-rich groundwaters during Duncannon time. The presence of extensive hematite-rich mudstones and siltstones in the Duncannon Member is consistent with such an origin. Such red-beds are inferred to form by oxidation and dehydration of iron minerals above the water table (Walker, 1967). This oxidation and dehydration process, which would be promoted by arid conditions in which the water table was well below the flood plain, would release uranium adsorbed to organic matter and crystalline Fe oxides, and allow transport by surface and ground waters.

The following conditions must occur in order to create a flow of ground water within an alluvial plain: a significant slope must exist in the water table, a permeable unit and a means for entry of surface water into the

aquifer must be available. Upland faulting during later Duncannon or pre-Spechty Kopf time might be one way of exposing the lower Duncannon, and allowing entry of ground water. Uplift and erosion of the updrainage margin of the Catskill would also create exposure suitable for recharge. Both of these mechanisms are possible, but neither are supported by any currently known evidence.

Regarding (2), the periods of peneplanation and associated subtropical climate suggested by Wilson and Fairbridge (1971) offer a second possible mechanism of uranium enrichment as well as a solution to the age problem at Penn Haven Junction. If some uranium minerals were already disseminated in the Catskill rocks during Duncannon time, these minerals could have been remobilized and concentrated during a period of peneplanation at the same time that final lithification occurred. We know of no positive evidence for this alternative.

ORIGIN OF TYPE 3 DEPOSITS

The redbed copper-uranium occurrences in the Lycoming-Sullivan-Columbia County area are localized within reducing zones in the Catskill Formation, but differ from the Penn Haven Junction type in having a predominance of copper and in lacking a redox boundary geometrically related to ore (i.e., the "ore" is stratabound). It is possible that mineralization occurred during sedimentation, or that the copper and uranium arrived at different times.

Because the copper replaces plant material, it is clear that the copper emplaced from solution, and that the conditions for solubility and precipitation of Cu are important. Figure 21 illustrates the behavior of Cu in a dilute water with a low content of sulfur. Copper is immobile under reducing conditions and at pH greater than 5.6. It is mobile only in relatively acid, oxidizing waters. Such waters are uncommon as ground waters, especially in thick piles of sedimentary material. Essentially no copper is present in normal stream waters, as predicted by the diagram. Inclusion of CO₂ in the system decreases the solubility by stabilizing malachite, which is less soluble than CuO. Known complexes of Cu with carbonate are weak, and do not offset the effect of malachite. Increased amounts of dissolved sulfur have a small but negligible effect (Rose, 1976). Under some conditions, dissolved organic matter may complex enough copper to provide meaningful transport at near-neutral pH, but in most streams and ground waters the amount of organic matter is too low (10 ppm) to affect solubility significantly (Reuter and Perdue, 1977). Organic-rich waters seem particularly unlikely in a redbed sequence.

The only common anion that significantly increases solubility of Cu is chloride (Cl⁻). Because of very strong complexes of Cu⁺ with Cl⁻, the solubility of copper in solutions like sea water is about 100 ppm at pH 7, as shown in Figure 22. In agreement with this, most redbed copper deposits appear to have formed from brines derived by dissolution of evaporites or from circulation of connate marine waters (Rose, 1976).

Several mechanisms might allow the circulation of Cl⁻-bearing waters through the Catskill:

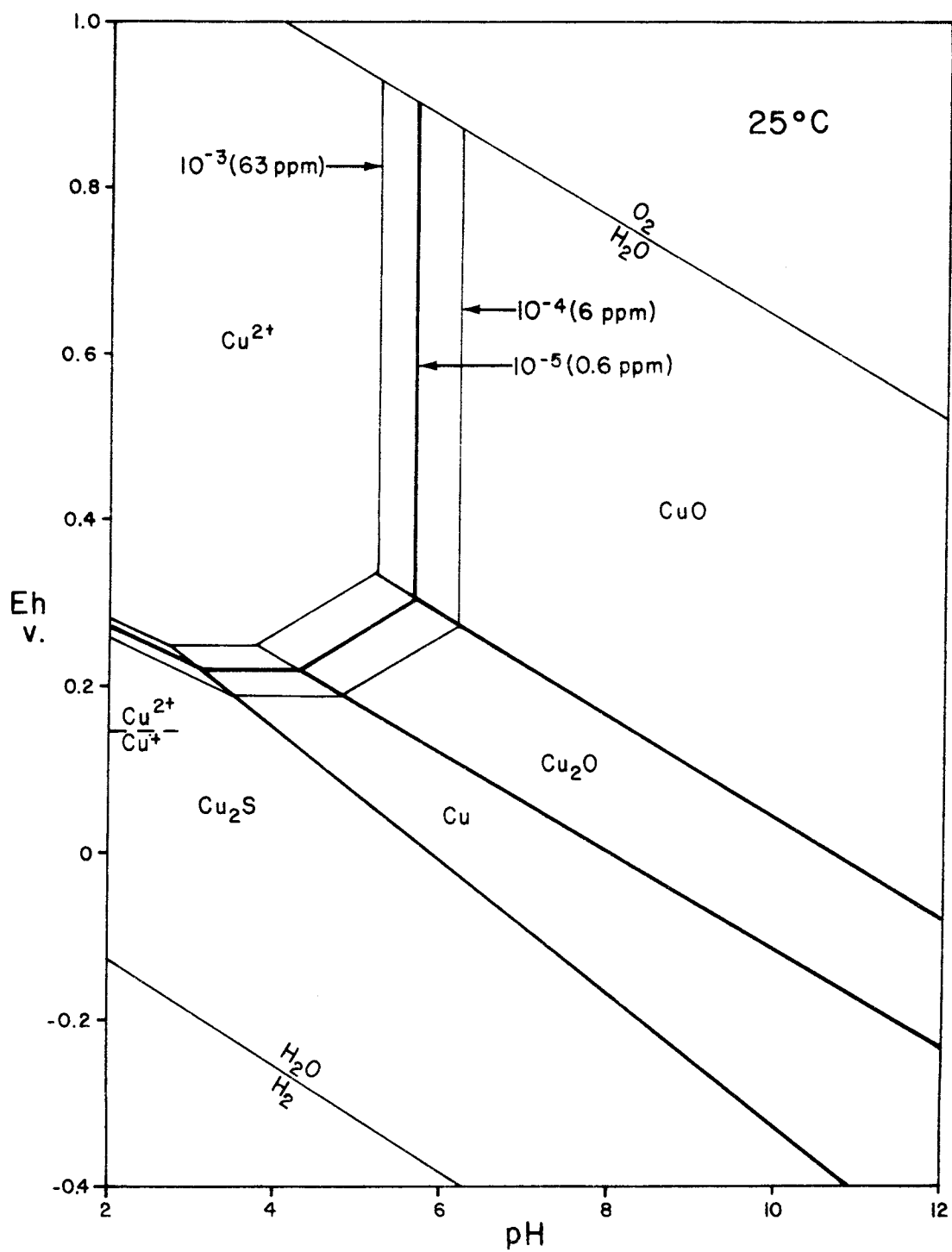


Figure 21. Eh-pH diagram for system Cu-O-H-S, 25°C, $S = 10^{-4}$ m. From Rose, 1976, Figure 1, p. 1037.

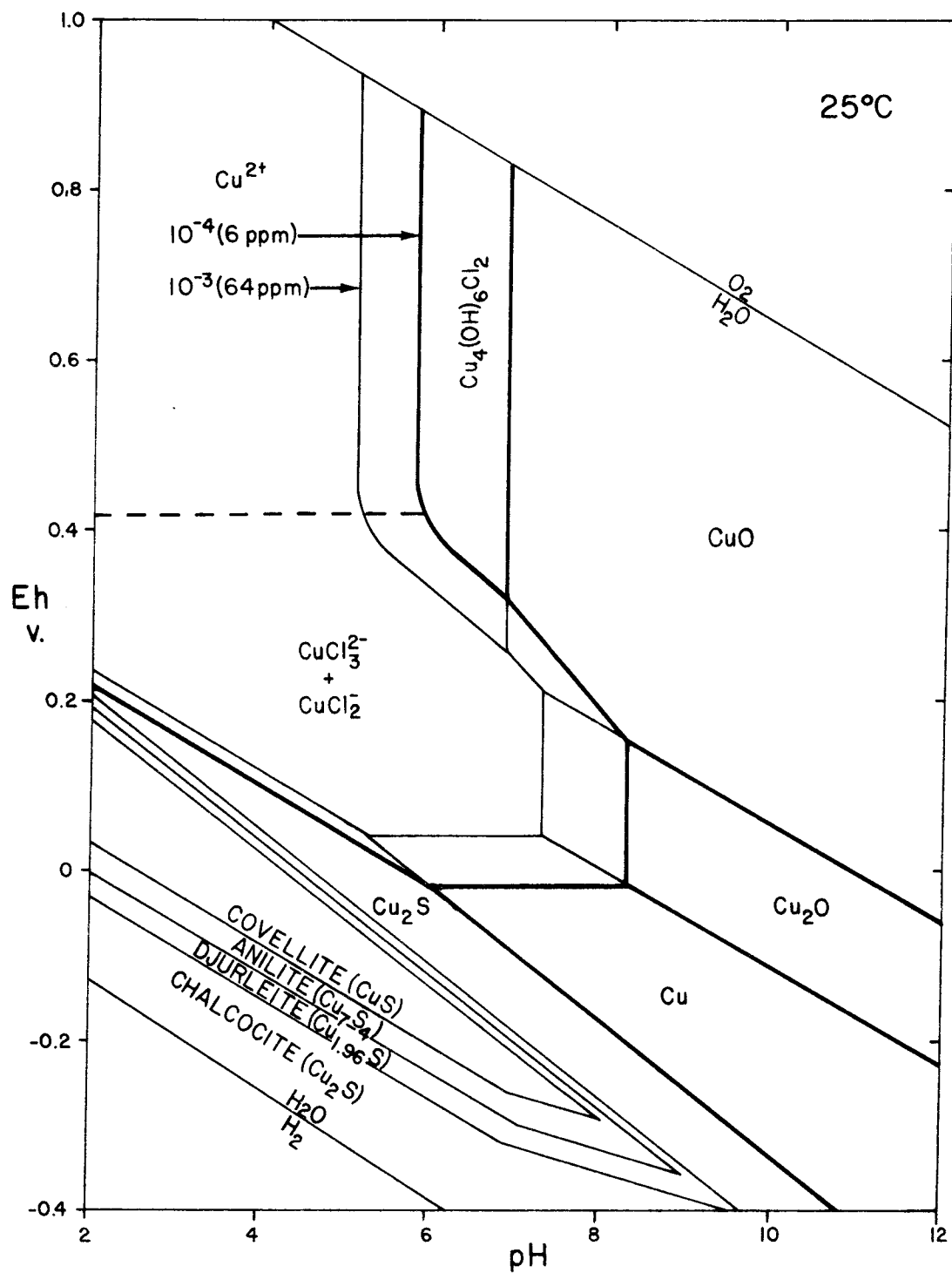


Figure 22. Eh-pH diagram for system Cu-O-H-S-Cl, 25°C, $S = 10^{-4}$ m, $\text{Cl}^- = 0.5$ m as NaCl. From Rose, 1976, Figure 2, p. 1040.

1. The pore water from underlying Devonian marine sediments (Lock Haven Formation) must have escaped from this section during diagenesis and lithification, and some may have flowed through the redbeds.

2. Brines derived from Silurian evaporites which underlie northwestern Pennsylvania and extend under the area of most abundant redbed copper-uranium deposits (Fergusson and Prather, 1968) may have circulated through the Catskill Formation.

3. The Mississippian-Devonian transition zone between the Catskill and Burgoon Formations may have had a brief marine transgression during its origin. During the transgression and regression marine pore water may have entered the Catskill, perhaps by displacing the lower density fresh water in the Catskill.

4. The lower portion of the Catskill Formation is clearly a transitional marine-nonmarine zone so that Cl^- -rich waters must have occupied the sandstones in this portion of the section. It is possible that the basal sandstones in some of the fining-upward cycles in the middle and upper Catskill are tidal in origin rather than fluvial. Copper occurrences are especially common in the middle of the Catskill.

The circulation of a Cl -bearing water through the redbeds would allow leaching of copper from the sediments, very likely by extraction from Fe-oxide coatings where copper is known to concentrate. These fluids could then circulate through the more permeable portions of the section until they encountered an accumulation of organic matter. At such a locality, bacterial reduction of sulfate to sulfide would occur, using the reducing environment of the organic matter as a source of food for bacterial metabolism. The H_2S , CH_4 , and other reduced products of this reaction would be transported downflow, and hematite throughout the zone would be dissolved and the iron converted to Fe^{2+} , which might, in part, enter a chlorite group mineral.

As indicated by Figure 23, uranium can be transported in the more oxidizing portion of the field of cuprous chloride complexing, so that the Cl -rich waters, if at the appropriate Eh (i.e., well within the stability field of hematite), would leach uranium as well as copper. The uranium would also be precipitated by encountering a reducing environment.

Strong adsorption of uranium by amorphous Fe oxides might result in fixation of considerable U in the Fe-oxide coatings in the detrital material in streams. Crystallization of the amorphous Fe oxides in the overbank muds to hematite would tend to release the adsorbed uranium and make it available to groundwater, either at the time of sedimentation or later.

In summary, the Cu-U occurrences of the region are suggested to result from infiltration by weakly oxidizing Cl -bearing waters of marine or evaporite origin through the redbed sequence, either during deposition if tidal conditions pertained, or at a later period. These solutions leached Cu and U from Fe oxides and transported them until they encountered a reducing environment, where the Cu and U were precipitated.

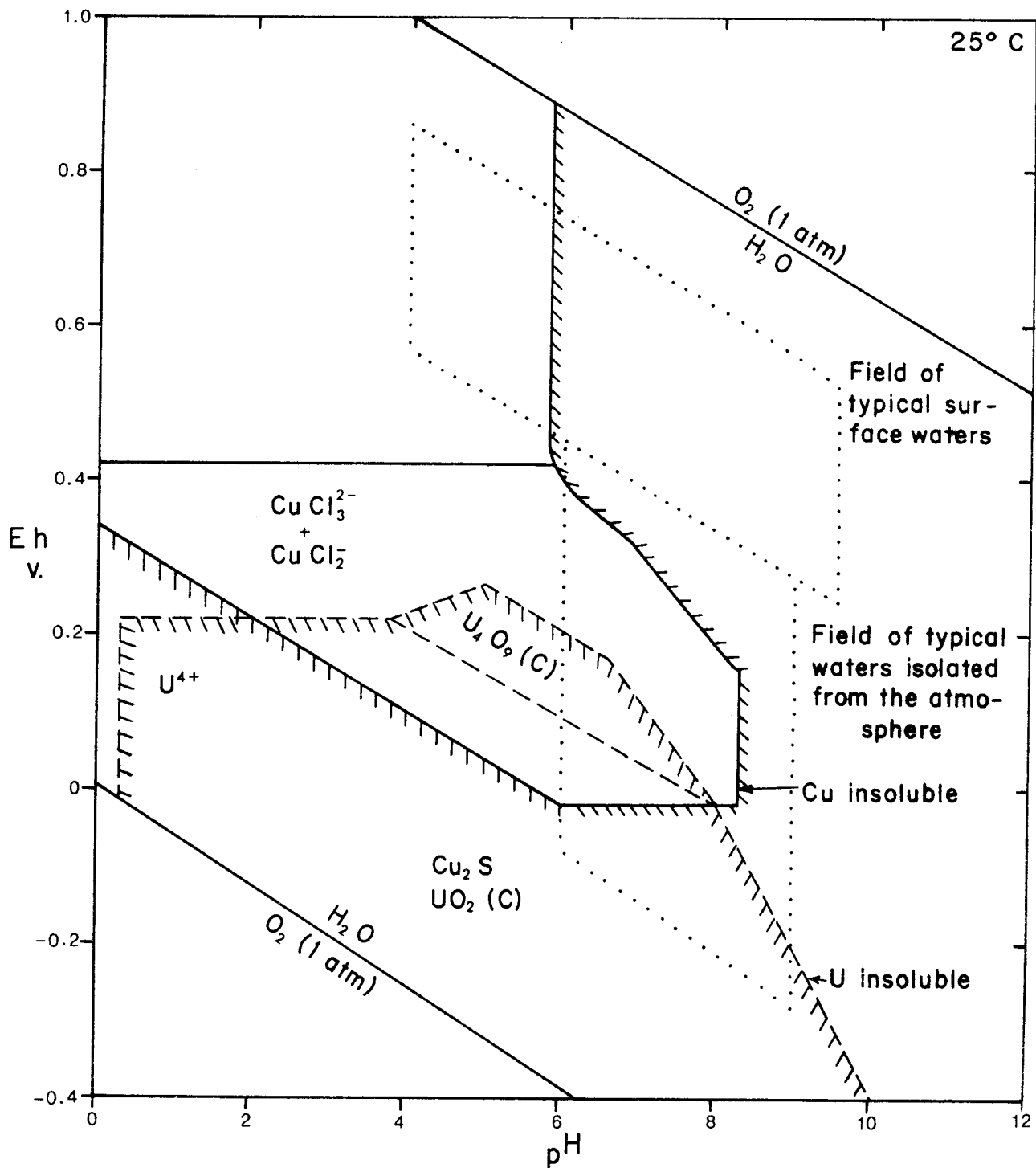


Figure 23. Mobility of Cu and U in chloride brines showing conditions under which both Cu and U are soluble. Solid lines define Cu fields. Dashed lines define U fields. Dotted lines define water fields. A - U insoluble. B - Cu insoluble.

ORIGIN OF TYPE 2 DEPOSITS

The occurrences at Mt. Pisgah are within a carbonaceous, conglomeratic sandstone, so they conform to some of the features outlined for Types 1 and 3 deposits. However, no clearly defined redox boundary can be detected within the sandstone, so an origin like the Penn Haven Junction occurrence cannot be easily applied. It is possible that the characteristics of an oxidized, permeable ground-water conduit have been obscured by reduction after deposition of uranium, or that this occurrence involves mechanism such as transport of uranium in colloidal organic material and flocculation within the site of the present orebody. The mechanism responsible for emplacement of this deposit remains even more open for speculation than do those for the other types.

URANIUM EXPLORATION METHODS

Exploration methods may be conveniently classified into (a) reconnaissance and detailed methods, and (b) into geological, geochemical, and geophysical methods. A good exploration program combines these in a form that results in the most definitive results for the least cost. This section summarizes some of the methods that seem applicable in the region and reports on published test surveys.

RECONNAISSANCE METHODS

Based on the preceding discussion, the location of major sediment-input systems into the Appalachian basin during Catskill time may be a regional guide to favorable areas for uranium. Although the Lehigh River defines the approximate center of one system, as yet the trends and locations of specific major channels within the system, especially those of high permeability, are not known, but are of primary importance as controls for Penn Haven Junction-type deposits. Seven other major input areas are hypothesized within the Catskill complex of Pennsylvania and may warrant investigation using the Lehigh River sediment-input system model. The source of sediment being fed into the basin is another feature of probable importance, but has only had cursory evaluation.

Structural adjustments, such as faulting and uplift near the margins of the basin, may have favorable effects in promoting circulation of ground waters through the section. The proximity of a channel system open to the surface at its up-drainage end and in contact with a significant body of reducing sandstone within a few kilometers down drainage would seem to be a highly favorable location for ore.

The localization of Type 1 prospects within the basal Duncannon and uppermost Clark's Ferry Members of the Catskill Formation appears to be a most important guide, possibly related to changes in source area, climate, or tectonics. An obvious related geological factor is the depth to the favorable horizon. Because of the large amplitude of folds in the Ridge and Valley province, the Catskill Formation is covered to great depths in many synclines and is eroded away in many anticlines. Localities where the favorable part of the section is at or near the surface are relatively limited in this province. In contrast, the sediments in the Pocono Plateau and in

north-central Pennsylvania are relatively flat-lying, so that more extensive zones are within practical exploration and mining depth. The future importance of deep solution-mining of uranium cannot yet be evaluated.

Reconnaissance geochemical methods that have achieved positive results in the region include analysis of uranium in stream sediments, and uranium and radon in ground water. Test surveys and experiments by Rose (1976) and Rose and Keith (1976) showed that sampling of stream sediments at a density of about 1 sample per 2.6 square kilometers would produce anomalies at and near the known U occurrences, both near Jim Thorpe and in north-central Pennsylvania. However, a selective extraction of U in organic matter and on surfaces of grains was necessary, because the contrast of anomalies is only 2 to 4 times background. A digestion in hydrogen peroxide and acetic acid was used to extract the uranium, but similar results probably could have been obtained with nitric acid digestion. Total uranium probably would not have shown anomalies. Wider spacing of samples in the Jim Thorpe area probably would have resulted in missing the existence of a mineralized area.

Test surveys using uranium and radon in ground water are reported by Korner and Rose (1977), Rose and Korner (in press), Price and others (1976), and Applin and Langmuir (in press). In north-central Pennsylvania, the uranium content of even relatively widely-spaced samples of ground water (1 sample/260 km²) probably would detect the existence of a favorable province. However, the limited work to date on ground waters in the Jim Thorpe area indicates very low uranium values except within a hundred meters or so of the prospects. This appears to result from relatively thorough leaching of uranium from the sandy soils and quartzitic rocks of the area, the control of ground water movement predominantly by joints and the restriction of most wells to the upland areas, so that analyzed ground waters are close to their recharge zones and have not encountered much rock.

In contrast, distinct radon anomalies were detected in ground waters not only in the Beaver Lake area but also the Jim Thorpe area. Apparently, uranium or its decay products remain in the limonites along fractures in the rocks, and the radon leaks from the limonite into the waters. A combination of radon and uranium analyses in ground water appears to form a good reconnaissance method (Rose and Korner, in press) of uranium exploration.

Experiments with uranium in stream waters suggest that anomalies may be present, but that values are (1) extremely low most of the time, (2) near or below the detection limits of most analytical methods, and (3) that anomalies fluctuate by very large factors, perhaps as much as 100 between dry periods and normal to wet periods (Rose and Keith, 1976; Rose and others, 1976; Price and others, 1976). Lesure and others (1977) studied several elements in stream sediments in Bradford, Columbia and Lycoming Counties.

The major reconnaissance geophysical method is airborne radiometric measurement. Test surveys on a small scale in the 1950's demonstrated that anomalies could be obtained by flying directly over the known occurrences (Klemic and Cooper, 1975). More recent surveys using gamma spectrometry to separate U, Th, and K indicate that relatively common anomalies are obtained in a northwest-trending zone passing through the vicinity of Jim Thorpe and extending southeast across the lower Paleozoic, Precambrian Reading Prong,

Triassic basin, and into the Coastal Plain (LKB Resources, 1978). No regional anomaly has as yet been detected within the Catskill Formation. This survey remains to be interpreted in detail, but the method is clearly of great value in detecting surface anomalies and general provinces.

DETAILED EXPLORATION METHODS

The recognition and tracing of paleo-stream channels and associated oxidation-reduction effects is probably the most valuable geological approach in detailed exploration for deposits of the Penn Haven Junction type. In areas of good exposure, these features can be mapped in outcrop. Measurements of cross-bedding and other sedimentary structures may aid geologic projections into unexposed areas. The channels and redox effects (hematite staining, possibly Ti oxide mineralogy) can be detected in drill holes and used to guide further drilling, as is done in the western United States. Geochemically, the mineralizing channels are anomalous in uranium and can be detected by chemical analysis of core samples and probably by gamma-ray logs.

The standard techniques of soil sampling, gamma-ray surveys, and radon in soil-gas surveys are applicable in searching for deposits at shallow to moderate depth. However, because of the strong stratigraphic control of uranium ore, these types of surveys will only be useful in selected areas.

ENVIRONMENTAL CONCERNS

Although no substantial amount of uranium has as yet been mined commercially in Pennsylvania, the potential for such raises the issue of environmental concern. In addition to the usual problems associated with mining, either surface or subsurface, uranium has its own special problems. Our intent here is not an exhaustive treatment of the subject, but to draw attention to some of the potential and existing problems.

We cannot, at present, postulate the geometry of an orebody in the Lycoming-Sullivan-Columbia Counties area. Nor can we offer evidence to suggest ore mining in the near future. Therefore, we cannot postulate what mining method might be used. Any method, should ore mining ever occur in the area, would be subject to Federal regulations already in existence.

The Carbon County uranium deposits occur in locations unsuitable for open pit mining and underground mining would be required. Natural decay of uranium produces the gas radon which is heavier than air and would tend to collect in mines rather than be released to the atmosphere as it is at present. Because available data indicates that exposure to quantities of radon gas increases susceptibility to lung cancer, especially good ventilation is required in subsurface uranium mines. Storage of waste rock prior to mine backfilling is a potential problem (Rankin, 1978).

Four additional environmental concerns exist:

(1) The drill-hole spring located 180 m W of the western adit at Mt. Pisgah is now used as a normal, daily source of drinking water by a surprisingly large number of local residents. Korner and Rose (1977, p. 147) determined that this water contained 6631 pCi/l of radon. Of the 150 ground

water samples from uraniferous and barren rock in Pennsylvania analyzed by Korner and Rose, this is the largest amount of radon found. Daily consumption of such water should be seriously questioned for health reasons.

(2) Because the Pennsylvania uranium deposits are relatively low grade, cost of transportation of mined ore to the nearest currently available processing plant (Colorado) would probably be prohibitively expensive. Therefore, a processing plant in eastern United States, not necessarily in Pennsylvania, would be required. Such plants have a variety of potential health and environmental concerns requiring careful regulation and management. Currently, the extraction of 2 kg of uranium oxide from a metric ton of ore produces up to 3800 liters of chemically toxic and radioactive liquid waste (Howard and Remson, 1978, p. 327). Disposal of such waste would require careful adherence to Federal regulations.

(3) The Penn Haven Junction uranium deposits occur within the Lehigh River gorge. The segment of this river valley between Jim Thorpe and the Francis E. Walter dam NE of White Haven, including the gorge at least to the upper rim and in some places farther, has been designated as part of the Pennsylvania Scenic Rivers Inventory (Dept. Environmental Resources, 1975). As of August 18, 1978, all studies and public hearings on the river segment were complete, and a summary report had been prepared recommending that the above mentioned segment of the Lehigh River be designated as a component of the Pennsylvania Scenic Rivers System. This report was submitted to the Governor and the Legislature for their consideration and action. As yet, no streams have been so designated by the Pennsylvania legislature, therefore, it is not possible to indicate what impact, if any, such designation might have on uranium mining within or adjacent to the scenic corridor.

(4) The same part of the Lehigh River discussed above in (3) is scheduled to become a State Park and slow progress toward this end is being made. The Pennsylvania legislature appropriated funds to initiate land acquisition for this park in 1968. Approximately 11 percent of the total anticipated land acquisition has occurred to date. The creation of this park could place further constraints on uranium mining in the Penn Haven Junction and Jim Thorpe areas.

REFERENCES CITED

- Allen, J. R. L., 1965, Fining-upwards cycles in alluvial successions: Liverpool Geol. Soc. and Manchester Geol. Assoc., Geol. Jour., 4:229-246.
- _____ and Friend, P. F., 1968, Deposition of the Catskill facies, Appalachian region: with notes on some other Old Red Sandstone basins, in Klein, G. deV. (ed.), Late Paleozoic and Mesozoic continental sedimentation, northeastern North America: Geol. Soc. Amer. Spec. Paper 106, p. 21-74.
- Applin, K. R. and Langmuir, D., in press, Evaluation of groundwater as a prospecting tool for uranium deposits in Pennsylvania: Dept. of Energy Open File Rpt. GJO-1659-4.
- Austin, G. S., 1970, Weathering of the Sioux quartzite near New Ulm, Minnesota, as related to Cretaceous climates: Jour. Sed. Petrol., 40:184-193.
- Barrell, J., 1912, Criteria for the recognition of ancient delta deposits: Geol. Soc. Amer. Bull., 23:377-446.
- _____, 1913, The Upper Devonian delta of the Appalachian geosyncline: Part I. The delta and its relations to the interior sea: Am. Jour. Sci., 4th ser., 36:429-472.
- _____, 1914a, The Upper Devonian delta of the Appalachian geosyncline: Part II. Factors controlling the present limits of strata: Am. Jour. Sci., 4th ser., 37:87-109.
- _____, 1914b, The Upper Devonian delta of the Appalachian geosyncline: Part III. The relations of the delta to Appalachia: Am. Jour. Sci., 4th ser., 37:225-253.
- Berg, T. M., 1975, Geology and mineral resources of the Brodheadsville quadrangle, Monroe and Carbon Counties, Pennsylvania: Pa. Geol. Survey, 4th ser., Atlas 205a, 60 p., 2 maps.
- _____, Sevon, W. D. and Bucek, M. F., 1977, Geology and mineral resources of the Pocono Pines and Mount Pocono quadrangles, Monroe County, Pennsylvania: Pa. Geol. Survey, 4th ser., Atlas 204cd, 66 p., 2 maps.
- Bird, J. M. and Dewey, J. F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen: Geol. Soc. Amer. Bull., 81:1031-1060.
- Brown, L. F., Jr., Cleaves, A. W., II, and Erxleben, A. W., 1973, Pennsylvanian depositional systems in north-central Texas: Bur. Econ. Geol., Univ. Texas, Austin, Guidebook No. 14, 122 p.
- Burtner, R. L., 1964, Paleocurrent and petrographic analysis of the Catskill facies of southeastern New York and northeastern Pennsylvania: Unpublished PhD thesis, Harvard Univ., Cambridge, Mass.
- Colton, G. W., 1970, The Appalachian Basin - its depositional sequences and their geologic relationships, in Fisher, G. W. and others (eds.), Studies of Appalachian geology: New York, Interscience Publishers, p. 5-47.
- Dennison, J. M. and deWitt, W., Jr., 1972, Redbed zone produced by sea level drop at beginning of Devonian Cohocton age delimits Fulton and Augusta Lobes of Catskill delta complex, in Dennison, J. M. and others, Stratigraphy, sedimentology, and structure of Silurian and Devonian rocks along the Allegheny Front in Bedford County, Pennsylvania, Allegany County, Maryland, and Mineral and Grant Counties, West Virginia: Guidebook, 37th Ann. Field Conf. Pa. Geologists, Pa. Geol. Survey, p. 109-114.

- Dept. Environmental Resources, 1975, The Pennsylvania scenic rivers inventory: D.E.R., The Wild and Scenic Rivers Task Force, 111 p.
- Dietz, R. S., 1972, Geosynclines, mountains, and continent building: *Scientific American*, vol. 226, no. 3, p. 30-38.
- Dyson, J. L., 1954, Relation of stratigraphy and structure to uranium occurrence near Mauch Chunk, Pennsylvania: *Proc. Pa. Acad. Sci.*, 28:124-134.
- Epstein, J. B. and Epstein, A. G., 1972, The Shawangunk Formation (Upper Ordovician(?) to Middle Silurian) in eastern Pennsylvania: *U. S. Geol. Survey Prof. Paper* 744, 45 p.
- _____, Sevon, W. D. and Glaeser, J. D., 1974, Geology and mineral resources of the Lehigh and Palmerton quadrangles, Carbon and Northampton Counties, Pennsylvania: *Pa. Geol. Survey*, 4th ser., Atlas 195cd, 460 p., 4 pls.
- Fail, R. T. and Wells, R. B., 1970, A fault near Hazleton: *Pa. Geol. Survey*, 4th ser., *Pa. Geology*, vol. 1, no. 5, p. 9-10.
- Fergusson, W. B. and Prather, B. A., 1968, Salt deposits in the Salina Group in Pennsylvania: *Pa. Geol. Survey*, 4th ser., *Mineral Resources Rept.* 58, 41 p.
- Finkelman, R. B. and Klemic, H., 1976, Brannerite from the Penn Haven Junction uranium occurrence, Carbon County, Pennsylvania: *U. S. Geol. Survey Jour. Research*, 4:715-716.
- Fischer, R. P., 1970, Similarities, differences, and some genetic problems of the Wyoming and Colorado Plateau types of uranium deposits in sandstone: *Econ. Geol.*, 65:778-784.
- Gaucher, E. H., 1959, Copper uranium deposits in Pennsylvania: *Econ. Geol.*, 54:1126.
- Gault, H. R., Dalhausen, J. K. and Yeakel, L., 1957, Note on a partial section of the Pottsville-Mauch Chunk transition near Jim Thorpe, Pennsylvania: *Pa. Acad. Sci. Proc.*, 31:114-119.
- Genth, F. A., 1875, Preliminary report on the mineralogy of Pennsylvania: *Pa. Geol. Survey*, 2nd ser., *Rept. B*, p. 144.
- Glaeser, J. D., 1974, Upper Devonian stratigraphy and sedimentary environments in northeastern Pennsylvania: *Pa. Geol. Survey*, 4th ser., *Gen. Geol. Rept.* 63, 89 p.
- Gordon, S. G., 1922, The mineralogy of Pennsylvania: *Acad. Natural Sci. of Philadelphia Spec. Pub.* 1, 255 p.
- Graham, S. A., Dickinson, W. R. and Ingersoll, R. V., 1975, Himalayan-Bengal model for flysch dispersal in the Appalachian-Ouachita system: *Geol. Soc. Amer. Bull.*, 86:273-286.
- Gray, C. and Shepps, V. C., 1960, Geologic map of Pennsylvania: *Pa. Geol. Survey*, 4th ser., Map 1, scale 1:250,000.
- Harshman, E. N., 1974, Distribution of elements in some roll-type uranium deposits (with discussion), in Ninninger, R. D. (chairman), *Formation of uranium ore deposits: I. A. E. A., Proc. Ser.*, No. STI/PUB/374, p. 169-183.
- Hatcher, R. D., Jr., 1972, Developmental model for the southern Appalachians: *Geol. Soc. Amer. Bull.*, 83:2735-2760.
- Hoque, M. U., 1968, Sedimentologic and paleocurrent study of Mauch Chunk sandstones (Mississippian) south-central and western Pennsylvania: *Amer. Assoc. Petrol. Geol. Bull.*, 52:246-263.
- Howard, A. D. and Remson, I., 1978, *Geology in environmental planning*: McGraw-Hill, Inc., 478 p.

- Humphreys, M. and Friedman, G. M., 1975, Late Devonian Catskill deltaic complex in north-central Pennsylvania, in Broussard, M. L. (ed.), *Deltas-models for exploration*: Houston Geol. Soc., 555 p.
- Kaiser, W. R., 1972, Delta cycles in the Middle Devonian of Central Pennsylvania: Unpublished PhD thesis, The Johns Hopkins Univ., Baltimore, Md.
- Klemic, H., 1962, Uranium occurrences in sedimentary rocks of Pennsylvania: U. S. Geol. Survey Bull. 1107-D, p. 243-288.
- _____, and Baker, R. C., 1954, Occurrences of uranium in Carbon County, Pennsylvania: U. S. Geol. Survey Circ. 350, 8 p.
- _____, Warman, J. C. and Taylor, A. R., 1963, Geology and uranium occurrences of the northern half of the Lehigh, Pennsylvania, quadrangle and adjoining areas: U. S. Geol. Survey Bull. 1138, 97 p.
- _____, and Cooper, M. C., 1975, Airborne radioactivity survey of parts of Carbon, Schuylkill, and Monroe Counties, Pennsylvania: U. S. Geol. Survey Open File Rept. 75-91.
- Korner, L. A. and Rose, A. W., 1977, Radon in streams and ground waters as a guide to uranium deposits in Pennsylvania: Energy Research and Development Adm., Grand Junction, Colo., Open file rept. GJO-1659-2, 152 p.
- Langmuir, D., 1978, Uranium solution-mineral equilibria at low temperature with application to sedimentary ore deposits: *Geochim. et Cosmochim. Acta*, 42:547-569.
- Lesure, F. G., Motooka, J. M. and Weis, P. L., 1977, Exploration geochemical studies of some sandstone copper-uranium deposits, Bradford, Columbia, and Lycoming Counties, Pennsylvania: U. S. Geol. Survey Jour. Research, 5:609-621.
- LKB Resources, Inc., 1978, NURE aerial gamma ray and magnetic reconnaissance survey; Thorpe area, Neward NK18-11 quadrangle: Dept. of Energy, Grand Junction, Colo., GJBX-16, '78, vol. I and II.
- Mahar, D. L., 1978, Geology and geochemistry of uranium deposits near Beaver Lake, Sullivan County, Pennsylvania: Unpublished MSc thesis, The Pennsylvania State Univ., 142 p.
- McCauley, J. F., 1957a, Preliminary report on the sedimentary uranium occurrences in the state of Pennsylvania: Pa. Geol. Survey, 4th ser., PR 152, 22 p.
- _____, 1957b, Supergene copper uranium deposits, Nova Scotia: *Econ. Geol.*, 53:1038-1042.
- _____, 1961, Uranium in Pennsylvania: Pa. Geol. Survey, 4th ser., Bull. M43, 71 p.
- McCave, I. N., 1968, Shallow and marginal marine sediments associated with the Catskill complex in the Middle Devonian of New York, in Klein, G. deV. (ed.), *Late Paleozoic and Mesozoic continental sedimentation, northeastern North America*: Geol. Soc. Amer. Spec. Paper 106, p. 75-107.
- McIver, N. L., 1961, Upper Devonian marine sedimentation in the central Appalachians: Unpublished PhD thesis, The Johns Hopkins Univ., Baltimore, Md.
- McKeown, F. A., 1949, Preliminary report of uranium deposits near Mauch Chunk, Pennsylvania: Unpublished U. S. Geol. Survey Trace Elements Memo. Rept. 19.
- McKerrow, W. S. and Ziegler, A. M., 1972, Paleozoic oceans: *Nature (phys. sci.)*, 240:92-94.
- Meckel, L. D., 1967, Origin of Pottsville conglomerates (Pennsylvanian) in the central Appalachians: *Geol. Soc. Amer. Bull.*, 78:223-258.
- _____, 1970, Paleozoic alluvial deposition in the central Appalachians: a summary, in Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and

- Weaver, K. N. (eds.), Studies of Appalachian geology: central and southern: New York, Interscience Publishers, p. 49-67.
- Miller, B. L., 1911, The mineral pigments of Pennsylvania: Pa. Geol. Survey, 3rd ser., Rept. No. 4, 101 p.
- Montgomery, A., 1954, Uranium minerals of the Mauch Chunk area, Pennsylvania: Proc. Pa. Acad. Sci., 28:102-110.
- _____, 1969, The mineralogy of Pennsylvania 1922-1965: Acad. Nat. Sci. of Phila. Sp. Pub. No. 9, 104 p.
- Morton, E., 1946, Josiah White, prince of pioneers: New York, Stephen Daye Press, 300 p.
- Nickelsen, R. P., 1963, Fold patterns and continuous deformation mechanisms of the central Pennsylvania folded Appalachians, in Tectonics and Cambro-Ordovician stratigraphy in the central Appalachians of Pennsylvania: Pittsburgh Geol. Soc. and Appalachian Geol. Soc. field conf. guidebook, Sept. 1963, Pittsburgh, Pa., Pittsburgh Geol. Soc., p. 13-29.
- Odom, A. L. and Fullagar, P. D., 1973, Geochronologic and tectonic relationships between the Inner Piedmont, Brevard Zone, and Blue Ridge belts, North Carolina: Amer. Jour. Sci., Cooper vol. 273-A, p. 133-149.
- Pelletier, B. R., 1958, Pocono paleocurrents in Pennsylvania and Maryland: Geol. Soc. Amer. Bull., 69:1033-1064.
- Pennsylvania Geological Survey, Geologic field trip guide Interstate 81 from Harrisburg to Hazleton: Pa. Geol. Survey, 4th ser., 7 p.
- Price, V., Ferguson, R. B. and Baucom, E. I., 1976, Orientation study in the Williamsport, Pennsylvania area: Energy Research and Development Adm., Grand Junction, Colo., Open file report DPST-76-141-3 (GJBX-53), 12 p.
- Rankin, D. W., 1975, The continental margin of eastern North America in the southern Appalachians: the opening and closing of the proto-Atlantic ocean: Amer. Jour. Sci., 275-A:298-336.
- Rankin, R., 1978, Uranium tailings pose health hazard: Harrisburg, The Patriot-News Co., The Patriot, August 19, 1978, p. 14.
- Reuter, J. H., and Perdue, E. M., 1977, Importance of heavy metal-organic matter interactions in natural waters: Geochim. et Cosmochim. Acta, 41:325-334.
- Root, S. I., 1973, Structure, basin development, and tectogenesis in the Pennsylvania portion of the folded Appalachians, in DeJong, K. A. and Scholten, R. (eds.), Gravity and tectonics: New York, John Wiley and Sons, p. 343-360.
- Rose, A. W., 1970, Atlas of Pennsylvania's mineral resources - pt. 3, Metal mines and occurrences in Pennsylvania: Pa. Geol. Survey, 4th ser., Bull. M 50, pt. 3, 14 p.
- _____, 1976, The effect of cuprous chloride complexes in the origin of red-bed copper and related deposits: Econ. Geol., 71:1036-1048.
- _____, and Keith, M. L., 1976, Reconnaissance geochemical techniques for detecting uranium deposits in sandstones of northeastern Pennsylvania: Jour. Geochemical Explor., 6:119-137.
- _____, Keith, M. L. and Suhr, N. H., 1976, Geochemical drainage surveys for uranium: sampling and analytical methods based on trial surveys in Pennsylvania: Energy Research and Development Adm., Grand Junction, Colo., Open file rept. GJBX-28(76) (GJO-1645-1), 34 p.
- _____, Schmiermund, R. L. and Mahar, D. L., 1977, Geochemical dispersion of uranium near prospects in Pennsylvania: Energy Research and Development Adm., Grand Junction, Colo., Open file rept. GJBX-59(77), 87 p.
- Schenk, P. E., 1971, Southeastern Atlantic Canada, northwestern Africa, and continental drift: Canadian Jour. Earth Sci., 8:1218-1251.

- Schmiermund, R. L., 1977, Geology and geochemistry of uranium deposits near Penn Haven Junction, Carbon County, Pennsylvania: Unpublished MSc thesis, The Pennsylvania State Univ., 153 p.
- Schot, E. H. and Wegrzyn, R. S., 1974, Petrographic report, Catskill Formation, Penn Haven Junction anomaly: unpub. rept., Lucius Pitkin, Inc., to ERDA, Rept. no. RD-11.
- Sevon, W. D., 1968a, Lateral continuity of the Ridgeley, Schoharie-Esopus and Palmerton Formations in Carbon and Schuylkill Counties, Pennsylvania: Pa. Acad. Sci. Proc., 42:190-192.
- _____, 1968b, Subaqueous mudflow origin of basal Pocono rocks in northeastern Pennsylvania (Abs.): Northeastern Section Geol. Soc. Amer., 3rd Annual Meeting, Program, p. 53-54.
- _____, 1969a, The Pocono Formation in northeastern Pennsylvania: Guidebook, 34th Ann. Field Conf. Pa. Geologists, Pa. Geol. Survey, 129 p.
- _____, 1969b, Sedimentology of some Mississippian and Pleistocene deposits of northeastern Pennsylvania, in Subitzky, S. (ed.), Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: New Brunswick, N. J., Rutgers University Press, p. 214-234.
- _____, 1973, Glaciation and sedimentation in the Late Devonian and Early Mississippian of Pennsylvania (Abs.): Geol. Soc. Amer., Abstracts with Programs, vol. 5, no. 2, p. 218-219.
- _____, 1975a, Geology and mineral resources of the Christmans and Pohopoco Mountain quadrangles, Carbon and Monroe Counties, Pennsylvania: Pa. Geol. Survey, 4th ser., Atlas 195ab, 2 maps with text.
- _____, 1975b, Geology and mineral resources of the Hickory Run and Blakeslee quadrangles, Carbon and Monroe Counties, Pennsylvania: Pa. Geol. Survey, 4th ser., Atlas 194cd, 2 maps with text.
- Smith, A. G., Briden, J. C. and Drewry, G. E., 1973, Phanerozoic world maps: Paleont. Assoc. Spec. Paper in Paleontology 12, p. 1-42.
- Smith, R. C., II, 1977, Zimmerman uranium prospect, Carbon County: Pa. Geol. Survey, 4th ser., Pa. Geology, vol. 8, no. 6, p. 10-12.
- _____, 1978, The mineralogy of Pennsylvania 1966-1975: Ephrata, Penna., Friends of Mineralogy, Pa. Chapter, Inc., Spec. Pub. 1, 304 p.
- Stern, T. W., Stieff, L. R., Klemic, H. and Delevaux, M. H., 1960, Lead-isotope age studies in Carbon County, Pennsylvania, in Short papers in the geological sciences: U. S. Geol. Survey Prof. Paper 400-B, p. B45-B48.
- Van Houten, F. B., 1976, Late Variscan nonmarine deposits, northwestern Africa: implications for pre-drift North Atlantic reconstructions: Amer. Jour. Sci., 276:671-693.
- Walker, R. G., 1971, Nondeltaic depositional environments in the Catskill clastic wedge (Upper Devonian) of central Pennsylvania: Geol. Soc. Amer. Bull., 82:1305-1326.
- _____, 1972, Upper Devonian marine-nonmarine transition, southern Pennsylvania: Pa. Geol. Survey, 4th ser., G 62, 25 p.
- _____, and Harms, J. C., 1971, The Catskill Delta: a prograding muddy shoreline in central Pennsylvania: Jour. Geol., 79:381-399.
- Walker, T. R., 1967, Formation of red beds in modern and ancient deserts: Geol. Soc. Amer. Bull., 78:353-368.
- Walther, J., 1894, Lithogenesis der Gegenwart, Beobachtungen über die Bildung der Gesteine an der heutigen Erdoberfläche, dritten Teil einer Einleitung in die geologische historische Wissenschaft: Verlag von Gustav Fischer, Jena, section 8, p. 621.

- Wherry, E. T., 1912, A new occurrence of carnotite: *Am. Jour. Sci.*, 4th ser., 33:574-580.
- _____, 1914, Carnotite near Mauch Chunk, Pennsylvania: *U. S. Geol. Survey Bull.* 580-H, p. 147-151.
- Willard, B., Swartz, F. M. and Cleaves, A. B., 1939, The Devonian of Pennsylvania: *Pa. Geol. Survey*, 4th ser., Bull. G 19, 481 p.
- Wilson, J. T. and Fairbridge, R. W., 1971, Appalachian peneplains, paleosols and plate tectonics (Abs.): *Eos (Amer. Geophys. Union Trans.)*, vol. 52, no. 4, p. 350.
- Wood, G. H., Jr., 1974, Geologic map of the Nesquehoning quadrangle, Carbon and Schuylkill Counties, Pennsylvania: *U. S. Geol. Survey Map* GQ 1132.
- _____, Trexler, J. P., and Kehn, T. M., 1969, Geology of the west-central part of the Southern Anthracite field and adjoining areas, Pennsylvania: *U. S. Geol. Survey Prof. Paper* 602, 150 p.
- Woodrow, D. L., Fletcher, F. W. and Ahrusbark, W. F., 1973, Paleogeography and paleoclimate at the deposition sites of the Devonian Catskill and Old Red facies: *Geol. Soc. Amer. Bull.*, 84:3051-3064.
- Worsley, T. R., 1971, Terminal Cretaceous events: *Nature*, 230:318-320.
- Yeakel, L. S., Jr., 1962, Tuscarora, Juniata, and Bald Eagle paleocurrents and paleogeography in the central Appalachians: *Geol. Soc. Amer. Bull.*, 73:1515-1540.

ROAD LOG

DAY 1

Friday, 6 October, 1978

<u>Cum. Mil.</u>	<u>Inc. Mil.</u>	
0.0	0.0	LEAVE parking lot of Gus Genetti Motor Lodge. Turn LEFT onto PA Rte. 309 South. Route map is Figure 24.
2.1	2.1	STOP light. TURN LEFT onto PA Rte. 93.
6.5	4.4	TURN LEFT toward Weatherly.
10.7	4.2	STOP sign. TURN LEFT across bridge. Immediately after crossing bridge TURN RIGHT onto cindered road (former railroad bed) adjacent to railroad track that will be on left.
10.8	0.1	Cabled entrance to Penn Haven Junction access road.
13.4	2.6	Bridge over Black Creek.
15.9	2.5	Penn Haven Junction. Junction of Black Creek and Lehigh River.
16.3	0.4	STOP 1. Penn Haven Junction Uranium Occurrence (p. 59). LEAVE Stop 1 and return to Weatherly via same route.
19.2	2.9	Bridge over Black Creek.
21.8	2.6	Cabled entrance to Penn Haven Junction access road.
21.9	0.1	Junction with paved road. TURN LEFT, cross bridge and TURN LEFT again.
24.3	2.4	STOP sign. TURN LEFT onto PA Rte. 93.
30.1	5.8	STOP sign. Junction PA Rte. 93 and U. S. Rte. 209. TURN LEFT onto U. S. Rte. 209 North.
32.3	2.2	Site of STOP 4 on left. CONTINUE straight ahead.
33.1	0.8	STOP light. Junction PA Rte. 903. CONTINUE straight ahead. Type locality of Mauch Chunk Formation on right.
33.5	0.4	STOP light. Downtown Jim Thorpe. CONTINUE straight ahead. Note fine old stone buildings.
35.4	1.9	TURN LEFT toward Flagstaff Park.
37.5	2.1	STOP 2. Flagstaff Mountain Park and Lunch (p. 64). LEAVE STOP 2. CONTINUE straight ahead.

<u>Cum. Mil.</u>	<u>Inc. Mil.</u>	
38.5	1.0	STOP sign. TURN LEFT.
38.6	0.1	Road fork. BEAR RIGHT. Steep grade ahead, buses in low gear.
38.9	0.3	STOP sign. Junction with U. S. Rte. 209. TURN RIGHT onto U. S. Rte. 209 North.
39.3	0.4	Road on left is alternate route to STOP 3. Can turn left, go under railroad and follow cinder road as far as possible (about 0.4 mile). Park and then walk 10 to 15 minutes to STOP 3.
40.5	1.2	TURN LEFT onto South Street after passing through STOP light in center of Lehighton.
40.7	0.2	Cabled entrance to railroad access road. Follow this road north as far as railroad bridge over Lehigh River.
43.2	2.5	STOP 3. Packerton Junction Interchange. Type 1 uranium occurrence (p. 66). LEAVE STOP 3. Return to U. S. Rte. 209 via same route.
45.7	2.5	Cabled entrance to railroad access road.
45.9	0.2	STOP light. Turn right onto U. S. Rte. 209 South.
47.8	1.9	Big Chief drive-in on left. North margin of parking lot is start of continuous outcrop through Berry Run, Clark's Ferry and Duncannon Members of the Catskill Formation.
49.3	1.5	STOP light. TURN RIGHT at center of Jim Thorpe.
49.7	0.4	STOP light. Junction PA Rte. 903. CONTINUE straight ahead.
50.6	0.9	STOP 4. Mt. Pisgah uranium occurrence (p. 71). LEAVE STOP 4. CONTINUE straight ahead on PA Rte. 209.
52.7	2.1	Junction U. S. Rte. 209 and PA Rte. 93. CONTINUE straight ahead.
54.4	1.7	Road fork. BEAR RIGHT on PA Rte. 54 West.
63.6	9.2	STOP light. Junction PA Rtes. 54 and 309. CONTINUE straight ahead on PA Rte. 54.
65.7	2.1	Village of Barnesville.

<u>Cum. Mil.</u>	<u>Inc. Mil.</u>	
67.6	1.9	TURN LEFT staying on PA Rte 54. (Going straight ahead is an alternate route to get on I 81 at the Delano interchange).
67.9	0.3	Site of Bavarian Beer Festival on left.
70.8	2.9	TURN LEFT onto Interstate I 81 North toward Hazleton.
78.1	7.3	STOP 5. Spring Mountain thrust fault (p. 75). LEAVE STOP 5. CONTINUE ahead.
82.8	4.7	EXIT RIGHT onto PA Rte. 924.
84.7	1.9	TURN LEFT onto South Broad Street.
85.3	0.6	STOP light. TURN RIGHT following PA Rte. 924.
86.4	1.1	STOP light. TURN LEFT onto PA Rte. 309 North.
87.6	1.2	TURN RIGHT into Gus Genetti Motor Lodge parking lot. END of first day. See you later.

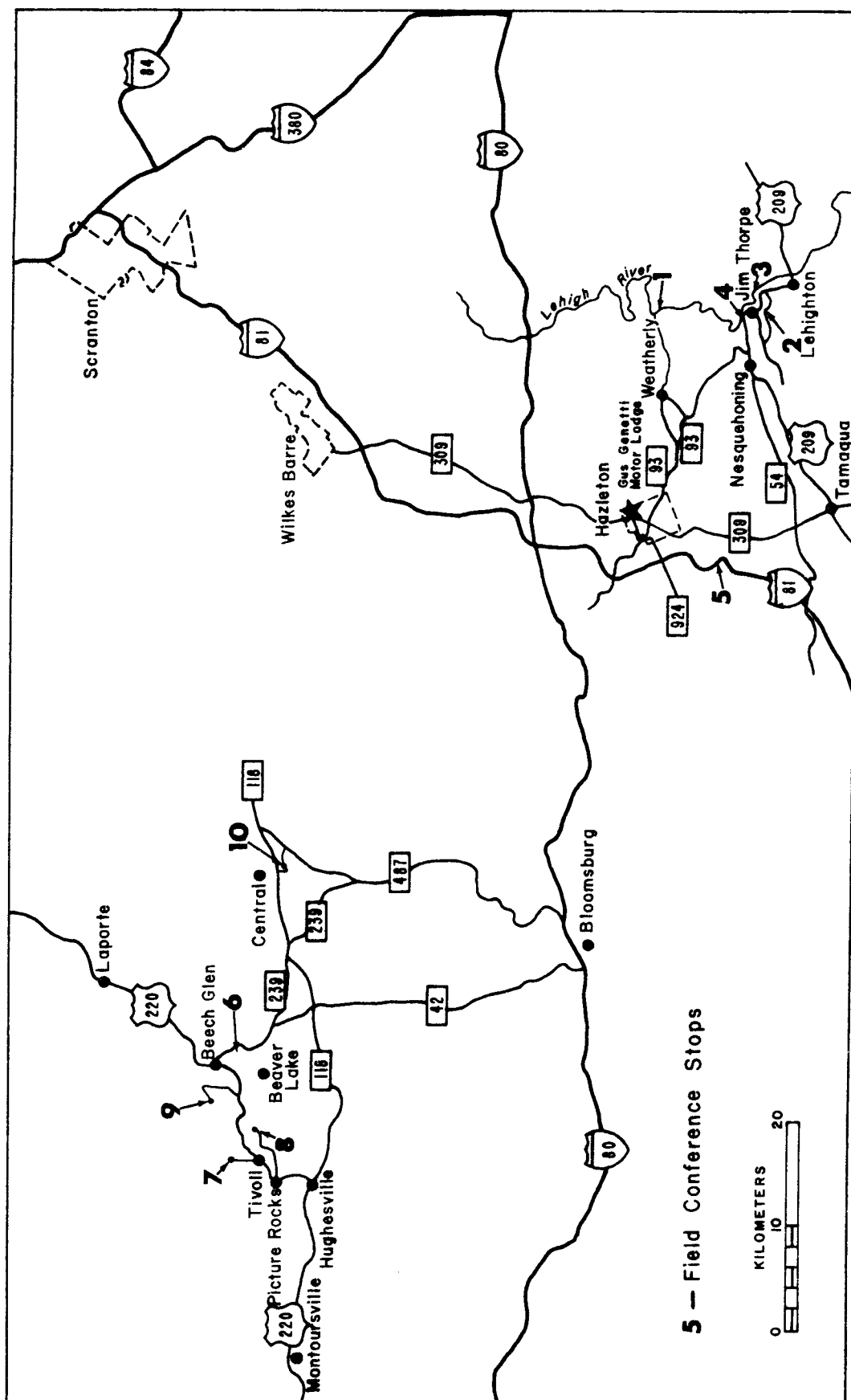


Figure 24. Route map for 1978 Field Conference of Pennsylvania Geologists.

ROAD LOG

DAY 2

Saturday, 7 October 1978

<u>Cum. Mil.</u>	<u>Inc. Mil.</u>	
0.0	0.0	LEAVE parking lot of Gus Genetti Motor Lodge. TURN RIGHT onto PA Rte. 309 North. Route map is Figure 24.
5.8	5.8	EXIT PA Rte. 309 North onto Interstate I-80W.
36.0	30.2	EXIT Interstate I-80W onto PA Rte. 42 North.
36.3	0.3	YIELD sign. BEAR RIGHT onto PA Rte. 42 North.
37.3	1.0	STOP sign. TURN LEFT following PA Rte. 42 North.
54.4	17.1	STOP sign. Junction PA Rtes. 42 and 118. CONTINUE straight ahead.
57.4	3.0	STOP sign. BEAR LEFT following PA Rte. 42 North. For the next 0.8 mile note well-developed Woodfordian end moraine.
60.3	2.9	TURN LEFT onto small dirt road. Continue straight on road to sharp left turn at 0.2 mile. Turn LEFT and continue to quarry.
60.7	0.4	STOP 6. John Jordan borrow pit. Type 3 uranium occurrence (p. 77). LEAVE STOP 6. RETURN to PA Rte. 42 North via same route.
61.1	0.4	STOP sign. TURN LEFT onto PA Rte. 42 North.
62.8	1.7	STOP sign. Junction PA Rte. 42 and U.S. Rte. 220. TURN LEFT onto U.S. Rte. 220 South.
63.7	0.9	Outcrop of red Catskill Formation on left. All red rock seen between here and Stop 10 will be Catskill Formation.
64.4	0.7	Lycoming County line.
67.4	3.0	Cross Muncy Creek.
69.3	1.9	End of excellent outcrop of Catskill Formation. Sequence displays red, lower delta plain sediments overlain by gray marine sediments. Represents one and possibly two transgressions and regressions. More good exposure in ledges up slope. Good parking 0.2 miles ahead on left.

<u>Cum. Mil.</u>	<u>Inc. Mil.</u>	
70.0	0.7	Village of Tivoli.
70.2	0.2	Cross small bridge and TURN RIGHT onto paved road.
71.8	1.6	STOP 7. McCauley Prospect 24. Type 3 uranium occurrence (p. 80). LEAVE STOP 7 and return to U.S. Rte 220 via same route.
73.3	1.5	STOP sign. Junction with U.S. Rte. 220. TURN RIGHT onto U.S. Rte. 220 South.
73.6	0.3	Outcrop of Upper Devonian Lock Haven Formation on right.
75.1	1.5	Village of Picture Rocks.
75.3	0.2	TURN LEFT onto Water Street.
75.5	0.2	STOP sign. TURN LEFT onto Boston Road and cross bridge.
75.6	0.1	Road fork. BEAR RIGHT onto Cemetary Road.
76.7	1.1	Road fork. BEAR LEFT.
77.9	1.2	Outcrops in road bed of marine siltstones within Catskill Formation. These siltstones mark the uppermost part of the basal marine-nonmarine transition zone.
78.2	0.3	Road intersection. CONTINUE straight ahead.
78.4	0.2	Borrow pit on right in gray marine shales of Catskill Formation.
78.5	0.1	Gate to Bowling Green Corporation property.
79.2	0.7	STOP 8. McCauley Prospect 22. Type 3 uranium occurrence (p. 82). LEAVE STOP 8 and return to U.S. Rte. 220 via same route.
79.9	0.7	Gate to Bowling Green Corporation property.
80.2	0.3	Road intersection. CONTINUE straight ahead.
81.7	1.5	Road fork. BEAR RIGHT.
82.8	1.1	Road fork. CONTINUE straight ahead onto Boston Road.
82.9	0.1	Cross bridge over Munch Creek and TURN RIGHT onto Water Street immediately after crossing bridge.

<u>Cum. Mil.</u>	<u>Inc. Mil.</u>	
83.1	0.2	STOP sign. Junction with U.S. Rte. 220. TURN RIGHT onto U.S. Rte. 220 North.
85.0	1.9	Village of Tivoli.
85.8	0.8	Start of excellent section on left (described at mileage 69.3).
87.7	1.9	Village of Glen Mawr.
88.1	0.4	Cross Muncy Creek.
90.4	2.3	TURN LEFT onto paved road. Kedron United Methodist Church on right after turn.
90.8	0.4	Sullivan County line.
91.6	0.8	Road fork. BEAR LEFT staying on paved road.
93.0	1.4	Road fork. TURN LEFT onto Golder Hill Road.
94.1	1.1	Cross bridge.
94.2	0.1	Road fork. TURN RIGHT. Stone house on right.
94.4	0.2	STOP 9. McCauley Prospect 28. Type 3 uranium occurrence (p. 86).
		LEAVE STOP 9 and return to U.S. Rte. 220 via same route.
94.6	0.2	STOP sign. TURN LEFT onto Golder Hill Road.
95.8	1.2	STOP sign. TURN RIGHT onto paved road.
98.4	2.7	STOP sign. Junction with U.S. Rte 220. TURN LEFT onto U.S. Rte. 220 North.
99.2	0.8	Sullivan County line.
100.6	1.4	Village of Beech Glen.
100.9	0.3	Junction U.S. Rte 220 and PA Rte. 42. TURN RIGHT onto PA Rte. 42 South.
101.7	0.8	North Mountain on left. Upper slopes and crest are Mississippian-Devonian transition zone sandstones, siltstones and shales. Burgoon Formation underlies fire tower at top.
104.7	3.0	Very well developed Late Wisconsinan end moraine topography between here and Franklin Church ahead on left.

<u>Cum. Mil.</u>	<u>Inc. Mil.</u>	
105.3	0.6	Junction PA Rtes. 42 and 239. BEAR LEFT on PA Rte. 239 South.
110.2	4.9	STOP sign. Junction PA Rtes. 239 and 118. TURN LEFT onto PA Rte. 118 East.
113.8	3.6	Cross roads. Continue straight ahead.
114.2	0.4	Cross roads. TURN RIGHT toward Grassmere Park.
114.3	0.1	Entrance to Grassmere Park on right. CONTINUE straight ahead across steel bridge.
114.5	0.2	STOP sign. TURN LEFT.
114.7	0.2	STOP 10. McCauley Prospects 12 and 13. Type 3 uranium occurrences (p. 90). LEAVE STOP 10. CONTINUE straight ahead.
115.1	0.4	Small abandoned road on right leads to vicinity of McCauley Prospects 9 and 10.
116.9	1.8	STOP sign. TURN RIGHT onto PA Rte. 487 South.
118.7	1.8	Passing through Late Wisconsinan end moraine.
120.5	1.8	Road now on surface of Late Wisconsinan outwash plain (valley train).
121.4	0.9	Borough of Benton.
137.0	15.6	Junction of PA Rte. 487 and Interstate I-80. TURN LEFT onto Interstate I-80 E.
160.6	23.6	Junction of Interstates I-80 E and I-81 S. CONTINUE straight ahead.
163.7	3.1	EXIT RIGHT to PA Rte. 309.
163.9	0.2	STOP sign. TURN RIGHT onto PA Rte. 309 South.
169.7	5.8	TURN LEFT into Gus Genetti Motor Lodge parking lot. END OF TRIP! Have a safe journey home.

STOP 1. Penn Haven Junction uranium occurrences.

The Penn Haven Junction uranium occurrences (Klemic and others, 1963) are exposed discontinuously in the Lehigh River gorge from Penn Haven Junction south for approximately 2.5 km (Map 1, Appendix). The entire field conference group will visit the roll front exposed on the west side of the Lehigh River. Those not desiring to participate in extended discussion at the roll front (see cover), will have the option of hiking to and seeing one of the following: (1) the minor yellow secondary U minerals on the more weathered E shore continuation of the roll front, (2) a small Cu-U lens and the "feeder" conglomerate at Schmiermund's (1977) "Tank Hollow," and (3) the unique lithologies of the Spechty Kopf Formation in an excellent river-side exposure on the east bank of the Lehigh River.

The Penn Haven Junction roll front occurrence area is located on the west shore of the Lehigh River about 0.45 miles (0.75 km) SSE by road from the Lehigh Valley Railroad bridge over the Lehigh River at its confluence with Black Creek. Most of the land surrounding the occurrence is part of State Game Lands No. 141, but the roll front exposure in the railroad cut is reported to be within the ConRail right-of-way and under lease to Exxon. Broad Mountain to the west of the railroad cut is privately owned and, based on the new bulldozer access road, is being actively explored. Similarly, numerous deep drill holes have been spotted on the private tracts fringing State Game Lands No. 141.

The roll front exposure proper is located about 225 m S of where Maple Hollow enters the Lehigh River and 140 m NW of "Ice Box Hollow," Lehigh Township, Carbon County, in the Christmans quadrangle. The elevation estimated from the topographic map is 730 feet (222 m). The latitude and longitude are 40°56'28"N/75°44'38"W.

As described in detail by Klemic and others (1963) and Schmiermund (1977), the main "C" roll is about 25 m long and 1 m thick with typical surface radioactivities of about 0.5-2 mR/hr. Most interesting, perhaps, is the discordant north end of the roll where the base to "C" crest height is almost 5 m. The third dimension was tested by Eastern Uranium, Inc. during the late 1950's and by Exxon in 1974, but the data are not available and the holes have been plugged.

The roll front zone is located essentially on the contact between the Clark's Ferry and Duncannon Members of the Catskill Formation (Sevon, 1975a; Rose and others, 1977). [At Penn Haven Junction, the thickness of the Duncannon has been measured as 230 m from the Clark's Ferry transition to the base of the distinctive Spechty Kopf Formation (Rose and others, 1977)]. The top of the outcrop (Figure 25) exposes a 2 to 5 m thick, tan to pinkish, coarse-grained sandstone-conglomerate which constitutes the hypothesized feeder channel (Figure 15, p. 26) and (Klemic and others, 1963, Plate 2). Beneath this conglomeratic lens, there is a discordant zone 6 to 7 m thick of oxidized sandstones which parallels the overlying conglomerate. The oxidized sandstones terminate across a gradational contact with reduced sandstone less than a meter south of the crest of the roll (Rose and others, 1977). The roll front itself appears to represent uranium which has been immobilized by reduced rocks into a partial halo around the oxidized conglomeratic lens and sandstones. Note that the crest of the roll front, which



Figure 25. Uranium-bearing rocks of the uppermost Clark's Ferry Member or lowermost Duncannon Member of the Catskill Formation. Outcrop occurs along the Conrail railroad track on the west side of the Lehigh River about 0.75 km SSE from the railroad bridge over the Lehigh River at the confluence with Black Creek. Scale is divided into feet. The "C-roll" is to the left of the scale.

contains the richest bulk uranium ore, is located beneath the area where the conglomeratic lens thins. This, as well as the facing direction of the "C" crest, suggests that the uranium-bearing solutions were advancing toward the northwest. As will also be noted for "Tank Hollow," uranium could be concentrated on the redox boundary above the feeder conglomerate, but fresh exposures are not available at this particular site to verify this.

Rose and Schmiermund (Schmiermund, 1977, p. 71; Rose and others, 1977, p. 24) analyzed representative, channel-collected samples through the north end of the roll front ore zone and found them to contain 1,100 ppm U, 850 ppm Pb, and 130 ppm Se. They found that a high-graded chip sample from the same area contains 5,200 ppm U, 2,700 ppm Pb, and 390 ppm Se. Can you detect an odor of freshly-broken ore samples from this area? Some geologists claim the ability to smell an Se compound here.

Klemic and others (1963) reported that the primary ore minerals within the roll front are uraninite and clausthalite (PbSe). The uraninite is reported to occur as black or dark-gray specks about 5 micrometers in diameter, occurring interstitially to the clastic grains. The clausthalite occurs in angular, interstitial grains up to about 1 mm and, like the uraninite, tends to be most concentrated in laminae. In hand sample, the clausthalite resembles its cousin, galena (PbS). The ore host is a fine-grained, gray sandstone which is reported by Klemic and others (1963, p. 78) to contain abundant chlorite and sericite. Scattered blebs of pyrite up to about 5 mm occur in rich ore as well as rare chalcopryrite.

Secondary minerals reported by Klemic and others (1963) include kasolite, uranophane, and possibly, red earthy "selenium bloom" near weathered clausthalite. Schot and Wegrzyn (1974) also verified sklodowskite ($\text{Mg}(\text{UO}_2)_2(\text{SiO}_3\text{OH})_2 \cdot 5\text{H}_2\text{O}$) in association with uraninite within authigenic chlorite. During reconnaissance for the field conference, the secondary uranium phosphates phosphuranylite, renardite(?), meta-autunite(?), and rare torbernite(?) were observed in a tan to gray, coarse-grained sandstone with quartz pebbles and shale chips. The minerals were noted 4 m NW of the roll front "C" and 0.5 m above the railroad grade.

A 1.7 m long and 4 mm thick, uraninite-rich laminae near smaller clausthalite laminae was noted at the base of the roll front during studies for the field conference. It is centered about 2 m S of the crest of the "C" roll. The radioactivity of mere 2 cm x 2 mm chips from this laminae are up to 18 mR/hr. This is the highest natural activity known in Pennsylvania. X-ray diffractometer scans of the laminae show that it consists of major amounts of uraninite and quartz, minor kasolite and a feldspar, possibly orthoclase, and probable traces of "illite," a chlorite, and albite. The sparse canary yellow secondary mineral which formed on the upper surface of the laminae is probably renardite ($\text{Pb}(\text{UO}_2)_4(\text{PO}_4)_2(\text{OH})_4 \cdot 7\text{H}_2\text{O}$). The more abundant, earthy-tan coating is kasolite. Assays and trace element analyses of the laminae are in progress. U-Pb isotopic age determinations of uraninite from the fresh, clausthalite-free interior of the laminae are recommended.

A previously undescribed, uraniferous plant fragment zone up to 5 cm thick occurs in an olive gray to dark gray, fine-grained, micaceous sandstone located 37.5 m south of the north limit of the roll front "C" crest, and at the approximate railroad track elevation. An exposure 60 cm long has an average radioactivity of 0.7 mR/hr with activities diminishing rapidly above and below. Sparse amounts of brownish-yellow and greenish-yellow secondary uranium minerals were noted in close association with the plant fragments, here largely replaced by a chlorite. Prominent bedding plane slickensides and abundant vuggy, quartz-filled fractures occur in the dark gray, fine-grained sandstone immediately above the plant fragment zone. This plant fragment zone has a probable lateral extension along outcrop of 8 m as indicated by the 30 cm thick, tabular radioactive zone shown in Plate 2 of Klemic and others (1963).

Option 1: East shore uranium occurrences.

The eastern continuation of the Penn Haven Junction roll front zone (Figure 16, p. 27) is exposed in the abandoned railroad cut 226 m SE of Maple Hollow, Penn Forest Township, just above the old railroad grade level. The latitude and longitude are 40°56'24"N/75°44'32"W.

This occurrence, about 120 m along strike from the west shore occurrence, consists of three en echelon "C-rolls" "...producing a nearly continuous mineralized zone over 250 feet [75 m] long (see Klemic et al., 1963) with sporadic extensions over another 100 foot [30 m] interval" (Rose and others, 1977, p. 12 & 14). The conglomerate feeder is present, but less well defined here and the steepness of the outcrop hinders detailed study.

The secondary uranium minerals at this occurrence include: phosphuranylite ($?, \text{Ca}(\text{UO}_2)_4(\text{PO}_4)_2(\text{OH})_4 \cdot 7\text{H}_2\text{O}$), fourmarierite ($\text{PbU}_4\text{O}_{13} \cdot 4\text{H}_2\text{O}$),

dewindtite ($?, \text{Pb}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 3\text{H}_2\text{O}$), vandendriesscheite ($\text{PbU}_7\text{O}_{22} \cdot 12\text{H}_2\text{O}$), possible meta-uranocircite ($\text{Ba}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$), and unidentified bright yellow coatings. The maximum radioactivity observed in the vicinity of the secondary minerals is about 3 mR/hr.

Option 2. "Tank Hollow" uranium occurrences.

Those opting to visit the "Tank Hollow" area of Schmiermund (the real Tank Hollow is located 4.5 km to the NE) will have the opportunity to observe trace mineralization in and above the "feeder" conglomerate. The Cu-U mineralized outcrop to be examined is located about 35 m SW of "Tank Hollow" at an elevation of approximately 710 feet (216 m). The latitude and longitude are $40^\circ 55' 38'' \text{N} / 75^\circ 44' 44'' \text{W}$.

The Cu-U bearing fossil plant zone is exposed for 1.8 m along bedding and has a maximum thickness of 25 cm. The host rock is a greenish gray, very micaceous, coarse-grained sandstone with sparse quartz pebbles. The maximum radioactivity on contact is only 0.20 mR/hr. The mineralized zone is part of a reduced series of sandstone beds overlain by the pinkish feeder conglomerate located 55 cm above and by grayish-red, micaceous sandstone with coarse, greenish mica, located 45 cm below. Rose and others (1977, p. 14) note that this Cu-bearing plant fossil zone is actually enclosed within the oxidized "feeder" conglomerate. The finder of the Cu zone interprets this outcrop as one where the quantity of reducing plant trash was adequate to "buffer" the Eh and prevent remobilization of oxidized uranium by the roll-front forming process. Malachite is the only "ore" mineral that has been observed here.

The other occurrences found by Schmiermund (1977) in "Tank Hollow" occur in somewhat weathered rock above the feeder conglomerate and appear to lack the fossil plant fragments and copper enrichment of the lower zone. The "Tank Hollow" occurrences are located in Figure 26.

An emerald green mica can be observed on the top of the bluff about 50 m N of "Tank Hollow." Schmiermund (1977) identified the mica, which occurs along slickensides and replaces shale chips, as a chromium-bearing muscovite. X-ray powder diffraction data tend to fit the vanadium-bearing mica, roscelite. The mean refractive index is 1.606 ± 0.003 . Semi-quantitative, trace element analyses are in progress. Chromium, typically a dispersed element in sedimentary rocks, has apparently been remobilized and concentrated by the roll front-forming process, but the geochemical and geometrical relations are unclear.

An occurrence with metatorbernite in reduced sandstone with shale chips has been extensively drilled about 0.75 mile (1.2 km) by road NNE of "Tank Hollow." This occurrence is about 0.15 mile (0.25 km) SSW of "Ice Box Hollow" and 0.25 mile (0.4 km) by road (or 390 m by pacing) SSW of the crest of the roll front. The recent, extensive drilling suggests more than a casual interest in the occurrence.

The center of the western Butcher Hollow uranium occurrence of Klemic and others (1963, Plate 2) is located 254 m S of "Tank Hollow." The occurrence is of limited lateral extent and is exposed in a small anticline in the Duncannon Member of the Catskill Formation. The latitude and longitude are $40^\circ 55' 13'' \text{N} / 75^\circ 44' 32'' \text{W}$.

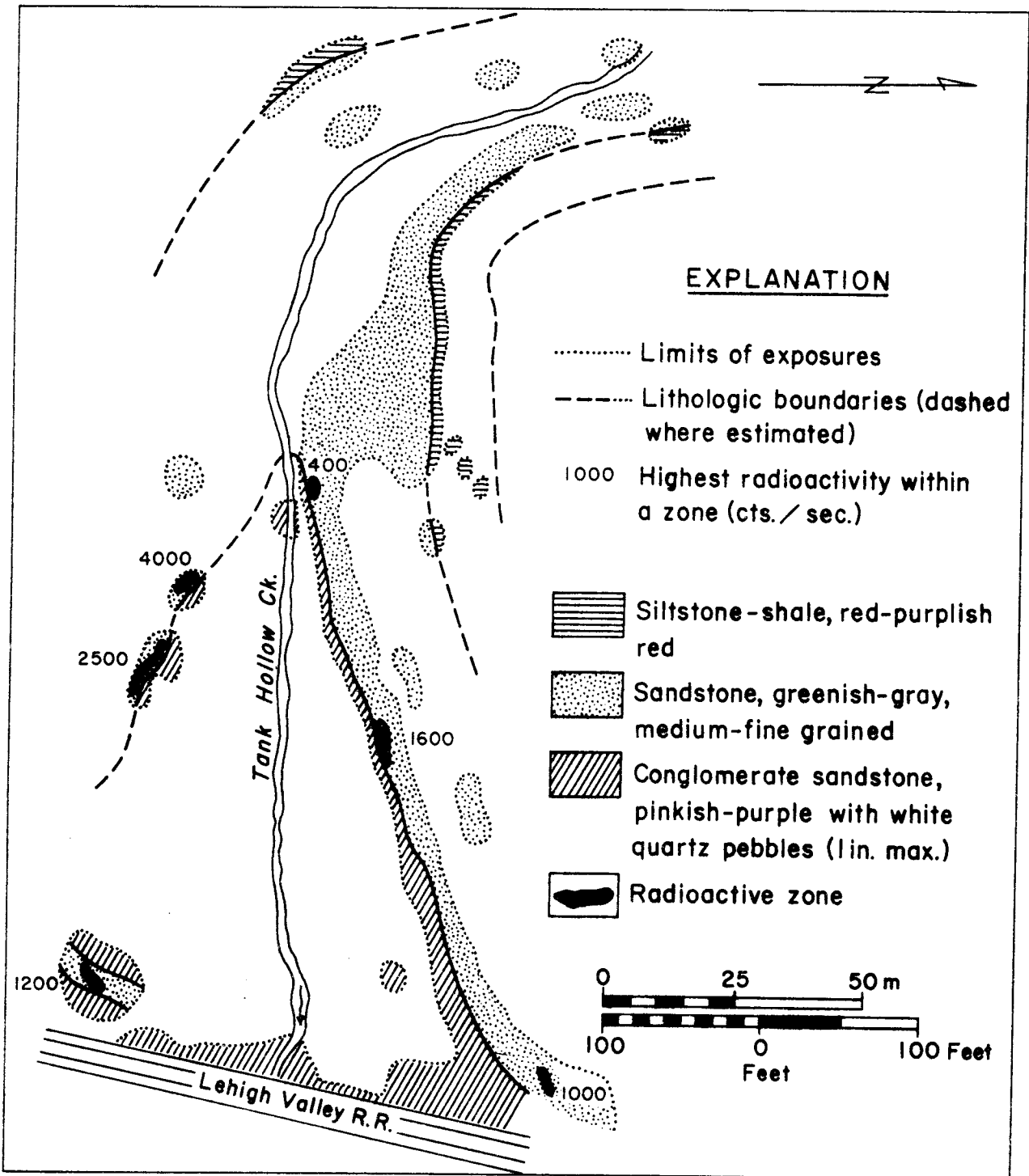


Figure 26. Map of known uranium occurrences in rocks of the Catskill Formation at "Tank Hollow Creek," on the west side of the Lehigh River, 1.85 km south of Penn Haven Junction. From Schmiermund, 1977, Plate 4.

Radioactivities up to about 3 mR/hr were obtained 19 m S of the Butcher Hollow anticlinal crest and 1.2 m above the railroad grade. The highest readings are centered above and below a small, 12 cm thick and 40 cm long slump(?) structure consisting chiefly of grayish-olive siltstone-shale with an average radioactivity of 1.3 mR/hr. Using a 1.0 mR/hr cutoff, there is 50 cm of medium dark gray, medium-grained sandstone above the slump structure with an average radioactivity of 2.0 mR/hr. The upper zone contains primary pyrite, rare clausthalite(?) and uraninite(?). Ten cm of medium dark gray to very dusky red-purple, coarse-grained, graywacke sandstone with shale clasts and sparse quartz pebbles occur below the slump structure. This zone also contains primary pyrite and probable uraninite and has an average radioactivity of 1.5 mR/hr. The maximum radioactivity observed at Butcher Hollow, 4 mR/hr was obtained after removal of the weathered part of the zone which contained secondary uranophane and rare metatorbernite. The radioactivity of this uraniferous zone drops to 0.08 mR/hr 1 m to the north of the slump structure, but maintains an average of 0.7 mR/hr for 3.5 m to the south.

Option 3. Spechty Kopf Formation.

Rocks of the Spechty Kopf Formation are exposed along the east bank of the Lehigh River (40°56'39"N/75°44'44"W) a few tens of meters south of the railroad bridge over the Lehigh River. At the base of the sequence are 2.7 m of gray to grayish-red sandstone overlain by 1.8 m of grayish-red siltstone. These units are the uppermost beds of the Duncannon Member of the Catskill Formation. Above a disconformable contact with the red siltstone, the Spechty Kopf Formation comprises a gradational sequence as follows: 7.3 m of polymictic diamictite containing the pebble suite described on page 11; 5.9 m of pebbly mudstone with clasts up to 10 cm in diameter; 1.9 m of laminite; and 26.6 m of planar-bedded and rippled sandstones with interbedded siltstones. This sequence is described in greater detail elsewhere (Sevon, 1975a, Plate 2, Section 4) and the origin of this part of the Spechty Kopf has been contemplated several times (Sevon, 1968b; 1969a & b; 1973). The polymictic diamictite resembles a tillite, the pebbly mudstone probably requires deposition in a subaqueous environment, as does the laminite, and the sandstones have some resemblance to beach sediments. This interesting sequence probably holds the key to events in the central Appalachian basin at the end of the Upper Devonian.

STOP 2. Flagstaff Mountain Park: Peneplains, visual wonders and LUNCH!

Flagstaff Mountain Park is on the crest of Mauch Chunk Ridge 0.8 km south of the center of Jim Thorpe. The park pavilion is at an elevation of about 1305 feet (397 m) and the Lehigh River directly below is at an elevation of about 510 feet (155 m). Maximum local relief occurs to the northeast at the river bend across from Packerton Junction (Stop 3) where elevations of 500 feet (152 m) and 1480 feet (451 m) give 299 m of relief. The elevation at the base of the Bear Mountain fire tower farther to the northeast is 1685 feet (514 m). Figure 27 is a panoramic view from the pavilion.

The pavilion sits on the uppermost part of the Berry Run Member of the Catskill Formation and the contact with the overlying Clark's Ferry Member is just to the north of the pavilion. The rocks here and in the valley below dip generally between 70° and 80° toward N40W into the Mount Pisgah syncline which has its axis 1.7 km to the north.



Figure 27.

Panoramic view from the pavilion at Flagstaff Mountain Park, Carbon County, Pennsylvania. U. S. Route 209 at right margin. Bear Mountain with fire tower at skyline extreme right. Railroad tracks either side of Lehigh River. Stop 3 is just out of sight near the right (south) end of the railroad bridge across the Lehigh River near right margin. Pocono Formation forms crest of long spur running from right margin to center. Jim Thorpe sewage treatment plant in lower left center opposite excellent section of Spechty Kopf Formation along Conrail railroad track. Town of Jim Thorpe in lower left central left of Lehigh River. Dark building with steeple in center of Jim Thorpe is county court house. White house immediately behind is Asa Packer mansion. Bridge in center is Pa. Route 903 to East Jim Thorpe and points NE. Straight line distance from center of bridge ENE to Bear Mountain fire tower is 3.15 km. Mt. Pisgah is dark hill at skyline on left. Whole skyline is Schooley peneplain level.

The NE-SW trending segment of the Lehigh River seen below is cutting into the Duncannon Member of the Catskill Formation and approximately parallels bedding strike. Some Duncannon rocks crop out near the base of the valley wall north of this segment, but most of the slope is Spechty Kopf Formation. The narrow crest of the ridge is formed on basal conglomerates of the Pocono Formation.

The somewhat concordant, upper elevations which can be imagined here correspond to the remnants of the Schooley peneplane surface that presumably existed about 60,000,000 years ago. Subsequent dissection has apparently resulted in superimposition of the Lehigh River onto the rocks underlying this surface. The relationship of the present course of the Lehigh to the structure of the area is shown in Figure 1.

The former existence of subdued landscapes throughout most of the world during the Upper Cretaceous is fairly well established (Worsley, 1971) and the presence in North America of humid subtropical conditions at least as far north as Minnesota seems reasonable (Austin, 1970). Under such conditions acidic waters introduced into groundwater circulation systems would carry silica and other minerals in solution which would be precipitated when more alkaline conditions were encountered. If, as Wilson and Fairbridge (1971) have suggested, three such events have occurred at 200×10^6 , 130×10^6 and 60×10^6 years ago and their postulated landscape existed, then ample opportunity has occurred for the development of silicified sandstones and conglomerates as well as mineral concentrations such as those being observed in this area.

Nestled in the valley between Mt. Pisgah and Mauch Chunk Ridge is the town of Jim Thorpe, formerly Mauch Chunk, the birthplace of the Olympian Jim Thorpe, and sometimes locally called the Switzerland of America. One hundred and fifty years ago, Mauch Chunk abounded in activity when anthracite coal was king and the Lehigh Valley Railroad and the Lehigh Canal carried it south to market. Asa Packer, founder of the Lehigh Valley Railroad and Lehigh University, made his fortune here and his former home is the prominent large white house uphill from the red Carbon County court house at the center of town. The stone structures along the river banks by the Jim Thorpe sewage treatment plant at the bend in the river are remnants of the successful Lehigh Canal constructed by Josiah White, one of the builders of Mauch Chunk (Morton, 1946). Jim Thorpe is an interesting and historical town with some fascinating architecture. Jim Thorpe is cited in the Stratigraphic Code as a type example of procedure: a formation name (Mauch Chunk) is not changed when the locality name (Mauch Chunk) is changed (Jim Thorpe).

STOP 3. Packerton Junction. Type 1 uranium occurrence.

The Mauch Chunk Ridge U occurrence exposed at Packerton Junction is located 1.38 km E of the old train station in Jim Thorpe, Mahoning Twp., Carbon County, Pennsylvania, in the Lehighton quadrangle. The occurrence is exposed in the ConRail (formerly Central of New Jersey) railroad cut at Packerton Junction (Figure 28). The occurrence can best be relocated by walking 75 m S65E from the center of the ConRail (formerly Lehigh Valley) bridge over the Lehigh River to near a concrete signalman's shelter and thence 65 m S39E to the outcrop. The elevation estimated from the topographic map is 525 feet (160 m). The latitude and longitude are $40^{\circ}51'49''\text{N}/75^{\circ}43'20''\text{W}$.



Figure 28. Mauch Chunk Ridge uranium occurrence at Packerton Junction, 1.38 km E of the old train station in Jim Thorpe, is in uppermost part of the Clark's Ferry Member of the Catskill Formation. Scale is divided into feet.

Similar to the Zimmerman Prospect (Smith, 1977) located 220 m along strike to the ENE and the west end of Klemic's (1962) Prospect 25 located 1.2 km along strike to the WSW (Map 2, Appendix), a small amount of prospecting was done at Packerton Junction in the 1950's. Here, the only evidence of prospecting remaining today is the few, shallow drill holes. The undercutting of the ledge is a more recent testimony to the industry of mineral collectors.

The Packerton Junction uranium occurrence is in the uppermost part of the Clark's Ferry Member of the Catskill Formation. The presumed base of the overlying Duncannon Member is 5.45 m above the main uranium lens (Table 3). The contact between the two members is not always distinct, but is placed at the base of the first fining-upward cycle in a dominantly red sequence. The Clark's Ferry Member comprises braided-river sandstones and conglomeratic sandstones (Figure 7, p. 18) which are admirably exposed on U.S. Route 209 above this stop. The Duncannon Member, equally well-exposed on the road above this stop, represents a series of meandering-river deposits (Figure 10, p. 20) thought to have been deposited in a fine-grained meander-belt. Twelve fining-upward cycles occur in the exposures along U.S. Route 209.

The mineralized ore zone itself is in a light olive-gray (5Y5/2), coarse-grained sandstone with abundant medium gray (N5) shale chips and rounded quartz pebbles up to 2.4 x 1.4 cm. The mineralization pinches out immediately up dip: 2.7 m from base level, the radioactivity is only 0.1 mR/hr and 0.05 just above this. Using a 0.15 mR/hr cutoff, the mineralized zone has a maximum thickness of 40 cm. A Geiger probe inserted 85 cm into the 1954 Lehigh Coal and Navigation Co. hole parallel to bedding encountered 0.4 mR/hr for its length. Obviously, the mass effect on the radioactivity is substantial.

The typical radioactivity within the cleft is 2.5 mR/hr, and the maximum is 4.0 mR/hr. This latter can be obtained on the black, carbonaceous, pyritic plant fragments and seams rather than the yellow and green secondary uranium minerals. Typically, the carbonaceous plant fragments have a more nearly cylindrical cross-section than fragments from most Catskill uranium occurrences. Yellow and green U secondary minerals are often haloed around such carbonaceous plant fragments. Plant fragments 17 cm long have been observed within this zonation. Several leaner U-bearing zones are briefly described in the stratigraphic section presented in Table 3.

Bedding near the main mineralized zone trends N65E and dips 65° towards N25W. The orientation of slickenside surfaces is somewhat more variable. Typically, the surfaces trend about N70E and dip 80° toward N30W with a lineation trend of N10W and a plunge of 75°. Traditional interpretation of the "chatter" on most of the slickensides suggests that the footwall has moved downward relative to the hanging wall, thus making these surfaces small reverse faults presumably reflecting bedding slip outward from the center of the Mt. Pisgah syncline. Note that the two best mineralized zones at Packerton Junction are closely associated with "reverse faults." However, it would not be surprising to find that the most competent, massive sandstone-conglomerate beds have also been the most permeable prior to folding.

The minerals from this occurrence include: francevillite ($\text{Ba}(\text{UO}_2)_2(\text{VO}_4)_2 \cdot 5\text{H}_2\text{O}$) as bright, canary yellow, microcrystalline coatings on shale clasts and limonite-stained sandstone; meta-uranocircite ($?, \text{Ba}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$) as greenish, micaceous flakes that are fluorescent brilliant green; meta-autunite ($\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 2-6\text{H}_2\text{O}$) as yellowish green micaceous flakes that are fluorescent brilliant green; meta-torbernite ($\text{Cu}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$) as bright apple green, micaceous flakes; pyrite as rich disseminations in the carbonaceous seams and plant fragments; and several unidentifiable, orange, secondary, uranium minerals.

The Mauch Chunk Ridge U.S. Route 209 U occurrence, not to be examined on this field conference, is located on the S side of U.S. Route 209, 0.5 km SSE of the old train station in Jim Thorpe. Using a 0.1 mR/hr cutoff, the main U-bearing zone here is 1.6 m thick. Radioactivity at the center of this zone is 1.6 mR/hr and this tapers off gradually toward the margins. The host rock here is an olive gray (5Y4/1), medium- to coarse-grained, micaceous sandstone with gray shale chips. The primary mineral has not been identified, but phosphuranylite, meta-autunite, uranophane, meta-uranocircite(?), and rare billietite ($\text{BaU}_6\text{O}_{19} \cdot 11\text{H}_2\text{O}$) have been found on the cliff. (Note the presence of Ba-bearing secondary species here, just as along strike at the Packerton Junction occurrence.) Other uraniferous zones in the Mauch Chunk Ridge

U.S. Route 209 roadcut are summarized in Table 4. Note that the stratigraphic range for uraniferous beds is about 10 m and that gray sandstone beds occur in the Duncannon Member of the Catskill Formation.

Table 3. Stratigraphic section of the uppermost part of the Clark's Ferry and the lowermost part of the Duncannon Members of the Catskill Formation exposed in the ConRail (Central of New Jersey) railroad cut at Packerton Junction, Mauch Chunk Ridge, Carbon County, Pennsylvania.

<u>Thickness</u> (meters)	<u>Radioactivity</u> (± 0.02 mR/hr)	<u>Petrology</u>
> 5	0.03	Grayish red (5R4/2), fine-grained, micaceous sandstone.
0.9	0.02	Pale brown (5YR5/2), fine- to medium-grained sandstone.
~ 5.5	0.02	Grayish red (10R4/2) to brownish gray (5YR4/1), coarse-grained sandstone with conglomeratic zones. Colors somewhat variable.
0.8	0.03	Pale brown (5YR5/2) coarse-grained sandstone-quartz pebble conglomerate. Top of bed is a slickenside surface.
0.4	0.04	Grayish red (5R4/2), fine-grained, micaceous sandstone.
2.1	0.03	Grayish red (5R4/2) quartz-pebble conglomerate.
0.6	0.04	Grayish red (5R4/2), coarse-grained sandstone with dusky red (5R3/4) shale clasts. Base of Duncannon Member.
0.4	0.15	Olive gray (5Y4/1) coarse-grained sandstone-quartz pebble conglomerate. Top of Clark's Ferry Member. Trace secondary uranium minerals.
1.2	0.06	Light olive gray (5Y5/2), slightly micaceous, coarse-grained sandstone.
1.1	0.05	Light olive gray (5Y5/2), medium-grained sandstone.
0.35	0.03	Light olive gray (5Y5/2), silty mudstone to siltstone containing shale clasts.
2.4	0.04	Light olive gray (5Y5/2), medium- to coarse-grained massive bedded sandstone. Very large slickenside surface.
0.4 max.	0.15-2.5	Light olive gray (5Y5/2), coarse-grained sandstone with medium gray (N5) shale chips, and pyritic, carbonaceous plant fragments. Main mineralized zone. See text.
1.0	0.12	Light olive gray (5Y4/1) to light gray (N7), medium- to coarse-grained, thick-bedded sandstone with a few quartz pebbles.
1.1	0.05	Medium light gray (N6), fine- to coarse-grained sandstone that is highly micaceous in some zones and has greenish gray (5GY6/1) shale clasts in others.

Table 3. (Continued)

<u>Thickness</u> (meters)	<u>Radioactivity</u> (± 0.02 mR/hr)	<u>Petrology</u>
3.8	0.03	Medium gray (N5), coarse-grained sandstone with scattered quartz pebble and one sheared 0.3 m thick conglomeratic zone. Trace pyrite in fresh gray sandstone.
0.2	0.03	Medium dark gray (N4) shale.
4.2	0.03	Light olive gray (5Y5/2), medium- to coarse-grained sandstone.
0.8	0.03	Olive gray (5Y3/2) to grayish red (5R4/2) siltstone and shale.
1.2	0.03-0.04	Dark greenish gray (5GY4/1) siltstone to grayish olive green (5GY3/2), fine-grained, highly micaceous (on bedding) sandstone.
0.04	0.02-0.03	Between light olive gray (5Y6/1) and olive gray (5Y4/1), coarse-grained sandstone.
1.0	0.03	Grayish olive (10Y4/2), thick to thin-bedded, fine- to medium-grained, very micaceous (on bedding) sandstone.
3.0	0.06 avg. 0.10 max.	Light olive gray (5Y5/2), coarse-grained, sandstone with scattered quartz pebbles.
1.0	0.03-0.04	Light olive gray (5Y5/2), fine- to medium-grained, micaceous (on bedding) sandstone.
0.5	0.03-0.04	Olive gray (5Y4/1), coarse-grained sandstone with shale chips and quartz pebbles. At the white-striped, green-trunked maple tree at ground level, this bed is oxidized to a grayish red (5R4/2) color.
3.3	0.03	Light olive gray (5Y5/2), fine- to medium-grained, slightly micaceous sandstone with siltstone laminae at the tops of a few beds.
1.4	0.03-0.04	Medium light gray (N6) to medium gray (N5), medium- to coarse-grained sandstone.
0.4	0.06 avg. 0.12 max.	Medium dark gray (N4) to medium gray (N5), medium-grained, micaceous sandstone with sparse plant fossils. Medium dark gray (N4) shale clasts in upper part. Lower part not significantly radioactive.
3.7	0.02	Grayish red (5R4/2), coarse-grained sandstone with sparse quartz pebbles.
1.5	0.02	Olive gray (5Y4/1), very coarse-grained sandstone-quartz pebble conglomerate with grayish red (5R4/2) siltstone and shale clasts.
End of description		Packerton Junction Interchange shed is 25 m from the projection of the bottom of the described section onto the gravel road.

Table 4. Summary of uraniferous beds exposed in the Duncannon and Clark's Ferry Members of the Catskill Formation, Mauch Chunk Ridge, U.S. Route 209, S of Jim Thorpe, Carbon County, Pennsylvania.

<u>Approx. Strat. Position relative to main zone</u>	<u>Thickness (meters)</u>	<u>Radioactivity (mR/hr $\pm$ 0.5)</u>	<u>Petrology</u>
8 m below	0.5	≥ 0.1 mR/hr av. 0.45 max.	Medium dark gray (N4), medium- to coarse-grained, micaceous sandstone.
Main zone	1.6	≥ 0.1 at margins up to 1.6 at center	Olive gray (5Y4/1), medium- to coarse-grained, micaceous sandstone with gray shale chips. (Bearing from here to town clock tower is N27W.
17 m above	0.7	≥ 0.1 1.0 max.	Light olive gray (5Y5/2), medium-grained, micaceous sandstone. Trace metatorbernite.
19 m above	0.25	≥ 0.1	Olive gray (5Y4/1), fine-grained, micaceous sandstone. This zone is overlain by predominantly reddish-gray sandstone, but immediately above is a red shale chip-quartz pebble conglomerate.
24 m above	0.9	≥ 0.05 av. 0.15 max.	Grayish olive (10Y4/2) siltstone. Includes fine-grained sandstone laminae. R is erratic. Rock above is predominantly pinkish gray, coarse-grained sandstone-quartz pebble conglomerate.
89 m above	0.35	~ 0.1 av. 0.15 max.	Medium dark gray (N4), fine- to medium-grained micaceous sandstone. R increases uniformly from cutoff of 0.05 to 0.15 at center. (Bearing from here to town clock tower is N10W).

STOP 4. Mount Pisgah. Type 2 uranium occurrence.

CAUTION: U.S. Route 209 is heavily travelled and the berm is narrow--be careful.

The Mount Pisgah uranium-vanadium occurrence is located in the roadcuts on the S side of U.S. Route 209, approximately 1.3 km NW of the train station in Jim Thorpe, Mauch Chunk Township, Carbon County, Pennsylvania, in the Lehighton quadrangle. The occurrence consists of mineralization for over 500 m along the highway and three small adits dug by the Lehigh Coal and Navigation Company in 1953. McCauley (1961, p. 9) reports that 300 tons of

ore were removed from the adits in order to qualify for an Atomic Energy Commission production bonus. These adits were backfilled just prior to efforts to obtain quantitative data for the field conference. At present, the motive for the backfilling is unknown. The elevation estimated from the topographic map is about 675 feet (205 m). The western adit (Figure 29), to be examined on this field conference, is located 180 m E of the horizontal drill hole spring located 4 m W of highway survey station 4/80. The latitude and longitude of the western adit are $40^{\circ}52'20''\text{N}/75^{\circ}44'53''\text{W}$. The other two adits are located 384 and 397 m to the E along U.S. Route 209 from the W adit.

The U and V at Mount Pisgah occur in a series of large lenses of quartz pebble conglomerate lithology within red siltstones and shales. The sequence has been described as the transition between these Pennsylvanian Pottsville and Mississippian Mauch Chunk Formations. Epstein and others (1974) include this transition within the Mauch Chunk Formation for reasons stated on page 204 of their report. Dyson (1954) called it the "U" member of the Mauch Chunk Formation.



Figure 29. Westernmost uranium exploration adit on the north side of Mt. Pisgah along U. S. Route 209 about 1.5 km NW of the train station in Jim Thorpe, Carbon County, Pennsylvania. Scale is divided into feet and stands in front of the backfilled adit.

As shown in Figure 4 of McCauley (1961), the uranium-bearing part of the lens penetrated by the western adit is about 40 m long and 2.5 m thick using a cutoff of 1 mR/hr. The host rock is a carbonaceous, coarse-grained sandstone and quartz pebble conglomerate. Dyson (1954) reported an average thickness of 14 m for this middle unit of his "U" member of the Mauch Chunk Formation. Thin sections of fresh samples of the carbonaceous conglomerate reveal that an optically clear calcite cement is very common. This and the common, thin calcareous coatings on the outcrops and tremendous predominance of tyuyamunite over carnotite(?) suggest that calcite is typically a minor to major mineral. Dyson's upper unit consists of an average of 6.4 m of dark gray sandstone and siltstone overlain by red shale to sandstone. McCauley notes that the upper unit thickens to about 15 m near the eastern end of the occurrence. Dyson's lower unit, in which the two eastern adits are located, is described as consisting of a dark gray sandstone and siltstone, of which only 2 to 3 m are exposed (McCauley, 1961, p. 11).

Klemic (1963) reports fossil logs with a southwestward orientation in the uranium-bearing zones. Most of these, however, were observed in the now inaccessible eastern adits.

The Mount Pisgah occurrence is exposed on the northern limb of the southwest-plunging Mt. Pisgah syncline, approximately in the zone of the speculative Pottschunk Fault (Epstein and others, 1974, Plate 1). Without the benefit of the adit cross sections, precise bedding is difficult to measure because of the numerous slickenside and shear surfaces. Bedding at the W adit was estimated from two possible compositional surfaces as dipping 65° toward S2W. McCauley notes that bedding steepens from 25 to 55° from east to west at the occurrence. Two sets of slickensides have been observed near the W adit. For set A, the surfaces trend N77E, 62S and the lineations N10W, 61S. For set B, the surfaces trend E-W, 46°S and the lineations N, 46°S. Traditional interpretation of the "chatter" on the slickenside surfaces suggests that the hanging wall has moved up. Those slickensided "reverse faults" within ore zones are typically coated with copious amounts of the secondary U-V mineral, tyuyamunite. Carnotite may also be present, but each of the 10 or so samples checked by the Pennsylvania Geological Survey over the years by X-ray powder diffraction appear to be tyuyamunite.

According to Smith (1978, p. 100-103), the primary uranium mineral is coffinite ($\text{U}(\text{SiO}_4)$) based on X-ray powder diffraction and quantitative electron microprobe analyses. Based on the U/Pb elemental ratio from the probe analyses, Smith estimated the age as $333 \pm 35 \times 10^6$ years. This is rather old compared to the generally accepted estimate of 270 ± 5 to 350 ± 10 for the Carboniferous. The error limits for the coffinite reflect only the analytical uncertainty in the PbO and U_3O_8 determinations and the actual error could be very large with this sort of estimate. Because of the greater potential for leaching of U compared to Pb, the age estimate at least suggests the occurrence is not the result of recent remobilization.

Probable coffinite occurs in an area 8.55 m E of the center of the W adit, about 1 m above road level. The coffinite occurs as minute, pitchy black grains in the matrix of the carbonaceous, quartz pebble (up to 9 cm) conglomerate. Here, a 28 cm thick and 1.75 m long zone has a radioactivity of 5 mR/hr with a maximum of approximately 15 mR/hr near the center. Hand samples removed from the outcrop have activities of up to approximately 8 mR/hr.

Assays of the channeled 28-cm sample are in progress. The horizontal drill hole located 1.1 m above road level and 25 cm W of the channeled samples has a radioactivity which gradually increases from the outcrop surface to a maximum of 6.0 mR/hr at 80 cm back into the hole. The fracture surface excavated 8.7 m E of the W adit center (field conference stop) exposes bright yellow tyuyamunite.

The pyritic zones located 5.65 m W of the center of the W adit are somewhat unusual for the Mt. Pisgah occurrence, but were discovered too late to investigate thoroughly. In hand specimen, the pyrite appears to replace the matrix of the conglomerate, much as the calcite does elsewhere. Indeed, the pyrite may have replaced calcite during a remobilization stage. Because of the absence of verified U-V at this horizon elsewhere in Carbon or Schuylkill counties, one of the writers (Smith) suspects that the occurrence might represent remobilization of U during Alleghanian orogenesis from an upper Catskill Formation occurrence that had an inadequate Eh reducing buffer capacity (i.e., not enough carbon). If such an occurrence had existed 1400 m at depth, this transition zone might have been the first permeable, carbonaceous trap encountered by ascending solutions. Or, is this occurrence a clue to uranium in the carbonaceous plant debris zones in the shallow Pocono Formation or even the lowermost, non-economic coals in the Pottsville Formation above? Klemic's (1963, p. 84) references to a roll-like distribution of uranium around barren rock and the pervasive shearing tend to suggest that at least some type of redistribution of primary uranium minerals has occurred.

Virulent rumor has it that Rocky Mountain Energy Corp. encountered ore-grade vanadium during core drilling above the level of U.S. Route 209, but that their holes were not deep enough to test the U-bearing zone. Assays for the commercial, diamond-sawn channel samples to the E and W of the W adit are not available, but radiometric sections are reported in Table 5 and Rose and others (1976) reported 0.18% U, 0.59% V₂O₅, and 0.30% C for a series of chips collected through the ore zone just E of the W adit. Assays up to 1.8% U₃O₈ are reported (Klemic, 1963, p. 85), but the intervals represented are unspecified. Assuming a third dimension of 15 m, the 40x2.5 m lens penetrated by the western adit would contain about 4,500 metric tons of ore. If the ore contains 0.15% U₃O₈ and 0.5% V₂O₅, the respective values for this lens would be 750 K \$ and 150 K \$.

Autunite was first reported from Mauch Chunk by Genth in 1875. Wherry described the occurrence of carnotite (K₂(UO₂)₂(VO₄)₂·3H₂O) from Mauch Chunk 1912. Unfortunately, Wherry's K₂O analysis was done "by difference" and even so, the analysis showed a greater mole percent of CaO than K₂O. In modern terminology, this mineral would be tyuyamunite (Ca(UO₂)₂(VO₄)₂·5-8H₂O), as are all samples checked in recent years.

The minerals which have been verified from the Mt. Pisgah occurrence are tabulated below:

Common: Coffinite as minute, pitchy black grains; calcite as white cleavages common in the conglomerate matrix, also as thin, fluorescent bright green coatings from underhangs; tyuyamunite as bright canary to greenish-yellow crystalline coatings on slickensides, fractures, quartz pebbles, and in the weathered sandstone matrix; uranophane as pale cream yellow to orange coatings; zircon as minute, detrital grains in the conglomerate.

Uncommon: Beta-uranophane as canary to slightly greenish-yellow coatings that fluoresce a dull green from the eastern adits; liebigite as yellow-green crusts that fluoresce brilliant bluish-green; pyrite as massive replacements of matrix to conglomerate.

Rare: Kasolite(?); andersonite as bright yellowish green, water-soluble micro crystals; schroekingerite as minute, greenish-yellow scales which fluoresce green (Montgomery, 1969).

Table 5. Radioactive sections for the commercial, diamond-sawn channels near the westernmost uranium-exploration adit along U.S. Route 209, Mt. Pisgah, Carbon County, Pennsylvania.

<u>Eastern Channel¹</u>			<u>Western Channel²</u>	
Thickness	Radioactivity (mR/hr)		Thickness	Radioactivity (mR/hr)
25 cm	5±	cgl. above channel spl., ore as far as reached.	45 cm	1.2±0.2, above channel spl.
			40 cm	2.5±1 above channel spl.
			40 cm	4±1 very black ore. ³
85 cm	1.5±0.5	cgl.	25 cm	2±.5
50 cm	0.5±0.1	ss	45 cm	1.2±.2
25 cm	1.0±0.2	cgl.	65 cm	0.7±.1 only ss with scattered pebbles.
30 cm	1.5±0.5	cgl. richer at top		
15 cm	2.0±0.2	cgl.	<u>2.60 m</u>	
20 cm	5±2	cgl. partly below channel		
<u>2.50 m</u>				
Base of exposure			Base of exposure	
1. The eastern channel is 2.25 m long against the outcrop and located 11 m E of the center of the W adit.				
2. The western channel is 1.7 m long against the outcrop and located 4.1 m W of the center of the W adit. These two channel samples bracket the interval mined by the W adit and suggest an ore zone here at least 2.5 m thick.				
3. X-ray diffractometer data indicates, quartz, "illite," chlorite, and probable coffinite in approximately decreasing order.				

STOP 5. Spring Mountain thrust fault.

Park in area between highway and northbound access road of Exit 39.
Caution - walk off the pavement. Watch for falling rock. This exposure is on a curve and traffic may not be able to see you.

A very deep road cut in Spring Mountain exposes a syncline with rock layers dipping gently south at the north end and gently north at the south end (Figure 30). The syncline has been disrupted by one major and several minor faults, the primary result being that the south side of the syncline has been thrust over the north side by at least 15 m. This exposure was briefly described elsewhere by Faill and Wells (1970) and the Pennsylvania Geological Survey.

The contact of the Pennsylvanian Pottsville Formation (Tumbling Run Member) and the Mississippian Mauch Chunk Formation is marked by the change from reddish, brownish and gray shaly rock (Mauch Chunk) to lighter gray shaly

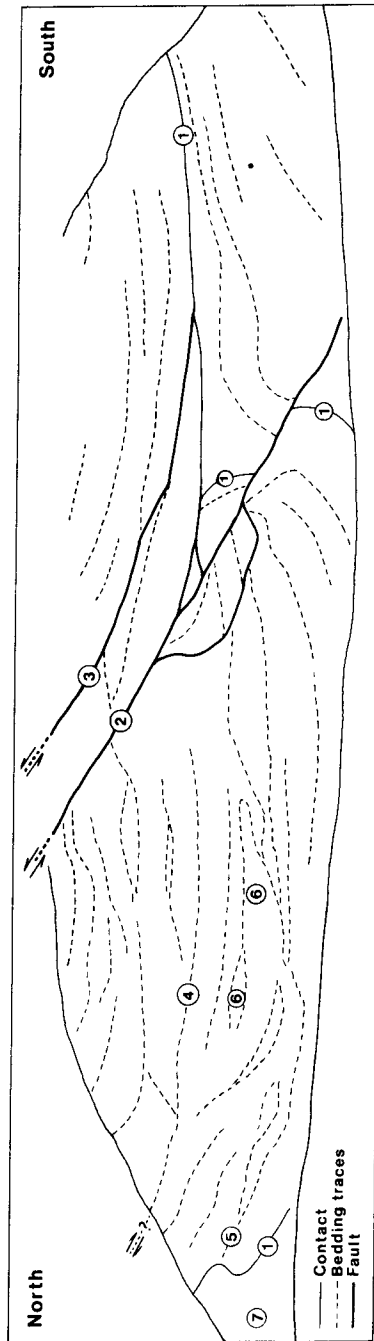


Figure 30. Spring Mountain thrust fault exposed along the north-bound lane of U. S. Interstate 80 about 8 km SSW of Hazleton, Pennsylvania, at $40^{\circ}53'18''\text{N}/76^{\circ}01'10''\text{W}$, Conyngham quadrangle. Rocks in lower part of cut are in the transition zone between the Mauch Chunk (lower) and Pottsville Formations. Pottsville Formation exposed in the upper part of the cut.

rock (Mauch Chunk) to light gray and brown sandstone and conglomerates (Pottsville). This is the uppermost part of the Mauch Chunk-Pottsville transition zone. The lower part of this zone is well exposed in the next road cut to the south (northbound lane).

The sketch (Figure 30) shows the important geologic features that are numbered to correspond with the following discussion.

(1) The prominent change from reddish shaly rocks (below) to lighter grayish sandstones and conglomerates marks the transition zone between the Mauch Chunk and Pottsville Formations.

(2) The prominent south-dipping discontinuity is a reverse fault that has moved the south part of the syncline upward and northeast over the north part of the syncline.

(3) This less prominent south-dipping discontinuity is a reverse fault also but apparently has moved the layers only a meter or so.

(4) and (5) These two discontinuities appear to be faults that nearly parallel the layers of rock, but they may be original bedding surfaces. The amount of movement, if any, that has occurred at these breaks, has not been determined. Many of the discontinuities and intersections of the layers of sandstones are apparently primary in origin and result from scour and fill in a fluvial environment.

(6) The large, rounded, discontinuous blocks of sandstone that are surrounded by finer-grained material may be pieces of sandstone that slumped from originally continuous layers.

(7) The vertical or near vertical fracturing that crosses the south dipping layers is cleavage.

STOP 6. Jordan borrow pit. Type 3 uranium occurrence.

The John Jordan borrow pit is located 0.8 km SW of Hemlock Grove and 2.15 km SE of Beech Glen, Davidson Township, Sullivan County, in the Sonestown quadrangle (Map 3, Appendix). The occurrence is exposed by a semi-active borrow pit. The elevation of the pit is estimated to be 1150 feet (350 m). The latitude and longitude are 40°18'42"N/76°34'38"W.

John Jordan, one of the most energetic prospectors during the 1950's uranium boom and partner of Anthony Gill, now blasts "shale" on demand for relatives and friends. His borrow pit just happens to be located in one of the most extensive Cu-trace U-bearing lenses known in the area. A long driveway, recently built for a nephew about halfway to Beech Glen, is paved with rock containing abundant azurite and malachite. Fortunately for this purpose, the U content of the "shale" is low.

This prospect is located near the lower part of the upper third of the Catskill Formation, approximately 260 m below the top of the formation (total thickness about 1070 m). Bedding dips 3° toward N60E and the dominant joint system is vertical with N30W strike. The sequence comprises red floodplain silts and clays overlain by a scoured surface and presumed channel sands

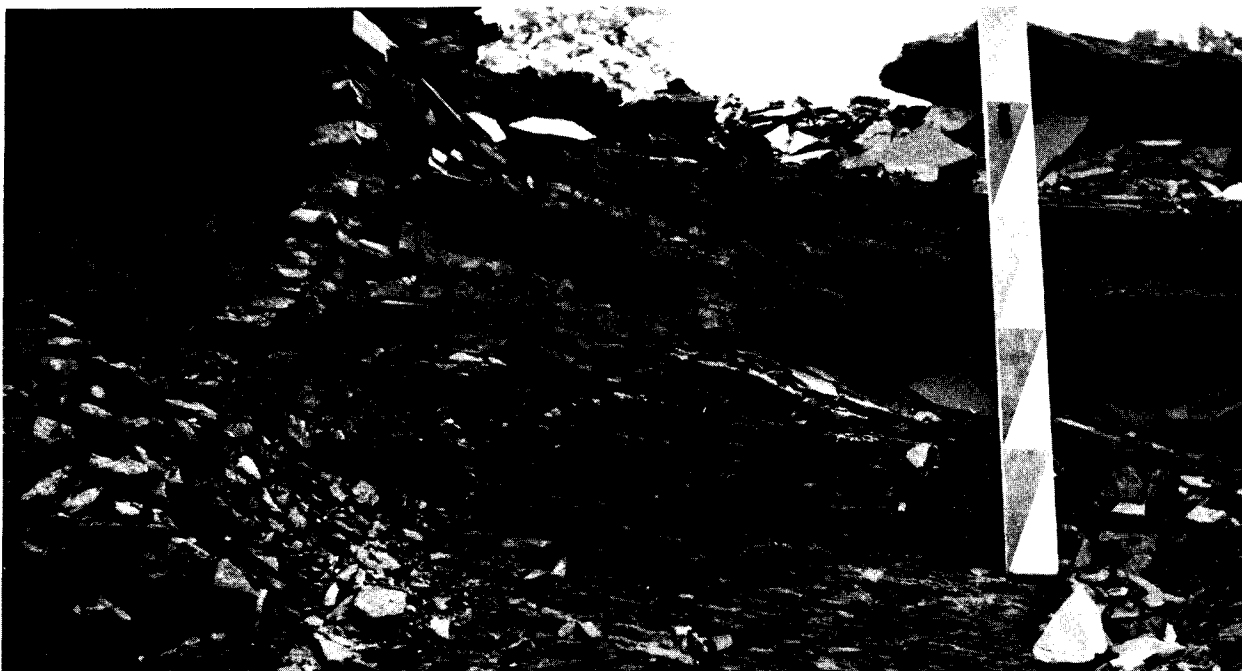


Figure 31. Crossbedded, gray and red channel(?) sandstones overlying red, flood basin claystones in John Jordon borrow pit 2.15 km SE of Beech Glen, Sullivan County, Pennsylvania. Rocks occur in lower part of upper third of the Catskill Formation. Mineralization occurs in the sandstones immediately above the erosional contact. Scale is divided into feet.

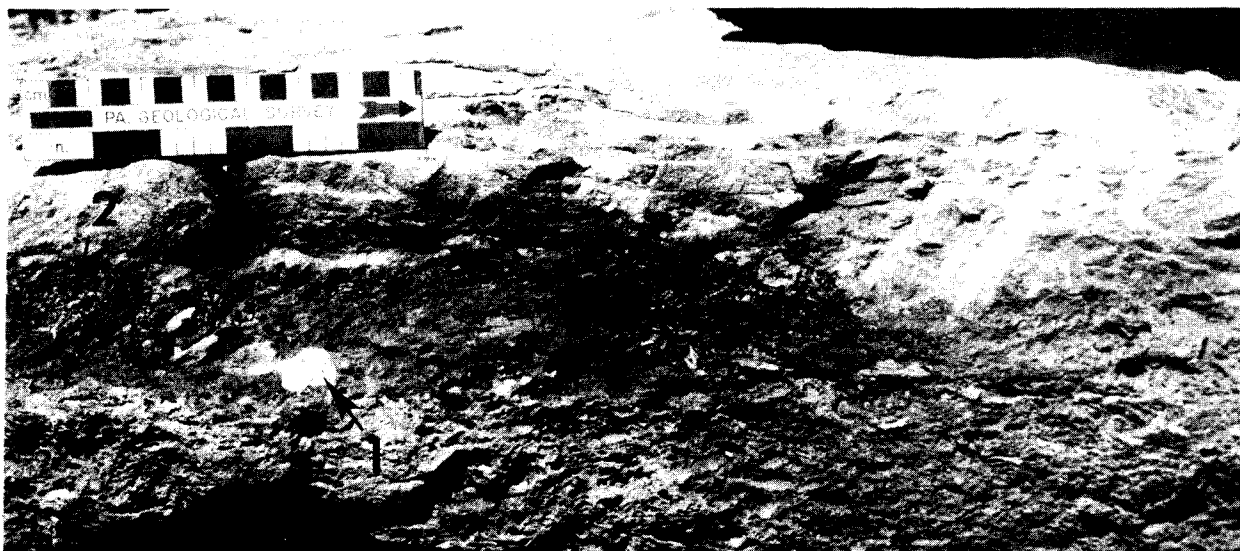


Figure 32. Typical weathered surface of a calcareous breccia in the Catskill Formation at the John Jordon borrow pit, 2.15 km SE of Beech Glen, Sullivan County, Pennsylvania. Pitted surface results from solution of calcium carbonate cement and is dark brown to black in color. Note sharp gradation into sandstone. 1 - shale clasts. 2 - calcium carbonate nodules.

(Figure 31). Relief on the scoured surface is small and lag deposits (calcareous breccia) on this surface appear as small, isolated pockets. Deposition of the sands was probably in a broad, shallow, perhaps poorly defined channel. Figure 32 shows a typical calcareous breccia.

The stratigraphy exposed as of 7/25/78 in the SW part of the pit is described in Table 6. This section is much leaner in Cu than those partly exposed earlier in 1978. Then, the Cu zone was almost continuously exposed for 30 m along the west side of the pit.

Malachite and trace uranium in sandstone with carbonaceous plant fragments can be found 60 m W of the pit at the same horizon, and gray, reduced sandstone with a slightly high background can be observed for 120 m to the N of this. Portions of this latter area also contain phosphatic fish remains including complete crossopterygian fish scales. In both the borrow pit and farther to the west, carbonaceous plant fragments up to 3 x 30 cm with activities up to 0.3 mR/hr have been found, but in general, the richer ones are only 0.1 mR/hr.

The minerals observed at the Jordan borrow pit include:

Common: Malachite as coatings and small botryoids; azurite as coatings and microcrystals; calcite as white or red-stained coatings, tiny globules, and scalenohedral microcrystals; opal var. hyalite as fluorescent, very thin coatings and micro-botryoids on or under calcite.

Uncommon: Apatite in vertebrate fossils including complete crossopterygian fish scales.

Rare: Djurleite replacing carbonaceous plant fragments; bornite; pyrite.

Table 6. Stratigraphic section exposed on 7/25/78 in the SW side of the John Jordan borrow pit, 2.15 km SE of Beech Glen, Sullivan County, Pennsylvania.

<u>Thickness</u> (cm)	<u>Radioactivity</u> (mR/hr $\pm$ 0.02)	<u>Petrology</u>
> 100	.02	Grayish red (5R4/2), fine- to medium-grained, flaggy, micaceous sandstone. Calcite and hyalite opal (fluorescent in U.V.) on bedding surfaces. Some bedding surfaces with parting-step lineations and others with ripple marks.
15	.02-.03	Medium light gray to medium gray (N6-N5), fine- to medium-grained, micaceous sandstone.
6	.05	Mottled medium gray (N5) to grayish brown (5YR3/2) calcareous breccia with phosphatic fish remains, scattered carbonaceous plant fragments (near top), brick red, and greenish gray shale chips.*
25	.03	Grayish red (5R4/2) siltstone with mottled color due to cm-sized reduced zones which are colored greenish gray (5G6/1).

Table 6. (Continued)

<u>Thickness</u> (cm)	<u>Radioactivity</u> (mR/hr $\pm$ 0.02)	<u>Petrology</u>
> 160	.03-.04	Grayish red (10R4/2) siltstone and mudstone with red shale clasts. Moderate amounts of burrows, rootlets and fish plate fragments.

*Although the calcareous breccia occurs as discontinuous lenses along the pit walls, the reduced zone appears to be continuous. Float quarried earlier in 1978 shows that the calcareous breccia was then up to 27 cm thick and of mottled gray, brownish gray, and greenish gray color. Fish remains include complete crossopterygian scales. The top of the calcareous breccia was marked by carbonaceous plant fragments up to 28 cm long at the contact with the overlying sandstone bed. The bottom of the calcareous breccia was marked by grayish red (10R4/2) shale clasts up to approximately 10 cm long. However, the pit walls suggest that minimal channeling has occurred at the base of the calcareous breccia zone.

STOP 7. McCauley Prospect 24. Type 3 uranium occurrence.

McCauley Prospect 24, on the Joseph McGrath property, is located on the west side of a secondary road paralleling Fox Run, 2.45 km N of Tivoli, Shrewsbury Twp., Lycoming County, in the Picture Rocks quadrangle (Map 4, Appendix). The elevation is estimated to be about 930 feet (283 m). The latitude and longitude are 41°19'12"N/76°41'25"W. The adit entrance is about 210 m N of the McGrath house at a point 5.5 m west of the center of the road, here trending approximately N25W.

This prospect is located in the lower part of the Catskill Formation probably not more than 200 m above the top of the marine-nonmarine transition zone. The bedding dips about 2° toward N36W and the dominant joint system is vertical with N23E strike. The sequence comprises a fining-upward cycle of presumed fluvial origin. The scoured base of the cycle becomes obscured laterally and the amount of relief in the original scour channel is small. The calcareous breccia represents the channel lag deposit and the overlying sandstones are the point-bar deposits. Orientation of the channel is not known, but was probably N to NW. Figure 33 shows the outcrop.

The occurrence was prospected for copper with an adit dug prior to the 1950's uranium boom. The adit is 12.1 m long, 1.5 m wide, and 0.75 m high. For the first 9 m, the adit trends due west, but heads slightly NW beyond this. The back 3 m of the adit typically has 20 cm of water on the floor, leaving only about 50 cm of dry height for geologists. Those with larger diameters are discouraged from entering.

As determined with a Geiger counter along the outcrop, the lens is at least 21.7 m long and 1.8 m thick near the adit. This lens, actually compound, is concealed at both ends, but has thinned substantially. The radioactivity in the adit is typically 0.08 mR/hr with a few small areas up to a maximum of 0.3 mR/hr. The most radioactive areas on the outcrop yield approximately 0.15 mR/hr. Thus, the amount of uranium is negligible.



Figure 33. Crossbedded, gray, channel sandstones with basal calcareous breccia overlying red siltstones at the McCauley Prospect 24 outcrop, 2.45 km N of Tivoli, Lycoming County, Pennsylvania. Rock is in the lower part of the Catskill Formation. Scale is divided into feet and stands at the left side of the adit.

The stratigraphic section exposed on the S side of the adit entrance is described in Table 7. In general, the maximum grain size at McCauley Prospect 24 is a medium sand, but there is relatively little of this. The mineralized rock consists of calcareous breccia and gray sandstone. Coarse, detrital(?), muscovite flakes are common in the lens, but no phosphatic fish remains have been observed. Scattered malachite occurs in the gray siltstone beds. Abundant malachite and minor azurite occur with carbonaceous plant fragments in the calcareous breccia and overlying, fine- and medium-grained sandstone. The calcareous breccia also contains gray shale clasts and coarse muscovite flakes. Some "chalcocite" also occurs in coaly fragments in the sandstone. Manganese oxide dendrites are common on bedding and fracture surfaces. Overlying the mineralized rock exposed in the outcrop, there is an oxidized, fining-upward cycle with a few scattered pockets of calcareous breccia. Beds at the bottom of the cycle are massive, whereas those on top are flaggy.

Halfway back into the adit, the roof and upper 45 cm of the walls expose a medium-grained, gray sandstone in sharp contact with 3 cm of gray, calcareous breccia. Beneath the breccia, there is 6 cm of gray shale that is transitional to 45 cm of red shale-mudstone to red siltstone below. In the back of the adit, the roof exposes gray mudstone with trace malachite on an

erosional contact with the red shale and siltstone which comprise the walls. Thus, even the leanly-mineralized calcareous breccia and gray sandstone do not extend very far into the outcrop.

Table 7. Stratigraphic section exposed on the south side of the McCauley Prospect 24 adit, 2.45 km N of Tivoli, Lycoming County, Pennsylvania.

Thickness (cm)	Radioactivity (mR/hr $\pm$ 0.02)	Petrology
85	.02-.03	Grayish red (5R4/2), fine-grained, slightly micaceous sandstone. Mostly planar bedded with 1-2 cm bed thickness.
55	.02-.03	Pale brown (5YR5/2), fine- to medium-grained, micaceous sandstone. Includes a few, small calcareous breccia lenses up to 8 cm thick.
25	.02-.05	Medium light gray (N6), fine- to medium-grained, micaceous sandstone. Moderate malachite on bedding.
20	.05-.10	Medium light gray (N6), fine- and medium-grained, slightly micaceous sandstone with very abundant carbonaceous plant fragments and trace malachite stains. Includes azurite in the adit.
50	.04	Medium gray (N5), medium-grained, sandstone with abundant malachite and carbonaceous plant fossils up to 3 x 12 cm, especially, near the base. Contains trace "chalcocite"(?), azurite, and chrysocolla (some of the latter in plant fossil shrinkage cracks).
40	.05	Medium gray (N5), micaceous, calcareous breccia with gray shale chips and sparse red chips near the base. Contains malachite.
5	.02-.03	Grayish red (10R4/2), siltstone with fine-grained mica flakes.

STOP 8. McCauley Prospect 22. Type 3 uranium occurrence.

McCauley Prospect 22, on Bowling Green Corporation property, is located 3.1 km NE of Tivoli and 1.3 km SW of Glen Mawr, Penn Township, Lycoming County, Pennsylvania, in the Picture Rocks quadrangle (Map 4, Appendix). This prospect, on the SW side of a hill, faces a swamp and is located at an elevation of approximately 1050 feet (320 m). The approximate latitude and longitude are 41°18'10"N/76°39'26"W. This is about 1.3 km NE of the verbal description location given by McCauley (1961, p. 62) and 4.35 km NW of his latitude and longitude-derived location (in the next quadrangle to the E), but McCauley's Figure 13 furnishes evidence that the present stop is the same as his Prospect 22. Note, however, that despite Figure 13, there never was a quarry floor here.

This prospect is located in the lower part of the Catskill Formation less than 200 m above the base of the formation. The prospect occurs less than 50 m above the top of the uppermost known marine beds of the basal, marine-

nonmarine transition zone. The uppermost part of this zone is a transgressive-regressive sequence discussed and mapped by Mahar (1978). The sequence here comprises a fining-upward cycle with the following parts: (1) underlying red siltstone and claystone, (2) scoured surface with minor relief at top of redbeds, (3) basal lag deposits of calcareous breccia in localized lenses with shale clasts and carbonaceous debris, and (4) point bar deposits of crossbedded sandstone passing upward into mixed crossbedded, planar-bedded and rippled sandstones.

McCauley Prospect 22 consists of two adits, of different vintage, separated by 67 m along a S30E-trending trail. The NW adit (Figure 34), apparently dug in search of copper more than 50 years ago, is about 2.5 m above the swamp level, 4.8 m long, 1.7 m wide at the entrance, and 1.5 m in height. It trends N10E on a 6-15 cm thick calcareous breccia zone ($R=.07\pm.04$ mR/hr) with red and gray shale clasts and phosphatic fish fragments in a brownish gray (5YR4/1) rock with rare malachite stains. Above the calcareous



Figure 34. Crossbedded, gray to red sandstones of the Catskill Formation at the NW adit of McCauley Prospect 22, 3.1 km NE of Tivoli, Lycoming County, Pennsylvania. Scale is divided into feet and stands at right side of adit.

breccia in the adit there is 70 cm of a grayish to reddish brown (5Y4/1-5R4/2) flaggy sandstone ($R=.02-.03$), and below the calcareous breccia there is 35 cm of dark reddish brown (10R3/4) shaly siltstone ($R=.02-.03$). Bedding at the NW adit dips about 5° toward NE. Joints are vertical and trend N33E. Crossbedding appears to have consistent orientation and one measured crossbed unit dips 25° toward N25W. Crossbedding is well displayed at the NW adit and ripple bedding is best displayed in the large slumped block just NW of the adit. Only the barest traces of malachite were found on the dump to this adit. The average radioactivity measured on the dump with a Geiger counter, 0.04 mR/hr, is barely above background.

A lensoidal red sandstone occurs at the horizon of the breccia on the west side of the adit, near the entrance (Figure 35). The continuation of the sandstone lens into the overlying bed poses somewhat of a problem. Note that the feeble Cu-U mineralization in this adit has concentrated on the contacts of this sandstone lens.

The SE adit (Figure 36), excavated during the 1950's uranium boom, is slightly higher stratigraphically (8 m above the swamp level) and pursued a carbonaceous plant trash zone. The adit is 4.0 m long, 1.55 m wide, and 1.75 m high.

The adit parallels jointing, here vertical with a N33E trend. The radioactivity in the adit in contact with the 35 cm-thick carbonaceous plant trash zone is approximately 0.5 ± 0.02 mR/hr. The detailed stratigraphy at the SE side of the SE adit entrance is described in Table 8. Local variation is so rapid, that some of the details of correlation are lost over the 1.55 m to the NW side of the same adit. The entire reduced zone disappears within 6 m to the SE. Note, however, the malachite-stained carbonaceous "log" 3.5 m SE of the center of the SE adit. This "log" is 13 cm long and 1 cm thick. The radioactivity on contact here is 1-3 mR/hr for almost 1 m along strike.

The minerals observed at the SE adit and dump of McCauley Prospect 22 are listed below:

Common: Malachite, calcite (filling voids or replacing shale clasts).

Uncommon: Azurite, apatite (fish scale).

Rare: "Chalcocite"; chalcophyllite ($\text{Cu}_{18}\text{Al}_2(\text{AsO}_4)_3(\text{SO}_4)_3(\text{OH})_{27} \cdot 33\text{H}_2\text{O}$) as transparent, bluish green, micaceous flakes; digenite (Cu_9S_5) as metallic, bluish gray replacements of plant fragments (may have been anilite (Cu_7S_4) prior to grinding for X-ray powder diffraction); metazeunerite ($\text{Cu}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$)-metatorbernite ($\text{Cu}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$) as translucent, apple green, micaceous flakes with a slightly pearly luster; and brochantite ($\text{Cu}_4(\text{SO}_4)(\text{OH})_6$).

Six meters NW of the center of the SE adit, there was a small uranium zone with a maximum radioactivity of 4 mR/hr. This carbonaceous plant fragment zone was 30 cm thick and 70 cm long with a typical radioactivity of 1-2 mR/hr. A moderate amount of golden, secondary kasolite was found here in a brownish-gray (5YR4/1) to grayish red (5R4/2), mottled, micaceous, fine-grained sandstone-siltstone. Other minerals which were found at the

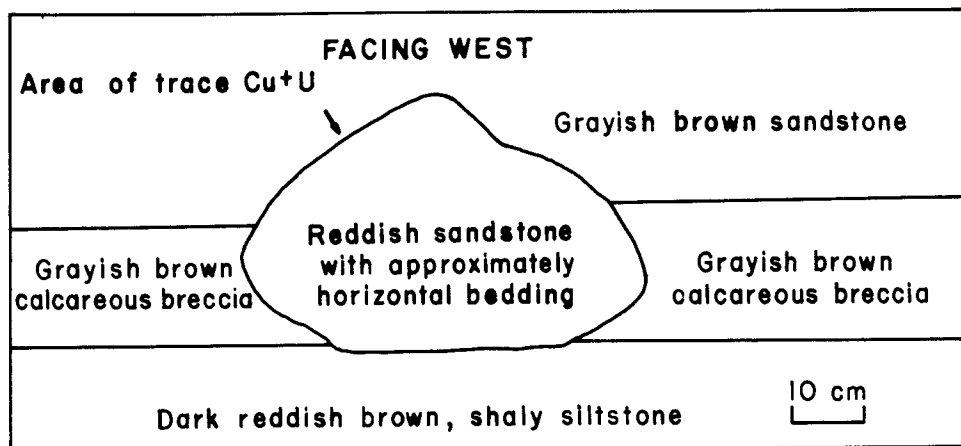


Figure 35. Lensoid sandstone and calcareous breccia on the vertical west wall of the NW adit at McCauley Prospect 22, 3.1 km NE of Tivoli, Lycoming County, Pennsylvania.



Figure 36. Planar bedded and crossbedded, gray to red sandstones of the Catskill Formation at the SE adit of McCauley Prospect 22, 3.1 km NE of Tivoli, Lycoming County, Pennsylvania. Scale is divided into feet and stands at right side of the adit.

former site include: malachite, trace linarite ($?, \text{PbCu}(\text{SO}_4)(\text{OH})_2$); brochantite ($\text{Cu}_4(\text{SO}_4)(\text{OH})_6$); and chrysocolla ($(\text{Cu}, \text{Al})_2\text{H}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot n\text{H}_2\text{O}$).

As shown in McCauley's Figure 13, a 20 cm-thick uranium zone with a typical radioactivity of 0.5-1.0 mR/hr was located 10.2 m NW of the center of the SE adit. "Chalcocite" occurs here, associated with abundant, large plant fragments. A hand sample of one of these had a maximum radioactivity of 1.7 mR/hr. Other minerals found at this site include: tennantite ($(\text{Cu}, \text{Fe})_{12}\text{As}_4\text{S}_{13}$); digenite (Cu_9S_5); chalcophyllite; unidentified, tiny peculiar, pistachio green "BB's" (also found with the As minerals at McCauley Prospect 17); malachite; and trace chalcopyrite.

A fourth uranium zone was located 19.2 m NW of the center of the SE adit. Moderately rich samples were collected here in mottled, micaceous sandstone at a level which is probably about 1 m below the stratigraphic level at the SE adit. The minerals observed here include: malachite; metazeunerite-metatorbernite as tiny apple-green micaceous flakes along plant fossils; and kasolite(?) as yellow powdery masses in plant fossils.

Table 8. Stratigraphic section exposed at the SE side of the entrance to the SE adit, McCauley Prospect 22, 2.45 km NE of Tivoli, Lycoming County, Pennsylvania.

Thickness (cm)	Radioactivity (mR/hr ± 0.02)	Petrology
> 200	.03	Grayish red (5R4/2) to dark reddish brown (10R3/4), fine-grained sandstone.
50	.05	Transition zone of medium gray (N5), fine-grained sandstone with interbedded 1 mm to 1 cm thick oxidized laminae.
35	0.5 $\pm$ 0.2	Medium gray (N5), fine-grained sandstone with carbonaceous plant fragments and malachite, especially near the base where it is thinner-bedded and contains more plant fragments.
30	.07 to .2 max.	Medium gray (N5) to medium dark gray (N4), calcareous breccia with numerous reddish shale clasts. Contains abundant malachite near the top. [May be replaced by dark gray (N4) siltstone in the adit on the NW side.]
> 90	.04	Grayish red (5R4/2), thin-bedded, fine-grained sandstone.

STOP 9. McCauley Prospect 28. Type 3 uranium occurrence.

McCauley Prospect 28, on the Jack G. Craft property, is located on the NW side of a secondary road along Rock Run, 0.75 km NE of a church by the same name, Shrewsbury Twp., Sullivan County, Pennsylvania, Picture Rocks quadrangle. The elevation is about 880 feet (268 m), and the occurrence is about 0.75 km NE of the boundary with Lycoming County. The latitude and longitude are 41°20'20"N/76°37'57"W. The adit entrance is 6 m N of the center of the road (Map 4, Appendix).

This prospect is located near the lower part of the upper third of the Catskill Formation, approximately 300 m below the top of the formation. Bedding is essentially horizontal and the dominant joint system is vertical with N26E strike. The sequence comprises a fining-upward cycle, with a scoured base, a channel lag deposit, an upward fining of grain size and an upward change in color from gray to red. Lateral relationships are obscure because of cover, but relief on the scoured base appears to be small. Figure 37 shows the adit and Figure 38 shows an outcrop 29 m to the SW.

McCauley (1961, p. 63-64) only noted the feeble mineralization in the adit, whereas, the more significant U mineralization is centered 36 m to the SW. The adit, apparently excavated in search of copper prior to the 1950's uranium boom, is 5.7 m deep, 1.3 m wide, 1.4 m high, and trends N18W. The stratigraphy exposed on the east side of the adit entrance is described in Table 9. The stratigraphy exposed at the back of the adit can be summarized as: Roof; >40 cm gray, pyritic(?), micaceous sandstone with abundant carbonaceous plant fragments up to 40 cm long; 25 cm gray siltstone; >10 cm gray, very calcareous breccia; 35 cm gray siltstone; 10 cm red, micaceous siltstone; floor. Using the 10-15 cm thick calcareous breccia as a marker, rapid changes can be noted over a mere 5.7 m. This and the fine grain size suggests that we are not dealing with a desirable ore trap.

No U minerals have been observed in the adit. Indeed, in this area, they seldom are on outcrops with radioactivities of 0.2 mR/hr. The moderate malachite and trace azurite and chrysocolla appear to have been derived from trace bornite and "chalcocite" in the calcareous breccia. In general, at McCauley Prospect 28, the Cu appears to have localized in the calcareous breccia and the U in the carbonaceous plant fragments.

During the reconnaissance for the 1978 Field Conference, a more significant uranium-bearing zone was noted in the same roadcut 36 m to the SW (Figure 38). This zone is 14 m long as defined with a Geiger counter, or twice that length as defined with a scintillometer using a 3X background cutoff for the latter.

Unlike many other occurrences in the Beaver Lake area, this 10 cm thick U zone lacks directly associated calcareous breccia, channeling into the underlying beds, and visible Cu mineralization. Instead, the maximum uranium concentration is near the middle of a 1.3 m thick, somewhat planar-bedded, highly micaceous, reduced series of sandstones. The yellow secondary uranium mineral intimately associated with the micaceous sandstone is kasolite ($\text{Pb}(\text{UO}_2)\text{SiO}_4 \cdot \text{H}_2\text{O}$). A trace of cerussite may also be present. The stratigraphic section exposed near the kasolite is described in Table 10. The vertical jointing that rather uniformly trends N26E appears unrelated to U mineralization.

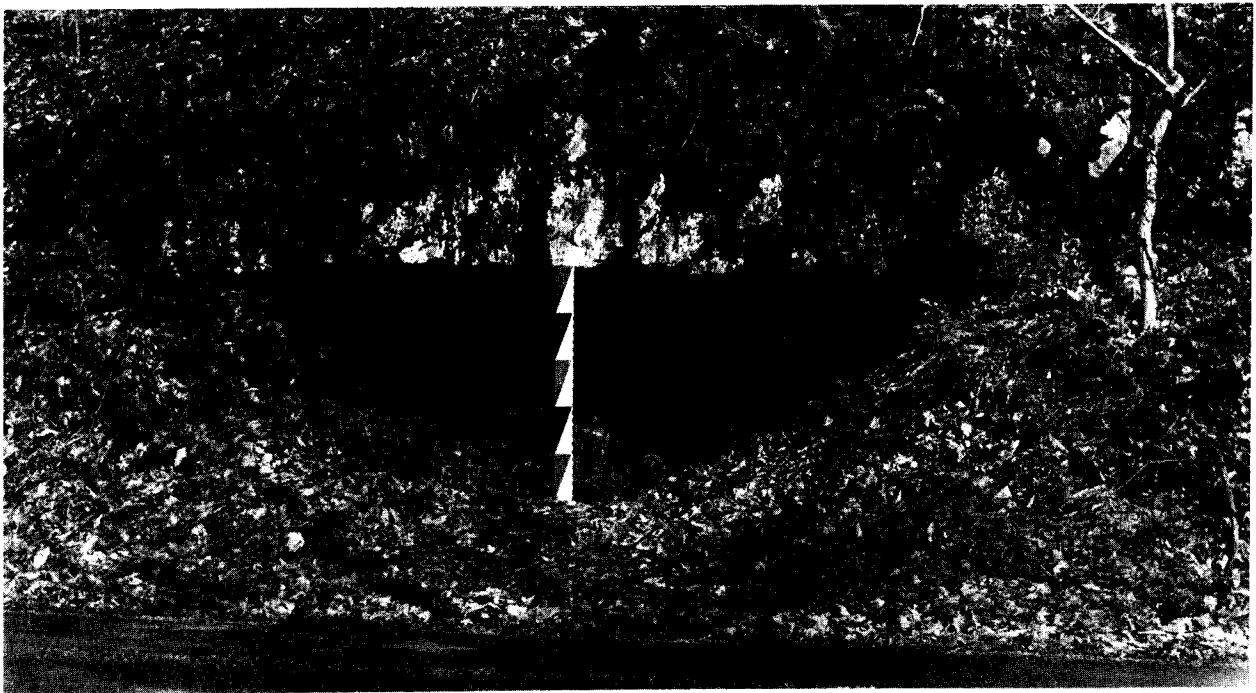


Figure 37. Gray sandstone of the Catskill Formation which forms the roof of an adit at McCauley Prospect 28, 0.75 km NE of Rock Run Church, Sullivan County, Pennsylvania. Scale is divided into feet and stands at left side of adit.



Figure 38. Crossbedded, gray sandstone of the Catskill Formation exposed along the W side of the road 29 m SW of the adit of McCauley Prospect 28, 0.75 km NE of Rock Run Church, Sullivan County, Pennsylvania. Scale is divided into feet and stands in approximate location of description presented in Table 9.

Table 9. Stratigraphic section of Catskill Formation rocks exposed on the east side of the McCauley Prospect 28 adit, 0.75 km NE of Rock Run Church, Shrewsbury Twp., Sullivan County, Pennsylvania.

<u>Thickness</u> (cm)	<u>Radioactivity</u> (mR/hr ± 0.02)	<u>Petrology</u>
> 100	.03-.04	Grayish red (10R4/2), fine-grained, micaceous sandstone.
115	.03-.08	Medium light gray (N6), fine- to medium-grained, micaceous sandstone. Includes a 10 cm sandstone bed at the base with abundant, large, carbonaceous plant fragments and a radioactivity of 0.15 mR/hr. This somewhat radioactive bed forms the roof of the adit.
~ 20	.5 avg.	Medium light gray (N6), very thinly-bedded, micaceous siltstone-sandstone with very abundant carbonaceous plant fragments.
42	.07	Medium gray (N5), very micaceous, inter-bedded siltstone and fine-grained, cross-bedded sandstone with very abundant, large, carbonaceous plant fragments. Includes 5 cm of dark greenish gray (5GY4/1) shale at the base.
15	.06	Medium light gray (N6), calcareous breccia with malachite staining and trace "chalcocite." Chrysocolla traces in the back of the adit. Phosphatic fish remains typically rimmed by malachite.
30	.06	Dark greenish gray (5GY4/1) shale.
> 35	.05	Brownish gray (5YR4/1) to grayish red (5R4/2) shale and mudstone.

Table 10. Stratigraphic section of Catskill Formation rocks at the Rock Run uranium occurrence, 29 m SW of McCauley Prospect 28 adit, 0.75 km NE of Rock Run Church, Shrewsbury Twp., Sullivan County, Pennsylvania.

<u>Thickness</u> (cm)	<u>Radioactivity</u> (mR/hr ± 0.02)	<u>Petrology</u>
> 200	.02-.03	Grayish red purple (5RP4/2), fine- to medium-grained, micaceous sandstone.
62	.04-.07	Medium light gray (N6), micaceous sandstone. The color change into the overlying oxidized beds appears to be transitional in places.
10	0.25-0.4 up to 2	Light olive gray (5Y5/2), fine- to medium-grained, flaggy, very micaceous sandstone. Minor kasolite. Contains an abundance of small, carbonaceous, plant fragments.
60	.05	Light olive gray (5Y5/2), medium-grained sandstone.
> 10	.03	Greenish gray (5GY6/1) siltstone to fissile, silty shale.

STOP 10. McCauley Prospects 12 and 13. Type 3 uranium occurrences.

These prospects occur in the upper part of the Catskill Formation, approximately 250 m below the top of the formation. Bedding appears to be nearly horizontal, but probably has a slight north dip. The sequence here demonstrates a local vertical range for uranium occurrence. Slight radioactivity is associated with azurite and malachite mineralization at a now-flooded adit and pit below road level almost directly downslope from McCauley Prospect 12 (Figure 39). McCauley Prospect 12 occurs 27 m above the flooded adit; McCauley Prospect 13, 10 m above Prospect 12; and a small trench with slight radioactivity near the hill crest, 9 m above Prospect 13. The total stratigraphic range for known uraniferous lenses at this stop is 46 m. The entire sequence appears to be dominated by red floodplain siltstones and claystones with some red and gray channel sandstones.

McCauley Prospect 12, on the Robert Kile-William Rupert property, is located 2.65 km S of the Jamison City road intersection at Central, in Sugarloaf Twp., Columbia County, Pennsylvania, in the Red Rock quadrangle (Map 5, Appendix). The prospect consists of a trench (Figure 40) that is 122 m N70W of the house and 55 m S50W of the McCauley Prospect 13 outcrop. The elevation of the trench is estimated to be 1085 feet (331 m) or about 10 m below Prospect 13. The latitude and longitude are 40°16'22"N/76°22'27"W.

The trench has a length of 10.3 m and maximum depth of 1.1 m. It trends S85W. The maximum radioactivity observed in the trench is 0.6 ± 0.1 mR/hr. The stratigraphic section exposed near the middle of the trench is described in Table 11. The west end of the trench exposes reduced rock, but the east end is slightly higher stratigraphically and only exposes an oxidized, calcareous sandstone. An excellent exposure occurs a few meters west of the trench. A scoured surface lacking calcareous breccia and carbonaceous debris can be traced along this outcrop. This scoured surface is at approximately the same elevation as the base of the trench and probably is the lateral equivalent of the mineralized zone.

Approximately 10 m NE of the E end of the trench, a stockpile with malachite-rich sand samples was found. The richest U-bearing hand sample consists of yellow and green secondary U minerals staining a plant fossil that has a radioactivity of 3 mR/hr. Several other hand samples with activities of 0.5 mR/hr were found.

The minerals observed in the trench and stockpile are listed below:

Common: Malachite as coatings and micro botryoids; covellite, digenite, and djurleite replacing plant fragments up to 8 cm long; "chalcocite" disseminated in sandstone and calcareous breccia; chalcocite replacing cylindrical fossil twigs; calcite and/or aragonite as tiny, clear masses along joints.

Uncommon: Chrysocolla(?).

Rare: Azurite as thin blue stains and microcrystals; barite as clear colorless cleavages up to 5 mm; apatite as phosphatic fish remains (from calcareous breccia), one showing "chalcocite" in fossae and as a partial replacement; and posnjakite ($\text{Cu}_4(\text{SO}_4)(\text{OH})_6 \cdot \text{H}_2\text{O}$).



Figure 39. Crossbedded sandstone of the Catskill Formation above a flooded adit on the S side of the road about 0.5 km SE of Grassmere Park, Columbia County, Pennsylvania ($41^{\circ}16'21''\text{N}/76^{\circ}22'27''\text{W}$ in Red Rock quadrangle). Pond is almost directly downslope from McCauley Prospect 12. Scale is divided into feet and hangs at left side of adit.



Figure 40. Ye olde prospectors contemplate the wonders of McCauley Prospect 12, 2.65 km S of the Jamison City road intersection at Central, Columbia County, Pennsylvania.

McCauley Prospect 13, on the Kile-Rupert property, is located 2.65 km S of the Jamison City road intersection in Central, Sugarloaf Township, Columbia County, Pennsylvania, in the Red Rock quadrangle. The mineralized portion of the outcrop is located 55 m N50E of the McCauley Prospect 12 trench, but at a 10 m greater elevation (approximately 1120 feet = 341 m) and on a bearing of N45W from the house. (The house appears to be slightly mislocated on the topographic map. As measured with a tape, the house is 40 m from the road.) The latitude and longitude of the prospect are 41°16'24"N/76°22'25"W.

Mineralization is confined to a calcareous breccia overlain by fine-grained sandstone (Figure 41). Although a calcareous breccia can be observed for tens of meters along the outcrop in either direction, only the 7 m of breccia continuously exposed here and in the next outcrop to the east are reduced (gray) and somewhat radioactive. The stratigraphic section at the center of the reduced zone is described in Table 12.

Table 11. Stratigraphic section of Catskill Formation rocks exposed near the middle of the McCauley Prospect 12 trench, 2.65 km S of the Jamison City road intersection at Central, Columbia County, Pennsylvania.

<u>Thickness</u> (cm)	<u>Radioactivity</u> (mR/hr $\pm$ 0.02)	<u>Petrology</u>
≥ 50	0.1 (- a bkg. here of 0.08)	Grayish red purple (5RP4/2), fine-grained, slightly micaceous, thin-bedded, flaggy sandstone.
34	0.1 (- a bkg. here of 0.1)	Brownish gray (5YR4/1), fine-grained, slightly micaceous sandstone.
15	0.1 (- a bkg. here of 0.13)	Dusky red (5R3/4), fine-grained, slightly micaceous sandstone. Includes 7 cm of calcareous breccia in one place.
15	0.6 $\pm$ 0.1	Calcareous breccia with variable, reduced colors. Contains abundant carbonaceous plant fragments, many replaced by covellite, digenite (anilite?), and djurleite. Includes small, medium dark gray (N4), fine-grained, micaceous sandstone lenses with disseminated "chalcocite." Abundant malachite. Rare, clear barite.
> 5	0.7 $\pm$ 0.1	Brownish gray (5YR4/1), extremely micaceous, fine-grained sandstone with somewhat variable, reduced colors. Abundant carbonaceous plant fragments and malachite. Minor "chalcocite."

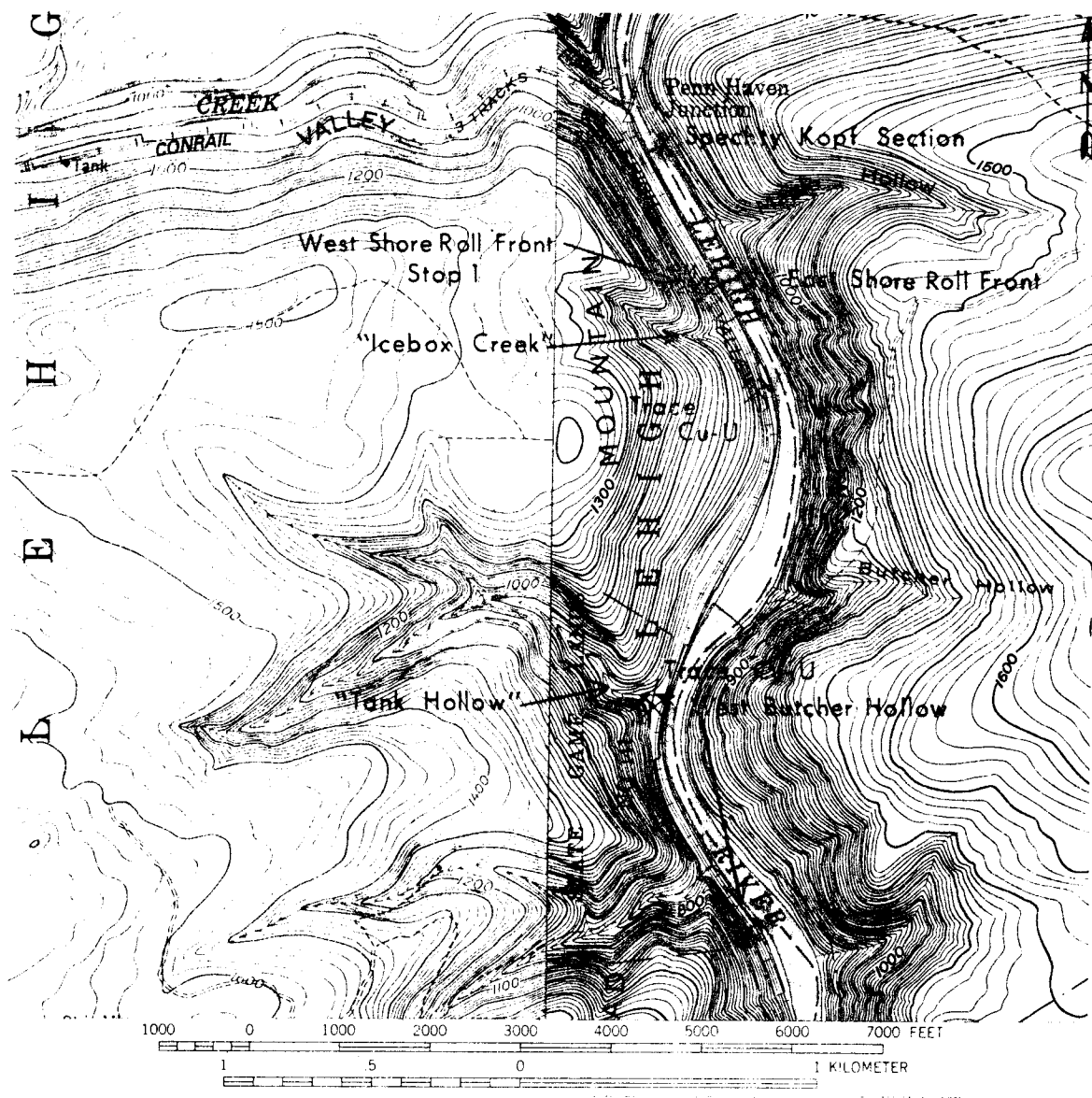


Figure 41. Calcareous breccia and gray to red sandstone of the Catskill Formation at McCauley Prospect 13, 2.65 km S of the Jamison City road intersection at Central, Columbia County, Pennsylvania. Scale divided into cm and inches.

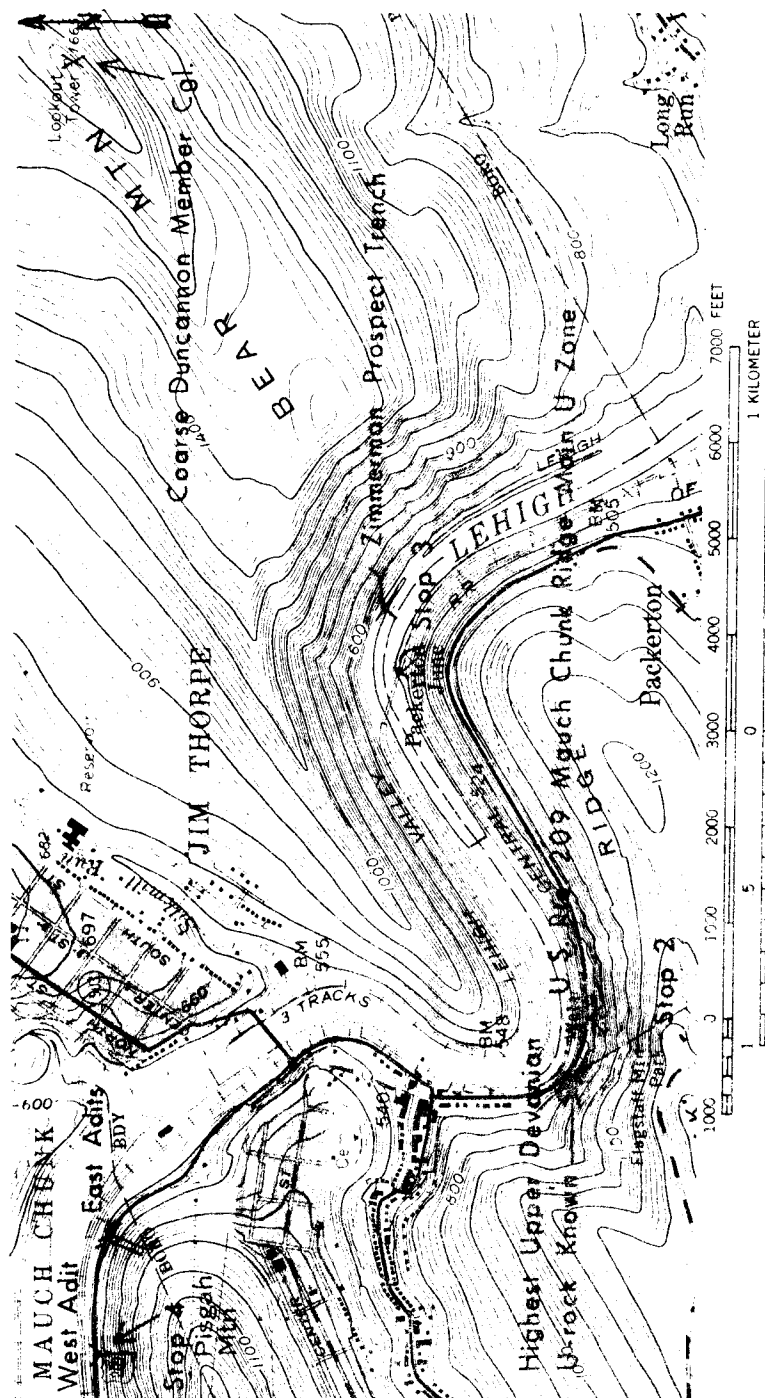
Table 12. Stratigraphic section of Catskill Formation rocks at McCauley Prospect 13, 2.65 km S of the Jamison City road intersection at Central, Columbia County, Pennsylvania.

<u>Thickness</u> (cm)	<u>Radioactivity</u> (mR/hr $\pm$ 0.02)	<u>Petrology</u>
> 100	0.03	Grayish red (5R4/2), fine- to medium-grained micaceous sandstone.
12	0.05	Medium light gray (N6), fine-grained slightly micaceous sandstone. Contains trace disseminated "chalcocite" and malachite. Carbonaceous plant fragments.
44	0.05-0.2	Medium gray (N5), calcareous breccia with sparse phosphatic fragments and scattered malachite. Includes trace "chalcocite" in carbonaceous plant fragments.
15	0.04	Grayish red (5R4/2), slightly micaceous, medium-grained sandstone.
60	0.03	Dark reddish brown (10R3/4), fissile shale with minor siltstone. Includes small plant fossils in reddish matrix.

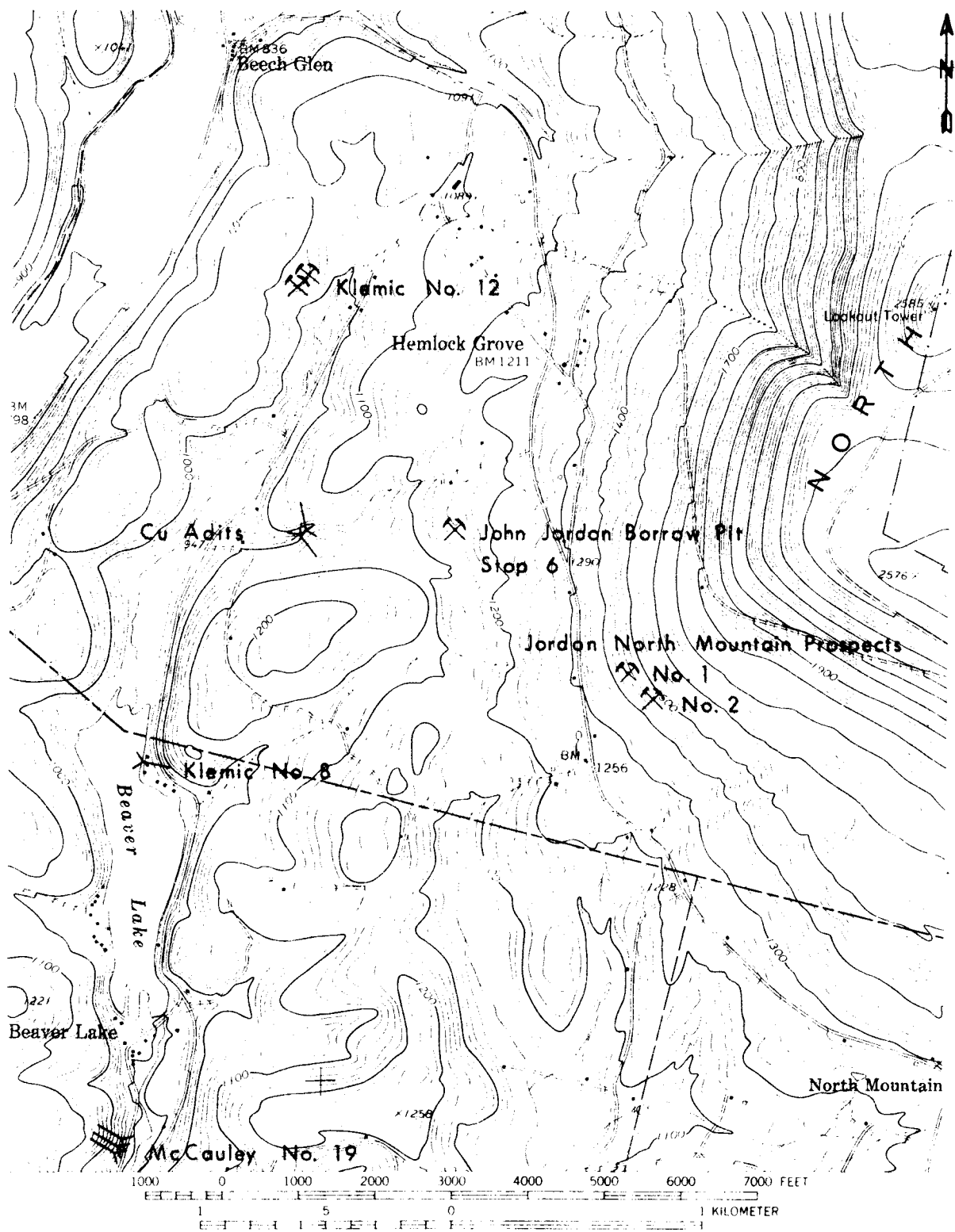
APPENDIX



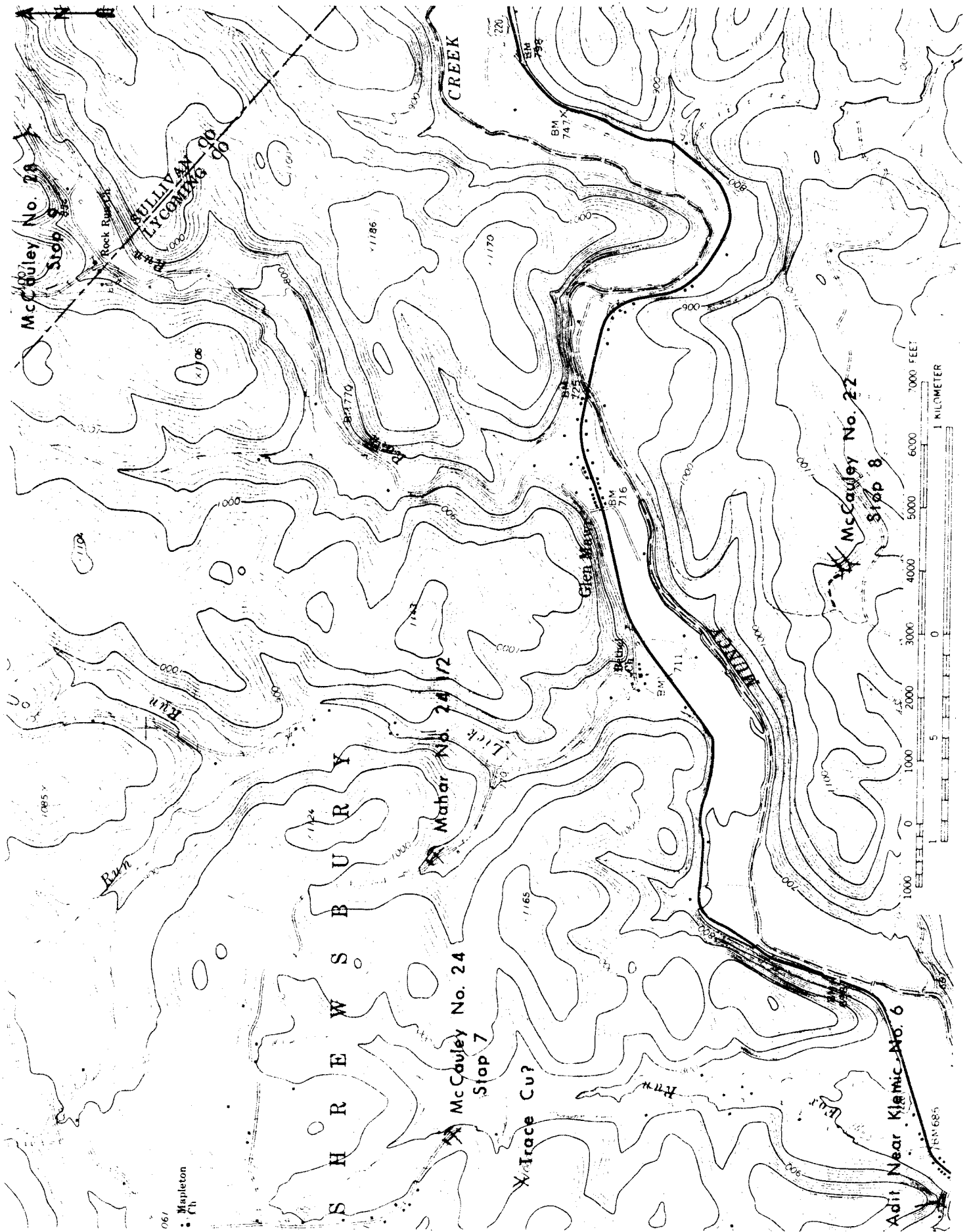
Map 1. Uranium occurrences in the Penn Haven Junction area. Weatherly (west) and Christmans quadrangles.



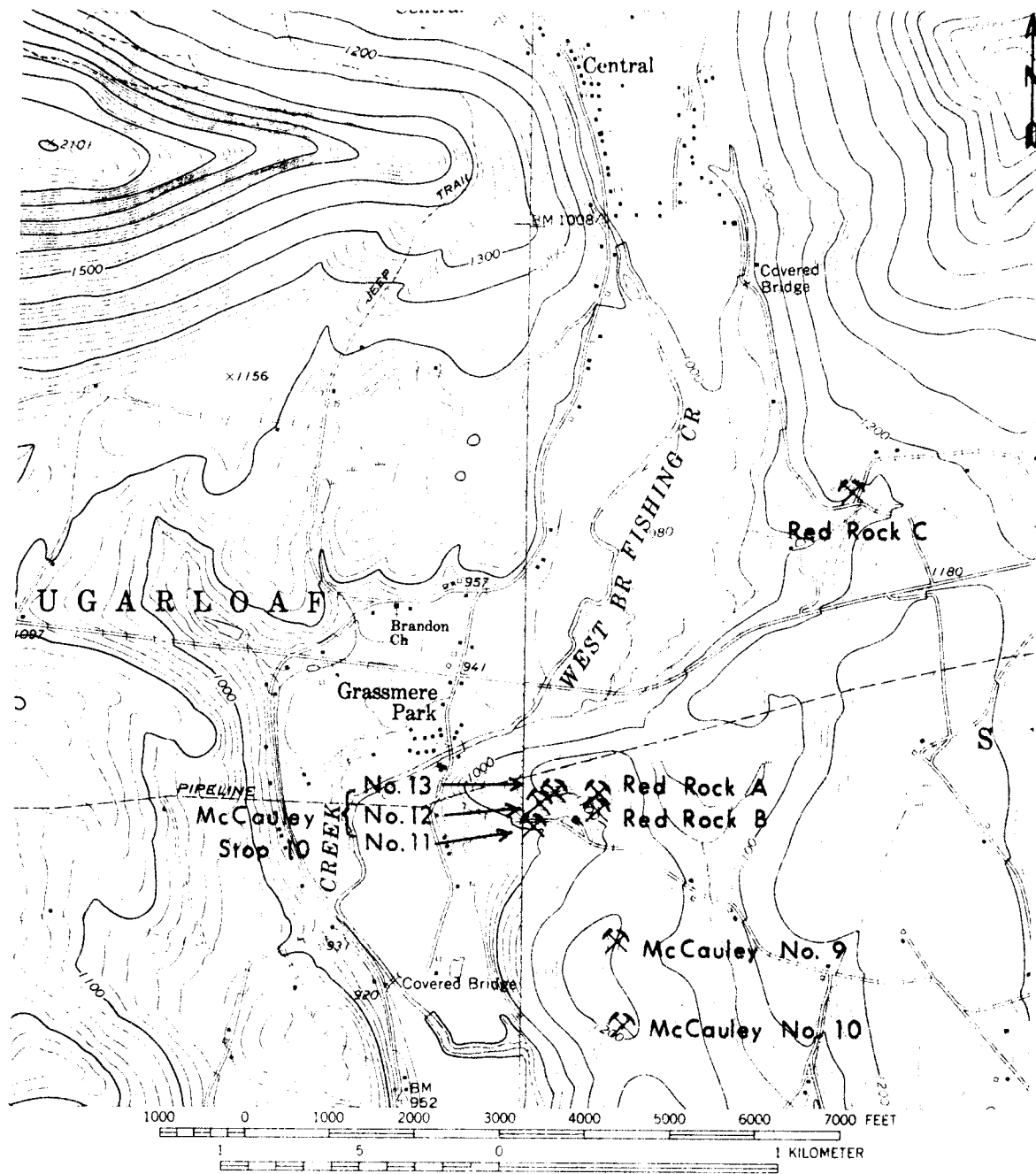
Map 2. Uranium occurrences in the Jim Thorpe area. Lehighton quadrangle.



Map 3. Uranium occurrences in the Beaver Lake area. Sonestown quadrangle.



Map 4 Uranium occurrences in the Glen Mawr area. Picture Rocks quadrangle



Map 5. Uranium occurrences in the Central area. Elk Grove (west) and Red Rock quadrangles.