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STRATIGRAPHY OF PRECAMBRIAN THROUGH CRETACEOUS STRATA OF PROBABLE FLUVIAL ORIGIN IN SOUTHEASTERN UNITED STATES AND THIER POTENTIAL AS URANIUM HOST ROCKS

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ABSTRACT

Most of the commercial deposits of uranium in the United States occur in fluvial arkosic sandstones deposited in intermontane basins. The most important host-rock attributes bearing on ore formation are: (1) abundance of dispersed carbonaceous trash and pyrite, (2) permeability to ground water movement, and (3) presence of mudstone beds or lenses that restrict and channel migration of ground water. Most of the ore is unoxidized and lies below the water table. The ore bodies are in large part genetically related to and distributed at the margins of large tongues of oxidative alteration that encroach on the indigenous reduzate facies of the sandstones.

Almost all of the presently known commercial ore occurs in post-Paleozoic formations in the western United States. Although uranium deposits have been found in the eastern United States, none is evidently of sufficient size to warrant mining.

The chief purpose of this report is to furnish information that will provide a basis for evaluating the fluvial sandstones of the southeastern United States as a possible source of uranium. The report is based on literature review supplemented by the writers' field experience. Roughly a thousand geologic documents were examined, and 404 are specifically cited in the discussion of 25 stratigraphic units which are or may be nonmarine fluvial and deltaic in origin. Maps are presented showing the outcrop pattern of each unit, with thickness and other information. A summary description is given of the stratigraphic occurrence, petrography, provenance, and sedimentary structures including indication of current vectors. Factors affecting ground water circulation, past or present, are evaluated in an effort to locate conditions favorable for uranium ore development. Redbeds may serve as indicators of oxidizing facies and are therefore important. The boundary between oxidizing (red or drab) and reduzate (gray, greenish, or black coloration) facies is delimited where possible. One aim of the report is to locate the counties in which each stratigraphic unit appears to be most favorable for uranium on the basis of host rock characteristics. This should facilitate field examination of the rocks for more specific indications of uranium deposits.

The following list indicates the stratigraphic units identified as nonmarine fluvial or deltaic strata, with (**) indicating high potential as a uranium source and (*) indicating moderate potential. These stratigraphic units are considered in this report.

(**) Black Creek Group (Cretaceous)
Tuscaloosa Group (Cretaceous)
(**) Newark Group (Triassic)
(**) Dunkard Group (Pennsylvanian-Permian)
(*) Conemaugh Group (Pennsylvanian)
(*) Allegheny Group (Pennsylvanian)
(**) Pottsville Group (Pennsylvanian)

(**) Mauch Chunk-Pennington Group (Mississippian)
(*) Maccrady-Stroubles Formation (Mississippian)
(*) Pocono-Price-Grainger Formations (Mississippian)
(**) Hampshire Formation (Devonian)
Bloomsburg Formation (Silurian)
Clinch-Tuscarora-Massanutten Sandstone (Silurian)
(*) Juniata Formation (Ordovician)
(*) Bays-Moccasin-Bowen Formations (Ordovician)
(*) Rome Formation (Cambrian)
Antietam-Erwin-Weisner Formations (Cambrian)
Cochran Formation (Late Precambrian)
Unicoi Formation (Late Precambrian)
Weverton Sandstone (Late Precambrian)
Mount Rogers Formation (Late Precambrian)
Swift Run Formation (Late Precambrian)
Ocoee Supergroup (Late Precambrian)
Other Precambrian(?) quartzites

The Hampshire Formation is the oldest redbed formation in the Appalachians which contains carbonaceous debris of land plants. It is moderately feldspathic, and attains a maximum thickness of about 3,000 feet in eastern West Virginia. The Hampshire Formation is present in several outcrop belts in Maryland, northern Virginia, and eastern West Virginia; it changes facies westward into the greenish gray Chemung Formation.

The Mauch Chunk and Pennington Groups are names used for equivalent strata respectively northeast and southwest of the West Virginia-Virginia boundary. Fluvial sandstones contain plant debris, and their colors may be reddish or greenish. A regional unconformity is present above these rocks over most of the region from Maryland to Alabama. The rocks are thickest in southern West Virginia, where they reach 3,300 feet in thickness and contain some coals.

The Pottsville Group contains the largest volume of sediment of any of the rocks considered to have high potential for uranium. From Maryland to Alabama the Pottsville contains quartz conglomeratic sandstones with abundant plant debris, and coal beds occur at many horizons. The feldspar content is very low, with many of the sandstones approaching glass sand in composition, but the lower Pottsville is somewhat more feldspathic. Pottsville sandstones are all grayish except in the Coosa coal basin in Alabama where limited quantities of reddish sandstone and shale occur.

The Dunkard Group contains large quantities of redbed shales associated with sandstones that always are greenish gray. Carbonaceous debris is present in channel sandstones, and coal beds are present. Feldspar content of the sandstones is moderate. Oxidizing facies is best developed in the southern part of the Dunkard Basin, so the most promising areas are in central and southern West Virginia.

Newark Group strata occur in four major fault-block basins in

Virginia and North Carolina and several minor basins. The Triassic sandstones tend to be arkosic redbeds. The central part of most of the basins contains some gray shaly interbeds, and coal locally is present. Plant debris occurs in some fluvial sandstones. These rocks dip usually to the east and attain thickness approaching 8,000 feet in the Deep River basin. Conditions appear favorable for development of uranium deposits.

The Black Creek Group is all in the reduzate facies, with gray to dark gray shales interbedded with quartzose sandstone. Lignite logs and debris are common, and may be pyritized. Uranium concentrations would probably occur only at shallow depths at the base of the present weathering profile. The strata have a gentle eastward dip on the Coastal Plain of North and South Carolina and Virginia.

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INTRODUCTION

Most commercial uranium deposits in the United States occur in fluvial sandstones, generally of Mesozoic and Cenozoic age and usually reddish or brownish in color associated with oxidation of originally carbonaceous and pyritiferous sandstones (Adler, 1970). In the southeastern United States, large volumes of probable fluvial strata occur in the Precambrian through earliest Permian sediments of the Appalachian Mountains, in the Triassic basins of the Piedmont Province, and in the Cretaceous portion of the Atlantic Coastal Plain. Relatively little attention has been given to the uranium potential of these strata because they are usually heavily covered by vegetation and often deeply weathered and because simply there has not yet been a chance discovery of commercial uranium in these strata to attract the attention of serious prospecting. The Southern Interstate Nuclear Board in a 1969 report, "Uranium in the Southern United States," pointed out that the fluvial strata are the most likely rocks to contain commercial uranium ore in the Southeastern states.

Sufficient information has accumulated about the geologic association of commercial uranium in fluvial sediments in western United States and elsewhere to examine meaningfully the probable fluvial rocks in the Southeast for the purpose of delineating the stratigraphic and geographic distribution of strata which bear characteristics which have been associated elsewhere with uraniferous deposits. The area under consideration includes all of southeastern United States from Maryland, Delaware, and West Virginia, southward to Mississippi. The rocks studied are all sedimentary and only in the more deformed portions of the Appalachians have they been at all metamorphosed. A total of 18 Phanerozoic stratigraphic units have been identified as probably at least partly fluvial in origin. Arranged according to age, they are as follows:

Black Creek Formation (Cretaceous)
Tuscaloosa Group (Cretaceous)
Newark Group (Triassic)
Dunkard Group (Pennsylvanian-Permian)

Monongahela Group (Pennsylvanian)
Conemaugh Group (Pennsylvanian)
Allegheny Group (Pennsylvanian)
Pottsville Group (Pennsylvanian)
Mauch Chunk-Pennington Formations (Mississippian)
Maccrady Formation (Mississippian)
Pocono-Prince Formations (Mississippian)
Hampshire Formation (Devonian)
Bloomsburg Formation (Silurian)
Clinch-Tuscarora-Massanutten Sandstone (Silurian)
Juniata Formation (Ordovician)
Bays-Moccasin Formations (Ordovician)
Rome Formation (Cambrian)
Antietam-Erwin-Weisner Quartzite (Cambrian)

Seven Late Precambrian units are considered briefly also.

Figure 1 shows the stratigraphic and geographic relations of these units. In Figure 1 the vertical dimension is time in years according to the Geological Society of London time scale (Harland, Smith, and Wilcock, 1964, p. 260-262) and the horizontal dimension is latitude. A diagonal hachured pattern indicates those strata which are probably at least partly fluvial. Stratigraphic names and positions of some related marine beds are also indicated. Facies changes between formations are designated by intertonguing patterns. Arbitrary changes in stratigraphic nomenclature are designated by wide vertical lines. Abrupt termination of fluvial beds by wide vertical lines indicates the limit of preservation or structural termination of the outcrop belt.

A map showing the geographic and thickness distribution of each unit is presented along with brief comments about the sedimentary structures, depositional patterns, and mineralogy. Bibliographic materials will be listed to enable geologists to begin on their own to appraise in more detail the uranium potential of each unit. Certain Precambrian rock units will be briefly considered as arkosic to quartzose quartzites which may be in part of fluvial origin.

We prepared this evaluation from the perspective of professional stratigraphers who are generally familiar with the association of uranium in fluvial sediments, but neither of whom has any direct experience with industrial production of uranium. We are familiar in varying degrees with the field relationships of the entire volume of rocks considered in this study. Our field experience has been heavily supplemented by the excellent cooperation of the library staff of the University of North Carolina, by theses and dissertations done at many universities, and by numerous conversations with geologists from various universities, government geological surveys, and to a lesser degree, with industrial geologists whose economic interests touched on certain of these fluvial rock bodies, even though their particular interest was with possibilities other than uranium potential. We hope that this perspective of stratigraphers will be a useful contribution to the economic

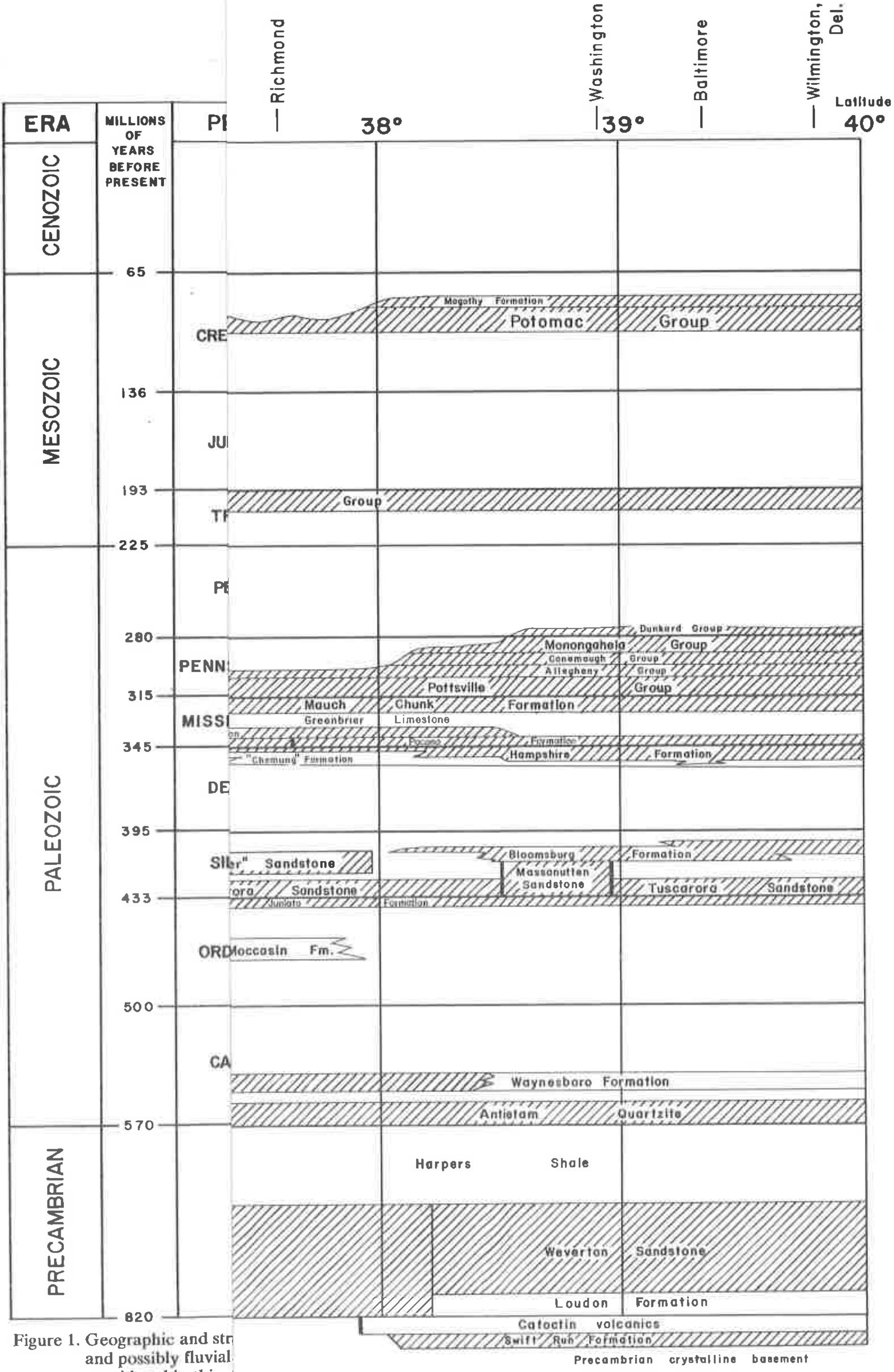


Figure 1. Geographic and str
and possibly fluvial
considered in this r

geology of uranium, and we sincerely feel that we have been able to pinpoint several factors which should help focus the uranium search more specifically to especially favorable rock bodies. In a general way, we have perhaps eliminated 80 percent of the stratigraphic volume in the Southeast from serious consideration, and in our final evaluation we select something like 5 percent of the total volume of sediments as fluvial rocks with associated characteristics such that they merit specific field and geochemical evaluations as potential uranium ore-bearing rocks.

The various maps in this study show the outcrop distribution of the fluvial strata, and consideration is also given to their subsurface distribution where they occur within 1,000 feet of the ground surface. It is unlikely at present that exploration would initially involve greater depths.

Draft copy of the contract report was completed at the end of 1971, with a cut-off date near the middle of that year for references used. Additional publications have appeared since then, but are not included as a part of this editorial revision.

Acknowledgments

The present publication is a slightly modified version of an open-file report prepared for the United States Atomic Energy Commission (Dennison and Wheeler, 1972) in fulfillment of Contract AT(30-1)-4168 awarded to the University of North Carolina at Chapel Hill. Two Atomic Energy Commission geologists have been especially helpful. Dr. Hans H. Adler has clarified the geochemical patterns of uranium concentration in fluvial strata, through numerous conversations and in his own scientific writings. Mr. Donald L. Hetland generously gave two days to show Dennison outcrop and subsurface stratigraphic relationships of uranium ore in the rather typical fluvial occurrence and certainly economically significant deposits of uranium in the Grants, New Mexico, region. They have especially helped us to see the applications of stratigraphy to the special patterns of the economic geology of uranium.

We have been greatly aided by students associated with the University of North Carolina. Thomas G. Beaman and David A. Kirchgessner were helpful as graduate student research assistants. Ronald R. Benson was especially helpful in map compilation, bringing together data from over a hundred maps and using optical systems to compile the information at the common compilation scale of 1:1,000,000 used to prepare all the maps developed for this project. At various times we utilized the drafting assistance of Herbert W. Ritzman, Virginia A. Finne, and Jack S. Whisnant. Mrs. Faye L. Modlin was patient with our typing needs, and she especially aided in editing the manuscript portions into a single package. Mrs. Cathy L. Mann also assisted with the typing.

One of the most rewarding aspects of this study has been the

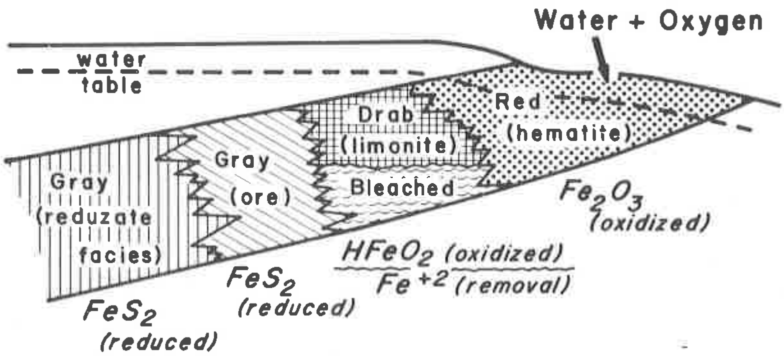
opportunity to work with the specialized talents of the scores of people who cooperated with us. Their contributions are especially appreciated, even if not always acknowledged in detail.

CRITERIA ASSOCIATED WITH FLUVIAL URANIUM DEPOSITS

Commercial uranium deposits commonly are associated with arkosic fluvial sandstones in a pyritiferous carbonaceous facies formed during or shortly after sandstone deposition. Usually the uranium content must be concentrated to commercially significant amounts by chemical transfer in oxygenated ground water and by precipitation of uranium at the border of the reduzate facies (Adler, 1970). Additional elements may also become concentrated by ground-water circulation crossing oxidation-reduction boundaries. Figure 2 illustrates geochemical facies changes in sandstone and identifies likely valences of associated elements in oxidized and reduced states. The geochemical cell hypothesis favored by Rackley, and others (1968) will be utilized in conjunction with geologic criteria which various authors have postulated to be significantly associated with commercial concentrations of uranium in fluvial sediments. These criteria will be applied to each of the 25 probably fluvial stratigraphic units in an attempt to indicate their favorable and unfavorable traits for uranium concentration.

Each of the 11 geologic associations listed below has been mentioned in various papers on uranium ore genesis in sandstone.

1. Fluvial depositional environment. The term fluvial environment seems to be rather loosely applied in uranium geology. Fundamentally it means any non-marine sediment, excluding swamp, lake, glacial and dune deposits. In its broadest application to uranium occurrences, fluvial deposits probably include the subenvironments of alluvial fan accumulations, flood plains along mature rivers, delta deposits where streams discharge into the sea or a lake, and probably even certain shoreline deposits, such as intertidal and supratidal mudflats. Strata suspected of belonging to any of these subenvironments are included in the present summary, and these strata are indicated by the diagonal line pattern in the stratigraphic chart of Figure 1. Strata containing obvious marine fossils clearly are not fluvial, as are those with appreciable thicknesses and geographic extent of bedded limestone, dolomite, evaporites, chert, or coal. Stratigraphic units are typically mapped in the field as formations and groups. Various beds in a particular formation may represent several environments, so that only a portion of the formation may be of fluvial origin, while other beds are paludal (swamp), lacustrine (lake), or marine deposits. Certain formations may contain some wave-winnowed beach deposits formed at the fluvial-marine boundary. In no case have nonmarine strata been found in this study which seem to be of dune origin. The diagonally marked intervals indicated as fluvial in the stratigraphic chart in Figure 1



Reduced	Oxidized
Fe^{+2}	Fe^{+3}
U^{+4}	U^{+6}
Cu^{+1}	Cu^{+2}
$Ag^{0\ or\ +1}$	Ag^{+1}
V^{+3}	$V^{+4\ or\ +5}$
Mo^{+4}	$Mo^{+5\ or\ +6}$
S^{-2}	S^{+6}
Se^{-2}	$Se^{0\ to\ +6}$

Figure 2. Diagrammatic cross-section of geochemical facies changes in sandstone resulting in accumulation of uranium and other elements by changes in oxidation potential of sedimentary material and paleo-groundwater system. The most likely valence state of associated elements is indicated for the reduced and oxidized zones. (After Adler, 1970; and Rackley, Shockey, and Dahill, 1968).

delimit the geographic and temporal occurrence of formations and groups of strata which are wholly or in part of fluvial origin, in the broadest sense defined above. Similarly, the various maps of each of the stratigraphic units indicate where outcropping strata of a particular age with at least some fluvial deposits occur, along with additional information on the subsurface limit of occurrence of fluvial sediments (whether terminated by facies change or by unconformity).

2. Sandstones are present. Uranium concentrations in commercial amounts occur only in permeable sandstones, principally formed

in point-bar deposits in stream channels. Siltstones and shale deposited in the interfluvial and flood plain facies are too impermeable to permit sufficient ground water circulation to concentrate ore bodies.

3. Sandstone is partly reddish (hematite) or drab brown color (limonite) or bleached in subsurface. Uranium is soluble in oxidizing environments, and is carried by ground water to the grayish reducing facies. Commercial concentrations of uranium are precipitated from ground water along or near the oxidized borders of the reduzate facies (Adler, 1970), forming roll-type deposits. Concentrations of selenium, vanadium, molybdenum, and occasionally lead, chromium, and copper can also form with uranium (Figure 2). Silver may behave similarly.

Many sandstones which are greenish or grayish when fresh may change to a brownish color when weathered, as ferrous iron minerals alter to ferric iron hydrates or limonite. In the warmer, moist climates of the more southern states in this study region, sublateritic weathering may even alter the strata to reddish hematite coloration. The coloration specified in the geologic condition favorable for uranium is not the simple weathering coloration within a few feet of the ground surface; instead the reddish and brownish coloration must persist at depth beyond the reach of surficial weathering and into the zone beneath the water table. If the sandstone is permeable, the presence of oxidized iron coloration implies the passage of oxygenated ground waters. If at greater depths in a structural basin the oxygen is consumed by chemical oxidation of pyrite and carbonaceous matter, than any uranium leached from the oxygenated sandstone or introduced with the ground water would tend to be concentrated at the reduzate boundary.

The problem of coloration of the stratigraphic units here evaluated will receive special attention, because there are several different coloration categories with different meanings. First, the probable fluviatile rocks will be noted for the presence or absence of any redbed coloration in unweathered rock, regardless of whether it is shale, siltstone, or sandstone lithology. Redbed coloration will mean the reddish color of hematite or the brownish colors of limonite. In several units studied the redbed colors are restricted to shales and siltstones and are unknown in the true sandstones or silty sandstones. It is important, therefore, to distinguish separately those units which contain redbed coloration and those probably more permeable units in which at least some of the sandstones are redbeds. Certain of the probable fluviatile stratigraphic units considered in this paper lack any redbed coloration, which puts them into a less interesting category with respect to uranium.

4. Strata contain carbonaceous material. Uranium ore preferentially concentrates in fluvial sediments containing disseminated organic material, whether finely comminuted or occurring as fossil logs and stems. Such organic debris in fluvial sediments could not have accumulated prior to the widespread appearance of vascular land plants at the end of the Early Devonian, although some land plants were probably present as early as Silurian time. With few exceptions, uranium

does not occur in commercial quantities in the extreme concentrations of organic materials into coal beds accumulated in swamp environments; probably the peat-lignite-bituminous coal strata are too impermeable to permit effective circulation of ground water, or the presence of so much carbon concentration does not permit uranium to become concentrated in the coaly strata.

Primary uranium deposits could accumulate where organic debris was deposited along bedding in paleostream channels. In the Ambrosia Lake area of New Mexico primary blanket ore deposits are attributed (Granger, 1968) to precipitation by humate-like substances deposited from meteoric solutions at the paleo-ground-water table.

One additional occurrence of organic debris in sediments deserves mention as a possible uranium-favorable situation. Nearshore marine sediments adjacent to deltaic deposits may contain significant amounts of driftwood debris, often associated with sandstones permeable enough to be petroleum reservoir rocks. These sandstones could serve as suitable places for precipitation of uranium ore from percolating ground-water solutions.

5. Sandstones contain pyrite. The presence of pyrite or marcasite in sandstone favors uranium concentration in roll-type deposits. These sulfides form unstable ionic sulfur species which may bring about uranium deposition (Granger and Warren, 1969). Pyritic material is commonly associated with petrifaction of wood debris in fluvial sediments, and pyrite cyrstals may also occur disseminated in sandstone independent of wood debris.

6. Probable source area for sandstones is granitic or gneissic terrain. Uranium in crystalline rocks tends to be associated with the sialic or lithophile minerals of granitic and gneisses (Mason, 1966, p. 46, 57). Typical granite contains 3. 7 ppm uranium, and typical diabase contains 0. 52 ppm, so that the average crustal rock has about 1. 8 ppm uranium. To reach a minimum profitable tenor of 0. 1 percent, the uranium in average crustal rock must be concentrated 500-fold by natural processes (Mason, 1966, p. 50). This association of uranium with sialic composition provides a natural source terrain to supply uranium to the clastic sediments in which uranium is diagenetically or epigenetically concentrated into ore bodies. Rackley, Shockey, and Dahill (1968) feel strongly that relatively uranium-rich sediments are deposited only basinward from uranium-rich source rocks. An original impermeable granite with relatively high uranium content, but far below ore concentrations, becomes transformed by weathering, erosional, and depositional processes into a permeable arkosic uranium source bed, capable of being a true protore for subsequent concentration into an ore body.

Other substantial opinion attributes the uranium to in-situ weathering and leaching of granitic rock by meteoric waters which subsequently enter the sediments. Because no source of uranium is evident in the eastern U. S., the writers have adopted the concept of host-rock leaching, realizing that this is restrictive and that other concepts of origin allow for a greater range of possibilities for ore development.

The concept that ore formation is dependent on host-rock leaching treats the sandstone as protore. Leaching of the protore is accompanied by oxidative alteration. The ore and altered ground make up a uranium cell. The terms protore and cell will be used in this report in this context. The reader should note that the term cell is not commonly found or used in the literature on uranium and that the term protore also has other meaning which differs from our usage. It should also be noted that the geochemical criteria used in this report to evaluate uranium potential are equally valid for and useful in conjunction with other source concepts such as derivation of uranium from tuffs or granites.

7. Uranium is concentrated from tuffaceous sediments. These could be tuffaceous interbeds or admixtures in fluvial sediments or the tuffs could be in strata overlying the ore-bearing sediments so that percolating ground water could leach uranium from the tuffs and concentrate uranium into an ore body in some appropriate sandstone at the margin of the reduzate facies. The chemical composition of sialic tuffs would be roughly comparable to that of granitic plutons. There are no tuffaceous strata preserved as Cenozoic terrestrial deposits in the Southeast which could have been leached to precipitate uranium into nearby older sandstones. Eocene tuffs are recorded in marine sediments offshore from the Southeast (Towe and Gibson, 1968; Gibson and Towe, 1971). In Highland County, Virginia, small felsic intrusives have been dated as Eocene (Fullagar and Bottino, 1969), and perhaps these plutons broke through the ground surface to form a local source of volcanic ash deposits which subsequently were totally removed by erosion. Other than these Eocene igneous occurrences, the only tuffs which could supply uranium to adjacent fluvial sediments are in the Upper Precambrian, Middle Ordovician and Pennsylvanian (Pottsville) strata.

8. The uranium is from deep-seated igneous sources. The igneous activity would have to be of appropriate chemical composition, and it would have to post-date the deposition of strata which could contain orebodies. Only three geologic possibilities exist in the Southeast. The extensive Triassic diabases are inappropriate in composition; they are associated principally as dikes with rare sills in the sediments of the Triassic basins (King, 1961), but they also cut across the Piedmont, Blue Ridge, and even into the Valley and Ridge Province (Dennison and Johnson, 1971). Ragland, Rogers, and Justus (1968) report extremely low uranium in North Carolina Triassic dolerite dikes, not exceeding 0.5 ppm and commonly below the detection limit of 0.1 ppm. A swarm of Jurassic alkalic dikes and plugs cuts Paleozoic strata near Staunton, Virginia (Johnson and Milton, 1955; Dennison and Johnson, 1971). The Eocene felsic intrusions (Fullagar and Bottino, 1969; Kettren, 1970a, 1970b) of Highland County, Virginia, could be appropriate in composition, but they are very small in volume. Dennison and Johnson (1971)

postulate, however, that the Eocene sills and dikes are mere apophyses from a much larger, still-cooling deep pluton in Bath and Highland Counties, Virginia.

9. Sandstones are feldspathic. The fluvial sandstones considered for this report will be noted whether they fall into the following categories as used by Pettijohn (1957, p. 292): arkose, feldspathic quartzite, or feldspathic graywacke; orthoquartzite or protoquartzite; and lithic graywacke or subgraywacke. The uranium-bearing sandstones are usually described in the literature as arkosic. Subgraywacke sandstones are not important as uranium host rocks, even though they may contain modest amounts of feldspar, and subgraywacke is common in fluvial deposits. The reducing character of graywackes indicated by their dark color, and pyrite and carbonaceous matter suggest that they should have suitable chemical environments for uranium deposition (Adler, 1970); the absence of ore concentrations may result from low permeability. Orthoquartzite and protoquartzite may occur in multicycle sediments deposited by fluvial processes or reworked into beach deposits; their uranium contents may be too low for uranium protore.

10. Tectonism produces regional tilting which affects ground water circulation. A regional tilting after sedimentation establishes gradients down which ground waters may move to precipitate uranium at appropriate geochemical boundaries. Gentle tilting slows oxidation of the sandstones and permits ground water leaching and concentration of uranium over a large area. This condition may apply to several ancient coastal plain situations in both the Appalachian Basin and the Atlantic Coastal Plain. Tectonism resulting in steep folds would tend to reduce the size of the circulation system compared to that formed by gentle warping.

11. Sandstones are overlain by broad erosional unconformities. Regional unconformities a short distance above an appropriate fluvial sandstone may have an effect on potential uranium concentration, since the regional tilting which produced the unconformity would affect ground water circulation patterns shortly after sandstone deposition. Several excellent examples occur in the region studied in this project. The strata above the unconformity may later become tilted by an entirely different tectonic pattern which is unrelated to water circulation patterns developed during the formation of the unconformity.

These 11 geologic conditions which may be favorable to uranium ore accumulation will be considered when evaluating the uranium-bearing potential of each major stratigraphic unit considered in this report.

Table 1 lists for each of the 18 Paleozoic and Mesozoic stratigraphic units studied a summary of the characteristics present which might be associated with potential uranium concentrations according to these various hypotheses just summarized. An X in the appropriate rectangle indicates definite presence of the characteristic in at least part of the outcrop belt, and a question mark indicates possible presence of the characteristic.

Table 1. Potential uranium-associated characteristics in Paleozoic and Mesozoic stratigraphic units studied.

	Probable fluvial beds	Sandstones present	Reddish or brownish beds present	Reddish or brownish sandstones present in fresh rock	Carbonaceous material	Coal beds	Pyritic sandstones	Probable source area of sandstones is granitic or gneissic	Probable source area of sandstones is reworked older sediments	Tuffaceous admixtures	Bentonites reported	Arkose, feldspathic quartzite, or feldspathic graywacke	Lithic graywacke or subgraywacke	Protoquartzite or orthoquartzite	Unconformity at least locally reported at base of overlying strata
Black Creek Fm.	x	x			x		x	x						x	x
Tuscaloosa Group	x	x	x		x			x				x	x		x
Newark Group	x	x	x	x	x	x		x				x			x
Dunkard Group	x	x	x		x	x	?	?	x				x		
Monongahela Group	x	x	x		x	x	x	?					x		
Conemaugh Group	x	x	x		x	x	x	?					x		
Allegheny Group	x	x	x		x	x	x	?			x		x	x	
Pottsville Group	x	x	x	x	x	x	x	?	x		?	?	x	x	x
Mauch Chunk-Pennington Fms.	x	x	x	x	x	x	x	x					x		x
Maccrady Fm.	x	x	x	x	x	x		x				?	x		?
Pocono-Price Fms.	x	x	x		x	x	?	x	x			x	x	x	x
Hampshire Fm.	x	x	x	x	x	x	x	x	?			x	x	?	x
Bloomsburg Fm.	x	x	x	x				x	x			?	?		x
Clinch-Tuscarora Massanutten	x	x					x	?	x				?	x	x
Juniata Fm.	x	x	x	x				x	x			?	x	x	x
Bays-Moccasin	x	x	x	x			x	x	x	x	x	x	x	x	x
Rome Fm.	x	x	x	x				x				?	?		
Antietam-Erwin-Weisner Qtz.	x	x	x					x	x			?	?	x	

STRATIGRAPHIC DESCRIPTIONS

The stratigraphic units of the Southeast which are probably fluvial in origin for at least part of their extent will be treated in chronologic order from oldest to youngest. Wheeler is responsible for the summary of the Mesozoic strata; Dennison prepared the comments on Paleozoic and Precambrian rocks.

Sedimentary structures and the occurrence of fossils help distinguish the fluvial deposits of the Paleozoic rocks more readily than for the Precambrian. Several Precambrian rock bodies are mentioned as arkosic in composition and possibly fluvial in origin. Not enough work has been done on the sedimentology of the Precambrian rocks to indicate decisively the patterns of deposition which could allow assignment to fluvial deposition, such as type of cross-bedding, channels, and fining-upward cycles. Most of these Precambrian rock bodies are metamorphosed, so that permeabilities are low and ground water circulation may be relatively ineffective for potential concentration of uranium ores.

The outcrops and subsurface data for the various stratigraphic units evaluated in this report were plotted geographically on a 1:1,000,000 scale base, a copy of which is included in the Dennison and Wheeler (1972) open-file report.

Late Precambrian

The sedimentary sequence of the Southeast rests unconformably on a basement complex which shows the effects of the Grenville metamorphism about 1.0 to 1.3 billion years ago (Fullagar, 1971). In Figure 3 a line indicates the boundary separating Grenville age crystalline basement (870-970 million years) on the east from slightly older basement rocks (1,040-1,340 million years) on the west, based on well data summarized by King (1970, p. 8-16). East of the boundary the Precambrian basement rocks are mainly granite and gneiss with interlayered schist, amphibolite and marble. West of the boundary the Precambrian basement rocks are less altered and are volcanics, argillites, quartzites, limestones and shallow intrusives. In the Southeast the true basement beneath this unconformity is exposed only in the core of the faulted Blue Ridge anticlinorium between Pennsylvania and North Carolina near Bryson City, North Carolina. The unconformably overlying rock sequence locally contains near its base the Catoctin-Swift Run-Mount Rogers volcanic and interbedded sedimentary sequence which Rankin, Stern, Reed, and Newell (1969) have dated as 820 million years.

Table 2 summarizes the stratigraphic nomenclature and age relations of the Late Precambrian and lowest Cambrian clastics in the Southeast.

The Ocoee Group underlies the Cochran (=Unicoi) Formation with little or no unconformity, so the age of the top of the Ocoee Group

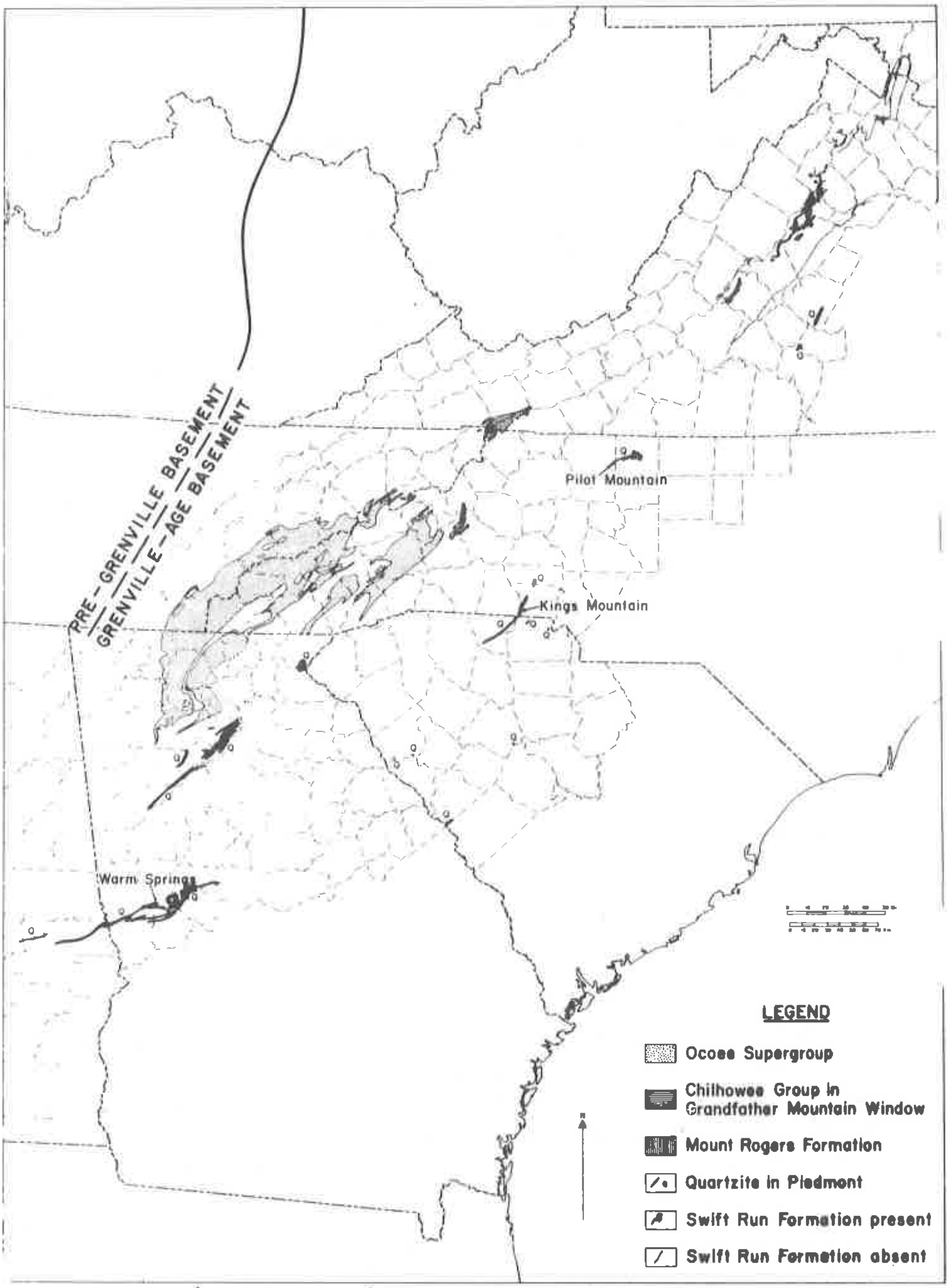


Figure 3. Outcrops of selected possibly fluvial sediments of Precambrian age.

Table 2. Chilhowee Group and other Late Precambrian stratigraphic nomenclature in the Southeast.

	Eastern Albemarle County, Va. (Nelson, 1962)	Washington County, Md. (Cloos, 1951)	Rockingham County, Va. (King, 1950)	N.C., Va., Tenn. junction (King and Ferguson, 1960)	Grandfather Mountain Window, N.C. (Bryant and Reed, 1970)	Great Smoky National Park (King, Neuman and Hadley, 1968)	Alabama (Butts, 1926)
Lower Cambrian	Everona Ls. (Cambrian?)	Tomstown Dolomite	Tomstown Dolomite	Shady Dolomite	Shady Dolomite	Shady Dolomite	Shady Limestone
	Absent ?	Antietam Quartzite	Antietam Quartzite (Chilhowee Group)	Erwin Formation (Chilhowee Group)	Chilhowee Group	Helenmode Fm. Hesse Qtz. Murray Shale Nebo Quartzite (Chilhowee Group)	Weisner Quartzite
Precambrian		Harpers Shale	Harpers Formation (Chilhowee Group)	Hampton Formation (Chilhowee Group)		Nichols Shale (Chilhowee Group)	Not exposed
		Weverton Qtz.	Weverton Fm. (Chilhowee Group)	Unicoi Formation (Chilhowee Group)		Cochran Formation (Chilhowee Group)	
	Loudoun Fm.	Loudoun Fm.	Loudoun Fm. (Chilhowee Group)				
	Catoctin Fm.	Catoctin Fm.	Catoctin Fm.	Mount Rogers Formation	Absent	Ocoee Group	
	Swift Run Fm.	Swift Run Fm.	Swift Run Fm.				
	crystalline basement	crystalline basement	crystalline basement	crystalline basement	crystalline basement	crystalline basement	

is probably about 820 million years, the same as the Mount Rogers volcanics. The basal Cambrian fossil zones in the Weisner-Erwin-Antietam quartzites are dated radiometrically elsewhere in the world as about 570 million years (Harland, and others, 1964). The intervening lower Chilhowee Group strata shown in Figure 1 represent a quarter billion years of sedimentary accumulation (nearly as long as the Paleozoic Erathem) without recognizable unconformity.

Ocoee Supergroup.--The oldest sedimentary sequence in the Southeast is the Ocoee Series or Supergroup of the Great Smoky Mountain region of Tennessee and North Carolina. The Ocoee extends from the vicinity of Asheville, North Carolina, southwest 175 miles at least as far as Cartersville, Georgia (Fairley, 1966). The distribution of the Ocoee is shown in Figure 3. The Ocoee consists of several formations with a total thickness of 40,000 feet or more. The stratigraphy has been summarized by Rodgers (1953, p. 23-34), by King, Hadley, Neuman, and Hamilton (1958), by Hadley and Goldsmith (1963), by King (1964), by Neuman and Nelson (1965), and by King, Neuman and Hadley (1968). King (1970, p. 38-44) briefly summarized knowledge about the Ocoee. Hadley (1970) has prepared an excellent longer summary paper. The rocks of the Ocoee Series are of sedimentary origin but have been metamorphosed to varying degrees, with metamorphism increasing to the southeast. At the northwest edge of the Great Smoky foothills the shales are unaltered or are represented by slates; these give way southeastward to phyllites and schists. Mineral assemblages of the amphi-

Table 3. Stratigraphic units of the Ocoee Series, Tennessee and North Carolina (Hadley, 1970).

AGE	NORTH OF AND BELOW GREENBRIER FAULT				SOUTH OF AND ABOVE GREENBRIER FAULT		
CAMBRIAN AND CAMBRIAN?	CHILHOWEE GROUP		Cochran or Unicoi Formation and higher units	Correlation between these sequences not established	ROCKS OF MURPHY BELT		Nantahala State and higher units (PRECAMBRIAN(?) and early PALEOZOIC(?))
			DISCONFORMITY(?)				LITHOLOGIC BREAK BUT PROBABLY COMFORMABLE
LATER PRECAMBRIAN	OCOEE SUPERGROUP	WALDEN CREEK GROUP	Sandsuck Formation Wilhite Formation Shields Formation Licklog Formation		OCOEE SUPERGROUP	GREAT SMOKY GROUP	Unnamed higher strata Anakeesta Formation Thunderhead Sandstone Elkmont Sandstone
			FAULT CONTACT SEQUENCE UNCERTAIN				
			Unclassified formations				
		SNOWBIRD GROUP	Metcalf Phyllite Pigeon Siltstone Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation			SNOWBIRD GROUP	Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation
			UNCONFORMITY				UNCONFORMITY
EARLIER PRECAMBRIAN	Granitic and gneissic rocks				Granitic and gneissic rocks		

bolite facies are developed over wide areas; staurolite and kyanite are common, but metamorphic grain sizes are smaller and obliteration of sedimentary structures less, than in rocks of similar grade in most regions. Sandstones are recrystallized and their grain size modified, but their sedimentary aspect and the distinctiveness of their beds are clearly preserved almost everywhere (King, Hadley, Neuman, and Hamilton, 1958, p. 951). On the southeast side of the Great Smoky Mountains the basal Ocoee rests unconformably on earlier felsic granites and micaceous and amphibolitic gneisses. In the northwest part of the mountains the Ocoee appears succeeded (perhaps unconformably) by the Cochran Formation of the basal Chilhowee Group. Ocoee outcrops are severely broken up by faulting. The Ocoee is divided into three groups and numerous formations in a classification established by King, Hadley, Neuman, and Hamilton (1958) (Table 3). Ocoee strata include conglomerates, arkoses, feldspathic quartzite, graywackes, siltstones, and shales altered to phyllites. Current structures are common; graded-bedding is present in many sandstones. Fossils are absent from the Ocoee Supergroup. The source terrane was granitic or gneissic to yield high feldspar content. Sedimentary structures and the great thickness suggest relatively deep water origin for most of the Ocoee; probably it is chiefly marine. Associated carbonates support this interpretation of marine origin. There is no suggestion of fluvial deposition, according to most authors, but Hanselman, Conolly, and Horne (1971) suggest that sedimentary structures indicate shallow water and even deltaic environments in the Upper Ocoee Walden Creek Group and in the Chilhowee Group interval along U. S. Route 129 in Blount County, Tennessee.

The feldspathic nature of the sandstones could conceivably provide a protore of uranium. Feldspar is most abundant in the lower Ocoee. Regional metamorphism appears to predate the folding and faulting which brought the rocks to their present attitude. The metamorphism would reduce permeability to nearly zero, so circulating ground water probably has not been able to concentrate uranium to any appreciable extent in feldspathic sandstones and conglomerates in the Ocoee Supergroup.

The full thickness of the Snowbird Group can be sēen only in the northeastern part of the Great Smoky Mountains, where it is 13,000 feet thick. The Snowbird Group consists entirely of metamorphosed clastic strata derived largely from granite and gneiss. All but the finest-grained rocks in the Snowbird are highly feldspathic, so that feldspar commonly exceeds quartz in abundance. The most abundant rocks are arkose, feldspathic sandstone, and argillaceous siltstone with lesser amounts of graywacke and shale. The lower 100 feet of the Wading Branch Formation is distinctly less feldspathic and consists of metamorphosed shale and graywacke (Hadley and Goldsmith, 1963, p. B27). Most of the Snowbird strata are well bedded. Graded beds are rare except in the basal graywacke. The upper beds are cross-bedded. A cross section in King, Hadley, Neuman, and Hamilton (1958, p. 956) shows a facies decrease in grain size to the northwest from Longarm Quartzite to Roaring Fork Sandstone to Pigeon Siltstone. According to Hadley (1970, p. 249) both facies and cross-beds indicate clastic transport from the east or southeast into a westward deepening basin. Only this lowest part of the Ocoee shows a southeastern or eastern source terrane. The upper Ocoee (Great Smoky and Walden Creek Group) through Lower Ordovician clastic strata show a northwestward or cratonic source for clastics, followed by a Middle Ordovician and later Paleozoic return to a dominant southeastern source for clastics.

The Great Smoky Group (up to 25,000 feet thick) consists of coarse-grained, graded-bedded sandstone with interbeds of slate or schist. Sandstones contain quartz, potassium feldspar, a little plagioclase, chips of slate, and pebbles of leucogranite. Grain size decreases southwestward toward Georgia, where conglomeratic zones are rare, and thickness correspondingly decreases to 15,000 feet. King (1970, p. 43) interprets the Great Smoky Group as graded bedding accumulations in a marine tectonic trench. The fact that sediments decrease in grain size toward the southwest suggests that the trough was filled from its northeastern end. The Great Smoky Group is conformable on the Snowbird Group.

The Walden Creek Group is separated from the Great Smoky Group by faults, so the Great Smoky-Walden Creek stratigraphic relationships are unclear except that both are younger than the Snowbird

Group. The Walden Creek Group is about 10,000 feet thick. The Walden Creek is the most heterogeneous of the three Groups. It consists of dark to sandy argillite interbedded with siltstone and fine to coarse, feldspathic sandstone. The sandstone tends to be less feldspathic than in the Snowbird Group. Graded bedding, load casts, flame structures and slump structures suggest a turbidite origin for parts of the Walden Creek Group. Roundstone quartz-pebble conglomerate in beds 1-200 feet thick is characteristic of the Walden Creek Group; other pebbles consist of limestone, chert, quartzite, siltstone, hornfels, and granite. The Wilhite Formation is the only Ocoee formation which contains important amounts of carbonate rocks; the Wilhite is 3,500 feet thick and contains some limestone and dolomite interbedded with mostly argillaceous to sandy strata. Calcareous quartz sandstone and orthoquartzite northeast of Pigeon River with well-rounded and well-sorted grains are suggestive of aeolian origin (Hadley, 1970, p. 251). In the western Great Smoky Mountains Hadley suggests shallow to deep water origin for the Walden Creek Group, perhaps mostly near sea level. Sedimentary features indicate a source to the north for the clastics of the Walden Creek Group.

Swift Run Formation. --In Virginia and Maryland on the east and west flank of the Blue Ridge anticlinorium, the crystalline basement is overlain by 0-2,600 feet of tuffaceous sediments and detrital quartzites and phyllites to schist known as the Swift Run Tuff or Formation (Figure 4), named from Swift Run Gap along U. S. 33 in Rockingham and Greene Counties, Virginia (Stose and Stose, 1944, p. 410). The Swift Run is overlain in turn by the meta-basalts of the Catoctin Formation. The surface on top of the billion-year-old Precambrian crystalline basement had considerable relief, and it was buried unconformably by volcanic and sedimentary overlap. There is no evidence of extensive marine deposits so the sediments are probably chiefly fluvial infillings of topographic lows.

At the north end of the Blue Ridge in Frederick County, Maryland, Stose and Stose (1946, p. 18-28) describe the Swift Run Tuff as blue and green blebby tuff, sericite schist, and a sericitic quartzite with glossy and blue detrital quartz grains. Locally it contains marble. The marble overlies arkosic quartzite which in turn rests on the crystalline basement and underlies the Catoctin metabasalt. Nickelsen (1956, p. 243-244) divided the Swift Run Formation near the Potomac into a lower member (0-150 feet) with highly sericitic quartzite with sericitic phyllite and containing quartz cobbles up to 4 inches in diameter, and an upper member (50-200 feet), primarily phyllitic with scattered grains of quartz.

Near Luray, Virginia, Reed (1955, p. 880) reported that the sediments beneath the Catoctin consist of mostly poorly sorted arkoses, conglomerates, and graywackes with a total thickness ranging from a few inches up to 150 feet. Relief beneath the unconformity on the buried crystalline terrane is reported as 450-1,000 feet near Luray.

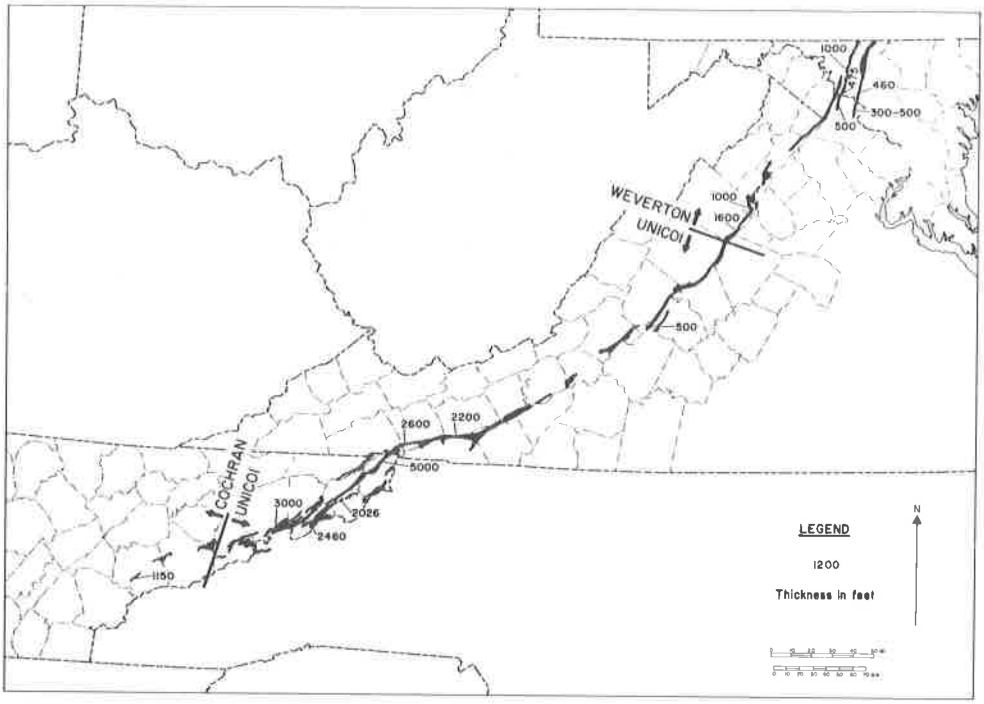


Figure 4. Outcrops of Late Precambrian Weverton, Unicoi, and Cochran Formations.

In the Elkton area of Virginia, King (1950) describes the Swift Run Formation as 0-100 feet of arkosic quartzite, locally conglomeratic, with interbeds of slate and pyroclastic rocks totalling 0-100 feet in thickness. There the tuffaceous element is subordinate to sedimentary layers, so he called the unit Swift Run Formation rather than Swift Run Tuff.

Bloomer and Bloomer (1947, p. 95) proposed the name Oronoco Formation for a formation in the Buena Vista Quadrangle of Virginia underlying the Catoctin metabasalt and composed of conglomerate, arkosic sandstone, tuff, andesite, quartzite, phyllite, and slate. Later Bloomer (1950) recognized the equivalence of his Oronoco to the Swift Run and abandoned Oronoco as a formation name. Bloomer and Werner (1955) describe the Swift Run Formation of central Virginia as 0-400 feet of graywackes, subgraywackes and volcanics that unconformably overlie the basement complex and conformably underlie the Catoctin greenstone of the Blue Ridge. In central Virginia the Swift Run overlaps the basement complex from east to west.

Other recent references describing the Swift Run Formation on the west flank of the Blue Ridge anticlinorium are Bick (1960), Brent (1960), Allen (1963), Werner (1966), and Allen (1967).

In the Buchannon and Arnold Valley Quadrangles at latitude 37°30' N the Unicoi is mapped as directly overlying the Blue Ridge crystalline complex with no intervening Swift Run Formation (Spencer, 1967).

On the east flank of the Blue Ridge anticlinorium the Swift Run Formation has been described by Parker (1968) in the Lincoln and Bluemont Quadrangles in Loudoun County, Virginia, where the formation consists of hundreds of feet of arkoses and phyllites with some recrystallized limestone lenses. Parker minimized the volcanic nature of the Swift Run and interpreted it as a sequence of sedimentary beds which is typical of a transgressive sea environment: coarse clastic materials grading upward to progressively finer and more uniform size particles, succeeded by colloidal-type deposits which included clastic grains, in turn succeeded by chemical precipitates.

Furcron (1939, p. 37) reported marble beneath the Catoctin in what appears to be the stratigraphic position of the Swift Run Formation east of Marshall, Fauquier County, Virginia.

Nelson (1962) has described the Swift Run Formation in Albemarle County, Virginia, as one to 2,200 feet of detrital quartzite and tuffaceous slates. The Swift Run on the east limb of the Blue Ridge anticlinorium increases greatly in thickness from the exposures on the west limb. At Sugar Hollow it is 1,380 feet thick. In the Charlottesville area the Swift Run Formation is 2,250 feet thick; the basal 300 feet is quartz conglomeratic overlain by 600 feet of quartzose sandstones followed by finer clastics and two greenstone lava flows. The Swift Run is 1,300 feet thick at the Nelson-Albemarle County border and 2,200 feet thick at the Orange-Albemarle County border. West of Eastham, Nelson reports 2,600 feet of Swift Run Formation.

Mount Rogers Formation.--The Mount Rogers Formation consists of some 10,000 feet of extrusive volcanic rocks, tuffs, and shaly to conglomeratic arkosic sediments all metamorphosed to low grade. They occur near the common junction of Virginia, North Carolina, and Tennessee (Figure 3). The main outcrop belt extends from Pond Mountain to Whitetop Mountain and Mount Rogers, with traces of the Mount Rogers strata preserved between the Unicoi Formation and the Precambrian crystalline basement as far northeast as U. S. Route 21 near Independence, Virginia. At Stack Ridge and Fodderstack Mountain three miles west of the tri-state junction two small outcrops of the basal Mount Rogers occur isolated from the main Mount Rogers exposures. The principal recent references to the Mount Rogers Formation are King and Ferguson (1960), Cooper (1961), Rankin (1967), Rankin (1970), and Rankin (1971).

The volcanic rocks range from basalt to rhyolite; intermediate compositions of flow rocks are uncommon. Thick masses of rhyolite constituting about 50 percent of the formation are the most distinctive features of the Mount Rogers and hold up the three highest mountains in Virginia.

The Mount Rogers Formation may be roughly divided into three parts. The lower part consists of interbedded strata, basalt, and rhyolite. Thick masses of rhyolite make up the middle part, and sedimentary rock containing minor basalt and rhyolite makes up the upper part. Calcareous sandstone and calcareous shale are sparingly present in parts of the Mount Rogers, but limestones are absent.

Strata of the lower Mount Rogers are characterized by somewhat metamorphosed gray to greenish gray, muddy-matrix conglomerate, gritty graywacke, laminated siltstone, shale, and minor calcareous sandstone. The rocks are semischists, and the conglomerate contains stretched pebbles and boulders.

Three rhyolite units have been mapped in the massive rhyolite forming the middle part of the Mount Rogers. The lower unit is probably lava flow. The middle unit is chiefly lava flow with local ash flow tuffs. The bulk of the upper rhyolite consists of ash-flow sheets suggesting a subaerial environment for this part of the Mount Rogers. The three rhyolites have an aggregate thickness of 5,000 feet or more, and Mount Rogers is thought to be near the approximate site of a volcanic center. Rankin, Stern, Reed and Newell (1969) report a uranium-lead age determination based on zircons from two rhyolite units within the Mount Rogers; the original age of accumulation of the Mount Rogers Formation is placed at 820 million years.

Arkose, rhythmite, laminated pebbly mudstone, and probably tillite, all maroon, characterize the Upper Mount Rogers. Numerous examples of soft-sediment deformation are preserved. The arkose may be cross-bedded, and graded bedding is exceptionally well developed in the rhythmites. Isolated clasts of Cranberry Gneiss have been dropped into soft fine-grained sediment, suggesting ice rafting. Evidence of Late Precambrian glaciation is reported from many parts of the world. Some clasts are up to a meter across. Interbedded with and above the rhythmites are massive, poorly sorted, muddy, red-matrix, polymict conglomerate-tillite. The close association of pebbly varved rocks with the conglomerate leads Rankin (1967, p. 12) to suggest that they are both of glacial origin.

King and Ferguson (1960, p. 31) point out that the Mount Rogers contains both angular clasts (agglomerate) and rounded pebbles of conglomerate. A lower red boulder conglomerate contains granite and granodiorite cobbles and boulders up to 3 feet in diameter and smaller pebbles of aplite, greenstone and vein quartz, set in siltstone matrix. The higher strata of the Mount Rogers consist largely of coarse arkosic sandstones with interbedded conglomerate consisting of pebbles of quartz and other resistant rocks. The upper conglomerates resemble those of the lower part of the Unicoi Formation which overlies them. King and Ferguson (1960, p. 31) suggest a fluvial origin for the lower boulder conglomerate. "The wide areal extent of the deposit and lack of any obvious content of volcanic material argue against a volcanic origin and suggest that the fragments were derived by various processes of subaerial erosion, transportation, and deposition."

The Mount Rogers Formation rests with nonconformity on the Cranberry Gneiss of the crystalline basement. The buried topography had considerable relief so that at one place or another nearly every Mount Rogers unit from bottom to top is in contact with the Cranberry. Boulder-size clasts of Cranberry Gneiss are found locally in all major sedimentary and volcanic units of the Mount Rogers. Rankin (1967, p. 13) has followed the Mount Rogers-Unicoi Formation contact for 30 miles along strike in the Shady Valley thrust sheet and found no evidence for an unconformity separating the two formations. To the southwest and northeast an unconformity has been reported beneath the Unicoi, which locally rests on crystalline basement.

In a section along U. S. Route 21 in Grayson County, Virginia, Cooper (1961, p. 19) interpreted interlayers of Mount Rogers tuffaceous sediments to be present in the basal 700 feet of the Unicoi Formation, which he regarded as 2,211 feet thick there. The uppermost Mount Rogers may be in part a facies equivalent of the basal Unicoi.

Bartlett and Kopp (1971) present evidence that can be interpreted to indicate that part of the Mount Rogers is marine. They report a well-preserved linguloid brachiopod from float which they believe came from a unit of maroon siltstones about 570 feet below the top of the Mount Rogers Group. Linguloid brachiopods commonly are near shore organisms, often occurring in brackish water.

Weverton Sandstone.--The massive and resistant Weverton Sandstone is named for exposures at Weverton in Washington County, Maryland. It conformably overlies the less massive Loudoun Formation composed of phyllite, quartzite, and conglomerate. The Weverton underlies the shales and sandstones of the Harpers Formation. Cloos (1951, p. 29-33) describes the Weverton as consisting mainly of fresh, light, partly milky-white quartz grains in a matrix of secondary recrystallized quartz. Some feldspar is common and magnetite is very abundant locally. There are several coarse and conglomeratic layers with a gray matrix, weathering brown. Thickness is distorted by tectonic flowing, but the Weverton along the Potomac River outcrops is 200-1,000 feet thick.

Stose and Stose (1946, p. 34-39) describe Weverton outcrops in Frederick County, Maryland. They mention 100 feet of dark, ferruginous, fine-grained quartzite at the base of the formation at Catoctin Mountain and other ferruginous beds at South Mountain.

Nickelsen (1956, p. 247-250) has described the Weverton in considerable detail in Loudoun County, Virginia, just south of the Weverton type locality. The total apparent thickness of the Weverton is 340-481 feet in his composite measured section, and he estimates an original thickness of the Weverton to be roughly 500 feet before tectonic stretching. He recognizes three quartzite members of the Weverton (65-108, 60-105, and 105-128 feet thick listed from base upward) with the intervening gaps of 50-60 feet (lower) and 60-80 feet (upper) containing quartzitic phyllite. The Weverton is now a metaquartzite, but prior to metamorphism was an orthoquartzite. The heavy mineral assemblage indicates a mature sediment: ilmenite, magnetite, zircon, and sphene. There is no mention of feldspar in the description. The succeeding quartzite members become less well sorted than the member below it. Grains are chiefly 1-2 mm diameter, but commonly as large as 5 mm. The middle and upper quartzite members are conspicuously cross-bedded.

Whitaker (1955) examined the Weverton cross-beds in Frederick and Washington Counties, Maryland. The flat base of cross-bedding classifies the beds as planar cross-stratification. Cross-beds are concave or rarely straight, and they dip generally less than 20° from master-bedding. The length of the cross-strata is less than one foot. Measurement of 136 cross-strata reveals that the Weverton detritus came from the west, that is, from the craton.

In the Leesburg Quadrangle in Loudoun County, Virginia, the Weverton is 300-500 feet thick on the east limb of the Blue Ridge anticlinorium (Toewe, 1966). It is light-gray, vitreous, fine-grained, finely laminated or banded quartzite with phyllitic interlayers in the topmost few feet.

Farther south in the Warrenton Quadrangle Furcron (1939, p. 41-44) described the Loudoun Formation (Weverton in the sense now used along the Potomac) as blue-gray arkose colored by blue quartz and blue-gray feldspar. It is slaty and schistose to massive and may contain scattered pebbles of quartz and slate. In the western part of the Quadrangle Furcron reports Loudoun strata directly on Precambrian crystalline rocks (Swift Run Formation?), but near the Catoctin Mountain border fault numerous detached areas of fine-grained arkose occur upon the Catoctin in normal stratigraphic position for the Loudoun strata. Probably his stratigraphic succession is confused, but apparently fine-grained arkoses do occur just above the Catoctin near Warrenton.

Farther to the south on the east flank of the Blue Ridge anticlinorium in Albemarle County, Virginia, Nelson (1962, p. 29-30) indicates only shaly to sandy schistose rocks overlying the Catoctin volcanics. He assigned these strata to the Loudoun Formation which he records as 7,500 feet thick in eastern Albemarle County. Apparently the Weverton changed facies eastward away from its western source, or it was eroded before deposition of the Cambrian or Ordovician Everona Limestone which overlies the Loudoun Formation as mapped by Nelson east of Charlottesville. Using more modern nomenclature, Brown (1970, p. 345) correlates part of the Evington Group above the Catoctin east of Charlottesville with the Weverton-Loudoun sequence. In the Lynchburg Quadrangle the Evington Group appears to be dominantly deep water marine; current bedding is extremely rare, and thin laminations and graded bedding are common. He suggests that the Mount Athos Quartzite may represent Chilhowee or younger clastics washed into the miogeosyncline from the west. The calcareous and feldspathic Mount Athos is coarsest and thickest to the west and locally contains a basal conglomerate with quartz pebbles an inch long.

The Weverton sandstone has been extensively trace on the west flank of the Blue Ridge anticlinorium until it passes into the Unicoi Formation, with an arbitrary name change at about latitude 38°15'. Woodward (1949) described the Weverton in Jefferson County, West Virginia, where he hesitatingly used the name Loudoun-Weverton Formation because of the then-current stratigraphic confusion in the exposures along the Potomac River.

Allen (1963, p. 48) described the Weverton in Greene County, Virginia, as consisting of thin beds of blue quartz conglomerate with iron-oxide cement, sandstones, arkosic sandstones, and intercalated siltstones which show indistinct slaty cleavage. Quartz veinlets and quartzite layers are common. It is probably about 500 feet thick.

In Rockingham County near Elkton, Virginia, King (1950, p. 17-19) used the name Weverton Formation rather than Weverton Sandstone. Total thickness of the Formation is 1,000-1,600 feet, with thickness increase resulting chiefly from variation in the lower of the three members. The lower member is chiefly pebbly quartzite with pebbles up to a half-inch in diameter, consisting of clear to blue quartz, jasper, and slate. The matrix is feldspathic. Interbeds are chiefly arkosic siltstone, commonly pale greenish. The lower member is 100-700 feet thick. The middle member of the Weverton consists of 100 feet of shale with some arkosic siltstones and fine sandstone. The upper member is about 700 feet thick and consists of interbeds of quartzite, sandstone, and siltstone. Quartzite cemented by iron oxide is the characteristic rock of the upper member occurring in beds 1-5 feet thick. Most of the quartzite in the upper member is medium-grained, and all is more or less feldspathic. Interbeds of fine sandstone and siltstone occur in the upper member. Indistinct traces of Scolithus occur in light-colored quartzite in the upper member.

South of the Elkton area there is an arbitrary name change from Weverton to Unicoi Formation for the basal strata of the Chilhowee Group (Figure 4).

Depositional environment for the Weverton is not clear because of the lack of fossils. Toewe (1966, p. 5) indicates that the Weverton is marine, but gives no evidence. Other writers do not give indication of depositional environment. Scolithus is common in the Silurian Tuscarora Sandstone which is considered fluvial or shoreline in origin, but which lacks associated marine fossils. The cross-bedded arkosic Weverton sandstones, which seem to be present only in the south, are probably immature sediments deposited near a granitic or gneissic source terrane to the west. The arkosic portion of the Weverton may be fluvial. Farther north along the west flank of the Blue Ridge and on the east flank of the anticlinorium the Weverton is orthoquartzite and very mature. This orthoquartzite has a western source, and it has been subjected to severe weathering during longer transport distance or multicycle erosion. The Weverton of the northern Blue Ridge may be fluvial or some or all of it may be marine. Certainly portions of the Weverton could be fluvial or deltaic. Detailed study of bedding characteristics is needed to help reveal its depositional environment.

Unicoi Formation. --From the vicinity of Waynesboro, Virginia, to northeastern Tennessee, the basal formation of the Chilhowee Group is called the Unicoi Formation, named for Unicoi County, Tennessee. The type locality was designated by King and Ferguson (1960, p. 36) at a section measured along the Nolichucky River southeast of Unaka Springs, where it is about 2,460 feet thick, with the base either faulted or unconformable on older sediments. Two amygdaloidal basalt flows 24 and 20 feet thick occur 1,285 and 2,121 feet, respectively, below the top of the Unicoi. Other lithologies in the type section are arkosic to quartzose quartzite and some conglomerate. A basal conglomerate contains pebbles of quartz and slate but not feldspar.

In the nearby section along the Doe River at Hampton 2,026 feet of Unicoi strata nonconformably overlie gneissic basement and underlie 470 feet of shale and sandstone of the Hampton Formation.

In northeast Tennessee the upper contact of the Unicoi Formation is placed at the top of a sequence of vitreous and arkosic quartzite beds that lies at a rather constant interval of 2,500 to 3,000 feet below the top of the Chilhowee Group and is the only persistent key horizon in the middle part of the Group.

The thickest sections in northeast Tennessee are in the Iron Mountains where about 5,000 feet of Unicoi are present, with the upper 1,000 feet containing more massive arkosic sandstone and quartzite. The present outcrops have been moved many miles along faults from their original positions, and the various fault blocks have shifted relative position.

In northeast Tennessee, there are up to three basalt flows with a maximum thickness of 100 feet. No clearly defined pillows were seen by King and Ferguson (1960, p. 37).

To the northeast in Smyth County 1.5 miles northeast of Konnarock, Virginia, Butts (1940a, p. 27-31) described a complete Unicoi section which is 2,604 feet thick and contains three amygdaloidal lava beds. There and at Trout Dale (Rankin, 1971, p. 49) the Unicoi conformably overlies the Mount Rogers volcanics. Miller (1944) describes and maps Unicoi outcrops near Trout Dale.

The Unicoi Formation is on the order of 2,200 feet thick along U. S. Route 21 in Grayson County, Virginia (Cooper, 1961, p. 18). There the Unicoi contains quartzites, graywackes, arkosic sandstones and conglomerates along with quartzose and polymictic conglomerates, siltstones, and three zones with amygdaloidal basalt flows. Graded bedding in the Unicoi suggests deep water deposition, not fluvial. Cross-bedding indicates a western clastic source from the crystalline basement of the craton.

Rankin (1970, p. 232; 1971, p. 49) discusses evidence of a pre-Unicoi erosional hiatus extending northeastward from a point between U. S. Route 21 and Fries in Grayson County, where he proposes post-Mount Rogers epeirogenic movement and erosion. Abundant felsic and mafic dikes, probably of Mount Rogers age, cut the Cranberry Gneiss, but are truncated by the nonconformity at the base of the Unicoi.

Between Grayson and Bedford Counties, Virginia, the base of the Unicoi is cut out by faulting. Bloomer and Werner (1955) described and mapped the Unicoi from near the James River northeast to Rockfish Gap east of Waynesboro. From the James River northeast to Montebello the Unicoi rests unconformably on the Pedlar Formation of the Precambrian basement complex. Northeast of Montebello the Unicoi rests directly on the Catoctin metabasalt with little or no unconformity. In the James River gorge the Unicoi Formation consists of about 500 feet of greenstone volcanics and intergradational conglomeratic graywackes, pebbly arkoses and pebbly quartzites. Some tuff layers are present. The Unicoi is only incipiently metamorphosed.

Between Waynesboro and Elkton an arbitrary name change occurs (Figure 4) and the Unicoi passes northeastward into the Weverton Formation (King, 1950).

The name Unicoi Formation is used in Tennessee for a distance of 50 miles south of the type locality along the Nolichucky River. An arbitrary name change from Unicoi Formation to Cochran Formation or Conglomerate occurs between Stone Mountain on the northeast and English Mountain to the southwest, at the approximate position of Interstate 40. Bearce (1969) described the Unicoi in the southwestern Bald Mountains as 3,000 feet of light-grey, medium- to thick-bedded, medium- to coarse-grained, feldspathic quartzite and arkose, brown to greenish-gray, medium- to thick-bedded, fine-grained, pyritic sandstone, and minor intervals of dark-gray platy siltstone. The lower half of the Unicoi becomes increasingly more arkosic and granular toward the base, and generally 10-70 feet of arkosic conglomerate with quartz and feldspar pebbles form the base of the formation. The association of brownish to greenish colors, arkosic beds and pyrite is interesting from a perspective of the search for uranium.

Brown (1970, p. 342) plotted paleocurrent directions for the Unicoi Formation in Virginia and Tennessee and obtained a composite vector mean transport direction toward S 82° E based on 260 readings.

Cochran Formation.--The name Cochran Formation is applied to the basal Chilhowee strata in Tennessee from English Mountain southwestward to Chilhowee Mountain and beyond nearly to the south border of Tennessee at the terminus of Chilhowee outcrops. The Cochran is 1,150 feet thick at its type section of Chilhowee Mountain (Newman and Nelson, 1965, p. D25). King (1964, p. 71-72) also describes its occurrence in the central Great Smoky Mountains. In the Great Smokies the Cochran is 1,000-1,250 feet thick.

The lower half of the Cochran on Chilhowee Mountain is largely maroon, crossbedded, pebbly arkose with streaks and layers of maroon shale and siltstone. The upper half is light-gray, white, or faintly pink vitreous arkose and quartzite. The top 40-50 feet is massive quartzite. Hematite concretions 1-4 inches in diameter dot the quartzite beds. The rock is about 10 percent feldspar. Both the top and bottom contacts are conformable. The Cochran lacks interbedded lava flows.

Whisonant (1970) reported a vector mean of cross beds with currents moving toward S 46° E for combined Cochran-Unicoi strata in Tennessee. Modal analysis indicates a significant direction of current flow toward the south-southeast octant.

Hanselman, Conolly, and Horne (1971) suggest from detailed outcrop studies along Route 129 in Blount County, Tennessee, at the south end of Chilhowee Mountain that the Ocoee-Chilhowee rocks are deltaic to shallow marine. The Chilhowee exposed there is all Cochran Formation.

The Cochran-Unicoi-Weverton strata form one continuous clastic unit that can be traced from southern Tennessee to Maryland along the west flank of the Blue Ridge and for a short distance southward into Virginia along the east flank. The following paleogeographic sketch seems to fit the available information. About 820 million years ago the margin of the billion-year-old crystalline craton was down-warped along a northeast to north axis trending more nearly north-south than the present outcrop belt. Volcanics were extruded from northeastern Tennessee to Pennsylvania (lower Unicoi, Mount Rogers, and Catoctin). Perhaps the lavas are absent from the Cochran because the depositional surface was too high in elevation for the lavas to flow from the east to that region. The continental margin continually depressed to the east and clastics were eroded from the granite and gneiss terrane and transported eastward into the basin. The outcrop belt cuts slightly oblique to shoreline trend. The Cochran was closest to the source, and it probably was partly deltaic or upstream fluvial. A little to the northeast arkosic but somewhat finer sediment accumulated farther from source, still probably partly as stream deposits. Absence of pillow structures in the lavas supports the interpretation of fluvial origin. Feldspathic sandstone persists to the southern occurrence of Weverton Formation, where the strata are a bit finer. In Maryland the Weverton is so low in feldspar content that the lithology is an orthoquartzite, the pebbles are smaller than to the south. On the east side of the Blue Ridge near Charlottesville all the Weverton strata apparently have changed facies into metamorphosed shaly beds. Following the Cochran-Unicoi-Weverton strata northeastward along present outcrop trend has the effect of taking the observer farther from source, with increasing mineralogic maturity of sands. Such a horizontal change in grain size and mineralogy is comparable to the vertical change from basal arkosic conglomerate upward to quartzose sandstone that accompanies burial of granitic land surface in many parts of the United States, such as the overlap of Late Cambrian seas in the Ozark region. This principle has a bearing on possible uranium protores.

A somewhat similar paleogeographic interpretation was recently put forth by Brown (1970), but the scheme offered here accounts for mineralogic variation as well as grain size. There is an implication that the Weverton orthoquartzites are first-cycle sands, subjected to more transport and alteration than the near-shore to fluvial Cochran-Unicoi-southwestern Weverton. Perhaps from Luray northeastward the Weverton is chiefly marine; south of there substantial fluvial deposits probably are present in the Weverton-Unicoi-Cochran beds, with fluvial strata probably becoming more abundant to the southwest. The interpretation presented here implies more fluvial strata than suggested in Brown's depositional model.

Other Precambrian(?) Quartzites.--In the Grandfather Mountain window of North Carolina, some 4,000 feet of Chilhowee Group strata are present in conformable stratigraphic succession beneath the Shady Dolomite (Bryant and Reed, 1970). A lower quartzite unit 800-2,200 feet thick consists of quartzite to feldspathic quartzite with thin interbeds of phyllite and some quartz pebble conglomerate. The lower quartzite is nonconformable on crystalline basement. A middle phyllite unit 150-400 feet thick contains phyllite with interbeds of gray to white quartzite. The upper unit of the Chilhowee Group is quartzite to feldspathic quartzite 1,300-2,500 feet thick with small amounts of phyllite interbeds. The upper unit is cross-bedded and contains Scolithus. The authors do not attempt to correlate these units with stratigraphic names in the Chilhowee Group on the west side of the Blue Ridge.

Butler and Dunn (1968) have mapped and described quartzites in the vicinity of Pilot Mountain and the Sauratown Mountains, North Carolina. The pure quartzite capping the Pilot Mountain is a horizontal bed 220 feet thick with cross-bedding indicating currents moving to the southeast. The quartzite thins to 10 feet only 1.5 miles west from the crest of Pilot Mountain.

The Kings Mountain Belt in North Carolina and South Carolina contains quartzite of indeterminate age, generally on strike with the Sauratown Mountain outcrops (Stuckey, 1965, p. 71-76; Overstreet and Bell, 1965a, 1965b; Griffin, 1970). Espenshade and Potter (1960) map layers of kyanite quartzite in Cleveland and Gaston Counties, North Carolina, and York County, South Carolina, and sillimanite quartzite in the latter two counties. The Wacoochee belt (Hewett and Crickmay, 1937) is part of a line of quartzite bands extending from South Carolina across Georgia past Pine Mountain (Adams, 1930; Clarke, 1952; Crickmay, 1952) as shown on the Georgia Department of Mines, Mining and Geology (1969) mineral resource map. The Hollis Quartzite near Warm Springs, Georgia, is pure to feldspathic quartzite 800-1,100 feet thick. A middle quartzite member of the overlying Manchester Formation is 200-800 feet thick. The Wacoochee belt extends into Alabama where it disappears beneath the Coastal Plain (Adams, 1930; Bentley, 1964). Griffin (1970, p. 112) proposed that the Wacoochee belt represents a southwestward projection of the Kings Mountain belt.

Espenshade and Potter (1960) discuss smaller areas with kyanite quartzite in the Farmville district of Virginia, in Buckingham, Prince Edward, and Charlotte Counties.

The higher grade metamorphic areas of the Piedmont probably are not significant for potential uranium content in the quartzites. Argillaceous and arkosic sandstones would metamorphose to schist and gneiss. Only the very pure quartz sandstones would remain as quartzites, and the presence of kyanite in some of them suggests extremely mature weathering with the aluminum in kaolinite or an aluminum oxide such as diaspore, gibbsite, or bauxite admixture in the original sediment. Furthermore, the permeability probably becomes progressively less with increasingly higher grade of metamorphism. However, in the Warm Springs area of Georgia there is indication of ground water circulation in the quartzites (Hewett and Crickmay, 1937).

Antietam-Erwin-Weisner Formations

From Pennsylvania to Alabama (Figure 5) the basal fossiliferous beds of the Lower Cambrian are represented by sandy clastic sediments known as the Antietam, Erwin, and Weisner Formations. Each formation locally contains sparse representation of the lowest Cambrian marine fossil zone, the Obolella faunal zone (Howell and others, 1944). Each locally contains massive, white orthoquartzite which resembles the Silurian Tuscarora Sandstone, a unit which has been interpreted as probably fluvial. Because fossils are scarce and because of the sandstone characteristics, the Antietam-Erwin-Weisner strata are considered in this report as possibly partly fluvial, even though portions of each are known to be marine. With the exception of exposures near the Potomac River, all outcrops of these strata are restricted to the west edge of the Blue Ridge Province. The outcrop belts are interrupted in places where the Blue Ridge has been thrust northwestward over Cambrian strata. The stratigraphic horizon of these beds is buried beneath the decollement surface in the Cambrian Rome Formation under the western part of the Valley and Ridge Province. Prior to orogenic disruption these beds formed a continuous wedge of clastic strata derived by erosion of the eastern edge of the craton to the west. Only along the Blue Ridge do lowest Cambrian strata come to the surface, and in all wells drilled deep enough to penetrate the horizon in the Appalachian Plateau the Antietam-Erwin-Weisner beds are missing by unconformity. Their original or present westward extent is therefore unknown.

It is impossible to draw an isopach map where a single outcrop belt occurs, so thicknesses reported in the literature are simply listed for each place as designated. Thicknesses probably have been tectonically distorted up to 25 percent by the intense deformation along the

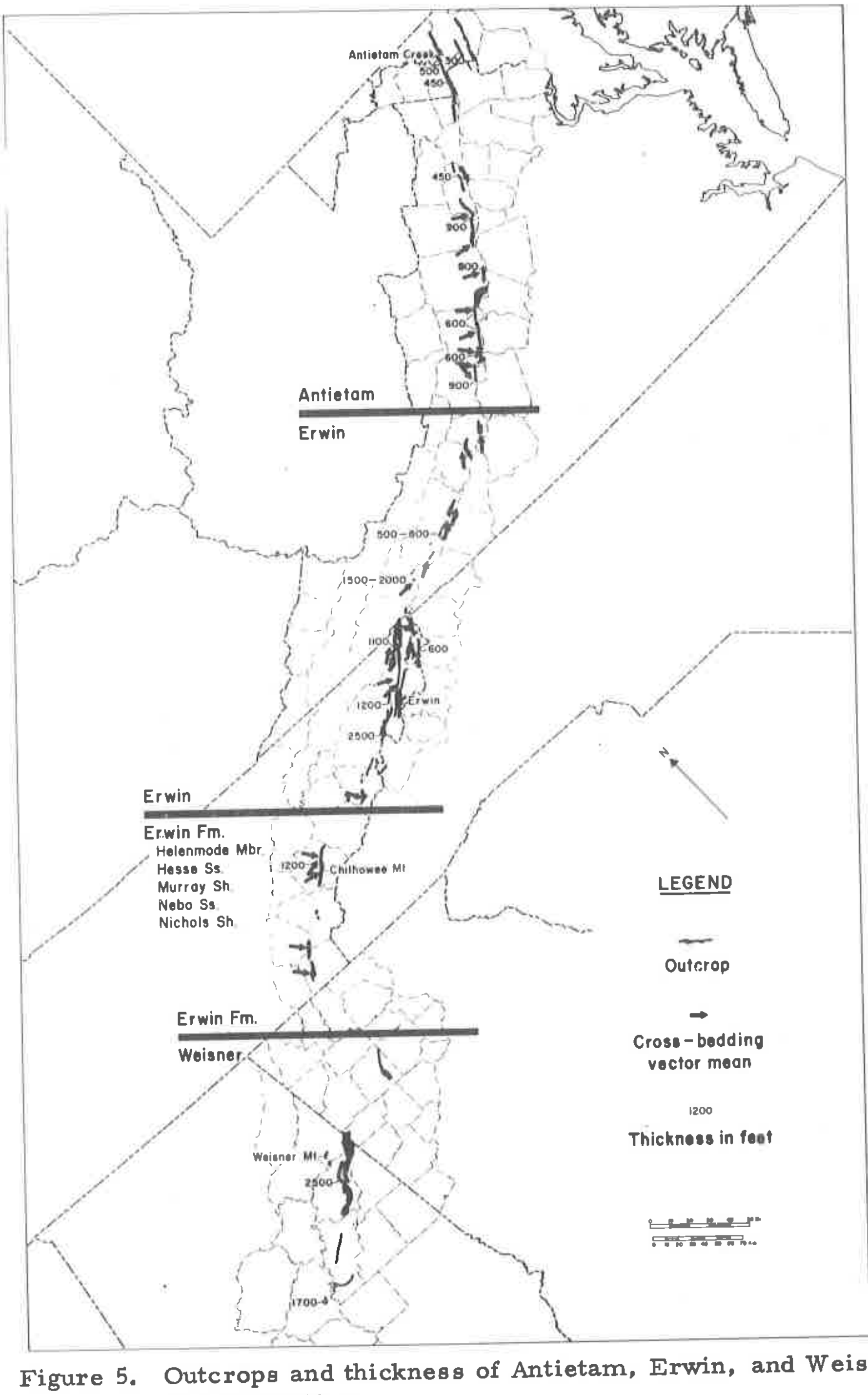


Figure 5. Outcrops and thickness of Antietam, Erwin, and Weisner Formations.

Blue Ridge, but general thickness trends can be envisioned.

There have been paleocurrent studies of crossbeds in the Antietam and Erwin Formations (Brown, 1970; Schwab, 1970; Whisonant, 1970) and vector mean transport direction for each locality is marked by an arrow in Figure 5. The point of the arrow is at the sample site. Source of the clastics was from the craton for the Antietam and Erwin strata. Paleocurrents have not been studied in the Weisner Sandstone, but presumably it too had a cratonic source.

The Antietam-Erwin-Weisner Formations are classified as the uppermost formation in the Chilhowee Group (Table 2).

Antietam Sandstone.--The type locality of the Antietam Sandstone is east of Antietam Creek in Washington County, Maryland, on the west flank of the Blue Ridge anticlinorium. In Washington County Cloos (1951, p. 39) characterizes the Antietam as pure, coarse-grained quartzose sandstone and quartzite with a lower dense, hard, partly bluish layer and an upper white one. The upper portion weathers friable and is coarser. It is cemented partly by calcite and partly by silica. The Antietam is about 500 feet thick at the type locality. A marine fauna from the type exposures contains Olenellus "thompsoni", Hyolithes communis, Obolella minor, and Scolithus linearis according to Woodward (1949, p. 120-121). The rock exhibits rude cleavage at its type locality and the top and bottom contacts are conformable.

The only Antietam outcrops on the east flank of the Blue Ridge are in Frederick County, Maryland, and Loudoun County, Virginia. These are described by Stose and Stose (1946) and Whitaker (1955). Metamorphism is more intense on the east side of the Blue Ridge anticlinorium than in the western outcrops. East of Frederick Valley the Antietam is largely quartz schist with beds of thinly-bedded, tough, gray quartzite.

Nickelsen (1956, p. 251-252) pieced together a good composite Antietam section in Jefferson County, West Virginia, where the formation is 450 feet thick. The Antietam there contains minor amounts of phyllite. The quartzites are well-sorted and fine-to-very fine-grained, with local conglomeratic layers and quartz pebbles up to 8 mm diameter. The sandstone commonly shows limonite specks. The mineral content is generally 80-90 percent quartz, 9-20 percent feldspar (microcline, orthoclase, and plagioclase) with traces of tourmaline, zircon, magnetite and apatite.

Farther southwest in Virginia the Antietam is described and mapped by Allen (1967), King (1950), Brent (1960), Werner (1966), Bloomer and Werner (1955), and Spencer (1968). At Elkton the Antietam is about 800 feet thick and King (1950, p. 21-22) divides it into two members of about equal thickness. The lower member is white vitreous quartzite with abundant Scolithus. The upper member is less resistant and contains white quartzite interbedded with brown sandstone, probably in part calcareous. The basal beds of the lower member are somewhat feldspathic. Schwab (1970) describes the Antietam mineralogy in considerable detail for central Virginia. Fifty percent of the samples studied were orthoquartzite and 25 percent were protoquartzite, but subarkose, arkose, subgraywacke, and (rarely) graywacke are locally abundant. Conglomeratic beds are present. The thin sections contained principally quartz (average 84 percent) with significant abundances of feldspar (5-30 percent) and lithic fragments (including polycrystalline quartz, chert, and orthoquartzite). Feldspar abundance decreases upward. He interpreted the clastic source as Precambrian crystalline and sedimentary rocks on the craton. Schwab believes that the Antietam of central Virginia was deposited by shallow marine currents flowing down a paleoslope from northwest to southeast.

Erwin Formation.--From Roanoke southward the name Erwin is used rather than Antietam. In Virginia it is called simply Erwin Sandstone, but in parts of Tennessee the Erwin Formation has been divided into four members (Table 2), and locally each of these has been mapped as a separate formation. The Erwin Formation was named for a town in Unicoi County, Tennessee. King and Ferguson (1960, p. 41, 115-116) designated as the type locality an exposure along the Nolichucky River at Unaka Springs where the Erwin is 1,220 feet thick. In northeast Tennessee the Erwin consists of interbedded layers of white vitreous quartzite, dark vitreous quartzite, siltstone, and shale. White quartzite constitutes only a small fraction of the formation.

In the Holston Mountain and Iron Mountain region four member names are used; the basal three are extended northward from Chilhowee Mountain in Blount County, Tennessee. The Nebo Quartzite consists of several beds of white and gray beds of vitreous quartzite 10-100 feet thick separated by shaly strata. The Murray Shale is dominantly sandy shale and siltstone with local thin beds of ferruginous quartzite. In the Holston and Iron Mountains the Hesse Quartzite contains as many as three white massive beds up to 50 feet thick; it contains large ripple marks and locally is conglomeratic. The Helenmode Member comprises generally shaly beds between the Shady Dolomite and the uppermost white quartzites of the Erwin. It was named for the Helenmode pyrite mine in Carter County and averages 100 feet thick or slightly less (King and Ferguson, 1960, p. 44-45, 122).

The Erwin is most sandy in the Mountain City window (eastern outcrop belt in northeastern Tennessee); this outcrop belt was located closest to the craton during sedimentation and prior to tectonic disruption. Rodgers (1953, p. 41) suggests that the proportion of clear quartz sandstone decreased southeastward across the original basin of deposition. If any portion of the Erwin is fluvial, the Mountain City window is most likely to be the site, notably some of the massive sandstones. In the Mountain City window the Erwin is not divided into members except the Helenmode Member at the top.

In southwest Virginia in the Glade Mountain area Miller (1944, p. 13-18) described the Erwin as 1,500-2,000 feet of quartzite and sandstone which is white to brownish and greenish and interbedded with some shale. The upper 50 feet locally contains conglomerate with pea-sized pebbles. Portions of the Erwin there are glauconitic.

The Erwin in Wythe County is described by Currier (1935), Stose and Stose (1957), and Cooper (1961, p. 21-22). Olenellus is reported there.

Bearce (1969) has described and mapped the Erwin in the Bald Mountains in Greene County, Tennessee. He describes the Erwin sandstones as light and pyritic, dark red quartzite, and light brown quartzite.

The Hesse, Murray, Nebo, and Helenmode strata along Chilhowee Mountain are described by Neuman and Nelson (1965, p. D23-D29). There the Nebo Quartzite at Mount Nebo is 290 feet thick. The basal 35 feet of Nebo is light olive green, fine-grained sandstone with up to 10 percent feldspar and a chloritic matrix. The remainder of the Nebo is light gray cross-bedded quartzite with abundant Scolithus. Parts of the Nebo may be nonmarine. The Murray Shale (350 feet thick at Murray Gap) consists of micaceous, silty shale and siltstone with thin-bedded, glauconitic and feldspathic sandstone in its upper half. Laurence and Palmer (1963) identified the Cambrian ostracod Indiana tennesseensis from 20-60 feet above the base of the Murray at its type locality. Thus the Murray, Hesse, and Helenmode members at Chilhowee Mountain are clearly Cambrian in age, and only the age of the Scolithus-bearing Nebo Sandstone is in doubt. The Hesse Quartzite (500 feet thick in type region) is light gray, medium- to coarse-grained quartzite with well-sorted and well-rounded grains set in siliceous cement. Some beds probably had a calcareous cement and a few beds near the top are glauconitic. The Hesse sand is better rounded than the Nebo. Scolithus is abundant. The Hesse has more characteristics of a marine second-cycle sand than the Nebo, although the absence of distinctive marine fossils suggests possible nonmarine origin. The Helenmode Formation or Member (estimated 50-175 feet thick on Chilhowee Mountain) consists of shale, siltstone, and interbedded quartz sandstone with abundant detrital mica and glauconite grains. It contains rare specimens of a marine fauna: Olenellus, Isoxys, Indiana, and Hyolithes. The Helenmode is transitional between the coarse clastics of the Chilhowee Group and the overlying Shady Dolomite.

Cross-bed patterns for the Erwin in Tennessee and Virginia (Brown, 1970, p. 343) suggest influx of clastics from a cratonic source in central Tennessee, with longshore drift to the northeast across Virginia (see Figure 5). Farther north in Virginia, a northwestern clastic source is evident for the Antietam Sandstone.

Parts of the coarser Erwin in Tennessee may be nonmarine. Perhaps it was simply because abundant fossils had not yet evolved, but fossils are notably absent in the coarser Erwin of Tennessee. Perhaps parts of the Tennessee Erwin is a subaerial delta accumulation, with the Virginia portions of the Erwin and probably all of the Antietam Sandstone representing shallow marine deposits.

Weisner Sandstone.--The Weisner Sandstone of Alabama and Georgia was named for Weisner Mountain in Cherokee County, Alabama. It was most recently described and mapped at its type locality by Causey (1965) who described the Weisner as grayish-orange and light-tan hard vitreous quartzite, sandstone, conglomerate, and sandy shale. The coarser rocks constitute a series of lenses, variable in extent and thickness, which are interbedded with the finer rocks. Quartzites are conspicuous, but the finer rocks compose the bulk of the formation. The thickness of the Weisner has not been determined in Cherokee County owing to faulting and inadequate exposure. Hayes (1902) listed a generalized thickness of 5,500 feet for the Rome Quadrangle and this value has been quoted by Causey and other writers. The purity of the Weisner quartzites is indicated by the fact that they once were quarried at Rock Run and at Piedmont to manufacture silica bricks.

Butts (1926, p. 62-64) states that the thickness of the Weisner had not been determined accurately except at Columbiana Mountain, Shelby County, Alabama, where it consists of 1,700 feet of shale, sandstone and conglomerate. There he reports at least six beds of quartzite 5-100 feet thick distributed throughout the formation. A basal quartzite 30 feet thick has quartz pebbles up to a quarter-inch diameter. The shale is dark bluish and weathers yellowish gray. Some hematitic layers are reported. At Choccolocco Mountain the Weisner is an estimated 2,500 feet thick.

Shaw (1970) has reinterpreted Weisner outcrop patterns in Kahatchee Ridge in Talladega County, Alabama.

Hayes (1902) expressed the opinion that the feldspar-pebble conglomerates in the Weisner at Indian Mountain are massive delta deposits and are probably derived from a southeastern source (no evidence for source direction is given). Warman and Causey (1962) have mapped and described the Weisner in Calhoun County.

At no place are rocks beneath the Weisner exposed. The north end of the Weisner outcrop is overridden by the Cartersville fault according to the interpretation of Butts and Gildersleeve (1948), but Kesler (1950) and Croft (1963) show the Weisner outcrops extending northeast into Cherokee County, Georgia. Figure 5 is after the map in Butts and Gildersleeve (1948). Kesler (1950) described the Weisner Formation in Bartow County as consisting principally of metashale but containing many beds of metaconglomerate, metasiltstone, and crystalline dolomite and limestone. The Weisner thickness is probably 2,000 feet or more, but its full thickness cannot be determined. The only fossils are Scolithus. Some of the sandstones and conglomerates are feldspathic, but it is not clear whether the feldspar is detrital or results from recrystallization. Poorly preserved cross-bedding is reported. Limestone in beds up to 10 feet thick and some dolomite also occur in the Weisner at Cartersville. Kesler includes Hayes' Pinelog Conglomerate as part of the Weisner Formation.

In a more recent report on Bartow County, Croft (1963) writes of three distinctive lithologic units in the Weisner Formation. The lower unit consists of interbedded quartzite, sericite schist and conglomerate (Pinelog Conglomerate of previous reports). Graded-bedding is common. The lower unit has a gradational contact with a middle unit (100-200 feet thick) of sericite schist with some thin sandstone beds. The upper unit consists of thin-to-thick-bedded, fine-to coarse-grained sandstone and orthoquartzite interbedded with shale and schist. The sandstones in the upper unit are thick and massive and tend not to be graded. Sorting is better than in the lower unit. Some carbonates probably occur in the upper unit.

Rome Formation

The Lower Cambrian Rome Formation consists of red, green, and yellow shales and siltstones with lesser amounts of sandstone, dolomite, glauconite, chert and perhaps halite and gypsum. It is named for exposures mapped at Rome, Georgia, by Hayes (1902) where the base is concealed by faulting. The Rome is partly marine with representatives of the Olenellus fauna at scattered localities. Portions are nonmarine as evidenced by the reddish color, the general lack of marine fossils, and abundant mudcracks.

The Rome Formation occurs in several strike belts in the Valley and Ridge Province (Figure 6). The only complete sections of the Rome occur along the eastern outcrop belt where it conformably overlies the Shady Dolomite or the Tomstown Dolomite from central Virginia northward and conformably underlies the Conasauga Shale (greenish shale with an absence of the reddish shale which characterizes the underlying Rome), the Pumpkin Valley Shale (once considered part of the Rome Formation in Tennessee), the Rutledge Limestone, Honaker Dolomite, or, to the northeast in Virginia, the Elbrook Dolomite. The complexity of names of strata superadjacent to the Rome results from intertonguing of Conasauga Group shales with carbonate strata to the east and northeast, with separate names depending on the shale tongues present in the Middle Cambrian. The southern termination of Rome outcrops is where the formation is buried beneath the Coastal Plain. To the northeast in Virginia (Figure 6) the Rome changes to a carbonate facies and the name changes to the Waynesboro Formation (named for Waynesboro, Pennsylvania). The Rome Formation may be in part a facies equivalent of the Shady Dolomite and the Conasauga Shale and Elbrook Dolomite.

The Rome Formation is the decollement horizon which forms the master fault underlying the Valley and Ridge Province (Rodgers, 1970a, Chap. 3, p. 31-64), so that in all but the most eastern outcrop belts the basal Rome is sheared off by faulting. Many major thrusts appear as bedding plane faults localized in the Rome Formation. The incompetent Rome shales and siltstones generally appear thoroughly mashed, intensely folded, and slickensided in most outcrops, although

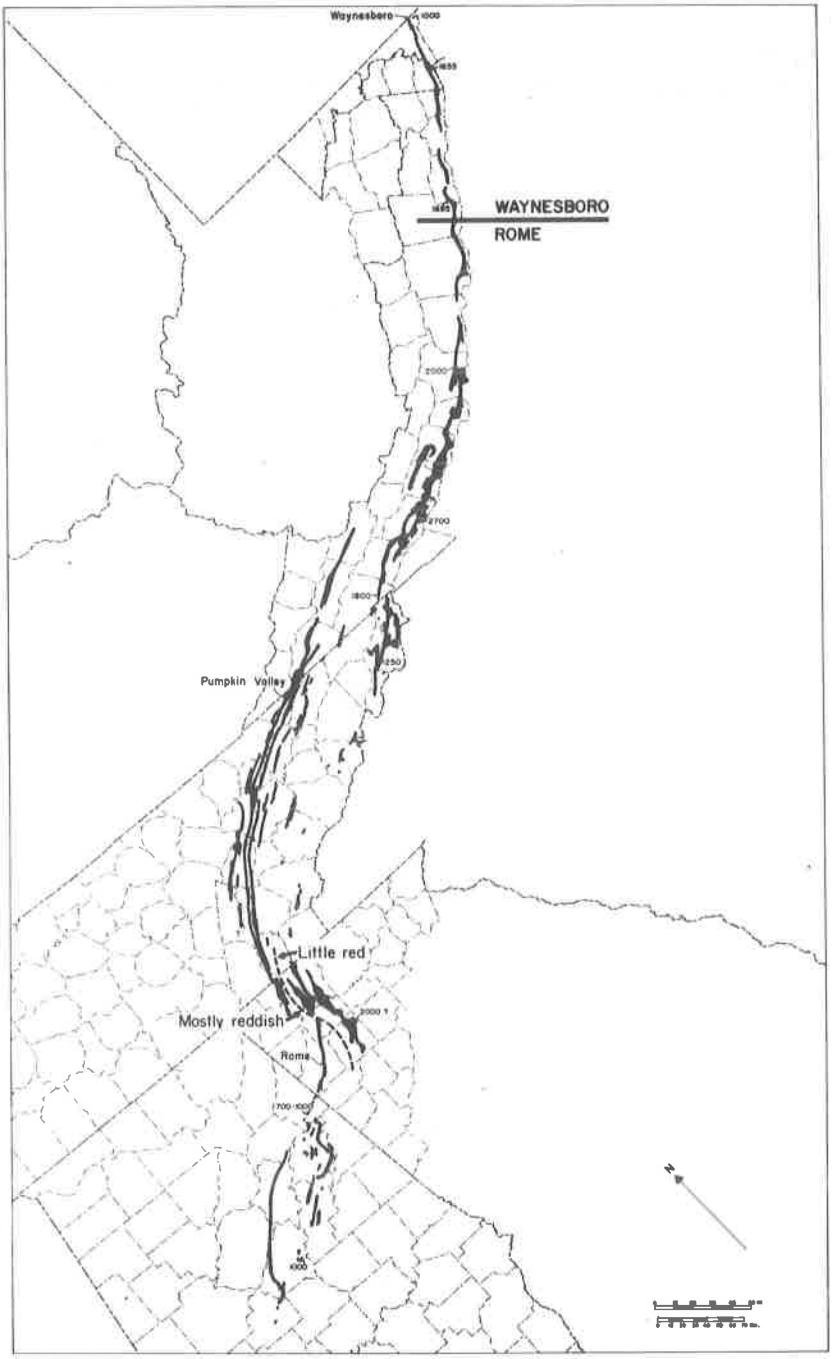


Figure 6. Outcrops and thickness of Rome and Waynesboro Formations.

the more massive sandstones are somewhat more competent. Because of intense deformation ground water circulation in the Rome is probably quite poor and layers of more permeable beds may be truncated in short distances by faults within the Rome. Individual Rome outcrop belts terminate chiefly by shifting of outcrop traces of faults to post-Rome strata, although along the Blue Ridge-Great Smoky-Cartersville fault traces the Rome is locally overthrust by pre-Rome strata. Some of the Rome exposures in western outcrops are at the core of anticlines. Summary descriptions of the Rome Formation are available for Alabama (Butts, 1926, p. 65-67), Georgia (Butts and Gildersleeve, 1948, p. 11-13), Tennessee (Rodgers, 1953, p. 43-46), and Virginia (Butts, 1940a, p. 56-67).

Thickness figures for the Rome are difficult to obtain because of poor exposures and structural complexity. Only a few complete Rome sections have been measured, and these are all in the eastern outcrop belt. Sources of thickness figures shown on Figure 6 are as follows, from south to north: Butts (1926, p. 66); Hayes (1902); Kesler (1950); King and Ferguson (1960), 1,250 and 1,800 feet; and Butts (1940a, p. 61-62). Thickness figures for the equivalent Waynesboro Formation are from the following sources, listed from south to north; King (1950); Woodward (1949, p. 149); and Cloos (1951, p. 41). Thicknesses of the faulted and incomplete portions of Rome reported from western outcrop belts are generally listed as on the order of a thousand feet.

In Alabama the Rome is a mixture of red and green shale, reddish or chocolate sandstone, light-gray rusty weathering sandstone, and local beds of fairly pure limestone and dolomite. The red shale and rusty weathering calcareous sandstone are the most distinctive markers of the formation. Chert is present in Calhoun and Talladega Counties. In Shelby County about 50 feet of calcareous sandstone occurs at the top of the Rome at Columbiana Mountain; limestone and ferruginous and calcareous sandstone occur in the Rome near Montevallo. The Rome in Alabama contains these marine Lower Cambrian fossils in green shale and argillaceous limestone: Olenellus, Micromitra, Obolus, Wimanella, Paedumias, and Wanneria. The Rome Formation is overlain conformably by the greenish shale, limestone, and dolomite of the Conasauga Formation, except in the Cahaba Valley of Shelby and St. Clair Counties where the Rome is immediately overlain by Ketona Dolomite, with the Conasauga apparently missing by unconformity (Butts, 1926, p. 70-71). There is no indication of the mineralogic composition of sandstone within the Rome of Alabama nor of directions of facies changes within the formation.

In Georgia the Rome Formation sandstones are fine-grained, green and red. The greenish sandstone is calcareous and weathers to a rusty color. Shale beds are both green and red. No accurate measurement of the Rome Formation in Georgia is possible according to Butts and Gildersleeve (1948, p. 13). Beds of red shale and lumpy, red mudrock are the most distinctive features of the Rome outcrop belt extending across Floyd County north to Resaca in northern Gordon County; northward in the same outcrop belt across Whitfield and Murray Counties reddish rocks are scarce or absent in the Rome and the formation is composed of yellowish shale with thin layers of greenish sandstone. In the strike belt passing through Catoosa County the reddish colors predominate. In the most eastern outcrop belt shown in Georgia only pinkish shale occurs along with gray shale, It thus appears that a line can be drawn across Georgia demarking the areas of bright reddish Rome from dominantly gray Rome on the east. This would suggest an eastward paleoslope with non-marine deposition restricted to the western outcrops.

In the Cartersville district of eastern Bartow County, Georgia, Kesler (1950, p. 12-17) describes the western exposures of the Rome Formation as mostly crystalline limestone and dolomite, and only the upper part consists of metashale which is highly calcareous. To the east these carbonate rocks thin and the Rome becomes more shaly. This facies change may not imply an eastern clastic source area; it may reflect metamorphic changes across the so-called Cartersville fault, which Kesler believes is really a metamorphic facies change rather than a fault. In the eastern part of the district Kesler reports considerable areas in the Rome Formation outcrop belt which are underlain by amphibolite. He interprets the amphibolite as metamorphosed carbonate rocks, which could explain the apparent eastward increase in shale abundance. There is also a possibility that the Rome was confused by Kesler with parts of the Shady Formation. He mentions no redbeds in the Rome near Cartersville; the metashales, metasiltstones, and thin sandstones are all greenish to dark gray. Some chert is present. These facts suggest that all of the Rome Formation is a marine deposit in the eastern outcrop belts. The Rome is at least 2,000 feet thick at Cartersville according to Kesler.

Croft (1963, p. FF12) noted the presence of graded bedding in the sandstones of the uppermost Rome Formation in Bartow County. Rodgers (1953, p. 44-45) describes the Rome of Tennessee as a heterogeneous and variegated mixture of sandstone, siltstone, shale, dolomite, and limestone. In Tennessee the lower Rome is shaly, with sandstone in the upper portion. Rodgers (1953, p. 43-45) places the top of the Rome at the highest sandy strata in that part of the section. To the northwest shale and siltstone predominate, but there are several prominent sandstone beds and locally one or two conglomerate layers; carbonate rocks are present only in minor amounts. To the southeast, however, especially in northeast Tennessee, dolomite makes up as much as half of the Rome, and sandstone is wanting showing that the main source of detrital material was to the northwest. Red or maroon predominates in the shale and siltstone to the southeast, but is subordinate in amount, though still prominent, to the northwest, except in the brightly colored lower part (Apison Shale Member). Olive green, light green, purple, and brown also occur, and some of the sandstone beds weather orange or yellow. Carbonate rocks are dark gray to the northwest, generally lighter to the southeast; dolomite layers as thick as 300 feet occur in the eastern outcrops at Bays Mountain east of Knoxville.

Shaly strata between the upper sandy Rome and the Rutledge Limestone were removed from the Rome to form the Pumpkin Valley Shale (Middle Cambrian) of Tennessee in the excellent Cambrian and Ordovician section which Rodgers and Kent (1948) described at Lee Valley, Hawkins County. In the type section they describe the Pumpkin Valley as 360 feet of greenish shale with some greenish siltstone and small amounts of limestone; some reddish shale occurs in the basal 247 feet of Pumpkin Valley. Reddish to brownish sandstone occurs in the upper 283 feet of the Rome there. The Lee Valley section is the only reasonably detailed published section of the Rome in Tennessee; only the upper 513 feet of the Rome is described. In Virginia, Georgia, and Alabama, reddish shaly beds equivalent to the Pumpkin Valley Shale probably are assigned to the Rome Formation.

Harris (1964) has studied the Rome and Conasauga clastic strata in a series of wells and outcrops extending southwest from Kentucky to Grainger County, Tennessee. He concluded that these clastics were deposited in a sea which transgressed northwestward. He believes that the Rome Formation probably ranges in age from Early Cambrian in eastern Tennessee to Middle Cambrian in Kentucky. The Rome in the subsurface of Virginia and Kentucky is mainly a glauconitic micaceous sandstone with minor amounts of siltstone, shale and limestone.

Brooks (1955) reported casts of halite crystal imprints in the Rome Formation of Grainger County, Tennessee. Dennison has seen these at several localities, always in reddish, mud-cracked siltstone associated with ripple marked strata nearby. These probably represent arid mudflats on the northwestern landward margin of the sea.

Using different evidence, Rodgers (1970b) postulated that Lower Cambrian evaporites were extensive in the Rome Formation. He envisioned that the Pulaski Fault is localized in the part of the basin with bedded halite. Gypsum and anhydrite beds extended farther north and west and, along with impervious shale layers, helped provide the major decollement zone which Rodgers believes underlies the Valley and Ridge Province. The postulated evaporites have been leached away at exposures. Cooper (1970) presents vigorous opposition to Rodger's proposal of significant evaporites in the Rome Formation of Tennessee and Virginia.

In southwestern Virginia the base of the Rome is commonly marked by red shale overlying the Shady Dolomite. Its top is defined as the uppermost clastic beds before passing upward into the Rutledge, Honaker, or Elbrook Formation carbonates. Red shale is the most striking feature of the Rome in Virginia. However, in actuality the red shale forms only a minor portion of the Rome in Virginia; greenish shale is very abundant. Layers of dolomite locally reach thicknesses of 50-100 feet. Near Roanoke, where the Rome is changing into the Waynesboro carbonate facies, the crystalline dolomite resembles that of the underlying Shady Dolomite. Butts (1940a, p. 58-60) gives a detailed description of the upper 1,282 feet of Rome in Washington County in thrust fault contact with Moccasin Limestone. The Rome there contains considerable limestone interbeds. A complete thickness of the Rome at Buchanan is given as about 2,000 feet in a section measured by Butts (1940a, p. 61-62); the Rome there contains very little reddish shale.

In Wythe County, Cooper (1961, p. 23-25) describes the Rome as chiefly carbonate with the proportion of shale and sandstone increasing westward. High-calcium limestone which Cooper assigns to the Rome Formation was designated the Ivanhoe Limestone Member of the Shady Dolomite by Currier (1935, p. 27-30). Cooper considers the Ivanhoe to be a tongue of Waynesboro Formation extending from the northeast. In Cooper's Rome Formation carbonates in the Speedwell-Wytheville area are twice as abundant as clastics. At Porter the Rome Formation is described by Cooper as 2,800 feet thick including the basal Ivanhoe Limestone Member (about 100 feet in the vicinity, so the thickness of the clastic Rome is plotted on Figure 6 as 2,700 feet). This thickness seems excessive, and it may be tectonically complicated.

The name Rome Formation has been extended northeastward across Virginia (Werner, 1966; Rader, 1967; Spencer, 1968) to Augusta County. Farther northeast at Elkton, Rockingham County, King (1950) used the name Waynesboro Formation. There he described a section of the Waynesboro as 1,685 feet of dolomitic and calcareous shale with blue limestone. Some of the shale is maroon red or reddish brown, but red colors are less common in the Waynesboro than in the equivalent Rome Formation of the southern Appalachians. Most of the shale is tan or greenish gray. Some siltstone is present. Intervals with over a hundred feet of continuous limestone occur in the Elkton area.

Brent (1960, p. 23-24) used the designation Rome (Waynesboro Formation for all of Rockingham County. He remarks that beds of red shale, green shale, sandstone, dolomite, and limestone all occur at various horizons in the formation, but shale is generally dominant. Thick beds of crystalline dolomite, which strongly resemble the Shady, occur in places.

The Waynesboro Formation extends across Jefferson County, West Virginia, where evidence of shallow water deposition is fairly common (ripple marks and mudcracks) according to Woodward (1949, p. 142-155). The entire Waynesboro seems essentially marine, however. Some reddish coloration persists in the shaly beds intercalated among limestones in Washington County, Maryland. Some sandstones are present there (Cloos, 1951, p. 41). The type locality of the

Waynesboro is in just north of the Pennsylvania border in Franklin County, where the formation is about 1,000 feet thick and consists of limestone, dolomite, shale and sandstone.

There is no mineral abundance indicated in any of the published Rome Formation descriptions. The Rome clastics were derived from the west, so the cratonic source area should have supplied considerable feldspar. The Rome sandstones do not appear whitish like orthoquartzites or dark like graywackes. Probably they are somewhat arkosic. Sandstone abundance definitely increases toward the northwest in successive outcrop belts.

The Rome Formation is probably partly fluvial or subaerial mudflats deposited on the western margin of the Lower Cambrian geosyncline. This is shown by the abundant mudcracks and conspicuous red coloration. Other portions of the Rome definitely are marine as indicated by the trilobite and brachiopod fauna and the presence of large amounts of dolomite (supratidal?), limestone and smaller quantities of glauconite and chert. More marine conditions prevailed to the east and northeast, so that northeastward the Rome passes into the totally marine Waynesboro Formation. The Rome clastics probably represent a regressive phase after the initial Cambrian transgression onto the craton with deposition of Shady Dolomite in the Appalachian miogeosyncline. If the Rome originated this way, then its clastics should be a mixture of reworked basin margin sands equivalent to the Shady and Chilhowee, plus first cycle sand derived from the crystalline terrane of the craton. By this logic the Rome sands should be moderately feldspathic, but not as feldspathic as the Chilhowee Group sands. Considerable sedimentologic, petrologic, and stratigraphic study is needed to characterize the Rome more adequately.

The Rome Formation is the youngest Paleozoic partially fluvial unit with a cratonic source. Beginning with the Bays clastics of Ordovician age, all subsequent fluvial deposits were deltaic or flood plain accumulations built out from an eastern or Appalachia source.

Bays-Moccasin-Bowen Formations

The Ordovician Taconic orogeny produced two pulses of deltaic deposition in the Southeast. The Blountian phase of the Taconic orogeny (Rodgers, 1953, p. 94; 1971, p. 1165) resulted in the deltaic or mud flat deposits of the Bays Formation and its offshore equivalent, the reddish shales and limestones of the Moccasin and Bowen Formations, extending from Alabama to Virginia. This phase of nonmarine deposition occurred in the late Black River and early Trenton Epochs according to the time classification of Twenhofel and others (1954) or in the Wilderness Age of Cooper (1956, Chart I). The Richmond Age Juniata Formation is part of the much more extensive nonmarine Queenston delta complex which covered the eastern Appalachian Basin from Ontario to Tennessee.

There is much more information about the Bays-Moccasin-Bowen reddish clastics of the Blountian phase than for the older stratigraphic units considered in this report. The type region of the Bays Formation, in the Bays Mountains of northeastern Tennessee, was studied by Cummings (1965), condensing his 1962 Ph. D. thesis at Michigan State University. The Bays, Moccasin, and Bowen Formations were studied over most of their extent by Hergenroder (1966) for a dissertation at Virginia Polytechnic Institute. Other principal data sources are Allen and Lester (1957) for Georgia and Woodward (1951, p. 185-211) for West Virginia.

The nonmarine strata of the Blount delta Bays Formation pass seaward (northwestward) into two reddish tongues of marine mudstones and limestones of the Moccasin and Bowen Formations, and these in turn change facies into other formations of non-red shaly limestones and limestones farther offshore. Some of the shales and siltstones are nonmarine, as shown by profuse mudcracks, and some are marine. The distribution of Bays-Moccasin-Bowen clastics shown in Figure 7 portrays the outcrop belts and cumulative thicknesses of detrital sediments (shale, siltstone, and sandstone), with limestone interbed thicknesses omitted regardless of whether the limestones were reddish or grayish in color. Isopach patterns are complicated by thrust faults. Thickness information and stratigraphic terminology of Figure 7 is based principally on measured sections presented by Hergenroder for his dissertation (1966), but not summarized there in an isopach map. Other sources add to the known areal extent of the Moccasin facies. The Moccasin facies in Alabama is formally recognized here for the first time. The origin of this isolated patch of Moccasin facies marine reddish shales and limestones can best be understood after considering the main Bays-Moccasin-Bowen outcrop belts from Georgia to Virginia.

Hergenroder (1966) showed an outcrop of Moccasin in the anticline at Rich Patch, Alleghany County, Virginia, apparently following the designation and mapping of Mocassin there by Butts (1940a, p. 186). Lesure (1957, p. 26-27) presents two detailed measured sections there of the Eggleston and Edinburg Limestones, and in neither section are Moccasin reddish beds present, so the Moccasin Formation seems not to extend northward to Alleghany County.

Table 4 shows nomenclature of the stratigraphic units associated with the clastic redbeds of the Bays, Moccasin, and Bowen Formations. The Moccasin and Bowen Formations are reddish limestone and marine shale strata separated by the Witten Limestone. Both the Moccasin and Bowen are red tongues of chiefly marine strata extending seaward from the partly nomarine strata of the Bays Formation. The Bowen tongue is not as extensive or thick as the Moccasin Formation. The geographic extents of the Bays, Moccasin, and Bowen Formations are indicated in Figure 7. To the northeast and northwest in Virginia, and to the northwest and west in Tennessee, Georgia, and Alabama, the reddish marine shales and limestones change facies to non-red

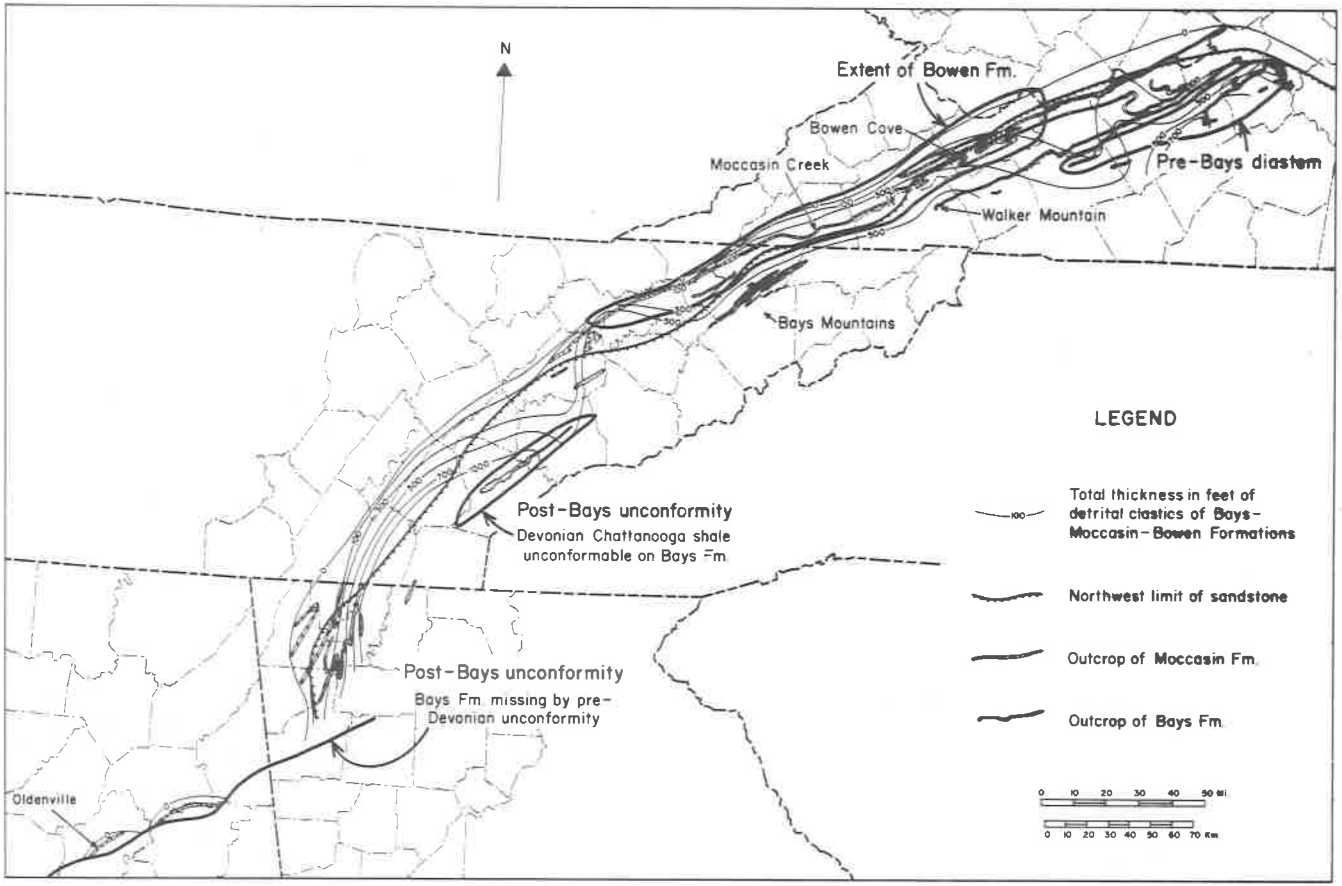


Figure 7. Outcrop belts and cumulative thickness of detrital sediments in Bays, Moccasin, and Bowen Formations.

Table 4. Strata associated with Bays-Moccasin-Bowen redbeds.

Stage	St. Clair County, Alabama	Whitfield County, Georgia	Monroe County, Tennessee	Hawkins County, Tennessee	Scott County, Virginia	Southern Washington County, Virginia	Tazewell County, Virginia	Roanoke County, Virginia
	Frog. Mt. Ss. (Dev.)		Chattanooga Shale (Dev.)					
Trenton Stage	Hiatus	Trenton Formation	Hiatus	Martinsburg Shale	M. Sh. / E Ls.	Martinsburg Shale	Eggleston Limestone	Martinsburg Shale
Trenton Stage	Chickamauga Limestone; "Moccasin" facies; Chickamauga Limestone	Bays Formation	Bays Formation	Bays Formation: upper red beds; middle sandstone member; lower red beds	Moccasin Formation	Bays Formation (Walker Mt. Ss. Mbr.)	Moccasin Formation	Bays Formation
Black River Stage					Witten Limestone		Witten Limestone	
Black River Stage					Bowen Formation		Bowen Formation	
Black River Stage	Little Oak Limestone	Sevier Shale	Sevier Shale	Sevier Shale	Wardell Limestone	Wassum Formation	Wardell Limestone	Liberty Hall Fm.

grayish limestones in successive outcrop belts of equivalent strata to the northwest. Figure 7 shows thickness of detrital clastics of shale and coarser strata only, so reddish argillaceous limestones with "Moccasin influence" persist slightly to the northwest of the zero isopach indicated on the map.

The bottom contact of the reddish Bays, Moccasin, Bowen strata is conformable everywhere according to Hergenroder with the exception of the Crockett Cove (with basal conglomeratic sandstone), Millers Cove and Catawba synclines (both containing reworked clasts of underlying Liberty Hall Formation. The locations of these minor diastem areas are shown in Figure 7 by an enclosing line.

Thickness and grain size of the Bays-Moccasin-Bowen reddish clastic sequence both increase regularly to the southeast, implying an eastern clastic source area. A hachured line on Figure 7 delimits the most western extent of sandstones in the Bays-Moccasin strata. The clastic wedge seems to thicken regularly to the southeast with the principal source near the Tennessee-Georgia boundary, although the source landmass probably extended from Virginia to Georgia.

Byron Cooper (1961, p. 41-42, 105-108; 1964) has maintained that the Bays-Moccasin strata provide a prime example for his theory of syndepositional formation of major synclines in the Appalachians. Cooper contends that the Bays clastics are thickest in the axial regions of major synclines and thinner on anticlinal axes. "The distribution of the coarser facies of the Moccasin is limited to the deeper, axial portions of major synclines which must have been the loci of active downwarps that attracted ingress of much coarse, unwashed sediment that by-passed the shallower portions of the sea floor" (Cooper, 1961, p. 42). The area where Cooper's idea can be evaluated is limited in extent in Virginia (Russell, Tazewell, Giles, Craig, Mongomery, Roanoke and Boutetourt Counties) because all other Bays-Moccasin outcrop belts are on the homoclinal east flank of anticlines. The data isopached in Figure 7 show an overwhelming pattern of persistent thickening to the southeast, and there is no evidence in the control points for Figure 7 to support Cooper's hypothesis. Perhaps this is simply because Hergenroder's sampling was not closely enough spaced to show the syndepositional tectonic patterns. Hergenroder did not discuss the syndepositional syncline hypothesis.

The thickest Bays strata (1,095 feet) are in Monroe County, Tennessee, in an outcrop belt where the Late Devonian Chattanooga Shale disconformably overlies the Middle Ordovician Bays Formation. Bays strata almost as thick (1,027 and 1,072 feet) occur in the two most eastern outcrop belts in Georgia, with apparently conformable contact between the Bays and overlying Sevier or Martinsburg shaly strata.

In the most southern part of Figure 7, south of the heavy line, an unconformity omits the horizon of the Bays strata, from near Rockmart, Polk County, Georgia, to eastern Jefferson County, Alabama. Evidence for this unconformity can be gathered from various sources of published maps and literature, but its best documentation is in the sections measured by Kiefer for a dissertation on the Devonian Frog Mountain Sandstone and from his pre-Frog Mountain paleogeologic map (Kiefer, 1970, p. 16). In the most extreme case Frog Mountain Sandstone rests unconformably on Newala Limestone, yet the span of this great unconformity represents the combined effects of pre-Middle Ordovician, pre-Red Mountain, pre-Armuchee, and pre-Frog Mountain unconformities which can be detected over various parts of Alabama and Georgia. In Alabama there are outcrop belts of probably Moccasin facies in St. Clair County and along the Etowah-Calhoun County border. In the railroad cut 0.8 mile east of Odenville, Butts (1926, p. 151) described two feet of Tetradium-bearing Chickamauga Limestone overlying a 130-foot unit of red and green shale and sandstone. Dennison visited this exposure in 1964 and was struck by the Moccasin-like lithology. Kiefer described this section (1970, p. 122-123) and also recorded 25+ feet of Ordovician reddish shale and pale yellowish brown, medium-grained sandstone in a second section two miles to the northeast. To the belt northeast and southwest of Odenville, the post-Ordovician unconformity has apparently truncated the Bays-Moccasin horizon, so that only a small patch of Moccasin remains of a former much greater extent. Along the Calhoun-Etowah County border, Warman and Causey (1962, p. 36) describe the Chickamauga Limestone as consisting of up to 100 feet of red calcareous shale and impure limestone. These reddish beds seem to be Moccasin facies also. In outcrop belts farther west the reddish shales of the Moccasin have changed facies to the non-red limestones of the Chickamauga. These Alabama patches of Moccasin lithology were probably part of a continuous area of redbed deposition extending to the present outcrop belts of Georgia and Tennessee. Post-Ordovician erosion removed some of the Moccasin prior to Devonian deposition.

Present-day outcrop belts of the Moccasin facies in Alabama, Georgia, and southern Tennessee now dip generally to the southeast in the steeply folded limbs of synclines. The dip was in the opposite direction in Devonian time. At the time of the pre-Devonian erosion, the Moccasin-Bays strata were gently dipping to the northwest over an area several counties in size. Ground water could have moved down dip in the exposed sandstones and redbeds to the reduzate facies at greater depths to the northwest. The present pattern of folds and faults resulted from a much later event (Permian?) which disrupted this ancient ground water circulation system to the present outcrop belts. Some of the Georgia outcrops have been displaced up to 29 miles in tectonic foreshortening (Kiefer and Dennison, 1972). If the feldspar content of the Bays is high enough, and if the reducing environment was suitable, this could have made a site favorable for Paleozoic concentration of uranium quite unrelated to present structural patterns. A comparable situation was developed in Monroe and Blount Counties, Tennessee, where just prior to Devonian Chattanooga Shale deposition the Bays Formation cropped out with a gentle northward dip. Ground water circulation may have favored uranium concentration. Farther northeast in the Bays synclinorium the uranium-favorable situation did not obtain because there was conformable deposition from the Bays nonmarine beds upward into the thousand feet or more of Martinsburg Shale marine strata as the Bays delta was inundated by the sea.

The lithology of the Moccasin strata in Alabama already has been described. In Tennessee and Virginia the Moccasin consists of calcareous siltstone with much calcareous mudstone (both grayish red) and some argillaceous to silty, reddish to light gray limestone. Fine-to very fine-grained sandstone interbeds (Bays facies) occur in the Moccasin in southeastern belts. In Giles County, Virginia, the lowest sandstone contains pebbles of quartz, chert, and quartzite up to 1 cm in diameter. A limestone intertongue occurs in the Moccasin of northeastern Tennessee. Mudcracks are locally abundant in the Moccasin, but less common than in the Bowen Formation. The mudstones show cleavage. Several bentonites occur in the upper part of the Moccasin, a factor which will be considered in more detail later. Linguloid brachiopods occur locally. The Moccasin Formation is probably a subaerial mud flat deposit passing northwestward into marine redbeds, which lose their reddish color and change to grayish, argillaceous limestones assigned different formation names farther offshore. Landward (southeastward) the Moccasin facies coarsens and the strata are principally nonmarine beds called the Bays Formation.

The Bowen Formation (Cooper and Prouty, 1943, p. 876-877) consists chiefly of very calcareous grayish red mudstone, with some limestone interbeds near its seaward limit. Mudcracks are characteristic of the Bowen, so it is probably a subaerial deposit which passes seaward as a reddish tongue of marine shale and then into limestone. Up to 20 feet of medium gray to light olive gray very calcareous sandstone occurs at the base of the Bowen. The Bowen reddish mudstone tongue merges southeastward into the Bays Formation.

The Bays Formation is more varied and coarser than the Moccasin and Bowen. The Bays contains shale, siltstone, sandstone, impure limestone, and conglomerates with pebbles of quartz and limestone. The formation is generally calcareous, and cleavage is commonly present. The Bays is characteristically grayish red, but some sandstones are light olive gray and others are nearly white. The Bays is a coarser-grained southeastern equivalent of the Bowen Formation, Witten Limestone, Moccasin Formation and Eggleston Limestone. Cross-beds indicate a southeastern clastic source. Other sedimentary structures include oscillation current ripples, graded bedding and mudcracks. At least some periods of mudflat exposure to the air are indicated. Several bentonite beds occur in the upper portion of the Bays Formation.

In its type region at the Bays Mountains the Bays Formation consists of a remarkably symmetrical cycle of sediments, described here from base upward: gray Sevier Shale passes upward into the lower red beds member (grayish red shale to sandstone with interbeds of light olive gray, graywacke to protoquartzite sandstone); a middle sandstone member of nearly white quartzitic sandstone up to 65 feet thick; and an upper redbed member of reddish shale to sandstone, with some whitish sandstone interbeds at the base. The upper redbeds are overlain by Martinsburg Formation, whose base is identified by the lowest occurrence of biosparite.

At Walker Mountain in Virginia, the Walker Mountain Sandstone Member separates the lower redbeds from the upper redbeds. The Walker Mountain Sandstone is believed to be equivalent to the middle sandstone member in the Bays synclinorium. The Walker Mountain Sandstone consists of up to 24 feet of yellowish gray to light olive gray, medium- to coarse-grained quartzose sandstone with quartz pebbles up to 15 mm in diameter.

The coarsest Bays strata occur in the Salem-Catawba syncline. A coarse sandstone to conglomerate with pebbles up to 27 mm diameter marks the base of the formation. Greenish gray to olive gray colors predominate over reddish gray in the belt.

The outcrop belt in Blount and Monroe Counties, Tennessee, contains the thickest Bays (up to 1,095 feet) even though its top is disconformably beveled up the Devonian Chattanooga Shale. The dominant lithology is grayish red, calcareous siltstone, but medium- to very coarse-grained, light gray, quartzose sandstone occurs near the top of the Bays.

In Georgia the Bays consists of reddish siltstone, shale and sandstone, with scattered light gray, quartzose sandstones near the top of the formation.

The Middle Ordovician is noted for over a score of bentonites which range in position from Murfreesboro Limestone to lower Martinsburg Shale. They have been studied especially by Rosenkrans (1936), Fox and Grant (1944), Allen and Lester (1957) and Hergenroder (1966). Strictly speaking, these range from K-bentonites to tuffs with biotite, muscovite, feldspar, quartz, hornblende, and pyroxene rather than true bentonites characterized by montmorillonite. The vast majority of the Ordovician bentonites in the southern Appalachians occur in 200 feet of strata including the top part of the Bays-Moccasin sequence and the lower Martinsburg-Trenton sequence. Hergenroder identified 19 bentonites and possible bentonites in one section of the Moccasin Formation and associated strata in Tazewell County, Virginia. Specific bentonites have served as important marker beds in local areas, and Hergenroder (1966, plate 12) suggests correlation of two bentonites from Georgia to Tazewell County, Virginia. Fox and Grant (1944, p. 323) extend these correlations of bentonites B-3 and B-6 to Etowah County, Alabama. Fox and Grant (1944, p. 332) suggest that the principal volcanic source was in central North Carolina, perhaps in the Uwharrie Mountains.

Mineralogy of sandstones in the Bays Formation has been studied by Cummings (1965) and by Hergenroder (1966). In the Bays Mountains Cummings studied heavy minerals (chief components are leucoxene, tourmaline, zircon, hornblende, ilmenite, magnetite, and epidote) and concluded that the coalesced delta deposits of the type Bays originated from an eastern source consisting of sediments (probably Ocoee and Chilhowee strata) and igneous and metamorphic rocks.

Hergenroder (1966, p. 85-95) described the sandstones of the Bays-Moccasin strata over the entire region of occurrence. Many of the sandstones are either feldspathic sandstones or lithic sandstones. Some are orthoquartzites and a few are graywackes. Most common are the grayish red sandstones which contain 50-75 percent quartz, 20-45 percent calcite, 1-3 percent opaque minerals, 0-6 percent feldspar and up to 1 percent chlorite, muscovite, and biotite. Most of the reddish sandstones are fine-grained, but some are coarse or conglomeratic. The grayish sandstones in the Bays contain up to 3 percent feldspar, up to 5 percent metaquartzite, and up to 1 percent chert and rock fragments. The opaque minerals in the gray sandstones are chiefly pyrite. The quartzites in the Bays contain up to 98 percent quartz, 0-3 percent feldspar, and up to 1 percent opaque minerals. Graywackes occur mostly in the Catawba syncline of Roanoke and Montgomery Counties, Virginia.

The Bays Formation appears to represent an assemblage of shoreline mudflat and delta deposits deposited along the seaward margin of a large land mass extending from the latitude of Roanoke, Virginia, to Rome, Georgia, rather than deposits extending out from a single small deltaic source in Tennessee as suggested by some writers. Stream channel deposits have not been identified, even in the eastern Bays outcrops. To the northwest the Bays strata were deposited in brackish water and the redbeds of the Moccasin-Bowen strata passed seaward into a reducing environment so that the reddish color was lost. Hergenroder (1966, p. 139) believed that the relatively clean quartzose sandstones were beach deposits or were carried by long shore currents. The lithic sandstones probably accumulated relatively rapidly near stream mouths. Graywackes are interpreted as flood deposits near stream mouths chiefly in Montgomery County, Virginia.

Geologic conditions in the Bays Formation are generally moderately favorable for uranium concentration, in spite of too low feldspar content and absence of organic matter for an effective reduzate environment. The Bays strata probably represent a source terrane of Piedmont crystalline rocks and reworked feldspathic Ocoee and Chilhowee rocks exposed to the east. Feldspar content in the Bays is discouragingly low. The amount of volcanic tuff admixture in the Bays is the greatest, however, of any Paleozoic or Mesozoic stratigraphic unit evaluated for this study. The sandstones are both reddish and grayish, and some are coarse enough to be quite permeable. At least locally, pyrite is present in the sandstones which could act as a reducing agent for uranium solution, even though land plants had not yet evolved. In middle Paleozoic time the sandy beds of the Bays were exposed in outcrop on the southeast, probably from Tennessee to Alabama, so that ground water could have circulated down a gentle northwestward to westward dip over an area several counties in size. Many of the conditions favorable to uranium concentration are found associated with the Bays-Moccasin strata.

Juniata Formation

The last Ordovician Queenston delta complex spread nonmarine redbeds of the Richmondian Stage (Twenhofel and others, 1954, Chart 2) from Ontario to Tennessee. The delta complex came from an eastern source and is named for the Queenston Formation, a redbed unit with a type locality at Queenston, Ontario. To the south across a buried interval, the redbed sequence emerges as the Juniata Formation, named for redbed outcrop along the Juniata River in Pennsylvania, where the thickness reaches 2,000 feet. In the outcrop belts of Tennessee and Virginia, the nonmarine Juniata Formation intertongues to the northwest with the reddish and gray marine strata of the Sequatchie Formation, named for Sequatchie Valley in Tennessee. In outcrops along the Cincinnati Arch and Nashville Dome equivalent strata are nonred limestones and shales designated as the Richmond Group. Figure 8 shows the geographic distribution of nomenclature used in Appalachian

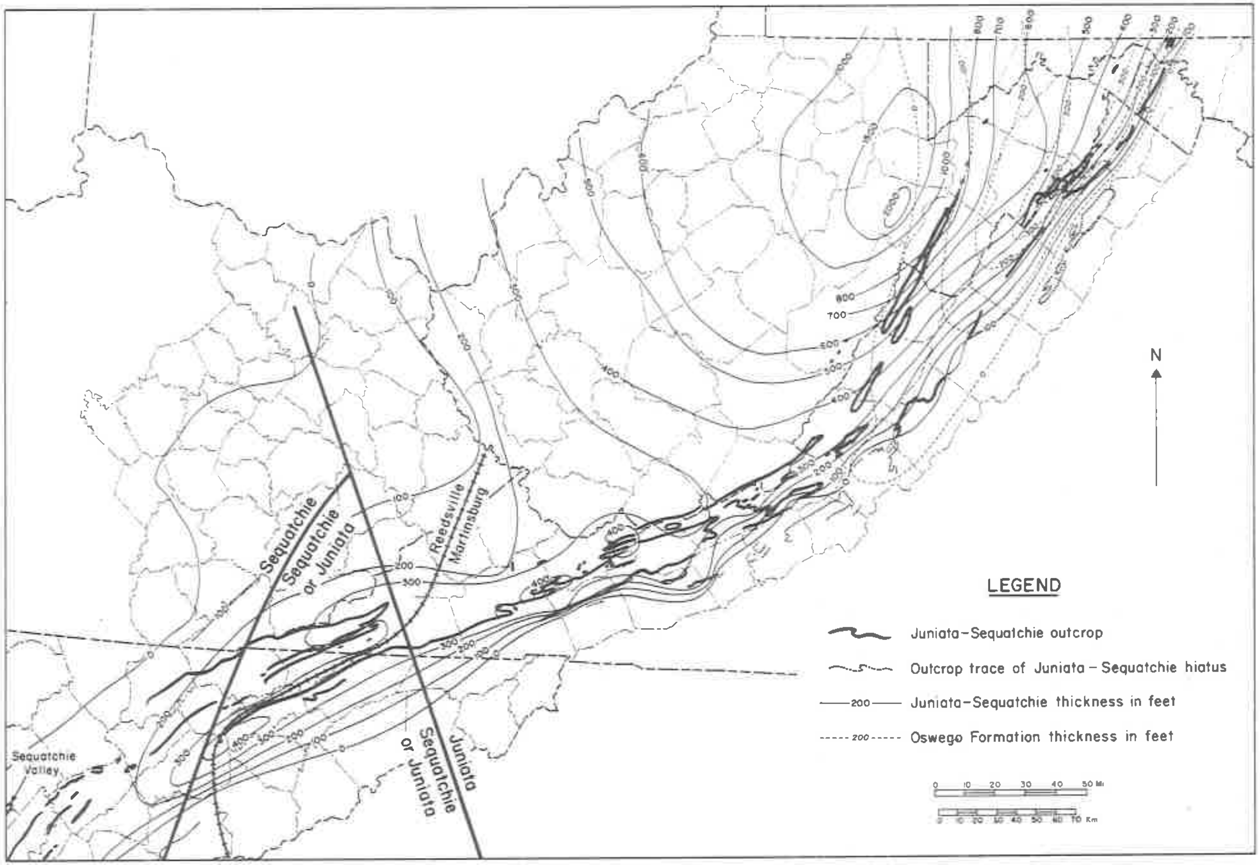


Figure 8. Outcrops and thickness of Juniata, Sequatchie, and Oswego Formations.

outcrop belts for the redbeds of the Queenston delta complex.

The Juniata Formation consists of calcareous to non-calcareous, silty, red shale with interbedded red sandstone. The Sequatchie Formation is generally pinkish to gray, fossiliferous, limy shale and argillaceous limestone. In the area with variable nomenclature, the choice of name depends on the specific criterion the geologist used for recognizing Sequatchie. In general the name Sequatchie has been extended northeast as U. S. Geological Survey mappers trace marine fossiliferous zones farther east into the reddish clastics. The easternmost application of the name Sequatchie probably represents approximately the maximum eastward extent of marine incursions onto the delta complex.

The occurrences of the Sequatchie and Juniata strata in Tennessee have been briefly summarized by Rodgers (1953, p. 97-98), and in Virginia they have been described by Butts (1940a, p. 221-229). Woodward (1951, p. 387-411) synthesized known information about the Juniata Formation of West Virginia and Maryland and prepared an isopach map of the Juniata (p. 400) for those states as well as adjacent portions of Virginia and Pennsylvania. The isopach map of the Juniata and Sequatchie Formation strata in Figure 8 was prepared using data from these sources, supplemented by numerous specific local thicknesses from quadrangle maps and theses, from Freeman's (1953) subsurface well sample descriptions in Kentucky and from Geolog sample descriptions in West Virginia.

The Juniata strata rest on the Oswego Sandstone in the northeastern part of Figure 8 and on the Martinsburg Shale elsewhere. The Sequatchie Formation rests on the Martinsburg Shale or Reedsville Shale.

The upper Martinsburg is a light olive gray silty shale to siltstone with marine fossils; to the southwest and west it changes facies to shaly limestone and calcareous shale and is assigned the name Reedsville Shale. The type locality of the Reedsville is in central Pennsylvania and the name can be extended to southwest Virginia and Tennessee through the subsurface, although it cannot be traced continuously on outcrop. Throughout the region the uppermost fossiliferous strata of the Martinsburg and Reedsville are distinguished by a fossil zone 50-200 feet thick known as the Orthorhynchula zone after one of its characteristic fossils, O. linneyi. Bretsky (1969, 1970) has studied these fossils in detail and concluded that this zone of the Maysvillian Stage is really a fossil community ecologic zone developed just offshore from nonmarine deposition of the Queenston delta.

In the Eastern Panhandle of West Virginia and adjacent Virginia, 0-400 feet of olive gray arkosic sandstone assigned to the Oswego Sandstone occurs between the Juniata and Martinsburg Formations. The Oswego is barren of marine fossils, although some vertical worm borings are present. The name Oswego is extended via the subsurface to West Virginia from outcrops in Oswego County, New York (Woodward, 1951, p. 376-387). The isopach map in Figure 8 is from Woodward

(1951, p. 382). The Oswego is mostly fine- to medium-grained, but locally contains quartz pebbles coarser than 32 mm in Frederick County, Virginia; grain size diminishes westward (Yeakel, 1962, p. 1533). Yeakel (1962, p. 1530) shows that cross-bedding vector mean current direction for the Oswego averages approximately due west in the Oswego occurrence area shown in Figure 8. A somewhat coarser and more commonly conglomeratic stratigraphic equivalent in central Pennsylvania is known as the Bald Eagle Sandstone.

Stratigraphic relations between the Juniata and Oswego Formations are not totally clear. Varied interpretations are possible, and each may be valid locally. The Oswego may be simply a coarser sandy facies equivalent to the Upper Martinsburg west of the zero isopach (Figure 8) of the Oswego. The Oswego may be a non-red color variant of the Juniata nonmarine beds. The local absence of the Oswego Sandstone may result from unconformity.

Certain outcrop belts along the southeast margin of the exposures of Upper Ordovician strata are designated in Figure 8 as outcrops of Juniata Formation hiatus. In all those fold belts the Juniata strata are missing by unconformity. In Blount County, Tennessee, the Upper Devonian Chattanooga Shale rests unconformably on Middle Ordovician Bays Formations (Figure 7). From Smyth to Boutetourt Counties, Virginia, outcrop belts designated as trace of Juniata hiatus have the Martinsburg Shale overlain by younger strata. In Smyth County, Martinsburg is overlain unconformably by Devonian Huntersville chert, but the uppermost Martinsburg contains _Orthorhynchula._ The unconformity there was overturned by later deformation; however, there appears to be a slight angular unconformity (Dennison, 1960, p. 202). In other outcrops from Pulaski to Boutetourt Counties the Clinch-Tuscarora sandstone rests unconformably on Martinsburg, with truncation extending locally below the _Orthorhynchula_ zone. In southern Augusta County and in the Massanutten synclinorium in Rockingham, Page, and Shenandoah Counties, Virginia, the Juniata is missing by unconformity and Massanutten Sandstone overlies Martinsburg Shale at a horizon below the _Orthorhynchula_ zone. Dennison (1970a, p. 25) has mapped on a palinspastic base the subcrop of the Juniata, Oswego, and Martinsburg strata beneath the basal Silurian. In the eastern outcrop belt from Pulaski to Shenandoah County the upturned coastal plain of the northwest side of the Appalachia landmass is clearly discernible on Dennison's map with a dip to the northwest following tilting and erosion accompanying the Taconic orogeny. At no single outcrop is an angular unconformity visible beneath the Silurian since the dip necessary to produce the beveling of the Juniata and Oswego is only a fraction of a degree. The abrupt eastward thinning and pinchout of the Juniata and Oswego Formations just west of the Massanutten outcrop belt is a result of this pre-Silurian unconformity.

Butts (1940a, p. 221) interpreted the absence of the Oswego in much of Virginia to indicate that a hiatus precedes the Juniata-

Sequatchie strata over most of Virginia. This seems unlikely, however, since the possibility of a facies change from sandstone near source to siltstone and shale (Martinsburg) farther away is an expected facies pattern.

The Oswego Sandstone may represent a normal coarsening upward as the deep water turbidite sedimentation of the Martinsburg was displaced by a subaerial delta environment of the Juniata Formation. The Oswego would be marine, shallow water sandstones comparable to the Chemung facies in the Devonian Catskill delta. The expected profusion of marine fossils does not occur in the Oswego Sandstone, however, so this interpretation is unlikely. The thin Orthorhynchula ecologic zone in silty to sandy beds at the top of the Martinsburg is apparently in an environmental setting comparable to the Chemung facies and fauna of the Devonian.

Yeakel (1962, p. 1536) considers the Oswego Sandstone to be a product of fluvial sedimentation, preceding the redbeds of the fluvial Juniata Formation. If this is true, then thicknesses from the Oswego isopachs shown in Figure 8 should be added to the Juniata thicknesses on the same map to obtain the total thickness of Queenston delta fluvial strata at any one locality. An interpretation of fluvial origin for the Oswego is favored by the absence of fossils except for borings. Thompson (1970a) also favored an alluvial origin for both the Oswego and Juniata of Pennsylvania. He recognizes a vertical succession of six lithofacies in the Reedsville, Bald Eagle, Juniata strata, which occurs independent of the traditional color boundary of the Juniata and Oswego Formations. He believes that the Bald Eagle-Juniata color boundary may be regarded as superimposed on a pre-existing lithofacies sequence and that the terms Bald Eagle and Juniata merely indicate rock color. This would account for seemingly erratic thickness of the two formations individually, but a fairly consistent pattern of combined thickness. In terms of uranium geology this suggests reduzate facies boundaries within a single alluvial deposit. Perhaps this situation is also true in Maryland, Virginia, and West Virginia.

A comparable interpretation is followed by Meckel (1970, p. 51-53) who combined the Juniata-Bald Eagle into a single redbed facies of the Taconic alluvial wedge. He cites Horowitz (1965) for suggesting the idea that the Bald Eagle was originally a red unit which was leached green by pore water expelled from the underlying marine Reedsville Formation.

Isopachs in Figure 8 show the thickness patterns of the Juniata-Sequatchie Formations on outcrop and in the subsurface of Kentucky and West Virginia. Rates of thickness change in the outcrop belt seem very abrupt, partly because the data are plotted on a present-day, nonpalinspastic base. Three wells in northeastern West Virginia have a thickness exceeding 1,000 feet. Part of this great thickness may be apparent because of tectonic thickening in the subsurface, but the pattern is consistent enough to suggest that the greatest depositional thickness of the Juniata extends from north-central West Virginia northeast into Pennsylvania.

Erratic thickness patterns along North Mountain in Frederick County, Virginia are now thought to be a result of faulting rather than unconformities. Butts and Edmundson (1966, p. 76-86) summarize their reasons for this interpretation after a long controversy, switching from their former position favoring complex unconformities as the cause of the erratic thicknesses in the Oswego through Needmore Formations along North Mountain.

Subsurface thickness values plotted in Kentucky are data Freeman (1951, 1953) listed for the stratigraphic interval containing reddish strata in the Richmond Group, so the zero isopach is the approximate pinchout of nonmarine redbeds and the general position of facies change to totally marine strata. The zero isopach representing loss of redbeds is generalized across Tennessee.

Abrupt thinning to the southeast of the Juniata in Washington, Smyth, and Pulaski Counties, Virginia is a result of erosional beveling in Devonian time. The position of the southeastern zero isopach across Tennessee is inferred, since there are no Juniata strata preserved in extreme northeastern Tennessee.

The top contact of the Juniata Formation is placed where a dominance of redbeds changes to mostly whitish sandstones of the overlying Tuscarora-Clinch Sandstone. The transition interval may be several tens of feet thick, or the contact can be fairly abrupt. The top contact of the Juniata-Sequatchie Formations appears to be conformable everywhere in Figure 8. Because there is a pre-Clinch or pre-Tuscarora unconformity with Juniata missing in several outcrop belts, it is reasonable that this unconformity persists, yet is not clearly discernible at the base of the Tuscarora in some of the most eastern outcrop belts where Juniata Formation is preserved. A slight unconformity may occur at the Sequatchie-Rockwood formation boundary in southern Tennessee, since the pre-Devonian paleogeologic map Kiefer (1970, p. 16) presents for Alabama and Georgia shows clear evidence for a pre-Red Mountain (pre-Silurian) unconformity in eastern Alabama.

Lithofacies maps of the Juniata Formation have not been prepared, but compilation of the verbal descriptions in the literature indicates clearly that the sand content decreases toward the southwest in various outcrop belts. This is an apparent direction of fining because Yeakel (1962, p. 1529) shows a cross-bedding vector mean direction averaging nearly due west from the latitude of Hardy County, West Virginia north across Maryland, and the true transport direction and maximum rate of grain size decrease would have been westward rather than southwestward.

In West Virginia the main body of the Juniata consists of red mud rock and fine-grained, medium-bedded reddish sandstones of nonmarine origin (Woodward, 1951, p. 388-399). Greenish colors are present occasionally because of local reducing conditions, either at the time of deposition or much later. Cross-beds, ripple marks, and sun cracks are common. In Berkeley County the Juniata is described (Woodward, 1951, p. 391) as partially arkosic, hematite-cemented sandstone with clay galls or flattened shale pebbles and splotchy coloration.

Color and grain size variation in Shenandoah County, Virginia are noted by Woodward (1951, p. 393) where he describes in outcrop at Devil Hole Mountain alternations every 5-8 feet of cycles in a vertical succession consisting of gray-buff sandstone with clay galls at base, followed by somewhat arkosic sandstone, overlain by a few inches of reddish clay shale. Quartz conglomeratic zones occur in both red and gray sandstone. This seems from the description to be fining-upward cycles characteristic of fluvial deposition. Similar rhythmic sedimentation is recorded in Hardy County, West Virginia.

To the southwest in Pendleton County, Woodward (1951, p. 395) notes about half shaly-weathering beds in the Juniata at Germany Valley, indicating a general decrease in clastic grain size to the west or southwest. Farther southwest in Pocahontas and Monroe Counties shales are important in Woodward's description (1951, p. 396-397) of the Juniata. Near Bluefield in Mercer County, Woodward (1951, p. 399) describes the Juniata as dark maroon mealy shales and lumpy silty mud rocks which are more of the marine type than the nonmarine redbeds of areas farther north. He gives no evidence supporting his environmental interpretation, but it apparently is based chiefly on grain size and bedding characteristics. A similar environmental interpretation of transitional marine-nonmarine interbeds is indicated for the Bluefield region on a map prepared by Thompson (1970b, p. 1272).

In Virginia, Butts (1940a, p. 223) described a section of Juniata in Highland County consisting of 725 feet of about equal sandstone with the remainder shale to mud rock. This is the thickest Juniata exposure in the Virginias or Maryland. In a section measured along New River at the Giles-Pulaski County boundary, Cooper (1963, p. 24) describes the Juniata as 165 feet of poorly exposed sandstone and shale, reddish brown with green blotches. Farther to the southwest the Juniata changes facies to the Sequatchie Formation where Butts (1940a, p. 226-227) describes sections measured at Stickleyville and Cumberland Gap in Lee County.

Published petrographic descriptions of the sandstones in the Juniata are inadequate. Yeakel (1962, p. 1524) summarizes the petrography over the area from eastern Pennsylvania to northern Virginia in the following manner. Both the Juniata and Bald Eagle range from subgraywacke to protoquartzite. The sand framework, subangular to well-rounded, ranges from 96 to 73 percent. Quartz plus chert ranges from 96 to 32 percent, but chert alone never exceeds 10 percent. Beds richer than 75 percent in these minerals are restricted to the upper Juniata. Rock fragments, 3-54 percent, include many sedimentary and low grade metamorphic types. Potash feldspar, ranging from 1 to 18 percent, is largely restricted to the Bald Eagle and especially to the lower beds transitional into the Reedsville Formation.

The Juniata of southwestern Virginia represents deposition on high tidal flats according to Thompson (1970b). In that area the rocks of the Juniata facies are red, silty and clayey, pelletal dolomicrites and dolomitic shales, and contain abundant evidences of desiccation and intermittent scouring. The supratidal dolomite is interpreted to have formed on the high tidal flats by precipitation from evaporating pore waters trapped in the sediment after periodic floodings, comparable to the origin generally accepted for modern Bahama dolomites. Thompson notes that this is the first documentation of dolomitization on clastic tidal flats reported from ancient rocks. An infaunal element produced isolated vertical burrow structures in the Juniata facies of southwest Virginia.

Thompson described characteristic Sequatchie facies as gray biomicrites and biomicrudites representing offshore-subtidal deposition on a shallow, open shelf. Sequatchie rocks show evidence of periodic current scouring and are not visibly burrowed or desiccated. Rocks deposited in an environment intermediate between the characteristic Sequatchie and Juniata facies accumulated on low tidal flats or in very shallow-subtidal nearshore zones; these rocks contain both vertical and horizontal burrow structures and are extensively bioturbated and mottled.

In the Duffield Quadrangle, Harris and Miller (1958) used the term Sequatchie Formation even in the southeastern Clinch Mountain strike belt of Scott County, Virginia, because the lower two-thirds of the formation contains a marine fauna of brachiopods, pelecypods and bryozoans. The red color dominates, however: interbedded calcareous grayish red siltstone with some interbedded greenish-gray argillaceous limestone and shale. Clearly the 325 feet of Sequatchie there is intertonguing marine and nonmarine, and it was so indicated by Thompson (1970b, p. 1272).

The reddish color of the Juniata-Sequatchie is conspicuous all along the Clinch Mountain strike belt to Knox County. The revised geologic map of Tennessee (Hardeman and others, 1966) uses the terminology Juniata Formation east of a line extending from Knox County to Cumberland Gap, and Sequatchie Formation is the name applied west of that line (see Figure 8). Geologic quadrangle descriptions indicate increasing carbonate percentage and marine faunal abundance to the west in the area shown in Figure 8 where various workers have used both the names Juniata or Sequatchie.

In the southwestern corner of Figure 8 all the beds are marine and the reddish color is displaced by a dominance of grayish marine shales and limestone. The Sequatchie strata there are of no concern to this report on fluvial sediments.

The various conditions outlined in this summary of Juniata-Oswego stratigraphic relations suggest a potential uranium concentration area extending from Alleghany and Rockbridge Counties of Virginia northeast to western Shenandoah and Frederick Counties, Virginia, and on to Washington and Allegany Counties, Maryland. The conditions favoring localization of uranium there can be briefly summarized. The Juniata Formation contains somewhat feldspathic sandstones from Alleghany County to the northeast. The greenish Oswego Sandstone is limited in its occurrence to approximately the same area, and it is probably more feldspathic than the overlying Juniata redbeds. Yeakel (1962), Horowitz (1965), Thompson (1970a), and Meckel (1970) favored a fluvial origin for both the Oswego-Bald Eagle non-red facies and the Juniata redbed facies. The stratigraphic boundary between these two formations is a color change between oxidizing and reducing conditions. Erratic thickness changes among measured stratigraphic sections of these two formations suggests that the boundary may be a local reduzate facies coloration change of post-depositional origin. In Shenandoah County, Virginia, and Hardy County, West Virginia, red-green color alternations are present within the Juniata in a region with some of the coarsest clastic lithologies.

Potential uranium concentration along the West Virginia-Virginia border in the latitude of Rockingham, Shenandoah, and Frederick Counties is also favored by a paleoquifer system which operated in earliest Silurian time just after Juniata and Oswego deposition and probably before the sandstones became tightly cemented and rather impermeable. In the Massanutten syncline to the east the Juniata and Oswego Formations were removed by pre-Silurian erosion of the coastal plain of Appalachia which was tilted gently to the west. Silurian Massanutten Sandstone overlies Martinsburg Shale in that syncline. At some point between Massanutten Mountain and North Mountain cuestas of Oswego and Juniata sand in earliest Silurian time would have received ground water which would circulate down dip to the west. The western limit of ground water movement may have been determined by regional dip or by a permeability facies change as the sediments became finer-grained to the west. A potential uranium concentration cell could have resulted from these geologic conditions. The Ordovician strata probably lacked organic carbon to serve as a reducing agent, and pyrite is not noted in the very sparse petrographic data. The coloration patterns suggest, however, that a post-depositional geochemical cell may have been operational. The use of a palinspastic base map would facilitate understanding these geologic relations.

Comparable conditions suggesting an eastern uplift of the early Silurian coastal plain persist along the eastern outcrop belts south to Pulaski County, Virginia, but the Juniata and Oswego strata are fine-grained and less permeable there. An unconformity cuts out the Juniata south of Walker Mountain in Smyth County, Virginia, and the Juniata is present and quite thick only three miles to the northwest along Walker Mountain. Ground water circulation probably was restricted there, however, because of the dominant siltstone and shale character of the

Juniata Formation that far southwest.

The post-Ordovician unconformities recorded in Smyth County, Virginia and Blount County, Tennessee, suggest that the present-day easternmost belt of Juniata-Sequatchie outcrops was located only a few miles west of paleo-outcrops of Juniata-Sequatchie on the coastal plain of the Appalachia eastern landmass during the time of pre-Devonian erosion. The calcareous Juniata-Sequatchie mudstones there were probably too impermeable to allow ground waters to circulate through a structurally favorable potential uranium-cell system.

Present steep dips of Juniata-Oswego outcrops were produced by the Alleghany orogeny late in the Paleozoic Era, and present-day ground water circulation is geographically restricted by structural complexity. Ground water circulation patterns probably were much simpler and extended over broad areas during times of Silurian and Devonian exposure of the upturned eastern edge of the Appalachian Basin.

Tuscarora-Clinch-Massanutten Sandstone

Overlying the redbeds of the Juniata Formation with apparent conformity there occurs up to 400 feet of light gray to white orthoquarzite sandstone called the Tuscarora Sandstone in the north and the Clinch Sandstone in southwest Virginia and Tennessee. The Clinch and Tuscarora are assigned to the Lower Silurian Albion Series (Swartz and others, 1942). In the Massanutten syncline of northern Virginia, the Martinsburg Shale is unconformably overlain by 550-840 feet of white to light gray orthoquartzite known as the Massanutten Sandstone. The Massanutten Sandstone includes equivalents of the Tuscarora in its base and probably ranges up through late Niagaran or oldest Cayugen Epoch in age. All three sandstones have been interpreted both as fluvial and beach deposits. Their uranium potential is low because of their extreme mineralogic maturity and because they are tightly cemented by pressure solution. These are the most prominent ridge-forming sandstones in the Valley and Ridge Province.

Figure 9 shows the geographic distribution of stratigraphic names applied to this orthoquartzite. The Tuscarora Sandstone was named for Tuscarora Mountain in south-central Pennsylvania, and the name is extended south across Maryland, West Virginia, and in Virginia west of the Great Valley as far south as New River. The Clinch Sandstone was named for Clinch Mountain in Tennessee, but no detailed type section has ever been described. The Clinch, Tuscarora and Massanutten Sandstones are all medium to thick-bedded, very hard sandstones with only scattered partings of light gray to yellowish gray siltstone layers. To the west the Tuscarora becomes shaly and passes into the "Clinton" sands and shales of the subsurface eastern Ohio, and the Clinch similarly changes facies into the shaly, silty and hematite-bearing Rockwood Formation of Tennessee. In outcrops on the Cincinnati arch and the subsurface of eastern Kentucky limestone and dolomite

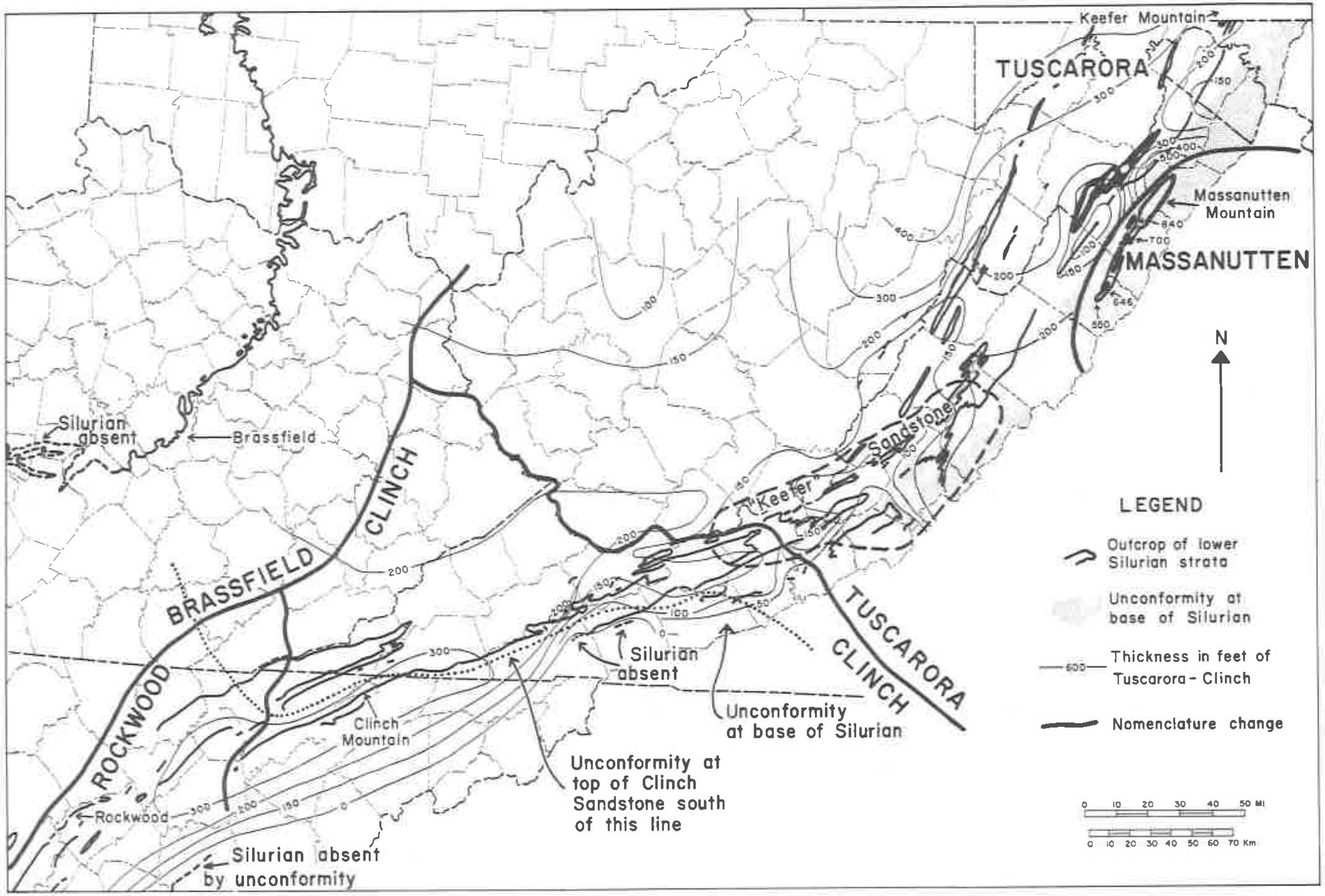


Figure 9. Outcrops and thickness of Tuscarora, Clinch, and Massanutten Sandstones.

facies equivalents are known as Brassfield Formation, a name which is also applied in Sequatchie Valley, Tennessee. In Lee County, Virginia, and adjacent Hancock and Claiborne Counties, Tennessee, where the facies change is occurring between the Clinch and Rockwood Formations, Miller and Fuller (1954, p. 140-149) divided the Clinch Formation into a lower Hagan Member consisting of 77 feet of greenish gray shale with scattered sandstone and limestone and an upper Poor Valley Ridge Member which is 183 feet thick and is comprised of nearly equal amounts of light gray to greenish white, fine-grained sandstone and greenish gray shale. Both members contain thin hematite beds and have a marine fauna composed chiefly of brachiopods. The Poor Valley Ridge Member also contains Arthrophycus, a fossil generally considered to be a littoral or nonmarine boring worm tube. The Clinch, Tuscarora, and Massanutten Sandstones lack any fossils except the supposed worm borings Scolithus and Arthrophycus, which is a principal argument for their fluvial rather than marine origin. The Rockwood and Brassfield Formations contain an abundant marine fauna.

The general stratigraphic characteristics of the Tuscarora, Clinch, and Massanutten Sandstones are summarized for various states in the following publications: Maryland, Swartz (1923a, p. 26-27); West Virginia, Woodward (1941, p. 30-50); Virginia, Butts (1940a, p. 229-237); and Tennessee, Rodgers (1953, p. 98-104). Perry (1962) has documented the subsurface intertonguing relationships of the Clinch-Tuscarora and Brassfield facies in several counties of eastern Kentucky and adjacent West Virginia and has linked these well descriptions with outcrop data in adjacent Virginia. Dennison (1970a) summarized Silurian stratigraphic relationships on a palinspastic base for much of West Virginia and Virginia, using published literature and unpublished thesis data. Replotting of Dennison's data onto the present-day outcrop map of the folded Lower Silurian provided the basis for much of the information in Figure 9.

The base of the Tuscarora Sandstone is probably conformable throughout the western outcrop belts and in the subsurface. In most outcrops there occur a few feet of interlayered white sandstones characteristic of the Tuscarora and reddish sandstones typical of the underlayering Juniata Formation. There may be a slight unconformity at the base of the Tuscarora along the Little North Mountain strike belt from Rockingham County, Virginia to Washington County, Maryland, judging from the fact that a conspicuous unconformity occurs in the Massanutten syncline where the contact of Massanutten Sandstone and Martinsburg Shale is a very distinct break, but with no angular discordance. This same unconformity is present beneath the Tuscarora in eastern outcrop belts from Augusta to Montgomery County, Virginia, and it can be traced south to Pulaski County along the easternmost outcrops of Clinch Sandstone. This unconformity can be detected because of the absence of the Juniata Formation (Figure 8) and the Tuscarora-Clinch Sandstone rests directly on Martinsburg Shale.

The Clinch Sandstone seems to be conformable on the underlying Juniata-Sequatchie strata throughout its western extent. The only recorded exception is in Lee County, Virginia, where Miller and Fuller (1954, p. 142) and Miller and Brosgé (1954, p. 77-78) interpret an unconformity at the base of the Hagan Shale Member of the Clinch, using for evidence a leaching of red coloration in the top two feet of the Sequatchie Formation and the presence of a basal sand 1.5 feet thick in the Hagan Shale with channels cut an inch or two deep into the top of the Sequatchie. At Hagan in the same county, however, 8 feet of transition beds occur between the Sequatchie and Hagan strata. This reported unconformity may be simply normal channelling at the base of a local sandstone and not represent an erosional break of regional significance.

Elsewhere in the region of Figure 9 there is no reported unconformity between the Rockwood and Sequatchie strata or between the Brassfield and Sequatchie-Richmond strata. A slight unconformity may occur at the Sequatchie-Rockwood Formation boundary in southern Tennessee, since the pre-Devonian paleogeologic map Kiefer (1970, p. 16) presents for Alabama and Georgia shows clear evidence of a pre-Red Mountain (pre-Silurian) unconformity in eastern Alabama.

Isopach patterns on Figure 9 show a nearly random thickness distribution as is common for orthoquartzites. In the region near the Rockwood-Clinch-Brassfield nomenclature junction thicknesses are for the entire Albion Series (all three formation lithologies) not just the white orthoquartzite lithology, with tapers to zero thickness by facies change to the west. From Clinch Mountain northeast the Clinch-Tuscarora thickness shown by isopachs is essentially all orthoquartzite whitish sandstone. Thickness tapers abruptly to zero in southeastern outcrop belts of the Clinch in Virginia because of erosional beveling (Dennison, 1970a) of the Silurian strata on the upturned coastal plain of Appalachia at several times during the later Silurian and early Devonian (identified by "Keefer" Sandstone, and Williamsport Sandstone clastics, by pre-Oriskany erosion, and by pre-Huntersville erosion). In Blount and Monroe Counties, Tennessee, the entire Silurian is cut out by pre-Chattanooga erosion.

In northern Virginia, the Tuscarora isopachs terminate abruptly against the region designated Massanutten Sandstone. This is because the Massanutten Sandstone represents the Lower plus Middle Silurian (Albion and Niagaran Series) rather than just the Albion Series as does the Tuscarora. Thickness in feet for the Massanutten Sandstone is indicated at localities described by Butts (1940a, p. 255), Brent (1960, p. 46-75), and Allen (1967, p. 33).

Tuscarora thickness along the adjacent Little North Mountain outcrop belt is quite variable. Dennison (1970a, p. 19) attributed the thin area in Rockingham and Shenandoah Counties to a positive tectonic feature which localized thin sedimentation and formed the weak zone which developed later into the North Mountain fault. The apparent Tuscarora thickness of 500 feet reported by Butts and Edmundson (1966, p.

41) near Wheatfield, Shenandoah County, Virginia, may represent intertongues of upper Massanutten Sandstone above the normal position of the Tuscarora. Silurian thicknesses adjacent to the North Mountain fault are complicated by faulting and only generalized stratigraphic relations can be distinguished from tectonic alteration of thickness (Butts and Edmundson, 1966, p. 76-86).

The isopach map in Figure 9 is not greatly different from earlier isopach maps of the Tuscarora Sandstone prepared by Woodward (1941, p. 86; 1951, p. 401), Yeakel (1962, p. 1522), or the generalized map prepared by Amsden (1955).

An unconformity occurs at the top of the Clinch and Rockwood strata south and west of the line indicated on Figure 9. Throughout the entire region mapped in Figure 9 the Albion Series was probably originally succeeded conformably by strata of the lower Niagaran Series (Clinton Formation or Group). The unconformity presently observed at the top of the Clinch-Rockwood strata in the area designated in Figure 9 was formed by Devonian erosion in one of three unconformities just prior to deposition of the Oriskany, Huntersville, or Chattanooga Formations. In a section measured at Clinch Mountain in Hawkins County, Tennessee (position of arrow labeling Clinch Mountain in Figure 9), Dennison and Boucot (1969) found that the Silurian sandstone is 310 feet thick, and the true Clinch is overlain unconformably by 18 feet of sandstone belonging to the Devonian Wildcat Valley Formation. In other words, at least locally the sandstone forming Clinch Mountain is not all assignable to the Clinch Sandstone.

The petrology of the Tuscarora Sandstone indicates that it is too mature mineralogically to be an effective uranium protore. Chen, Hunter, and Erwin (1965) describe several samples from throughout West Virginia as a low alumina orthoquartzite, consisting of over 98 percent quartz, with traces of chert grains, tourmaline, zircon, and hematite and small amounts of kaolin and chlorite. Folk (1960, p. 3-25) has described in detail the petrography of the Tuscarora Sandstones at Mills Gap, Berkeley County, West Virginia. The reddish transitional beds at the base of the Tuscarora there are siliceous immature subgraywacke, bordering on graywacke, and medium- to fine-grained. These are Juniata-lithology interbeds. The main mass of white Tuscarora there is 215 feet thick, with quartz pebbles up to 18 mm diameter. The lower portion of the main white Tuscarora is siliceous submature chert-bearing quartzose subgraywacke near the base while the upper part is a siliceous supermature orthoquartzite.

In Alleghany County, Virginia, Lesure (1957, p. 33) described the Tuscorora as a mosaic of interlocking, sutured quartz grains that make up over 90 percent of the rock. Quartz cement and sericite occur between the grains. Other minor accessory minerals include a little chert and tourmaline.

In Tennessee the Clinch Sandstone is also an orthoquartzite cemented by quartz.

Permeability is very slight in the Tuscarora and Clinch Sandstones because pressure solution has caused interpenetration of the grains and provided a silica cement.

Arthur W. Hayes is currently doing a petrographic study of the Tuscarora Sandstone in Virginia for a dissertation at Virginia Polytechnic Institute, and his study will yield considerable detailed compositional data for an area not yet studied in detail.

Yeakel (1962, p. 1526) has plotted cross-bedding vector means for the Tuscarora Sandstone in the eastern panhandle of West Virginia and adjacent Virginia and Maryland, along with the Massanutten Sandstone in Virginia. Current transport of clastics was to the west, northwest, and north in that region. Maximum diameter of vein-quartz pebbles decreased from a maximum in the 32-64 mm class at Massanutten Mountain to finer sizes in the same directions away from the maximum (Yeakel, 1962, p. 1531) in the area included in Figure 9 of this paper.

The origin of the Tuscarora has been variously interpreted as a beach, deltaic-estuarine, or fluvial deposit.

Folk (1960) considered the Juniata-Tuscarora transitional beds as deposited in a submerged deltaic-estuarine environment and the upper orthoquartzite as a beach sand formed during a period of declining relief. The source area to the southeast of Maryland and adjacent West Virginia consisted largely of older sediments and low-rank metamorphic rocks, but as erosion proceeded, the sedimentary cover was stripped off and plutonic igneous sources became of increasing importance. Dunbar and Rodgers, (1963, p. 50, 70) consider the Tuscarora-Clinch depositional environment as a shallow-water sand winnowed by a transgressing sea, comparable to the modern occurrence of sand on the continental shelf from Cape Cod to Cape Hatteras deposited during the period of post-glacial sea level rise.

Arguing against the open-marine origin of the Clinch-Tuscarora is its fossil content. Only the supposed worm borings of Scolithus and Arthrophycus occur, with the exception of a single Lingula brackish-water brachiopod reported by Woodward (1941, p. 48) from Giles County, Virginia. The Rockwood Formation to the west has an abundant normal marine fauna; such fossils should occur in the Tuscarora and Clinch if they are open-marine deposits.

Yeakel (1962, p. 1535) interpreted the outcropping area of Tuscarora as a low coastal plain of alluviation, grading into a shore zone with deltas and offshore bars due north of (on depositional strike with) the western Clinch outcrops. Yeakel's interpretation of the Tuscarora was accepted by Meckel (1970) and Hunter (1960; 1970, p. 105). Patchen (1968, p. 23) has pointed out that recent Tuscarora gas discoveries in northern West Virginia occur in the zone designated by Yeakel as fluvial, but west of Folk's proposed beach in marine sediments.

In central Virginia another whitish, silica-cement quartz sandstone occurs in the middle Silurian, known as the "Keefer" Sandstone. The area containing "Keefer" Sandstone is shown in Figure 9. The main body of "Keefer" Sandstone reaches a maximum thickness of 359 feet at Eagle Rock, Boutetourt County, Virginia (Dennison, 1970a, p. 141), but to the north, northeast and northwest it thins and changes facies perhaps into the shaly Clinton Formation and certainly into limestone and shale of the McKenzie Formation. The Clinton and McKenzie both have a normal marine fauna. Between the Clinton and McKenzie in characteristic development there occurs a few feet of true Keefer Sandstone which contains hematitic layers and a normal marine fauna. Certainly the thinner parts of the "Keefer" Sandstone are probably marine, but it is possible that part of the southeastern "Keefer" may include some fluvial deposits, based on lithologic similarity to the Tuscarora Sandstone. The "Keefer" is too quartzose to be a potential uranium protore. The "Keefer" Sandstone may be a southern development of a facies like the Massanutten Sandstone farther north with clean sand deposited along the southeastern margin of the basin during most of Albion (Tuscarora-Clinch) and Niagaran ("Keefer") time.

The Tuscarora-Clinch-Massanutten Sandstones are locally fluvial in origin, but their mineralogic composition and tight cementation exclude their consideration as uranium protores. The related "Keefer" Sandstone is principally a marine shoreline sand accumulation, but parts of it may be fluvial. Its mineralogic composition is too quartzose and similar to the Tuscarora for consideration as a uranium protore.

Bloomsburg Formation

The Bloomsburg Formation is a redbed association of claystone, siltstone, and sandstone named for outcrops of Bloomsburg in north-central Pennsylvania. It attains a thickness of over 2,000 feet in eastern Pennsylvania where it spans much of the Niagaran and Cayugan Epochs (Swartz and others, 1942). To the west and southwest it becomes finer-grained and thins by convergence and interfingering with the marine limestones and shales of the McKenzie and Wills Creek Formations until its tapered edge merges with the Williamsport Sandstone which is considered to mark the base of the Cayugan Series in West Virginia, Virginia, and Maryland (Woodward, 1941, p. 175). Figure 10 shows the outcrops of the Bloomsburg strata in these three states. In extreme eastern outcrop belts the Bloomsburg can be mapped as a separate redbed formation, but in western outcrops it is a sequence of redbed intertongues in marine strata. In this sense the reddish strata are lumped to form the Bloomsburg facies (Woodward, 1941, p. 150), whether it is a continuous sequence of strata or redbed intertongues. The thickness isopached in Figure 10 is the total thickness of redbed strata in the interval ranging in position from upper McKenzie through lower Tonoloway Formations where these marine units occur. In eastern areas these redbeds are probably partly fluvial sediments, but in the western limit of the various red tongues the strata are certainly marine. No nonmarine strata probably occur west of the

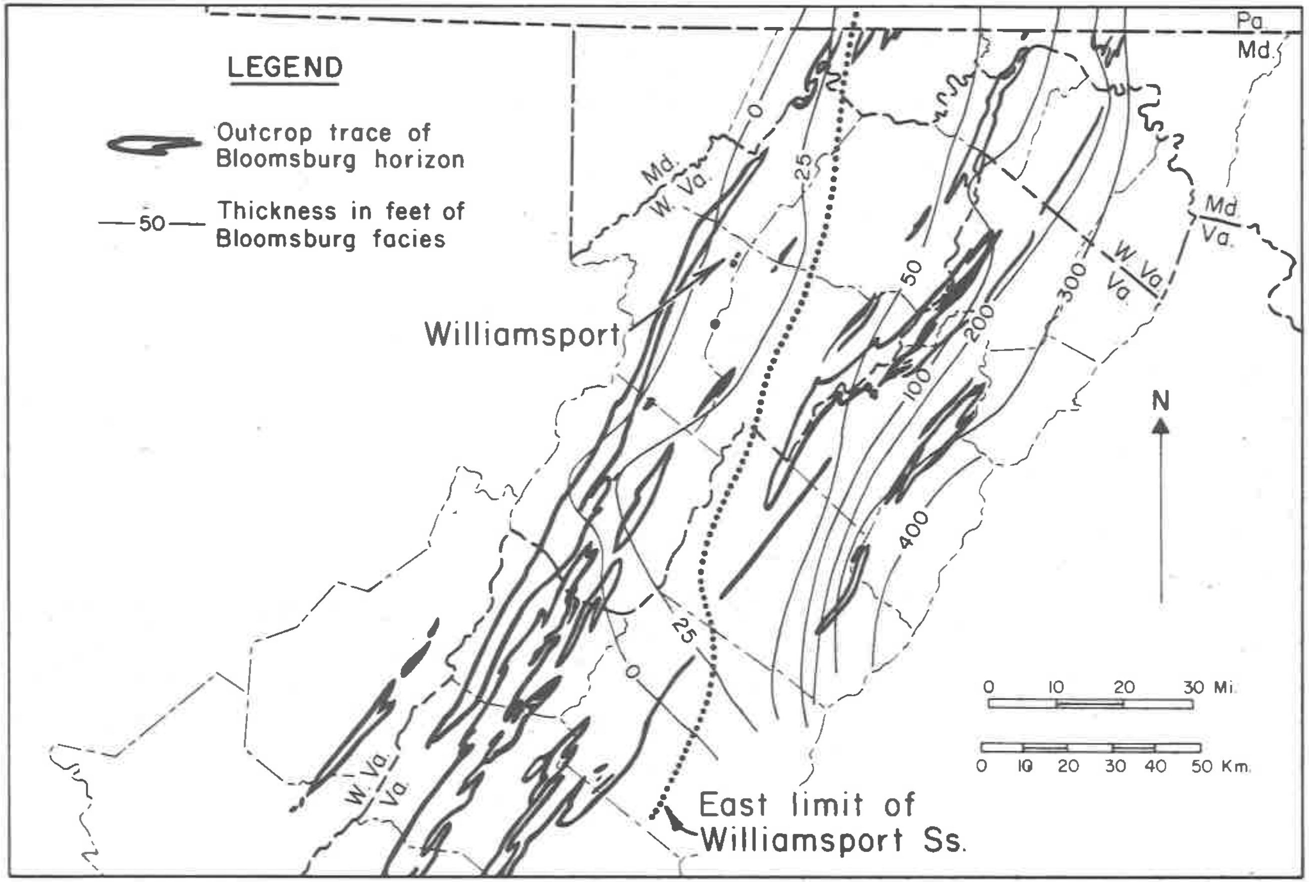


Figure 10. Outcrops of Bloomsburg and equivalent beds and thickness of Bloomsburg redbed facies.

50-feet isopach in Figure 10.

The most comprehensive study of the Bloomsburg Formation is by Hoskins (1961) who measured 17 stratigraphic sections in Pennsylvania, two in Maryland and one in West Virginia. The stratigraphy in Maryland is thoroughly documented by Swartz (1923a, 1923b). Woodward (1941, p. 149-175) summarized the stratigraphy of the Bloomsburg facies and Williamsport Sandstone in West Virginia. The Bloomsburg Formation was described in northern Virginia by Butts (1940a, p. 253-257), and more recently its distribution has been mapped and characteristics described by Brent (1960), Rader (1969), Butts and Edmundson (1966), and Allen (1967). Dennison (1970a) discussed the stratigraphic and sedimentary tectonic relationship of the Bloomsburg Formation and Williamsport Sandstone.

The Williamsport Sandstone occurs in outcrop and in the subsurface throughout the entire area shown in Figure 10 west of the indicated east limit of the Williamsport. The Williamsport consists of up to 40 feet of fine- to medium-grained, often calcareous quartz sandstone with scarce marine fauna, notably the ostracod Leperditia, which may indicate hypersaline conditions. In the area of Figure 10 east of the zero redbed isopach and west of the east limit of the mapped Williamsport Sandstone the Williamsport contains interbeds of reddish shale to sandstone which represent Bloomsburg muds swept westward until their reddish color was reduced in deeper water. Dennison (1970a, p. 12-13, 21) believes that the Williamsport Sandstone was produced by winnowing in a shallow sea at a time of eustatic lowering of sea level, and at the same time the red mudflats of the Bloomsburg facies reached their maximum westward extent.

Farther east in Maryland the main mass of Bloomsburg redbeds thickens and coarsens between the Wills Creek and McKenzie Formations. Scattered redbed sandstones occur in eastern outcrops from Washington County, Maryland, south to Augusta County, Virginia, but the main mass of the Bloomsburg facies in the area of thick occurrence is siltstone and shale. Some greenish streaks and mottling occur in the Bloomsburg facies. A few layers of hard white, quartzose sandstone occur in the Bloomsburg in eastern outcrops of Maryland. Swartz (1923a, p. 52) presents an excellent diagram showing how the Bloomsburg redbeds thicken to the east at the stratigraphic position of the Williamsport Sandstone, plus appearing to the east in sections of the McKenzie, Wills Creek, and Tonoloway marine formations. In Washington County the Rabble Run Redbed Member is conspicuous near the middle of the McKenzie Formation. The Rabble Run Member is also present in Morgan and Berkeley Counties, West Virginia. Reddish marine shale interbeds occur in the Wills Creek Formation in Washington County, Maryland. The Indian Spring redbeds in the lower Tonoloway Limestone occur in Washington County.

The Bloomsburg Formation is thickest in the area of Figure 10 in the Massanutten synclinorium, probably because these outcrops were tectonically displaced many miles to the west during the Alleghany orogeny in late Paleozoic time. Butts (1940a, p. 254-255) describes two sections in the Massanutten Mountain area, and these sections seem to be the basis of stratigraphic descriptions used by subsequent workers. At Woodstock Gap, Shenandoah County, the Bloomsburg totals 260 feet in thickness, with the upper 140 feet consisting of thick-bedded sandstone, mainly red, with partings of red shale. At Harshberger Gap, Rockingham County, the Bloomsburg is about 340 feet thick and contains scattered masses of red sandstone. Woodward (1941, p. 157) mentions a Bloomsburg exposure along Virginia Highway 261 in Massanutten Mountain, Shenandoah County where the Bloomsburg contains 185 feet of red shale and sandstone, which overlies about 60 feet of greenish conglomeratic sandstone, the correlation of which has not been fully studied. Robert C. Lagemann is currently doing a M.S. thesis at University of North Carolina, working out post-Massanutten Sandstone stratigraphy in the northernmost part of the Massanutten syncline. In the Massanutten syncline the Bloomsburg Formation underlies Wills Creek Formation and overlies the Massanutten Sandstone. Both top and bottom contacts of the Bloomsburg there are thought to be conformable.

Along Little North Mountain in Frederick County the Bloomsburg thickness is variable, partly because of faulting, and probably partly because of unconformities (Butts and Edmundson, 1966). Dennison does not believe the Bloomsburg is anywhere omitted by unconformity along Little North Mountain. At Baldwin Gap at the Shenandoah-Frederick County boundary Dennison made field notes in 1960 recording an estimated 200 feet of Bloomsburg Formation consisting of brown to red sandstone with some shale. In that vicinity, the Clinton Formation seems to be absent by unconformity at the base of the Bloomsburg, which rests directly on about 50 feet of Tuscarora Sandstone. Dennison (1961, p. 11) has mapped the Devonian Needmore Shale as unconformably overlying the Bloomsburg in part of southern Frederick County near Fawcetts Gap. It is only along Little North Mountain that there is any evidence of unconformities at the top or bottom of the Bloomsburg, and even there, the possibility is strong that there is omission of strata by faulting rather than by unconformity.

Dennison (1970a, p. 13) postulated that the Little North Mountain area was a Silurian positive axis which received thin Silurian sedimentation and restricted influx of Bloomsburg redbeds into the Appalachian Basin to the west. Later this area of thin Silurian sedimentation localized the weak zone of the North Mountain fault.

In Augusta County, Virginia, Rader (1969) recorded 50 feet of Bloomsburg reddish shale, siltstone, and sandstone at Buck Hill, but farther south at Buffalo Gap the Bloomsburg redbeds seem to have disappeared by facies change.

There is little petrographic information on the sandstones of the Bloomsburg. Hoskins (1961, p. 10) described Bloomsburg sandstones from Pennsylvania to West Virginia as containing up to 10 percent feldspar, with a composition of 70-90 percent quartz for most of the sandstones. Most of the Bloomsburg is a mudstone, so its average permeability is probably generally quite low. The mudstones show fracture cleavage more conspicuously and extending farther west in the folded outcrops than do the strata of the nearby formations. The composition and texture of the Bloomsburg strata are generally not suited for serious consideration as a uranium protore.

No carbonaceous matter was recorded in the Bloomsburg, although erect plants had appeared by early Silurian time in Maine (Schopf and others, 1966). Perhaps this absence of carbonaceous matter was related to the arid climate of the region as indicated by Cayugan-age casts of halite crystals in associated Wills Creek and Tonoloway strata.

In the study area of Figure 10 there is no mention of pyrite which could produce a uranium reduzate facies.

Source area for the Bloomsburg redbeds seems clearly to be toward the east and southeast, as indicated by the direction of increase of redbed thickness, coarsening, and the lithofacies patterns. There is no record of paleocurrent directions from cross-beds, if such structures are indeed present. Mud cracks are not noted in any of the Bloomsburg descriptions for the area shown in Figure 10, but they are common in the associated western shale and limestone facies of the Wills Creek Formation. If the Wills Creek was subjected to periodic desiccation, then certainly the redbed facies to the east was subject to even more prolonged subaerial exposure.

The eastern exposures of the Bloomsburg Formation in Figure 10 probably were deposited on broad flood plains or subaerial portions of deltas with a westward drainage. Supratidal mudflats were oxidized to reddish color, and the red muds were swept westward to intertidal zones and even into shallow neritic water of the McKenzie and Wills Creek Formations. The McKenzie had a normal marine fauna, but the Wills Creek and Tonoloway strata contain a restricted fauna dominated by <u>Leperditia</u> during the time of deposition of the Cayugan evaporites. Perhaps the shaly interbeds of the Wills Creek Formation represent the reduced coloration of Bloomsburg redbed muds carried westward into the early Cayugan Sea. Eustatic lowering of sea level resulted in a thin blanket of Williamsport Sandstone, which serves as an important gas reservoir rock (sometimes called Newburg sand) in western West Virginia (Patchen, 1968b).

Uranium potential of the Bloomsburg fluvial deposits is considered meager because of the high quartz content of the sands, the lack of permeable sands, and the absence of suitable reduzate facies with its carbonaceous or pyritic admixtures. The red coloration dies out in western outcrop belts because the strata merge westward into non-red marine beds. Only the extreme eastern outcrops have sufficient fluvial sandstone to be considered for uranium potential and these beds are rated as unfavorable because of composition and probable low permeability.

Hampshire Formation

The Upper Devonian Hampshire Formation is a fluvial redbed accumulation which formed the nonmarine uppermost portion of the Catskill delta complex in Maryland, eastern West Virginia, and northern Virginia. It is physically continuous with Catskill delta redbeds extending north to New York. Figure 11 shows thickness of the Hampshire Formation in outcrop and subsurface and the location of Hampshire outcrop belts in the Valley and Ridge and Appalachian Plateau Provinces.

At the beginning of the Late Devonian the area of Figure 11 that ultimately received Hampshire Formation sediments was a deep marine basin which, following the deposition of the widespread Tulley Limestone, began to be filled from the east by turbidite muds and siltstones. Sedimentation exceeded subsidence, and gradually the shoreline prograded westward so that the basin in vertical sequence received distal turbidites, proximal turbidites, shallow-water marine sediments affected at times by winnowing action, brackish near-shore sediments commonly with interbeds of brownish gray "redbed" coloration but containing the brachiopod Camarotoechia and nuculid pelecypods, and finally the nonmarine, dominately grayish red sandstones, siltstones, and shales of the Hampshire Formation. The Hampshire was named by Darton (1892) for exposures in Hampshire County, West Virginia. The base of the Hampshire Formation customarily is mapped at the highest occurrence of marine fossils, near the lowest introduction of bright grayish red strata. The upward loss of marine fauna and color change usually occur within a few feet of each other, and in nearly all outcrops Devonian marine fossils do not recur above the color boundary. Time of deposition of the Hampshire Formation approximately spans the Chautauquan Epoch, but perhaps in eastern areas it may extend upward into earliest Mississippian Period and downward into the Cohocton Age. The top of the Hampshire Formation is drawn where the redbeds pass upward into a dominance of yellowish gray sandstones and siltstones which comprise the Pocono Formation. Lowest Pocono strata may contain reddish interbeds of Hampshire-type shale and siltstone in the basal few tens of feet.

The Hampshire Formation of the Virginias and Maryland is roughly equivalent to the Catskill Formation of Pennsylvania and New York, but there is sufficient difference in application of the names that an arbitrary name change is justified at the south boundary of Pennsylvania. The name Catskill Formation is used for all Upper Devonian strata which contain reddish beds in Pennsylvania and New York, even though they may be redbeds intertonguing with marine layers. Catskill Formation strata include brownish gray marine redbeds as well as reddish gray nonmarine strata. As used in the Virginias and Maryland, reddish layers in the marine sequence are included in the "Chemung" Formation, or are assigned to the Foreknobs Formation of new

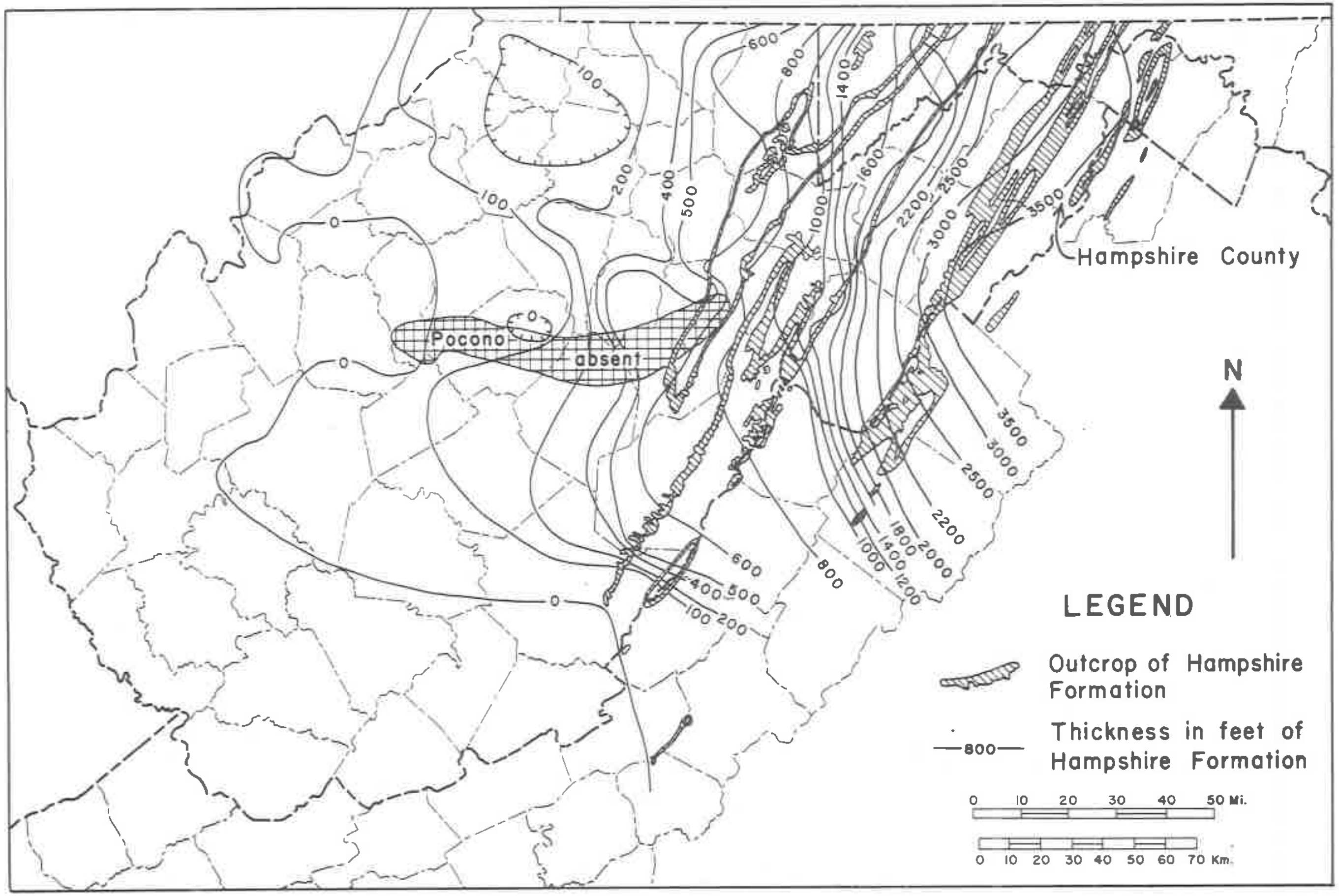


Figure 11. Outcrops and thickness of Hampshire Formation.

stratigraphic nomenclature proposed by Dennison (1970b) for exposures along Allegheny Front in the strike belt which passes through Mineral County, West Virginia. The isopach map of Figure 11 shows the thickness of the interval from the base of the Pocono Formation down to the highest marine fossils, that is the thickness of the Hampshire Formation.

Principal sources of outcrop data are the Devonian volumes for Maryland (Prosser and Swartz, 1913) and West Virginia (Woodward, 1943), and Virginia data are from Butts (1940a, p. 333-335), Brent (1960, p. 54-55), Butts and Edmundson (1966), and Rader (1969, p. 15). Dennison has measured the Hampshire Formation thickness in 9 sections extending along 88 miles of the Allegheny Front strike belt in Maryland and West Virginia, and these data are incorporated in a stratigraphic cross section just published (Dennison, 1971). Seven of these Hampshire Formation sections are described in bed-by-bed detail by Dennison.

Subsurface data for the Hampshire Formation isopachs were taken from well descriptions by Martens (1939, 1945). In subsurface areas with more than 300 feet of Hampshire Formation the stratigraphic range from the lowest to highest reddish sample interval was used for the Hampshire thickness. In western areas with less than 300 feet isopach thickness, there was considerable evidence for marine-nonmarine interbedding, so the total thickness of individual sample intervals described as reddish was used. Reddish gray nonmarine strata probably comprise most of the strata which appear in pulverized well cuttings as notably reddish in color. In general the zero isopach for reddish coloration in Figure 11 probably closely coincides with the west limit of fluvial sediments, but the zero subsurface isopach may be a few miles west of the termination of nonmarine deposits of the Catskill delta complex.

In outcrop belts the zero isopach does correspond to the westernmost occurrence of reddish gray nonmarine beds. Brownish gray, marine "redbeds" are present farther west and southwest in "Chemung" Formation outcrops at Pulaski, Pulaski County, Virginia (see also Cooper, 1939, p. 46) and at Caldwell, Greenbrier County, West Virginia. Geographic position of the dark-maroon sandstone in the upper Chemung described by Cooper (1944, p. 140) in the Burkes Garden Quadrangle in Bland County, Virginia, indicates these are probably also marine redbeds.

The isopach map of the Hampshire Formation presented in Figure 11 is generally similar to an earlier map prepared by Woodward (1943, p. 526), but there is a thickness difference as much as 300 feet locally in the central area (Preston County, West Virginia). Figure 11 shows no evidence for the axis of sedimentation indicated by Woodward in the Eastern Panhandle region of West Virginia.

The basal contact of the Hampshire Formation is a facies boundary (marine to nonmarine sedimentation) and is conformable and diachronous. Depositional strike was nearly north-south in the area of Figure 11 (note isopach trends) and maximum rate of thinning and facies change was from east to west. Prosser and Swartz (1913, p. 422) illustrate how the base of the Hampshire Formation climbs stratigraphically some 700 feet from the east to the west side of the Sideling Hill syncline in westernmost Washington County, Maryland, with a red-bed tongue in the Chemung Formation on the west side marking the position of the lowest Hampshire on the east side. Most of the westward thinning of the Hampshire strata is by westward facies replacement of the lower Hampshire by marine strata of the "Chemung" Formation lithology. Some of the westward thinning of the Hampshire Formation may also result from stratigraphic convergence. Part of the uppermost Hampshire in the east may be a facies equivalent of the Pocono Formation (Dally, 1956, p. 105-107).

Rate of thickness change is much less along strike belts than in east-west direction. In a distance of 96 miles along the Allegheny Front strike belt Dennison (1970b, p. 60) recorded 700 feet of upward shift of the basal boundary of the Hampshire Formation as a result of facies change toward the southwest into marine beds of an upper unnamed member of the Foreknobs Formation.

The Hampshire Formation contains about 80 percent reddish gray siltstone and fine sandstone, with the remainder nearly all reddish gray shale, along with a bit of yellowish gray sandstone (Pocono-type lithology) in the upper portion. It seems to become more silty to the southwest along the Allegheny Front, reflecting a grain-size decrease in an oblique section away from source. Some greenish shale streaks are conspicuous in the red siltstone. Desiccation cracks locally are present in siltstones and mudstones. The sandstones and siltstones occur in couplets with sandstone at the bottom grading upward into siltstone and lumpy red shale. There are often a few inches of basal light olive gray sandstone with shale chip inclusions, passing upward into massive reddish gray sandstone. This assemblage seems to be typical fining-upward cycles which characterize point bar fluvial deposits. Calcareous concretions commonly occur in the shales of overbank deposits in fluvial cycles, but this has been noted only in one section at Briery Gap Run, Pendleton County, West Virginia. The sandstones may channel a few inches to a few feet into the underlying beds, and locally a channel-fill conglomerate may occur on the basal sandstone, as at the U. S. Route 50 section in Mineral County, West Virginia. Other sandstone beds show no evidence of channeling. The best place to study bedding characteristics of the Hampshire Formation is along W. Va. Route 72 three miles north of St. George in Tucker County, where individual beds can be traced along a road cut for about 300 feet. In western outcrops where the Hampshire intertongues with marine strata, the Hampshire sandstone contain quartz-pebble conglomeratic layers, as seen a mile east of Marlinton, Pocahontas County along W. Va. Route 39. Such quartz-pebble zones seem absent farther toward the clastic source in truly alluvial deposits to the northeast and east, and they may represent lag deposits from shoreline winnowing in Pocahontas County.

The Hampshire Formation contains considerable organic debris, mostly stem and log fragments, but occasionally Archaeopteris leaves. A locality collected by Andrews and Phillips (1968) near Valley Head, Randolph County, West Virginia, has yielded the best-preserved Rhacophyton material in North America. Driftwood logs noted at various places are up to two feet long. No persistent coal beds are known, but a lenticular streak of coal an inch thick occurs along West Virginia Route 32 near Red Creek, Tucker County, West Virginia. Heck (1940) described a coal lens a foot thick 1.3 miles east of Parsons, Tucker County, West Virginia. Finely disseminated plant debris is common in the basal layers of Hampshire sandstones. Some of the plant material is preserved as pyritized stems rather than strictly carbonaceous material. Phosphatic material of fish bones and plates is known from several localities in Randolph and Pocohantas Counties, West Virginia and Allegany County, Maryland. Carbonaceous and pyritic material is abundant enough in the Hampshire Formation to be quite effective in establishing a potential uranium cell. The Hampshire Formation is the oldest Paleozoic fluvial deposit in the study region which contains significant amounts of carbonaceous material.

Little information is available on the petrography of the Hampshire Formation in the Virginias and Maryland. The few samples of sandstone which Dennison has thin sectioned from along the Allegheny Front outcrop belt are feldspathic to lithic graywacke with feldspar abundance not much greater than 10 percent. David A. Kirchgessner is doing a petrographic study of the underlying Foreknobs Formation along the Allegheny Front as a dissertation at the University of North Carolina and will obtain some petrographic data on the basal portion of the Hampshire Formation. Outcrop samples are difficult to study because hematite stain masks other grains and the finer feldspars alter to clays. Martens (1939, p. 23) summarized the petrography of nine subsurface samples of Hampshire sandstones (called Catskill by him). In his samples the percentage of "quartz is estimated to be about 65 to 80 and the feldspar to be about 1 to 20. There is likely to be more feldspar than this rather than less, because other minerals attached to many of the grains make them difficult to recognize. The heavy minerals in these Catskill sandstones are leucoxene, muscovite both as distinct flakes and sericitic aggregates, chlorite, biotite, zircon, tourmaline, rutile pyrite, apatite, anatase, brookite, xenotime, and ilmenite. Leeper (1963, p. 175) studied the Catskill Formation in Somerset County, Pennsylvania, just north of Garrett County, Maryland. Forty-three sandstone samples were analyzed as follows: 24 feldspathic graywackes, 14 feldspathic sandstones, 2 lithic graywackes, 2 protoquartzites and 1 arkose. In summary, the Hampshire Formation sandstones seem to contain enough feldspar to be considered as possible uranium protores.

Sandstones of the Hampshire Formation are somewhat argillaceous, but they are probably permeable enough to permit circulation of subsurface water. The principal oil and gas producing sands in the Catskill delta of West Virginia are all Chautauquan Epoch sands deposited a few miles west of the limit of Catskill redbeds at that time (Dennison, 1971). This is probably because petroleum forms in association with marine beds rather than because of lack of permeability of the sandstones in the Hampshire Formation. There is little difference other than color between the Hampshire sandstone strata and some of the "Chemung" beds deposited very near shore. Certain beds within the "Chemung", however, definitely have been winnowed and are more permeable than Hampshire sandstones (such as the Briery Gap and Pound Sandstone Members of the Foreknobs Formation of Dennison, 1970b, 1971).

Oxidation-reduction color changes are apparent in Hampshire sandstones. Some sandstone beds exhibit intertonguing of reddish and greenish layers. Greenish halos occur around carbonized wood fragments or mark the places where carbonaceous material has been removed during diagenesis. Joints in reddish sandstones sometimes are marked by greenish outlines. Greenish shale streaks occur scattered throughout the Hampshire redbeds. Along U. S. Route 250 in western Highland County, Virginia, a massive yellowish gray sandstone 173 feet thick, with wood debris scattered throughout, is present near the base of the Hampshire between conspicuous reddish gray sandstone strata. There is little or no evidence to suggest that red sandstone coloration results from present-day weathering of greenish sandstones in the Hampshire Formation. This does not rule out the possibility that the Hampshire red sandstones resulted from ground water or diagenetic alteration of hornblende or other minerals in originally greenish sandstones.

The top of the Hampshire Formation is probably conformable in most outcrop and subsurface areas shown in Figure 11. Dally (1956, p. 105-107) presents arguments that the basal Pocono passes by facies change into the upper part of the Hampshire Formation in southeastern West Virginia. In the area between Caldwell, Greenbrier County and Beverley, Randolph County, the Pocono and Hampshire thin and disappear in opposite directions and show a complementary relationship in thickness. Throughout this area in the individual sections, a 200 to 300 foot thick transition zone of interbedded red and non-red sediments separates the two units. It appears that the Pocono rocks in the southern part of the state intertongue northward into the Hampshire Formation (Dally, 1956, p. 105, plate 2). A similar intertonguing is suggested by Dally for eastern outcrops.

An unconformity appears to be definitely present at the top of the Hampshire Formation at Beverley, Randolph County, West Virginia, because the Pocono is completely absent and the Greenbrier Limestone rests directly on Hampshire Formation (Reger, 1931a, p. 155, 343; Dally, 1956, p. 126, 195, plate 2). Flowers (1956, p. 8, 14) showed that the Pocono is absent due either to non-deposition or erosion in parts of Webster, Upshur, and Randolph Counties. Dally, working in cooperation with Flowers, extended the area with no Pocono even farther westward into Braxton and Calhoun Counties (see Figure 11 for area where Dally records no Pocono). Dally (1956, p. 126-127) considers this to represent an Early Mississippian island standing above sea level. Comparison of Hampshire (Figure 11) and Pocono zero isopach localities suggest that locally in eastern Braxton County erosion cut so deeply as to remove all of the Hampshire Formation and expose the older "Chemung" Formation strata at one point on this island. It is not possible to speculate effectively what may have been ground water circulation patterns in Early Mississippian time near this island.

Paleocurrent information on the Hampshire strata in the area of Figure 11 is totally lacking except for measurements by Dennison along the Allegheny Front in West Virginia of cross-beds, ripple marks, and plant fragments. Vector mean of direction toward which the current was flowing is N64°W at Keyser and N85°W at Route 50 in Mineral County, and N76°W at Scheer and S62°W at Hopeville in Grant County. These results are comparable to those obtained by Leeper (1963, p. 175-176) in Somerset County, Pennsylvania, just north of Garrett County, Maryland. His cross-stratification vector mean for the Catskill was 311° (N49°W), and his results of measurements of groove casts, flute casts, ripple marks, and rill marks agree with this transport direction. Toward the south among these localities, there seems to be a southward shift of the current vector perhaps indicating the general shape of the Fulton lobe of the Catskill delta complex (see Dennison, 1971). Meckel (1970, p. 57) also generally mapped sediment transport toward the northwest for the Catskill delta in Maryland and northeastern West Virginia. No data are available for the southern part of the Hampshire Formation area mapped in Figure 11.

The Hampshire Formation of the Catskill delta complex in the Virginias and Maryland probably did not form in a birdfoot delta similar to that of the modern Mississippi River. The entire region in Figure 11 probably is on the south edge of the Fulton lobe of a delta complex, with a less permanent Augusta lobe centered in Augusta County, Virginia (Dennison, 1971). Rather than a single delta, a complex of alluvial deposits formed like along the modern Mississippi-Alabama-Florida coast or the Carolina coast. The Hampshire deposits are chiefly alluvial, rather than delta distributary. This is not greatly different from a thesis developed for the Catskill of Pennsylvania by R. G. Walker (1971) who maintains that there are no true deltaic depositional environments within the Catskill clastic wedge of south-central Pennsylvania. He maintains that the establishment of the Catskill clastic wedge in the east took place by the advance of a sandy shoreline on top of the proximal turbidites. The shoreline built forward rapidly, and resulted in the permanent establishment of an alluvial plain. As the alluvial plain widened during westward progradation, more and more sand was trapped on the alluvial plain and the shoreline became muddier and prograded more slowly. Such a model needs to be seriously examined for the Virginias and Maryland.

In summary, the Hampshire Formation deserves serious consideration in the search for uranium. It is moderately feldspathic and contains abundant organic debris along with pyritic material. Both reddish and greenish sandstones are present. In eastern areas all of the Hampshire Formation is close enough to the surface to be considered mineable. Dips are steep enough in western outcrop belts that the Hampshire Formation top drops to over a thousand feet beneath the ground surface within a mile or two of the outcrop belt. To the southwest in outcrop and to the west in the deep subsurface the Hampshire Formation changes facies into the marine beds of the "Chemung" marine, non-red strata.

There is one locality, at U. S. Route 50 in Mineral County, West Virginia, where nonmarine redbeds occur in strata below the Hampshire Formation. There the Blizzard Member of the Foreknobs Formation (Dennison, 1970b) is 442 feet thick and contains throughout most of its thickness grayish red sandstone and siltstone resembling the Hampshire Formation. The Blizzard Member there contains no marine fossils, but the overlying Pound Sandstone Member contains a few brachiopods. The Hampshire Formation rests directly on the top of the Pound Sandstone at Route 50. The Blizzard Member at Route 50 accumulated in a small Hampshire-type lithology subaerial distributary lobe (Dennison, 1971, p. 1185).

One other uranium possibility should not be overlooked, even though it does not directly involve fluvial strata. The Foreknobs Formation along the Allegheny Front or the upper "Chemung" Formation elsewhere is a nearshore marine accumulation containing abundant carbonaceous driftwood debris and pyritized wood fragments. "Chemung" and Foreknobs sandstones have the same detrital mineral composition as equivalent Hampshire Formation beds farther east, that is, they are feldspathic graywackes. Furthermore, these beds may be quite permeable as shown by the fact that the principal oil and gas produced from the Upper Devonian in West Virginia comes from rocks formed in the near-shore marine environment (Dennison, 1971, p. 1191). On outcrop some of the marine sandstones are brownish gray "redbeds" which are thought to represent an intermediate reduction state as the bright reddish gray mudflat and lower coastal plain muds and sands of the Hampshire Formation were swept westward into the reducing environment of the sea and ultimately reduced so that the red coloration completely altered to light olive gray or olive gray.

Pocono-Price-Grainger Formations

The Pocono, Price, and Grainger Formations are all predominately yellowish gray to light olive gray sandstone, siltstone and shale deposited during the Kinderhookian, Osagian, and Meramecian Epochs. In the east the Pocono and Price Formations (Figure 12) contain principally nonmarine beds with scattered coals; in the west they consist chiefly or totally of marine intertongues. The name Pocono is used for outcrops from Pennsylvania south across West Virginia and in Virginia south to the James River; Price Formation is the name used for equivalent beds in southwest Virginia. South of the Tennessee-Virginia boundary the equivalent Grainger Formation is a succession of sandstone, siltstone and shale, all generally light olive gray, and nearly totally marine, but perhaps containing some nonmarine beds. Farther west in Tennessee, the Grainger intertongues with the Fort Payne Chert. In northeastern Kentucky, equivalent marine clastic beds are called the Borden Group. In Ohio occur marine equivalents known as the Waverly Group with its succession of Bedford Shale, Berea Sandstone, Sunbury Shale, Cuyahoga Shale and Logan Formation.

Literature is scattered concerning the Pocono-Price-Grainger outcrop belts shown in Figure 12. The best summary analysis for West Virginia and Maryland is an unpublished dissertation by Dally (1956). He considered stratigraphic and paleontologic relationships, but did not do petrographic, cross-bed, or sedimentary structure studies. The only generalized statements for Virginia are by Butts (1940a, p. 336-350) and Cooper (1963, p. 60-61). Campbell and others (1925) treated the Pocono-Price coals of Virginia in remarkable detail, but offered little detailed information about the associated strata. A thesis by Kenneth R. Walker (1964) emphasized the petrography of three sections of the Price Formation and is the best petrographic characterization of the formation. The Grainger Formation has been briefly summarized by Rodgers (1953, p. 106-108), and was studied in detail by Kenneth O. Hasson (1971) for a dissertation at University of Tennessee. He has generously shared preliminary information for the summary compilation of Figure 12, and the present writer is indebted to Mr. Hasson for numerous provocative and informative discussions. The fossil flora of the nonmarine portions of the Price-Pocono strata has been studied by Read (1955), but the resulting time zonation is probably not as precise as that obtained by Dally (1956) from invertebrate fossils in the marine portions of the Pocono. K. R. Walker (1962) has published a generalized lithofacies and isopachous map of the Lower Mississippian Kinderhook plus Osage Series of eastern and east-central United States. Meckel (1970) presented a thoughtful analysis and depositional model of Pocono stratigraphy and sedimentology as part of a summary paper on Paleozoic alluvial deposits in the central Appalachians.

There is considerable nomenclatural variation in the area, chiefly reflecting differences in stratigraphic characteristics, but to a

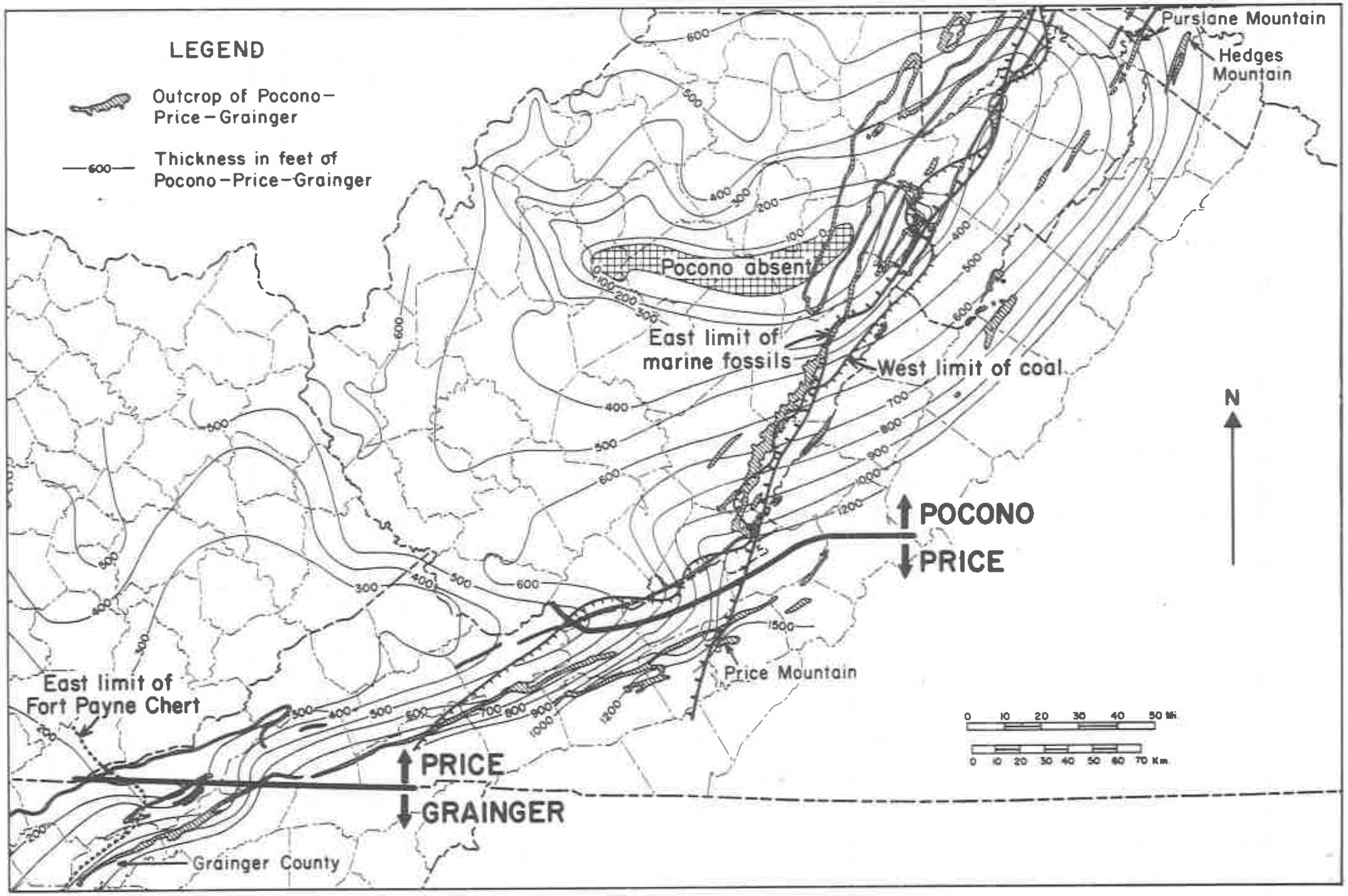


Figure 12. Outcrops and thickness of Pocono, Price, and Grainger Formations.

degree reflecting nomenclature traditions begun separately in various states and continued to the present time. Regional differences in Pocono-Price-Grainger stratigraphy and nomenclature will be briefly treated in the following paragraphs.

Several decades ago most workers placed an unconformity at the base of the Pocono-Price-Grainger strata in deference to the widespread belief at that time that each geologic system was separated by an unconformity from the underlying system. This bias has been succeeded by an examination of each formation on its own merits, and none of the recent literature places an unconformity below the Pocono-Price-Grainger strata. In the northeastern part of the area shown in Figure 12 the Pocono rests directly on the redbeds of the Hampshire Formation (areas shown in Figure 11). Dally (1956, p. 45) placed the base of the Pocono Group in northern and eastern West Virginia and in Maryland at the top of the highest redbed that can be related to the Hampshire Formation. The lower Pocono, as described previously in the treatment of the Hampshire Formation, contains transitional interlayers of red and non-red strata which Dally (1956) interprets as facies intertongues of Hampshire Formation. The marine fossils of the lowest Pocono range from basal Kinderhookian Series to basal Osagian Series, so that the top of the Hampshire Formation is probably a diachronous contact. In contrast, there is no clear lithologic boundary for the base of the Pocono in southern West Virginia. In that region the uppermost Devonian consists of olive gray marine sandstone and siltstone which is a facies equivalent of the Hampshire Formation redbeds to the northeast. Dally (1956, p. 51-55) placed the base of the Pocono Group in southern West Virginia above those beds which contain a distinct Chemung faunule (Devonian) and below those beds which contain the first elements of the Marlinton (Mississippian) fauna. He presents appropriate faunal lists for this determination. The same faunal criteria are appropriate for separating the Price Formation of Virginia from the underlying marine sandstones and siltstones of the "Chemung" Formation or from the Parrott Formation (Cooper, 1961, p. 59-60). In extreme southwestern Virginia, the Price Formation rests conformably on the Big Stone Gap Shale Member of the Chattanooga Shale, and in Tennessee the Grainger Formation conformably overlies the Chattanooga Shale.

In the outcrop belts along the Potomac River in extreme eastern West Virginia and adjacent Maryland, Stose and Swartz (1912) proposed a separate formation nomenclature within the Pocono Group which has remained generally in use to the present time. They divided the Pocono Group into the following formations, arranged in columnar section order:

Pinkerton Sandstone (125+ feet)

Massive white sandstone and quartz conglomerate, in part cross-bedded with a thin coal seam.

Myers Shale (800+ feet)
Largely bright-red crumbly sandy shale and thin argillaceous sandstones with thick cross-bedded dirty-gray gritty sandstone at base.

Hedges Shale (170 feet)
Dark gray to black carbonaceous shale containing thin seams of semianthracite coal.

Purslane Sandstone (180-310 feet)
Massive hard coarse white sandstone and milky quartz conglomerate, alternating with softer cross-bedded sandstone with a little shale and thin coal seams.

Rockwell Formation (500-540 feet)
Soft arkosic sandstone, fine hard conglomerate, and buff hackly shale; crumbly dark gray carbonaceous shale with thin coal seams near base in western part of area.

Rockwell Run and Purslane Mountain are in the Sideling Hill syncline (Figure 12) and Hedges Mountain, Myers, and Pinkerton Knob are in the Meadow Branch syncline outcrop region. The Rockwell Formation rests directly on the red micaceous sandstone and shale of the Catskill (Hampshire) formation in the Pawpaw-Hancock area. The Rockwell and Purslane strata are mapped in both the Sideling Hill and Meadow Branch synclines, but only the latter syncline in Berkeley and Morgan Counties, West Virginia, is deep enough to contain the strata mapped as Hedges, Myers, and Pinkerton Formations. The same classification and age assignment of these five formations was followed by Grimsley (1916, p. 136-166) in Berkeley and Morgan Counties, West Virginia, and Cloos (1951, p. 92-93) continued the nomenclature by using Purslane and Rockwell Formations to map and describe the exposures in Washington County, Maryland.

More recently, Read (1955), Dally (1956), Burford and Duncan (1967), and Burford, Clendening, and Duncan (1969) all restrict the Pocono Group to include only the Rockwell, Purslane, and Hedges Formations, for widely diverse reasons summarized below.

Read (1955, p. 10-11) reevaluated the paleobotanical evidence for the age of the Meadow Branch syncline beds. The Hedges Shale flora is clearly that of the Triphyllopteris zone, widespread in the upper part of the Pocono. No fossils well enough preserved for positive identification are known from the Myers and Pinkerton Formations. Lithologic evidence caused Read to favor correlation of the Myers Shale with Mauch Chunk Formation and the Pinkerton Sandstone with basal Pennsylvanian.

Dally (1956, p. 65) excluded the Myers Shale and overlying Pinkerton Sandstone from the Pocono Group because the red argillites of the Myers are a Maccrady or Mauch Chunk lithology and not similar to the Pocono lithologies. Dally used this interpretation in preparing a Pocono isopachous map, which was entered into the compilation for Figure 12 of the present paper.

Burford and Duncan (1967) concluded from careful field mapping that the entire Sleepy Creek (Meadow Branch) syncline is cut by a major northeast-trending longitudinal reverse fault. The fault appears to dip east with the east block upthrown. The Pinkerton and Purslane Sandstone appear to be the same unit repeated by faulting. Burford, Clendening, and Duncan (1969) correlated the Meyers and Pinkerton Formations with the Hampshire and Purslane Formations, considering the names Meyers and Pinkerton as invalid stratigraphic names. This interpretation was used for the new geologic map of West Virginia (Cardwell, Erwin, and Woodward, 1968), where the stratigraphic succession within the Pocono Group for extreme eastern West Virginia is shown as Rockwell Formation, Purslane Sandstone, and Hedges Shale.

Specific petrographic data are not available in the literature, but the association of coaly material and arkosic sandstone in the Rockwell Formation suggests that the lower Pocono of the extreme eastern outcrop belts merits consideration in the search for uranium protore, but the Purslane Sandstone and Hedges Shale probably have less desirable characteristics. Cross-bed measurements by Pelletier (1958, p. 1047) in the Sideling Hill syncline indicate a lower Pocono clastic transport direction toward nearly due west. It is noteworthy that all of his 14 sandstone samples from Maryland and Pennsylvania (exact location unspecified) continued less than 10 percent feldspar and were chiefly lithic arenites with some protoquartzites (Pelletier, 1958, Fig. 6). This is in marked contrast with the description of Stose and Swartz (1912) of the Rockwell Formation as an arkose. Additional petrographic study is needed.

The principal Pocono outcrops in West Virginia and Maryland are along the Allegheny Front at the east edge of the Appalachian Plateau and in the large folds in the eastern portion of the Plateau. In Randolph County the Pocono is absent (at Beverley) or notably thinned so that Dally divided the Pocono occurrence into a northern and southern region, each with separate nomenclature.

The Pocono of the northern area is classified by Dally (1956) as follows:

Greenbrier Limestone (Chesterian Series)

Pocono Group (Meramecian Series)

Burgoon Sandstone (35-251 feet)

Sandstone, gray to olive green, fine to coarse, thick-bedded, cross-bedded; local coaly lenses; sometimes conglomeratic. Named by Butts (1904) for Burgoon Run, Blair County, Pennsylvania.

Manheim Formation (58-376 feet)

Interbedded micaceous siltstones and shales, with local thin conglomeratic layers; some thin coaly shales with feebly developed cyclothems. Named for Manheim, Preston County.

Hampshire Formation (Osagian and Kinderhookian Series of Mississippian and Late Devonian)

Dally (1956 divided the Pocono of the southern area as follows:

Greenbrier Limestone Meramecian and Chesterian Series)

Chesterian portion

Meramecian portion

Denmar Limestone

Hillsdale Limestone

Maccrady Shale (Meramecian Series)

Pocono Group (Kinderhookian and Osagian Series)

Matoaka Formation (Kinderhookian and Osagian Series) (38-375 feet)

Sandstone, cross-bedded, locally conglomeratic; siltstone and sandstone exhibiting flow markings; and siltstone, chippy to hackly. Color is dark gray to greenish; weathers yellowish to brown. Contains massive sandstone at top overlain by coaly shales and occasional thin, impure coal. Named for Matoaka in Mercer County some 10 miles northwest of type exposure in east edge of Bluefield.

Sunbury Shale (Kinderhookian Series) (17-126 feet)

Shale, black, fissile; contains phosphate nodules in upper portion. Disappears northward by facies change into sandy beds. Named for Sunbury, Delaware County, Ohio (Hicks, 1878, p. 216, 220).

Marlinton Formation (Kinderhookian Series) (50-850 feet)

Sandstone, cross-bedded and siltstone, both weathering olive green to brown; locally conglomeratic. Basal contact is placed at lowest occurrence of Mississippian fauna and at top of those beds which contain a distinct Chemung faunule. Named for Marlinton, Pocahontas County.

Chemung Formation

Marine sandstone and siltstone, weathers olive gray.

Except for the Burgoon Sandstone and Sunbury Shale, none of the Pocono Formation names used by Dally have formal status due to the fact that his work was never published and appears only in dissertation and abstract form. All five Pocono formations in the Appalachian Plateau outcrop belts locally contain marine fossils, although the local autochthonous coals are nonmarine with distinct underclays.

Note that Dally considered the Pocono of the northern region to be the same age as the Maccrady Shale and lower Greenbrier Limestone in the southern region. Because of the thinned area in Randolph County he did not observe facies intertonguing in outcrop, but such a facies pattern should occur in the subsurface of western West Virginia.

Dally included no thin section descriptions of the Pocono, so there is a discouraging absence of mineralogic composition data on the Pocono of West Virginia. Martens (1939, p. 87) describes potash feldspar as common in the quartz sandstone from a well in Monongalia County.

In southern Somerset County, Pennsylvania, just north of Garrett County, Maryland, Leeper (1963, p. 177-179) classified 16 thin section samples of the Pocono as follows: 6 feldspathic sandstones, 3 subgraywackes, 3 protoquartzites, 2 feldspathic graywackes, 1 lithic graywacke, and 1 orthoquartzite.

In the Plateau outcrop belts of western Maryland, Pelletier (1958) obtained cross-bed vector means ranging from northwest to southwest with an average resultant vector transport direction toward about N75°W. Distribution pattern of a plot of maximum pebble size in the Pocono of Maryland also indicates clastic transport toward the west. In Somerset County, Pennsylvania, Leeper (1963, p. 178-179) recorded a vector mean transport direction toward N68°W.

The isolated synclines containing the lower portion of the Pocono in northwestern Virginia are inadequately characterized. Occurrences in Augusta and Rockingham Counties are described by Brent (1960, p. 55-56) and Rader (1969, p. 15-16), and the abandoned coal workings were described by R. W. Howell in the publication by Campbell and others (1925, p. 283-294). The sandstones are white to gray in color; some are graywacke. There are also olive green to dark gray shales and thin carbonaceous shales, along with coal beds up to 2.7 feet thick.

Read (1955, p. 11) described a detailed section of the upper Pocono at the Lewis Tunnel in Alleghany County, Virginia, where sandstones comprise nearly all of the 325 feet of strata exposed, but some siltstone interbeds occur along with three coal beds each one-half foot thick.

The Price Formation was named for Price Mountain, Montgomery County, Virginia. Cooper (1963, p. 59-62) considered that the type Price is 800-900 feet thick and is limited to a basal quartz pebble conglomeratic zone (Cloyd Conglomerate Member, named by Butts, 1940a, p. 343-347) which is 25 to 75 feet thick, and the overlying cross-bedded subgraywacke, graywacke, and arkosic sandstones with associated finer clastics and coal. The shales have a well-preserved *Protolepidodendron* and *Triphyllopteris* flora. The principal coal beds are the Merrimac seam (up to 8 feet thick) which occurs about 40 feet above the Langhorne seam (up to 6.7 feet of coal and carbonaceous shale).

Above the coal-bearing beds are 200 feet of shale and thin-bedded sandstone. The top of the Price Formation is arbitrarily placed at the abrupt change in color from brownish-gray to deep mahogany-red which is the characteristic color of the overlying Stroubles Formation. Cooper (1961, p. 59-60) isolates 490-600 feet of post-"Chemung" beds below the Cloyd Conglomerate and calls it the Parrott Formation, and removes it from the Price Formation. The Parrott consists chiefly of rusty-weathering sandstone and siltstone with abundant marine fossils. The name Parrott Formation has no formal status since it has been described only in thesis and guidebook format, so for Figure 12 the Price isopach thickness includes both the Parrott and Price (restricted) of Cooper, to be consistent with the usage of the majority of geologists.

Other significant measured descriptions of Price Formation outcrops occur scattered in the literature: along New River in Pulaski County (Cooper, 1963, p. 22-23); Pulaski, Pulaski County (Cooper, 1939, p. 51); Cloyds Mountain, Pulaski County (Walker, 1964, p. 104-110); Bluefield, Tazewell County (Butts, 1940a, p. 341-342; Cooper, 1944, p. 147-148); Walker, 1964, p. 102-103); 6 miles northwest of Wytheville, Wythe County (Walker, 1964, p. 97-101); Broadford Gap, Smyth County (Butts, 1940a, p. 340); Wooten Gap, Washington County (Bartlett and Webb, 1971, p. 66-67); 6 miles west-southwest of Gate City, Scott County (Butts, 1940a, p. 338-339); Little Stone Gap, Wise County (Butts, 1940a, p. 338); and Cumberland Gap, Lee County (Butts, 1940a, p. 338). Descriptions of the Price are also included in geologic quadrangle maps of the U. S. Geological Survey GQ series in southwest Virginia.

In general the lower Price contains olive gray marine beds with sandstone, siltstone and shale in the lower portion (probably Parrott Formation of Cooper, 1961), overlain by conglomeratic sandstone (Cloyd Member), overlain by cross-bedded sandstone, siltstone and coal. Grain size becomes finer to the west, and coals diminish in that direction, so that extreme southwestern Virginia in Lee, Wise and northwestern Scott Counties probably has a totally marine sequence comprising the Price Formation. The farthest southwest along the Clinch Mountain outcrop belt where coals and abundant plant fossils have been reported is Hayter Gap, Washington County, so definite non-marine Price strata are not recognized in extreme southwestern Virginia.

Walker (1964) did detailed petrographic studies on two sections. He designated the Wytheville section as a petrographic standard section for the Price Formation, and he made a petrographic comparison with the Bluefield section 21 miles to the northwest. Both localities contained much matrix in the sandstones, but feldspar commonly was 10-25 percent of the framework mineral composition.

A brief summary of Walker's description of the Wytheville section is contained in the following columnar section format:

Maccrady Formation (52 feet preserved beneath Pulaski fault)

Sandstone, siltstone, and shale; all maroon, extensively ripple marked.

Price Formation (1000 feet)

Member V. Sandstone, fine; siltstone; and shale; all grayish green, weathering brownish. Contains limestone beds 2 and 5 feet thick, 14 and 46 feet below the top, respectively. Near top of member feldspar attains 39 percent of framework minerals. Member is 114 feet thick. Probably developed on tidal mud flat and in lagoon.

Member IV. Shale and siltstone, light olive gray to medium olive brown, weathers medium yellowish brown. Feldspar content up to 36 percent of framework minerals. Member is 226 feet thick and probably accumulated on tidal mud flat.

Member III. Sandstone, fine- to medium-grained, and coarse siltstone; all greenish gray. Sandstones are graywacke to feldspathic graywacke, with plagioclase and orthoclase totalling up to 22 percent of framework minerals. Member totals 308 feet thick. Depositional environment interpreted as brackish water mudflat with slightly reducing conditions.

Member II. Sandstone, siltstone, and shale; grayish green when fresh. Sandstones are graywacke, subgraywacke and subarkose with up to 22 percent feldspar. Blossum Coal seam at top of member is 0.2 to several feet thick. Member is 298 feet thick. Depositional environment is transitional between marine and nonmarine.

Member I. Brownish sandstone and siltstone with stringers of conglomerate containing pebbles of vein quartz, composite metamorphic quartz, felds-par-quartz igneous rock fragments, and chert. Contains brachiopods and crinoid columnals. Member is 54 feet thick. Interpreted as quite marine environment with periodic influx of oxygenated density currents. Cloyd Conglomerate.

Parrott Formation (100+ feet)

Walker interpreted the Price as originating by progressive westward growth of a delta into marine waters with eventual decrease in rate of clastic supply and finally submergence of the subaerial mudflats beneath lagoonal waters. Mineralogic evidence in the Wytheville section indicates a gradual change of provenance during deposition from sedimentary near the base to low grade metamorphic near the center to plutonic near the top of the Price Formation.

The Bluefield section is generally similar to the Wytheville section; but there are certain notable differences: shaley beds are more conspicuous at Bluefield, and the entire formation is thinned (335 versus 1000 feet); the Cloyd Conglomerate thins to 24 feet; coal is absent and marine fossils occur throughout most of the Price. These factors are all caused by the greater distance of Bluefield from the clastic source area.

At Wooten Gap, Washington County, the Price seems to be even more marine, with glauconitic sandstones and siltstones, with marine fossils scattered throughout and totally lacking coals (Bartlett and Webb, 1971, p. 66-67). The Price there is thinned to about 570 feet.

South of the Tennessee-Virginia boundary the early Mississippian coarse clastics change nomenclature from the Price to the Grainger Formation, named for Grainger County, Tennessee (Campbell, 1893, p. 38). Rodgers (1953, p. 106-108) summarized the occurrence of the Grainger Formation and described it as consisting of "bluish, greenish, and brownish argillaceous shale, sandy shale, sandy siltstone, and generally silty and thin-bedded sandstone. Thin coaly beds and highly glauconitic sandstone layers occur in the upper half of the formation and locally, especially near the top, there are layers of coarse sandstone and even fine conglomerate."

Kenneth O. Hasson provided the following information from his dissertation (1971) study at University of Tennessee. He has seen no coal in the Grainger of Tennessee and doubts its presence; rather he considers the entire Grainger to be marine, based on the abundance of fossils and the presence of a glauconitic marker bed. The Grainger becomes finer and thins to the west. Tongues of Fort Payne Chert occur in the Grainger sections in western outcrops. A line delimiting the eastern-most occurrence of Fort Payne Chert is shown on Figure 12.

Thickness data isopached in Figure 12 are chiefly from Freeman (1951), Dally (1956), Walker (1964), and Hasson (1971). A line indicates the most eastern reported occurrence of marine fossils in the Pocono-Price strata. Another line showing the western limit of coal demarcates the westernmost occurrence of beds and lenses of nearly pure coal in the Pocono-Price, not merely carbonized wood fragments or coaly shales; this probably approximates the most western infilling of sub-aerial deltas into the early Mississippian sea. The Pocono-Price succession is a regressive sequence, so that the coaly layers are concentrated in the upper Pocono-Price and nonmarine beds generally overlie marine fossiliferous strata in the broad area of southern Virginia between the most eastern marine fossils and the most western coals.

A principal locus of deposition of Pocono clastics was the Fulton lobe in southern Pennsylvania (called Gay-Fink delta by Pepper and others, 1954). Pepper and others (1954) and Walker (1962) recognized the Virginia-Carolina delta consisting of Grainger and Price clastics.

The Red-Bedford delta and Cabin Creek delta of Pepper and others (1954) are represented in the subsurface of western West Virginia, but are not present in the outcrop belts shown in Figure 12.

The Pocono is the youngest formation preserved in eroded synclines of extreme eastern outcrops in Maryland and West Virginia and in isolated synclines of northern Virginia and along the Virginia-West Virginia boundary. The Price and Grainger Formations appear to be overlain conformably everywhere by Maccrady Formation redbeds. The Pocono is overlain, probably conformably, by the Maccrady Formation in West Virginia south of Randolph County. In the area of thinned Pocono Formation trending along an east-west axis in West Virginia, an unconformity probably occurs at the base of the Greenbrier Limestone. The Pocono of the northern region of the Appalachian Plateau in West Virginia probably passes conformably upward into Greenbrier Limestone. Dally (1956, p. 126) believes that sedimentation did not keep pace with subsidence in the eastern part of the Appalachian Basin in the late Osagian Epoch so that the eastern part of the Fulton delta lobe became submerged. The southwestern portion of the delta lobe in central West Virginia, however, remained above sea level by virtue of the fact that it was situated farther west in a more stable belt where subsidence proceeded at a much slower rate, or possibly stopped temporarily. This part of the Fulton lobe remained above sea level in the form of an island (the general area within the zero isopach outlined by Dally and shown in Figure 12) throughout all of Meramecian time, as indicated by the absence of Meramecian sediments in both the Greenbrier and Pocono Formations between the Hampshire Formation and the upper limestones of the Greenbrier Formation. Dally's interpretation of the presence and origin of the island exposed on outcrop near Beverley, Randolph County, seems reasonable.

The broad framework of Pocono-Price-Grainger Formation suggests that these non-red clastics represent several depositional environments. Classic interpretations of the Catskill delta complex in the Pocono and Catskill Mountains of Pennsylvania and New York are that Pocono non-red sandstone represents a depositional environment upstream from the main occurrence of mudflat redbeds along the coastline. However, the non-red Pocono-Price-Grainger strata which contain marine fossils were clearly deposited offshore to the west of the limit of red and presumably subaerial deposition; these western non-red beds may represent in part a reduction and winnowing of Catskill redbed strata swept westward into the sea, but most of this marine Pocono seems to have accumulated after the cessation of Catskill delta redbed deposition in eastern areas, indicating a marine transgression to the east. Clearly there is a dilemma in interpreting part of the Pocono as alluvial deposits upstream from the delta and part as offshore marine deposits, since the non-red Pocono is mapped as and seems to be a continuous stratigraphic formation between the two environments.

Meckel (1970) proposed a general model to account for the depositional patterns of the Pocono Formation northward from northern West Virginia. This model can be extended southward to Tennessee as follows. Meckel envisions the Acadian orogeny clastic wedge as consisting of, as follows, three time divisions from bottom upward. In an initial period of regional regression a redbed alluvial facies (Catskill or Hampshire Formation) changes eastward to a non-red conglomeratic facies (alluvial Pocono) and changes westward into marine Chemung sandstone facies. At the time of maximum alluviation the redbed facies is absent and the non-red alluvial facies intertongues directly with the non-red marine facies (intertonguing marine and nonmarine beds of Pocono and Price Formations). In the third stage regional transgression occurs because the rate of subsidence exceeds that of deposition as the source area wears down and the marine deposition advances eastward so that Pocono marine units overlie nonmarine units. A tidal mudflat redbed facies (Mauch Chunk or Maccrady Formation) develops which intertongues eastward with non-red Pocono lithology and westward with marine beds (Greenbrier Limestone). In Meckel's model maximum regression occurs at the end of active uplift and erosion of the source area. Rate of deposition is faster during the time of active uplift than in the quiet post-orogenic phase when the source area is being slowly worn down.

The Pocono and Price Formations merit more study for uranium occurrences in the strata which are nonmarine in origin. Feldspar content of the sandstones seems to be high enough locally to make them suitable uranium protores. Organic matter and coaly material should favor reduction of uranium circulating in ground water solutions. Unfortunately there seems to be no indication of oxidation of the Pocono strata to true redbeds in the weathering zone. Pocono sandstones serve effectively as petroleum reservoirs, so the Pocono-Price Formation is suitably permeable for uranium concentration. The Pocono and Price strata presently have relatively steep dips on outcrop as a result of the Alleghany orogeny at the end of the Paleozoic, so groundwater would not be transmitted for long distances and concentrate uranium leached over a large area. The Pocono-Price generally reaches depths of 1000 feet within a mile of the outcrop trace. The Grainger Formation should be excluded from serious uranium consideration because it appears to be entirely marine in origin.

Maccrady-Stroubles Formation

The Maccrady Formation is a succession of redbed shales and siltstones with local occurrences of sandstone, gypsum, anhydrite, and halite. It overlies the non-red clastics of the Price-Pocono-Grainger-Borden Formations in various parts of the area shown in Figure 13 and underlies the limestones of the Greenbrier and Newman Formations.

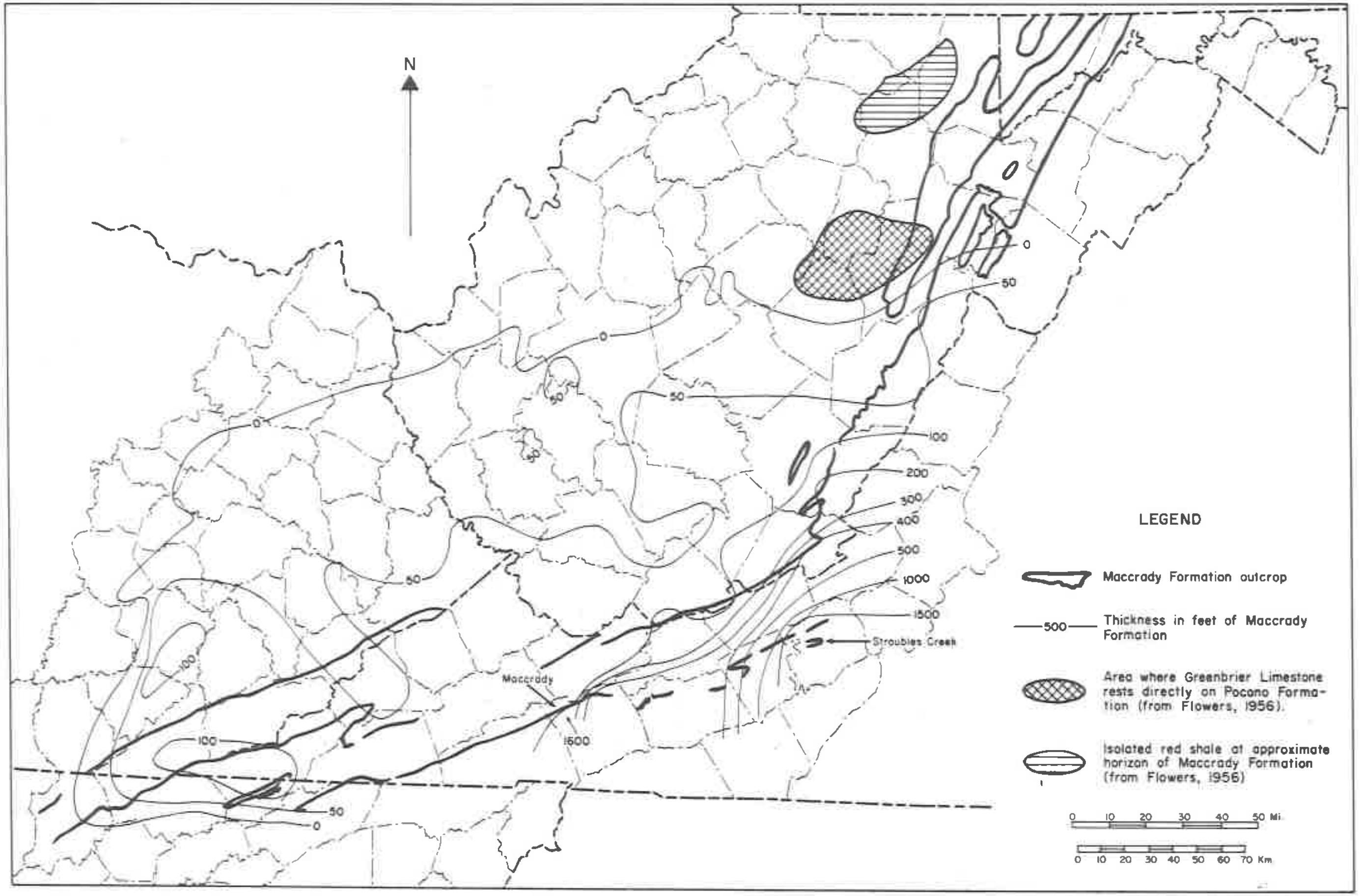


Figure 13. Outcrops and thickness of Maccrady Formation.

The name Maccrady Formation originally was applied (Stose, 1913, p. 234) to red shale and overlying non-red shale and shaly limestone below the crystalline limestone of the Newman Limestone and above the Price Sandstone at Maccrady, Smyth County, Virginia. Butts (1933, p. 37; 1940a, p. 351) restricted the definition of the Maccrady to include only the redbed strata and interbedded evaporites and removed from the Maccrady Formation the Warsaw-age limestone, argillaceous limestone and some sandstone; this latter stratigraphic unit subsequently was designated the Little Valley Limestone (Averitt, 1941, p. 17-21). The Little Valley Limestone Member of the Greenbrier Limestone underlies the Hillsdale Limestone and is 5-75 feet thick in southwestern Virginia (Cooper, 1944, p. 154-157; 1961, p. 63). The Maccrady Formation is about 60 feet thick in the type section at Maccrady, Smyth County, Virginia (Butts, 1940a, p. 351).

In the Price Mountain fenster and in the Saltville fault block in Montgomery County, Virginia, the redbed succession above the Price Formation is up to 1590 feet thick (Cooper, 1963, p. 22) and consists of mostly reddish siltstone and sandstone with some coal and contains only minor amounts of soft red shale and lacks evaporite beds. No Greenbrier Limestone occurs in the Montgomery County exposures because the Pulaski fault cuts off the top of the Maccrady-Stroubles redbed succession or because limestone has changed facies southeastward into clastics. Cooper (1961, p. 62) believed the lithologic differences in the Price Mountain area were sufficiently great to warrant the introduction of the new term Stroubles Formation, named after Stroubles Creek which crosses the outcrop belt (Lowry, 1971, p. 171). Cooper justified the name because of the coarser lithologic character and the greater thickness of the Stroubles as compared with the Maccrady, as well as his strong suspicion that the Stroubles contains younger strata than the type Maccrady, probably as young as early Chesterian Epoch.

The name Stroubles has dubious formal stratigraphic validity since it has never been mapped separately on a published map; it has been described only in thesis and guidebook format. Cooper never published a detailed description of the type section, apparently along Stroubles Creek, although a measured section of the Stroubles Formation at Belspring, Pulaski County, has been published (Cooper, 1963, p. 22).

Only a small portion of the Maccrady-Stroubles area shown in Figure 13 is probably nonmarine in origin and worthy of consideration for uranium protore in fluvial deposits. Probable nonmarine strata are restricted to Montgomery and Giles County, Virginia, and possibly Mercer and Monroe County, West Virginia, and Pulaski, Wythe, and Alleghany Counties, Virginia. The following treatment of the Maccrady-Stroubles Formations will emphasize the relationship of these possible fluvial clastics derived from the southeast to the marine shales and evaporites in the main area of Maccrady occurrence.

The best outcrop descriptions of the Maccrady and Stroubles

Formation in Virginia are in Stose (1913, p. 67-70), Cooper (1939, p. 54), Butts (1940a, p. 350-354), Cooper (1944, p. 151-154), Cooper (1961, p. 62-63), Cooper (1963, p. 22), and Bartlett and Webb (1971, pp. 37, 69). The Maccrady occurrence in West Virginia is summarized in the county report volumes for Tucker Conty (Reger, Price, and Tucker, 1923), Randolph County (Reger, 1931a), Pocahontas County (Price, 1929), Greenbrier County (Price and Heck, 1939), and Mercer, Monroe, and Summers Counties (Reger and Price, 1926).

Subsurface Maccrady descriptions occur in several county report volumes of the West Virginia Geological Survey and in the well sample descriptions of Martens (1939, 1945). Flowers (1956, p. 8) delimited on a map the north limit of occurrence of the Maccrady in the West Virginia subsurface; his limit generally agrees with Figure 13 of the present report, which, in addition to showing the north pinch-out of the Maccrady, is also the first isopach map ever prepared for the Maccrady (including Stoubles) Formation. Subsurface data for Kentucky is principally after Freeman (1951, 1953). The Maccrady strata of Tennessee outcrops have been briefly described by Rodgers (1953, p. 107) and in several U. S. Geological Survey quadrangle map descriptions in the GQ map series. The distribution shown in Figure 13 for Tennessee drew heavily on information provided by Kenneth O. Hasson.

The Maccrady Formation is probably conformable everywhere at its top and bottom contacts and no diastems are known to occur within it. A possible unconformity at the top of the formation may be present near the north limit of the Maccrady in West Virginia.

The area of thin Maccrady Formation (less than 100 feet thick) must be essentially isochronous throughout its extent. This conclusion is based on the widespread occurrence of evaporites in generally Warsaw-age strata at the approximate position of a few feet above and below the Greenbrier-Maccrady contact over much of southwest Virginia, both in the salt and gypsum area of the Greendale syncline of Smyth and Washington Counties (Stose, 1913; Withington, 1965; Cooper, 1966) and as anhydrite in wells drilled in Tazewell and Russell Counties, Virginia (Cooper, 1961, p. 63; Martens, 1945, p. 865) and in Boone, Kanawha, Lincoln, McDowell, Raleigh, and Wayne Counties, West Virginia (Martens, 1945). Freeman (1953, p. 178) reports gypsum from the Warsaw Limestone in a well in Grayson County, Kentucky. Such widespread but thin evaporites in a shallow sea probably result from a fairly limited time of regional aridity, and the persistence of stratigraphic position indicates that the top of the thin Maccrady strata is essentially isochronous. Maccrady deposition over a wide area may be related to eustatic rise of sea level and to marine inundation of the Price-Pocono deltas with evaporite deposition on the shallow shelf. Syndepositional subsidence of the Greendale syncline resulted in an unusual evaporite trap there, producing gypsum accumulations in commercial quantities near Plasterco, in Washington County and Locust Cove in Smyth County, Virginia, and commercial salt at Saltville, Smyth County (Cooper, 1964, p. 93-95; 1966).

Regional aridity in middle Mississippian time is also indicated by the presence of gypsum and anhydrite which have mined commercially since 1955 in southwestern Indiana from the lower part of the St. Louis limestone in the 120 feet of strata just overlying the Salem Limestone (French and Rooney, 1969, p. 3-15). The basal Member of the Greenbrier Limestone of southern West Virginia is the Hillsdale Limestone, which is considered to be equivalent to the St. Louis Limestone on the basis of Lithostrotionella and other fossils in the basal few feet and Syringopora virginica in the upper portion of the Hillsdale (Wells, 1950). In southern West Virginia, the underlying Maccrady is generally unfossiliferous and it is thought to span the range of the Keokuk, Warsaw, and Salem Limestones of the Mississippi Valley (Weller and others, 1948), but it could include some beds as young as early St. Louis in age.

The presence of regional aridity in middle Mississippian time could affect the weathering characteristics of clastics derived from the eastern Appalachia source area, resulting in more arkosic Maccrady-Stroubles clastic strata than the underlying Price-Pocono beds. This suggestion should be investigated by detailed petrographic sampling. There is no detailed information in the literature concerning the petrography of the Maccrady-Stroubles clastics.

Butts (1940a, p. 351) described the type section of the Maccrady Formation (as redefined by him) in the following section:

	Feet
Warsaw Limestone (lower 35 feet)	
5. Limestone, argillaceous, fossiliferous	30
4. Shale, gray	5
Maccrady Formation (60 feet)	
3. Not exposed	30
2. Shale, red	30
Price Formation	
1. Sandstone, gray and green, fine grained	10

The type section of the Maccrady Formation is on the northwest limb of the Greendale syncline, and is only 60 feet thick at most. Thickness of the Maccrady is much greater in the central portion of the syncline, where the Maccrady appears at least 2,000 feet thick (Withington, 1965, p. B30). Cooper (1964, p. 93-94) reports that the Maccrady thickens from 135 feet just northwest of Saltville to a formation at least 1,600 feet thick 1.1 miles to the southeast, where the Maccrady contains hundreds of feet of plastic clay shale, salt, gypsum, anhydrite, and dolomite which are absent on the northwest limb of outcrop. Withington (1965, p. B31) interpreted the great thickness of Maccrady as tectonic thickening beneath the overriding Saltville fault, with a sort of bulldozing affect piling up a great thickness of salt beneath the fault. Cooper (1964, 1966) considers the great thickness of salt to result from syndepositional subsidence of an evaporite basin along the axis of the

Greendale syncline, with only minor tectonic thickening of the Maccrady. Cooper's argument is supported by the fact that he can divide the Maccrady Formation into a lower siltstone member, a middle dolomite member, and an upper plastic shale member, all traceable throughout the syncline. Thickening toward the synclinal axis is most pronounced in the upper plastic shale member. Evaporite deposits are restricted to the upper plastic shale member of the Maccrady Formation and the basal few feet of the Little Valley Formation. The Little Valley Formation displays a four-fold thickness increase in the axial region of the fold. Cooper (1966, p. 23) concludes that the steeply dipping Locust Grove normal fault was a consedimentation break that produced a local fault trap of deposition in the synclinal axial region. The salt was tectonically fragmented during the period of overthrusting during the late Paleozoic. Gypsum resulted from later ground water hydration of anhydrite.

The trough of the Greendale syncline probably was open to seaways toward the southwest and the trough was probably restricted by tectonically positive areas along adjacent syndepositional anticlines. Isopachous data on Figure 13 suggest strongly that circulation in the Greendale syncline was restricted to the northeast by thick clastics of the Maccrady-Stroubles beds which probably filled in the northeast end of the syncline with a delta built up possibly to above sea level. This clastic wedge to the northeast may have been a major factor in localizing the evaporites near Saltville in the deepest portion of the subsiding syncline. It seems quite certain that the arid conditions were regional in extent so the localization of the salt must have been principally tectonic.

Thickness data which lead to an interpretation of a Maccrady-Stroubles Formation delta centered near Montgomery County, Virginia, are available at only a few points. In the Draper Mountain area of Pulaski County (Cooper, 1939, p. 54) no formations younger than the Maccrady are preserved, yet the portion of Maccrady present is about 500 feet thick. The Maccrady there is composed of reddish shale, mudrock, sandstone, and siltstone and greenish, brown and buff micaceous sandstones and shales. At Gap Mills, Monroe County, West Virginia, the Maccrady is recorded as 418 feet thick (Reger and Price, 1926, p. 230) with an estimated 200 feet of red shale overlying 218 feet of "shale, purple and variegated, sandy, with a little shaly sandstone." At Bickett Knob about 3 miles to the northwest in Monroe County (Reger and Price, 1926, p. 226), the Maccrady has thinned to 290 feet of mostly red shale with streaks of sandstone toward the base.

The post-Price redbeds are thickest in Montgomery and adjacent Pulaski Counties, Virginia, where Cooper (1961, 1963) has applied the name Stroubles Formation. Cooper (1963, p. 22) gives the following section of the Stroubles Formation at Belspring, Pulaski County:

Pulaski fault zone (Cambrian Elbrook Formation)
Stroubles Formation (1590 feet)

Siltstone, fine-grained sandstone, and shales; maroon-drab to drab-gray and brown, calcareous zones with sparse fossils including ramose and frondose bryozoans, Nuculites and Allorisma and broken brachiopods.	435 feet
Sandstone, dark reddish-brown to brownish-gray, fine-grained, in thick ledges separated by waxy gray to reddish shale.	845 feet
Shale, dark maroon to brown, waxy, soft, slightly calcareous; some intercalated sandy siltstones of similar color which are relatively nonresistant.	325 feet

Price Formation (975 feet)

Cooper (1961, p. 62) believes that some of the thick redbeds along New River are younger than Maccrady Formation; the upper Stroubles there contains Archimedes resembling fossils found in the Chesterian Series Bluefield Shale at Bluefield. The redbeds of the Pulaski-Blacksburg area are believed by Cooper to be a Mississippian magnafacies correlative in a general way with the Mauch Chunk redbeds of Pennsylvania, which succeed the Pocono Sandstone of about the same age as the Price Formation.

Two miles southeast of Blacksburg, Montgomery County, Virginia, the topmost Stroubles occurring beneath the Pulaski fault (Cooper, 1961, p. 62) consists of about 100 feet of conglomeratic sandstone, fossiliferous shale and siltstone, and a thin coal bed. Some of the Stroubles Formation is probably nonmarine.

The Stroubles delta lobe is at about the same geographic position as the thickest part of the Price (or Virginia-Carolina) delta in earlier Mississippian time. Perhaps a eustatic sea level rise caused inundation of the Price delta, and reduced it to a much smaller size in Maccrady time.

The area of thick Maccrady redbeds recorded chiefly from subsurface data near the common junction of Virginia, Kentucky and Tennessee may represent syndepositional subsidence and thick accumulation in the Middlesboro Syncline. The Borden and New Providence Formations of the Kentucky subsurface contains some reddish strata (Freeman, 1951, 1953), but this condition seems localized northwest of the zero Maccrady isopach. Some confusion of Maccrady with other redbeds may be present in the interpretation of data for Figure 13.

In northern outcrop belts the termination of the Maccrady seems to coincide with the south edge of an early Mississippian island postulated by Dally (1956, p. 126) and marked by thinned Pocono and even total erosion of the Pocono in Randolph County (see Figures 12 and 13). Following this logical basis, one can conclude that the Maccrady probably has an unconformable upper surface in parts of Randolph County, West Virginia, and to the west in the subsurface near the northern termination of the Maccrady. The general position of the northern pinch-out of Maccrady strata in Pendleton County, West Virginia, is based on field observations by Dennison.

An isolated patch of reddish strata between the Pocono and Greenbrier Formations in the subsurface of Preston, Taylor, Marion, and Monongalia Counties, West Virginia (see Figure 13) is indicated following the map prepared by Flowers (1956, p. 8) to show the beds immediately beneath the Greenbrier Limestone. This could represent Maccrady clastics which originally extended north of the later-developed post-Pocono island uplift, or it could be a post-Maccrady redbed deposit developed north of the island at the base of the Greenbrier in the Chesterian Epoch as Catskill redbeds were eroded from the center of the island (where the Pocono is completely absent) and carried northward into the sea. No Paleocurrent measurements are available to indicate transport directions of Maccrady clastics. Thickness and facies patterns suggest a source centered about Montgomery County, Virginia, probably from the drainage system that supplied the thick wedge of Price Formation clastics.

The redbed strata of the Maccrady Formation are probably chiefly marine in their extent over southern West Virginia, southwestern Virginia, and eastern Kentucky and Tennessee. The Maccrady seems to be a typical redbed association with evaporite sedimentation conditions. A clastic delta built out into the sea from the vicinity of Montgomery County, Virginia. Some fluvial or other nonmarine sedimentation is indicated from the reported association of redbeds and coal in the Stroubles Formation. Potential fluvial strata for uranium exploration should be sought in the Maccrady-Stroubles outcrops of Montgomery, Pulaski, Wythe, Giles, and Alleghany Counties, Virginia, and in Monroe and possibly adjacent parts of Mercer and Greenbrier Counties, West Virginia. Arid climate at that time may have resulted in unusually feldspathic clastics derived from the Appalachia source to the southeast. Palinspastic base map consideration in future studies of Maccrady-Stroubles outcrop data should aid interpretation of environmental reconstruction.

Mauch Chunk-Pennington Group

The Mauch Chunk and Pennington Groups are generally equivalent late Mississippian strata characterized by conspicuous redbeds and always overlain by the non-red Pottsville Group with prominent conglomeratic sandstones. The name Mauch Chunk comes from the town of Mauch Chunk (now called Jim Thorpe) at the edge of the anthracite field of Carbon County, Pennsylvania. At its type locality Mauch Chunk redbeds rest on the Pocono Formation and are conformably(?) overlain by Pennsylvanian Pottsville Group. The reddish clastics of the Mauch Chunk overlie the Greenbrier Limestone from southern

Pennsylvania south toward Virginia. Presumably the lower Mauch Chunk in its type area is a facies equivalent of the Greenbrier Limestone (Cooper, 1948, p. 259-260). The name Pennington Formation was taken from Pennington Gap, Lee County, Virginia (Campbell, 1893, p. 28, 37). The Pennington overlies the Greenbrier or Newman Limestone from Virginia and Kentucky to Alabama. The Pennington includes marine intertongues in western outcrops and is overlain, locally with unconformity, by the Pottsville Formation or Group. The geographic break of the Pennington-Mauch Chunk nomenclature is the southwestern border of West Virginia. In southern West Virginia and parts of Virginia and Kentucky, both the Pennington and Mauch Chunk Groups have been divided with separate formations shown on published maps (in area indicated in Figure 14). In northeastern West Virginia and Maryland, the term Mauch Chunk Formation is used. The designation Pennington is applied from extreme western Lee County, Virginia, south to Alabama.

Figure 14 shows the thickness of the Mauch Chunk-Pennington strata. Throughout the area mapped in Figure 14 the Mauch Chunk-Pennington strata are assigned to the Chester Series (Weller and others, 1948) and conformably overlie the Chesterian portion of the Greenbrier or Newman Limestone. In parts of the southeastern area the Mauch Chunk-Pennington apparently pass conformably upward into the Pottsville Group. On Figures 14 and 15 the area with pre-Pottsville unconformity is distinguished from the area with no erosional break in the stratigraphic record (as reported in the literature considered most reliable).

The thickest Mauch Chunk-Pennington occurs in southern West Virginia and adjacent Virginia, apparently corresponding to a continuing clastic influx from the Virginia-Carolina delta system (which first appeared in the early Mississippian and which can be identified in Price-Pocono and Maccrady depositional patterns). The mechanism of thinning away from this depositional maximum of 3500 feet to about 1800 feet in eastern West Virginia, to about 1000 feet along the Kentucky-West Virginia border, and to about 300 feet at the Kentucky-Tennessee border is thought to be by stratigraphic convergence, rather than by unconformity at the top of the Mauch-Chunk-Pennington. Beyond there the Mauch Chunk thickness is unconformably diminished at the top toward Maryland and toward the Nashville Dome, with total erosional removal of the Pennington in parts of eastern Kentucky and with erosional truncation of the Mauch Chunk in the West Virginia subsurface northwestward toward Ohio and Pennsylvania. In the extreme south the redbeds of the Mauch Chunk lose their coloration or are masked by clastics from a southern source, so that the Pennington horizon cannot be distinguished within the upper part of the Floyd Shale in parts of Georgia and Alabama, and perhaps the Pennington identity is also lost in the coarser clastics of the Parkwood Formation of Alabama (Figure 14).

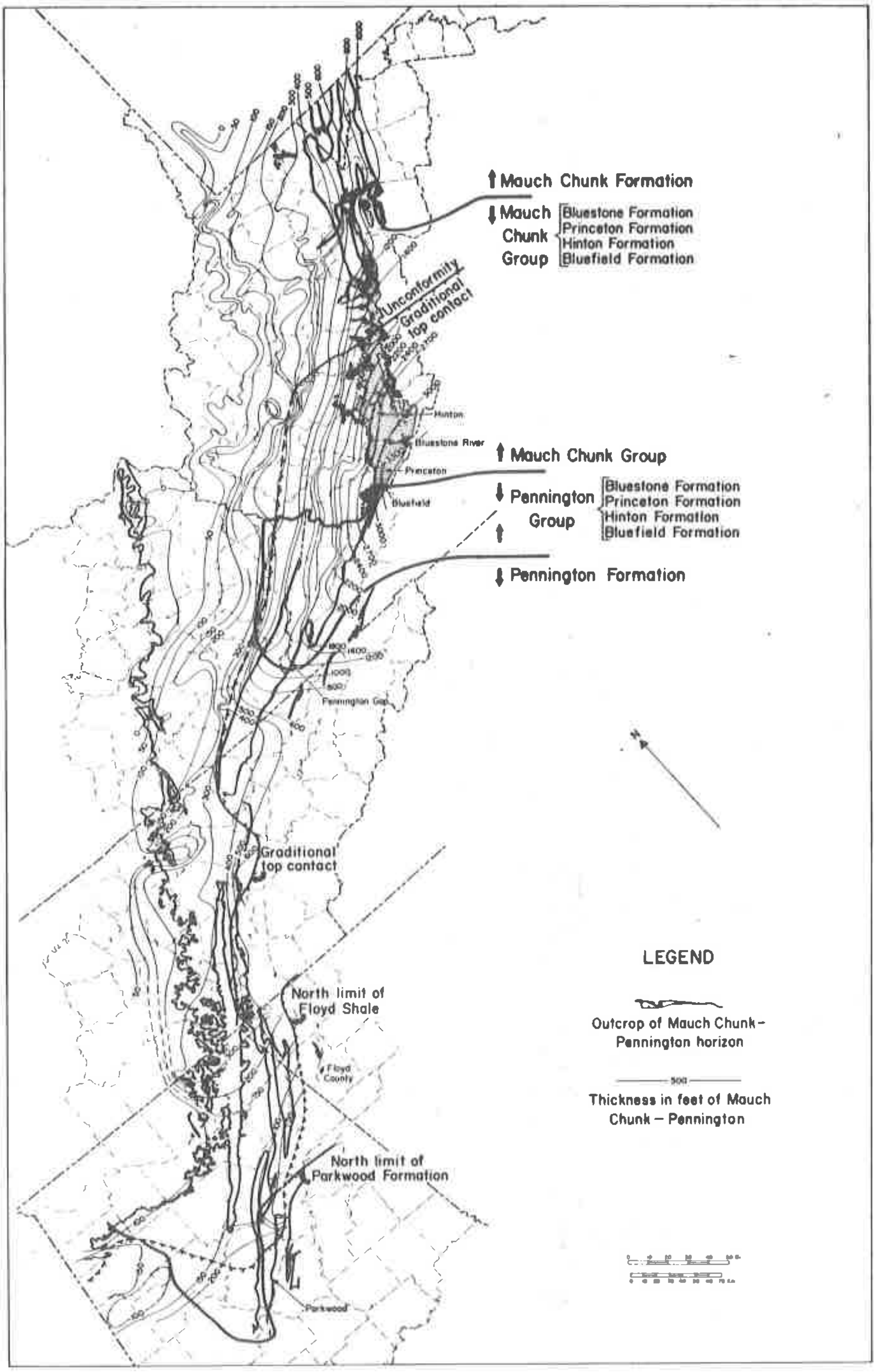


Figure 14. Outcrops and thickness of Mauch Chunk and Pennington Groups.

Cooper (1961, p. 62) believes that the upper portion of the Stroubles Formation may represent the lower part of the Mauch Chunk Group (Bluefield Formation), but for the present study the Stroubles was mapped entirely as equivalent to the Maccrady Formation (Figure 13), so no outcrops of Mauch Chunk-Pennington are shown southeast of Tazewell County, Virginia.

There is no indication of clastic transport direction in the Mauch Chunk-Pennington except general thickness (which may be confusing because of the unconformity at the top of the unit) and general pattern of loss of redbeds and appearance of interbedded limestone and dolomite toward the west and southwest in Tennessee and Alabama. There are no studies of cross-bed orientations in the area of Figure 14. Meckel (1970, p. 59), apparently using data from Pennsylvania and possibly Maryland, recorded a mean direction of N54°W for 39 Mauch Chunk cross-bed readings in the central Appalachians. Meckel (1970, p. 61) has interpreted fining-upward cycles in the Mauch Chunk as characteristic of fluvial deposition, with individual cycles from 10 to 100 feet thick.

Literature on the Mauch Chunk outcrops in Maryland and West Virginia is contained mostly in state geological survey reports. The only significant description in Maryland is for Garrett County (Amsden, 1954, p. 44-45). Outcrop descriptions are available for the following counties in West Virginia: Mineral and Grant (Reger and Tucker, 1924), Preston (Hennen and Reger, 1914), Monongalia (Hennen and Reger, 1913), Tucker (Reger, Price, and Tucker, 1923), Randolph (Reger, 1931a), Webster (Reger, Tucker, and Buchanan, 1920), Nicholas (Reger, Price, Tucker, and Sisler, 1921), Pocahontas (Price, 1929), Greenbrier (Price and Heck, 1939), Monroe, Summers, and Mercer (Reger and Price, 1926), and McDowell Counties (Hennen and Gawthrop, 1915). Three additional theses and one dissertation are also significant: McColloch (1957), Dyar (1957), Manspeizer (1958), and Thomas (1959). An excellent description of Mauch Chunk exposures along and near the West Virginia Turnpike is given by Cooper (1961, p. 67-74, 164-169).

No detailed Mauch Chunk published sections are available in the Potomac River drainage basin. The following composite section (modified from Dennison, 1955, p. 126-129) was pieced together on both sides of the North Branch at the Allegany-Mineral County boundary:

	Feet
Mauch Chunk Group (about 975 feet)	
22. Shale, silty, micaceous, dark gray, weathers yellowish gray and chippy. Resembles a poorly developed underclay.	3
21. Siltstone and fine sandstone, micaceous, thinly bedded, weathers moderate yellowish brown to reddish brown.	24

		Feet
20.	Sandstone and siltstone interbedded in beds up to 6 feet thick. Sandstone is quartzose, micaceous, medium to coarse, cross-bedded, and weathers moderate yellowish brown. Siltstone is micaceous and weathers pale olive.	44
19.	Covered.	110
18.	Sandstone, quartzose, micaceous, medium to coarse, cross-bedded, weathers olive gray.	28
17.	Covered. Probably consists of red shale with a little sandstone. Lithology is based on exposures along mountain road 3 miles west of Keyser.	280
16.	Siltstone and fine to medium quartz sandstone, micaceous and pale red.	66
15.	Sandstone, quartzose, medium-grained, micaceous, cross-bedded, contains plant fossils, weathers olive gray. Basal part is massive; top part is argillaceous.	113
14.	Sandstone and shale interbedded in equal amounts and in beds up to 4 feet thick. Quartzose sandstone is calcitic, micaceous, fine, and weathers light brownish gray. Shale is calcitic, micaceous, lumpy, and weathers grayish red except for a few pale green streaks.	35
13.	Sandstone and siltstone interbedded in equal amounts. Quartzose sandstone is fine to medium, calcitic, micaceous, shaly to massive, light brownish gray, and weathers olive gray. Siltstone weathers olive gray.	62
12.	Sandstone, quartzose, medium to coarse, partly cross-bedded, weathers light olive gray; center portion is argillaceous.	15
11.	Covered.	3
10.	Shale, calcitic, micaceous, lumpy, grayish red.	3
9.	Covered.	23
8.	Siltstone, and thinly bedded, fine, quartz sandstone, interbedded in equal amounts; micaceous, weathers light olive gray.	9
7.	Covered.	21
6.	Limestone, rather massive, medium gray, weathers greenish gray. Possibly Hinton(?) limestone of Reger and Tucker (1924, p. 275-276).	1
5.	Siltstone and fine, calcitic, quartz sandstone interbedded in equal amounts; micaceous,	

		Feet
	weathers light olive gray.	20
4.	Covered.	10
3.	Sandstone, quartzose, micaceous, fine, thinly bedded, grayish red, weathers light olive gray; interbedded with equal amounts of siltstone, lumpy, grayish red.	46
2.	Covered.	37
1.	Siltstone, lumpy, grayish red with pale green streaks. Contact with underlying Greenbrier Limestone is gradational.	22

Note that both reddish and greenish sandstones occur in the Mauch Chunk here. Directly above the Mauch Chunk, the basal sandstone of the Pottsville is 0.3-2.0 feet thick with 5 feet of erosional relief at the base of the Pennsylvanian. This unconformity separates the Kaskaskia Sequence from the Absaroka Sequence of Sloss (1963). In the terminology of H. E. Wheeler (1963) this unconformity is the discontinuity between the Tamaroa and Absaroka Sequences.

Exposures along the Baltimore and Ohio Railroad near Rowlesburg, Preston County, exhibit typical fining-upward cycles characteristic of fluvial deposits. The strata are nearly all reddish and occur in cycles tens of feet thick with sandstone at the base, grading upward to siltstone, containing in some cycles scattered limestone concretions at the top. The next overlying cycle frequently displays a few inches of erosional relief under the basal sandstone.

The Mauch Chunk Group was divided in great detail by Reger and Price (1926, p. 291-444) into a large number of named units in Mercer, Monroe, and Summers Counties, West Virginia. These divisions of the stratigraphic column are summarized below, with their Series changed to Group and their Groups reduced to Formation, bringing the nomenclature into accord with modern stratigraphic practice.

	Feet
Pottsville Group (1030+ feet)	
Pocahontas Formation (465 feet)	
105. Not described in detail	
104. Sandstone, Keystone	0-30
103. Coal, Keystone, streak	
102. Shale and sandstone	0-15
101. Shale, North Fork, black	0-20
100. Shale, sandy	0-15
Mauch Chunk Group (2200-3450 feet)	
Bluestone Formation (400-800 feet)	
99. Shale, red and variegated	50-200
98. Sandstone, Bent	40-60
97. Shale, Upper Bent, reddish or black	20-40
96. Limestone, Bent	0-1
95. Shale, Lower Bent, marine fossils	10-18

		Feet
94.	Coal, Hunt	0-1
93.	Sandstone, Hunt	10-20
92.	Shale, Hunt, green or red	10-20
91.	Sandstone, Bratton	10-20
90.	Shale, Bratton, red or greenish	25-30
89.	Sandstone, Upper Belcher	15-25
88.	Shale, Upper Belcher, red with fire clay	15-20
87.	Sandstone, Lower Belcher	15-25
86.	Shale, Lower Belcher, red, occasional marine fossils	20-30
85.	Sandstone, Upper Mud, brown	0-5
84.	Shale, Upper Mud, red	20-25
83.	Sandstone, Lower Mud, greenish gray or brown	0-5
82.	Shale, Lower Mud, red or green	15-20
81.	Sandstone, Glady Fork	25-40
80.	Shale, Pipestem, plant and marine fossils	30-44
79.	Coal, Pipestem	0-1
78.	Shale, Pride, occasional marine fossils	70-150
Princeton Conglomerate Formation (20-50 feet)		
77.	Sandstone, conglomeratic with quartz and limestone pebbles	20-50
Hinton Formation (800-1350 feet)		
76.	Shale, Terry, greenish with streaks of reddish, coal lenses	15-50
75.	Limestone, Terry, marine fauna	0-2
74.	Shale, Pluto, marine fossils	25-38
73.	Coal, Pluto	0-2
72.	Limestone, Pluto, marine fauna	0-2
71.	Shale, Lower Pluto, marine fauna	50-78
70.	Sandstone, Falls Mills	25-50
69.	Shale, Falls Mills, variegated with reds	25-40
68.	Limestone, Falls Mills, marine fauna	0-5
67.	Shale, Upper Fivemile, red, gray, and green	15-24
66.	Coal, Fivemile	0-1
65.	Shale, Lower Fivemile, marine and plant fossils	10-20
64.	Sandstone, Tallery	15-25
63.	Limestone, Tallery, marine fossils	1-2
62.	Shale, Upper Tallery, marine and plant fossils	10-13
61.	Coal, Tallery	0-1
60.	Shale, Lower Tallery, red and variegated	25-35
59.	Sandstone, Low Gap	20-30
58.	Limestone, Low Gap, marine fossils	1-2

		Feet
57.	Shale, Low Gap, red and variegated	5-8
56.	Sandstone, Avis	30-35
55.	Shale, Upper Avis, marine fossils	20-25
54.	Limestone, Avis, marine fossils	20-40
53.	Shale, Lower Avis, marine fossils	20-30
52.	Sandstone, Payne Branch	20-35
51.	Shale, Payne Branch, red and variegated	15-20
50.	Sandstone, Hackett	30-45
49.	Shale, Hackett, red, marine fossils in base	100-200
48.	Limestone, Trophet, marine fossils	3-5
47.	Shale, Upper Trophet, red	10-15
46.	Sandstone, Trophet	15-25
45.	Coal, Trophet	0-1
44.	Shale, Lower Trophet, red, with plant fossils	20-35
43.	Sandstone, Goodwyn, greenish and reddish	25-40
42.	Shale, Upper Goodwyn, marine fossils	5-10
41.	Coal, Goodwyn	0-1
40.	Shale, Lower Goodwyn, calcareous red and variegated	40-75
39.	Sandstone, Upper Bellepoint, reddish or greenish	30-40
38.	Shale, Upper Bellepoint, reddish and greenish, marine fauna	30-35
37.	Sandstone, Middle Bellepoint, greenish and reddish	15-25
36.	Limestone, Middle Bellepoint, marine fossils	0-3
35.	Shale, Middle Bellepoint, reddish and greenish, marine fossils	25-37
34.	Sandstone, Lower Bellepoint, greenish and reddish	15-25
33.	Shale, Lower Bellepoint, reddish and greenish, marine fossils	30-40
32.	Sandstone, Stony Gap, gray or white, coarse	35-85
Bluefield Formation (800-1250 feet)		
31.	Limestone, Coney, marine fossils	0-3
30.	Shale, Coney, red and variegated, marine and plant fossils	53-67
29.	Sandstone, Clayton, reddish brown	20-30
28.	Shale, Clayton, reddish and greenish, marine and plant fossils	50-80
27.	Sandstone, Graham	15-30
26.	Limestone, Graham, marine fossils	2-3

		Feet
25.	Shale, Upper Graham, marine and plant fossils	20-30
24.	Coal, Graham	1-2
23.	Shale, Lower Graham, reddish and variegated	50-75
22.	Sandstone, Bertha	30-50
21.	Shale, Upper Bertha, plant and marine fossils	45-75
20.	Limestone, Bertha, marine fossils	2-15
19.	Shale, Lower Bertha, greenish and reddish	65-90
18.	Sandstone, Bradshaw	30-50
17.	Limestone, Bradshaw, marine fossils	0-3
16.	Shale, Bradshaw, reddish and greenish, plant and marine fossils. Contains local lens of Red Sulphur Coal.	30-37
15.	Sandstone, Indian Mills	30-60
14.	Shale, Indian Mills, greenish and reddish, plant and marine fossils	60-70
13.	Limestone, Raines Corner, marine fossils	5-10
12.	Shale, Raines Corner, marine and plant fossils	5-8
11.	Coal, Raines Corner	1-2
10.	Shale, Possumtrot, plant fossils	4-25
9.	Sandstone, Droop, white, coarse	40-60
8.	Shale, Talcott, sandy, marine fauna	15-25
7.	Shale, Ada, fissile, marine fauna	30-60
6.	Limestone, Reynolds, marine fauna	10-15
5.	Shale, Bickett, red or sandy	20-25
4.	Sandstone, Webster Springs	5-10
3.	Limestone, Glenray, marine fauna. Locally contains lenticular Nemours Coal.	80-125
2.	Shale, Lillydale, marine fauna	80-115
Greenbrier Limestone		
1.	Limestone, Alderson, dark gray, sandy	75-325

The preceding summary stratigraphic column is arranged to emphasize several properties related to uranium exploration. All units with reported marine fossils are so designated, as well as all units with reported plant fossils. All units with reddish coloration are indicated, and the nonspecified units are grayish or greenish. Each reported coal horizon is noted. It is clear that the entire Mauch Chunk in these three counties contains intertonguing marine and nonmarine beds. Definite evidence of cyclothems is present, with both allochthonous and autochthonous coals. It would appear that the cyclothems are poorly developed because of the conspicuous marine influence in late Chester time; this is in marked contrast with the striking nonmarine character of the cyclothems in the overlying Pottsville Group. Most of the Mauch Chunk sandstones here are greenish or grayish (reduzate facies), but the following sandstones are described as reddish or variegated (oxidized facies): Clayton, Lower Bellepoint, Middle Bellepoint, and Upper Bellepoint (units 29, 34, 37, and 39). There is no specific information on abundance of feldspar in these or any other sandstones in the Mauch Chunk of West Virginia. These four and perhaps other Mauch Chunk sandstones should be studied in more detail for uranium potential in the area from Tazewell County, Virginia, northeastward at least across Monroe County, West Virginia. The percentage of reddish sandstones in the Mauch Chunk seems to increase northeastward across West Virginia to Maryland, and the percentage of marine interbeds decreases along the outcrop belts to the northeast.

Coals in the Mauch Chunk are best developed in southern West Virginia, and they decrease in prominence to the northeast, being known only as far north as Mingo District in southern Randolph County (Reger, 1931a, p. 277-316). Coals are also unknown in the equivalent Pennington Formation of extreme southwestern Virginia and Tennessee, where the Pennington is still reddish but contains more abundant non-red marine interbeds. In the southwestern area the Pennington contains little or no sandstone. Viewed in generalized perspective, the Pennington-Mauch Chunk strata outcropping along a generally northeastward trend seem to cut obliquely across depositional strike, with true fluvial deposits developed in northeastern West Virginia and Maryland outcrops, with coal-bearing deltaic deposits in southern West Virginia and Tazewell to Wise Counties, Virginia, and dominantly marine deposits with some nonmarine mudflat accumulations farther southwest toward Tennessee and west toward Kentucky. Uranium exploration probably should concentrate from Tazewell County, Virginia, northeast across West Virginia and Maryland. In the Mauch Chunk of southern West Virginia, nonmarine deposits seem concentrated in the upper portion. The prominent Avis Limestone represents an unusually large marine incursion, perhaps resulting from late Chester eustatic sea level changes reported elsewhere in the United States (Wheeler and Murray, 1957). This and other lesser eustatic sea level changes should leave a sedimentary imprint which would allow detailed correlation within the Mauch Chunk-Pennington in West Virginia, Virginia, and the subsurface of Kentucky. Mauch Chunk sandstones contain commercial petroleum in the subsurface, so permeability should be favorable for uranium cell development in the Mauch Chunk.

Contemporaneous tectonic activity affected sedimentary patterns in the accumulation basin, in addition to the effects of general late Chester regional paleoslope probably from southeast to northwest and the rather localized source area of the Virginia-Carolina delta. Thomas (1966) has convincingly demonstrated contemporary subsidence of the Hurricane Ridge syncline in Tazewell County, Virginia, and Mercer County, West Virginia, using outcrop and subsurface data. Strata are thickened in the bottom of the syncline, as well as more shaly in the trough axis. Partial reduction of maroon redbeds occurred in the deeper water along the trough, which was being fed by turbidity currents from the southeast. Contemporaneous deformation continued on into the Pennsylvanian, as shown by the fact that an angular unconformity reported (Thomas, 1966) on the southeast limb of the syncline indicates that Mauch Chunk beds were upturned and subjected to erosion prior to deposition of the overlying Pennsylvanian. Cooper (1961, Plate 50; 1971, Plate 17) presents a detailed cross section of these structural relations. Such a local angular unconformity could have resulted in groundwater redistribution of Mauch Chunk uranium content in early Pennsylvanian time. Burford (1969) disagrees with the structural interpretation posed by Thomas (1966) and Cooper (1961), doubting their interpretation of syndepositional subsidence of the Hurricane Ridge syncline.

Just before deposition of the lowest Pennsylvanian strata, the presently subsurface western extent of the Mauch Chunk was being eroded with a southeastward dipping ground slope and regional bedding dip toward the area of continuous depositional transition between the Mississippian and Pennsylvanian in the area from southern West Virginia to eastern Tennessee. This ancient reversal of paleoslope at the end of the Mississippian Period may have established uranium cells in the Mauch Chunk or Pennington Groups.

Present-day regional dip gently to the northwest in the Appalachian Plateau southern West Virginia outcrops establishes ground water circulation for another potential uranium cell.

The Pennington Group (Formation) has a complex nomenclature history, and its thickness patterns are affected by stratigraphic convergence to the west and southwest, by a regional unconformity at its top in many areas, and by probable facies change of the basal portion of the Pennington into upper Newman Limestone. Accompanying these patterns is a decrease in clastic grain size to the west and southwest and a decrease in red coloration in the same directions, along with introduction of more limestone and dolomite interbeds in those directions.

The Pennington Shale (now Group) was named by Campbell (1893, p. 28, 37) for a stratigraphic succession occurring between the Newman Limestone and Lee (Lookout) Conglomerate at Pennington Gap in Lee County, Virginia. No detailed section was measured there, but Campbell (1893, p. 37) did measure a reference section at Big Stone Gap, Wise County. The most recent description of the Big Stone Gap section was presented as follows by Butts (1940a, p. 394-395) with only a slight modification from Campbell:

	Thickness Ft.	In.
Lookout (Lee) Conglomerate, very coarse at base		
Pennington Formation (1025 feet)		
32. Green calcareous shale	5	7
31. Green and red sandstone	1	11
30. Blue shale	6	2
29. Coal	1	4
28. Bluish shale	10	4
27. Green sandstone	2	10
26. Olive-green shale	7	4
25. Soft, nonfissile, variegated shale	10	6
24. Sandstone	3	7
23. Soft red shale	8	0
22. Sandy shale	4	0
21. Bluish sandstone	19	0
20. Concealed, probably shale	506	10
19. White sandstone, cross-bedded	49	0
18. Conglomerate, white quartz pebbles; makes hogback	7	8
17. Bluish-yellow calcareous shale	27	0
16. Blue sandy shale	10	5
15. Limestone, very impure and fossiliferous	4	1
14. Calcareous and argillaceous sandstone	7	10
13. Calcareous shale, very fossiliferous	6	0
12. Blue sandstone, cross-bedded	12	0
11. Purple and green shale	9	5
10. Shale, slightly sandy	4	3
9. Green and purple shale	4	7
8. Argillaceous sandstone	8	4
7. Fine-grained sandstone	13	5
6. Sandstone regularly bedded	80	0
5. Sandstone, much cross-bedded (Stony Gap Sandstone)	107	0
4. Dark blue calcareous shale	9	0
3. Sandy shale	7	7
2. Argillaceous shale	3	0
1. Heavy sandstone (Stony Gap Sandstone)	67	0
Newman (Glen Dean) Limestone, shaly at top.		

Butts (1940a, p. 393) believed that the Pennington Formation represented only the Hinton Formation portion of the Mauch Chunck of West Virginia, and this age for the Pennington in the southern Appalachians is used on the correlation chart of the Mississippian formations of North America (Weller and others, 1948). Cooper (1944, p. 169-187) used the vertical succession of Bluefield, Pennington, Princeton, and Bluestone Formations in his detailed report on the Burkes Garden Quadrangle, Virginia. Extensive treatment of the Upper Mississippian clastics of southwest Virginia is given by Butts (1940a, p. 382-407). According to Butts (1940a, p. 382-393), the Bluefield Shale of West Virginia is equivalent to the shaly limestone of the Cove Creek Limestone (1,013 feet thick) in the Greendale Syncline in Washington County, Virginia. The Cove Creek, in turn is equivalent to the Glen Dean Limestone (a Kentucky name) at Cumberland Gap (380 feet). Butts considered the Hinton Formation of West Virginia to represent the entire Pennington Formation. He recognized the Princeton Conglomerate only in Tazewell County. The Bluestone Formation was considered absent by unconformity in Wise and Lee County (Butts, 1940a, p. 407), so that in extreme southwest Virginia, an erosional break was supposed to separate the Mississippian and Pennsylvanian strata.

Wilpolt and Marden (1949), using 72 subsurface and surface control points, demonstrated thinning by stratigraphic convergence of all formations in the Mauch Chunk Group northwest and southwest from Mercer County, West Virginia, and showed that the post-Newman strata at Pennington Gap range in age from Bluefield Formation through upper Bluestone Formation. No appreciable pre-Pennsylvanian unconformity seems present in the entire distance from southern West Virginia to Pennington Gap, nor in the subsurface of southeastern Kentucky. The Avis Limestone Member of the Hinton Formation provides a good marker bed for correlation in their sections. The youngest Pennington has the most nonmarine character including redbeds and some coal. Their lines of section should be studied in detail for data pertinent to uranium exploration. Englund (1964) has demonstrated intertonguing of upper Pennington and lower Lee Formation strata along the Cumberland Escarpment in Lee County, Virginia, thereby presenting evidence favoring continuous deposition and therefore no pre-Pennsylvanian unconformity there.

Harris and Miller (1958) proposed that the Pennington be raised to Group rank and include the Hinton, Princeton and Bluestone Formations, but exclude the Bluefield Formation. Such exclusion of the Bluefield seems unwise, since it occurs with apparent conformity at Pennington Gap.

The Pennington is also present in Kentucky along the southeastern part of the Cincinnati Arch outcrop belt. McFarlan (1943, p. 95) describes the Pennington of Kentucky as mainly shale with minor amounts of sandstone and limestone; color is gray to green with conspicuous zones of red. More detailed descriptions occur with the columnar sections on the maps of the U. S. Geological Survey GQ-map series which have recently been issued. To the north along the east flank of the Cincinnati Arch the Mauch Chunk-Pennington is beveled by pre-Pennsylvanian erosion, as is evident from the irregular isopach pattern in Figure 14. Subsurface data supporting this erosional truncation are largely from Martens (1939, 1945) and Freeman (1951, 1953).

Horne (1970) studied exposures along Interstate 64 in Rowan County, Kentucky, and postulated that lithologic and faunal differences between the traditional Mississippian Newman Limestone and the Pennsylvanian Lee Formation can be attributed to depositional environments. He proposed that no unconformity is present in that part of Kentucky between the Mississippian and Pennsylvanian strata. Wilson (1970) presents subsurface detail in Carter and Boyd Counties to the east which supports progressive westward beveling of the Pennington. Certainly the regional patterns in Figure 14 support the interpretation by Wilson rather than Horne, so that absence of the Mauch Chunk-Pennington in northeastern Kentucky and northwestern West Virginia seems to result from an unconformity rather than a facies change.

Flowers (1956) has described this unconformity in West Virginia, where not only is the Mauch Chunk truncated toward the northwest, but also the Greenbrier Limestone is beveled so that Pottsville rests directly on Pocono in part of northwestern West Virginia. Northwest-southeast trending stream channels are evident on the isopachous map of the Greenbrier, and Flowers (1956, p. 14-15) interprets them to represent rivers flowing northwestward. Regional understanding of the nature of the pre-Absaroka unconformity (Sloss, 1963; H. E. Wheeler, 1963) which increases in magnitude toward the craton suggests that instead, the streams were flowing toward the southeast away from the craton. The Wood County area of thinned Greenbrier even suggests southeastward merging of two streams. Flowers' isopach map indicates as much as 75-100 feet of relief on the southeastward dipping coastal plain, which could have set up significant paleoaquifer systems in the outcropping Mauch Chunk strata in what is now the subsurface of central West Virginia.

The Pennington of eastern Tennessee is briefly summarized by Rodgers (1953, p. 110-112), who characterized it as heterogeneous and varicolored, including red, purple, and green clay shale, pink, red, green and brown (normally calcareous) sandstone, and minor amounts of yellow shaly or silty fossiliferous limestone. More specific descriptions, yet quite generalized, are given on the columnar section of 7 1/2 minute geologic quadrangle maps published by the Tennessee Division of Geology and the U. S. Geological Survey. Subsurface thickness data on the Pennington of Tennessee is from Milhous (1959).

The following description of the Pennington Formation (220-250 feet thick) from the Sparta Quadrangle (Ferguson, 1969) is perhaps typical of the Pennington on the east flank of the Nashville Dome: "Shale, calcareous in part, variegated red, green, and olive-gray, occurs throughout formation; limestone, medium-dark gray and brownish-gray, cryptograined to medium-grained, oolitic in part, abundant fossil fragments, occurs in a zone 10 to 50 feet thick in upper part of formation and in thinner zones (less than 10 feet thick) throughout; sandstone and siltstone, calcareous in part, yellowish-orange to greenish-gray, very fine- to fine-grained, thin- to thick-bedded, occurs near middle of formation; claystone, red and green, occurs in middle of formation above and below the sandstone and siltstone; and dolomite or dolomitic limestone, commonly silty, light gray to brownish gray, micrograined to fine-grained, very thin- to thick-bedded, occurs throughout formation but more persistent and thinner at base." The sandstone is 5 to 10 feet thick. From this description there appears to be little, if any, fluvial strata in the Pennington there, although perhaps some subaerial coastal mudflats.

A petrographic and geochemical dissertation on the Pennington of Tennessee and southwest Virginia in progress by William J. Frazier at University of North Carolina should greatly aid interpretation of Pennington depositional environments.

Regional thickness patterns suggest erosional beveling of the Pennington westward onto the Nashville Dome. Not enough detailed stratigraphy has been done to evaluate possible westward truncation of marker beds. The isopachs in Figure 14 suggest a possible stream channel in Fentress County, Tennessee. An unconformity at the base of the Pennsylvanian is demonstrated by overstep of the Pennsylvanian, with the Raccoon Mountain Formation absent in the west so that the younger Sewanee Conglomerate in the upper part of the Gizzard Group rests directly on the Pennington in part of the area shown in Figure 15 with pre-Pennsylvanian unconformity in Tennessee.

The Pennington of Georgia has been briefly summarized by Butts and Gildersleeve (1948, p. 49). It is 100-200 feet thick and is predominently yellowish-weathering shale with characteristic beds of red shale; thin sandstone and limestone occur as minor constituents. Marine fossils are present. The Pennington coloration apparently disappears by facies change into the upper portion of the Floyd Shale (see Fig. 14), representing deeper marine waters which reduced the red coloration. No Pennington Formation or red coloration is noted just beneath the Pottsville in Floyd or eastern Chattooga Counties.

Alabama data on the Pennington and its probable facies equivalents (Floyd Shale and/or Parkwood Formation) comes from publications of the Alabama Geological Survey in county geologic summaries and water supply reports, plus interpretation of well log data presented by Bowles (1941) and McGlamery (1955). Butts (1926, p. 199-201) characterized the Pennington beds of Alabama as mainly argillaceous, partly cherty limestone, with which are associated shale beds, some of them red. The red shale is the characteristic feature of the Pennington to the north. The Pennington of Alabama is probably nowhere much over 300 feet thick, and is seldom less than 100 feet. The Pennington Formation and its stratigraphic relations with the Parkwood Formation and Floyd Shale are described in the guidebook edited by Smith (1967), and especially the articles therein by Thomas (1967) and Drahovzal (1967).

The Pennington is up to 300 feet in Jackson County, Alabama, but thins rapidly to the south and west. It consists of 65 feet of mostly limestone with 11 feet of maroon and gray shale at the base at Monte Sano Mountain, Madison County (Smith, ed., 1967, p. 67). Near Isbell, Franklin County, the Pennington is about 30 feet thick and consists of maroon and green mudstones interbedded with marine fossiliferous limestone. The upper contact of the Pennington with the overlying Parkwood Formation (180 feet thick) exhibits relief there, possibly representing an unconformity (Smith, ed., 1967, p. 138-140).

Thomas (1967, p. 5) shows the Pennington passing by facies change into the Parkwood Formation in Marion County. In this same diagram the upper Floyd Shale is shown as a facies geographically intermediate between the Bangor Limestone to the northeast and the coarser Parkwood Formation to the southwest. The Pennington thickness shown (Figure 14) for western Alabama is the stratigraphic range in the subsurface from the basal Pennsylvanian sandstone to the lowest redbed. Pennington thickness increases to the south because of stratigraphic divergence southwestward reflecting the Ouachita source of much of the Floyd and Parkwood clastics (Thomas, 1967). In St. Clair, Shelby, and Jefferson Counties, Alabama, the Pennington redbeds seem to disappear into the thicker and probably deeper water clastics of the Floyd Shale or possibly the Parkwood Formation.

Hooks (1961, p. 127-156) has described the stratigraphic relations near the Mississippian-Pennsylvania boundary in the Bucksville area of Jefferson, Bibb and Tuscaloosa Counties, Alabama, with thick Floyd (1,300-1,500 feet) and Parkwood (1,400 feet), but no Pennington Formation because of facies change into the other two formations.

There is some evidence supporting a southeastern source for the Parkwood of eastern Alabama and for the Floyd of eastern Alabama and Georgia. Some of the Pennington thinning along the outcrop belt westward across northern Alabama may be from a disconformity at the top of the Pennington increasing westward onto the south edge of the Nashville Dome, but some of the thinning may result from facies change of the lower Pennington westward into upper Bangor Limestone (Thomas, 1967, p. 5). Probably there are no nonmarine beds in the Pennington of Alabama, except possibly in Jackson County.

In summary, the Mauch Chunk-Pennington strata should be considered seriously in the search for uranium deposits. From southwest Virginia north to Maryland both reddish and greenish sandstones occur in probable nonmarine strata in the Pennington and especially the Mauch Chunk strata. Mineralogic content needs to be evaluated to see if these strata are sufficiently feldspathic to be considered uranium protore. Plant debris is abundant locally in Virginia, West Virginia, and Maryland. Clastics probably were derived from both the northeast in West Virginia and Maryland and from the southeastern Virginia-Carolina delta centered in southernmost West Virginia. In the general outcrop trend, more fluvial sediments probably occur to the northeast across West Virginia toward Maryland. A disconformity at the top of the Pennington-Mauch Chunk and a local angular unconformtiy probably set up late Paleozoic paleoaquifer systems which may have redistributed uranium in an original protore.

Pottsville Group

The Pottsville Group is a succession of cyclothemic, chiefly non-marine strata which comprise the lowest portion of the Pennsylvanian System from Pennsylvania to Alabama. The name is derived from Pottsville, Schuylkill County, Pennsylvania. The Pottsville Group in its type region in Pennsylvania is also used for the standard reference section of the Pottsville Series as applied in a widely used time-stratigraphic scheme for division of the Pennsylvanian System. In the most detailed measurement of the type section (Wood and others, 1956) the Pottsville is 1,116 feet thick and ranges from the uppermost redbeds of the Mauch Chunk Formation (with gradational contact) up to the top contact of the conglomerates of the Sharp Mountain Member with the lowest coaly shale beds associated with Buck Mountain coal. In the central and southern Appalachians the Pottsville Group is bounded at the base by the topmost shales and redbeds of the Mauch Chunk-Pennington. The lowest Pottsville beds are non-red sandstone or coal. In many places this contact is unconformable. In southern West Virginia, in its most complete Appalachian development, the Pottsville Group is divided from base upward into the Pocahontas, New River, and Kanawha Formations. The top of the Pottsville, where preserved from erosion, is everywhere conformable and passes into the overlying Allegheny Group. Figure 15 shows the distribution of Pottsville strata from Maryland to Alabama, along with the thickness of Pottsville Group present. West and southwest of a line of prominent dots no Paleozoic strata younger than Pottsville remain, so the isopached thickness is that of the erosionally preserved Pottsville.

The basal contact of the Pottsville Group was treated in moderate detail in the section on the Mauch Chunk-Pennington Group. Uninterrupted deposition between the Mississippian and Pennsylvanian Systems occurred generally in the southeast in the region southward from Greenbrier County, West Virginia (somewhat south of the line in Figure 15 showing the north limit of the Pocahontas Formation which disappears to the north by unconformable overstep). A pre-Pennsylvanian disconformity probably occurs high on the flanks of the Cincinnati Arch in Kentucky, Tennessee, and Alabama. Breganback and Wilson (1961) present detailed drill core documentation of this Pennsylvanian overstep westward onto the Cincinnati Arch in Tennessee and Kentucky. The area shown with pre-Pennsylvanian unconformity in the southern Appalachians is somewhat smaller than indicated in the map prepared by Stearns and Mitchum (1962, p. 87). This is partly because more recent work by Metzger (1965) returns to an old interpretation of northward thinning in the Warrior Basin of Alabama as a result of convergence rather than unconformable overstep. Geologic quadrangle mapping in the Cumberland Plateau of Tennessee since 1962 has emphasized the gradational nature of the Pennington-Pottsville contact in southeastern quadrangles, and the area which presumably has an unconformity with

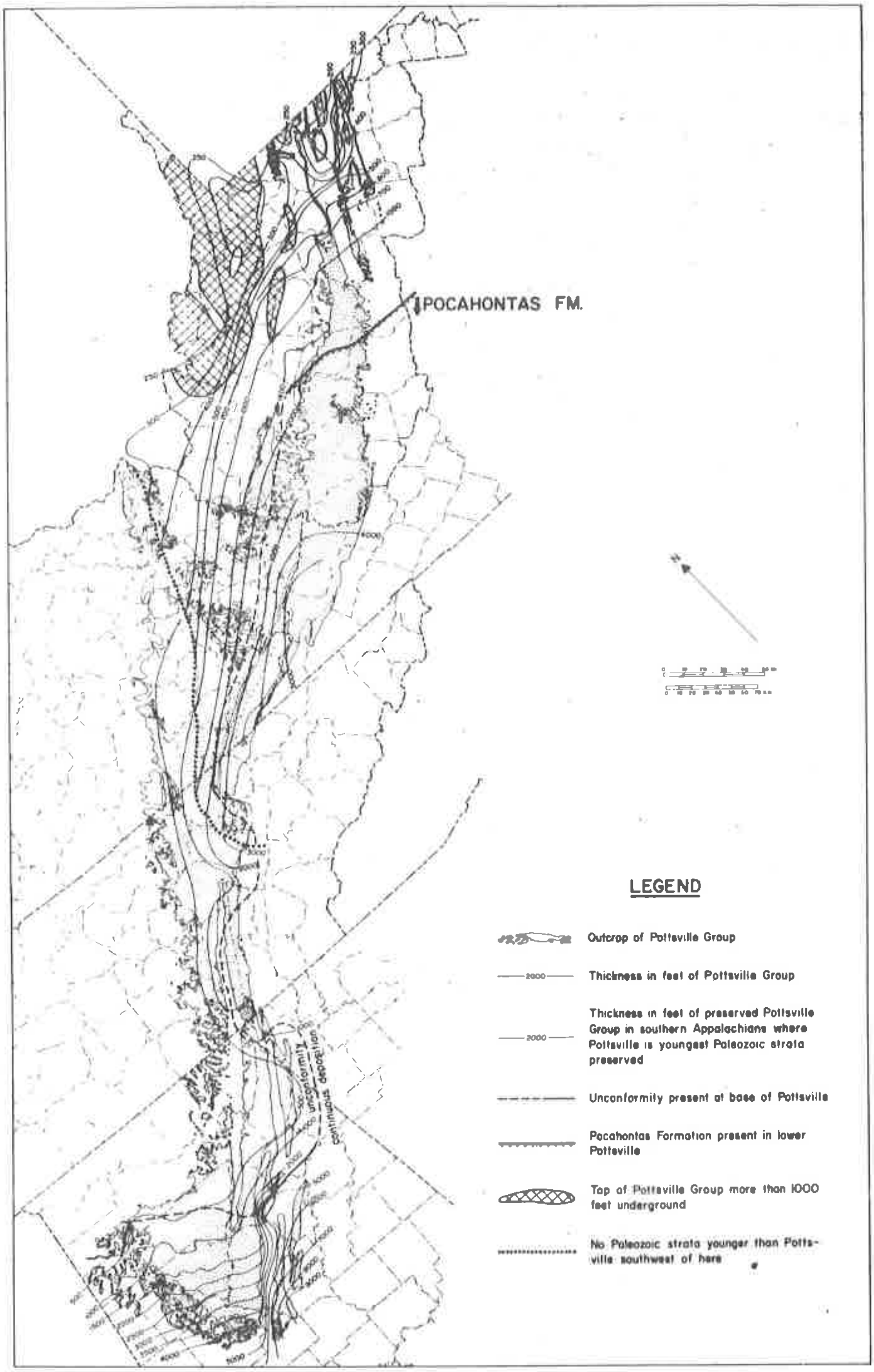


Figure 15. Outcrops and thickness of Pottsville Group.

stratigraphic overstep is restricted to the western Cumberland Plateau in Tennessee. For reasons discussed previously, Dennison prefers to reject the hypothesis of Horne (1970) that no unconformity exists beneath the Pennsylvanian outcrops on the northeast side of the Cincinnati Arch in Kentucky.

In Figure 15 no unconformity is indicated between the Mississippian and Pennsylvanian Systems in the Warrior Basin of Alabama, but Dennison envisions a generally simultaneous depositional change between the Pottsville and older sediments, rather than the very diachronous formation contacts proposed by Ferm and Erlich (1967) who postulate that the basal Pottsville, Parkwood, Floyd, and Pennington Formations are all contemporaneous facies of a prograding delta system.

Branson (1962, p. 99) has prepared a generalized pre-Pennsylvanian subcrop map extending from the Kentucky-West Virginia boundary northward across Ohio and Pennsylvania. He suggests that the Pottsville rests unconformably on the Hinton Formation strata from Randolph County, West Virginia, northward in all outcrops to Pennsylvania, contrary to the detailed sections in Randolph County (Reger, 1931a) and Tucker County (Reger, Price, and Tucker, 1923) where the Princeton and Bluestone Formations are measured and shown separately on geologic maps. Branson (1962, p. 101) shows the Pocahontas Group extending all the way from southern West Virginia northward to Pennsylvania. Dennison rejects Branson's interpretations in favor of the mapped configurations of the unconformity shown in Figures 14 and 15 of the present paper.

Thomas (1966) reported an angular unconformity between the Mauch Chunk and Pottsville on the southeast limb of the Hurricane Ridge syncline in Mercer County, West Virginia. Cooper (1961, Plate 50; 1971, Plate 17) further illustrates the structural relationships.

The stratigraphic horizon used for the top contact of the Pottsville Group is generally the same as in the Pennsylvanian System correlation chart of Moore and others (1944) with the exception of slight alterations in Tennessee. In Maryland and West Virginia, the isopached Pottsville thickness includes strata up to the top of the Homewood Sandstone. In northeastern Kentucky, the top of the Pottsville is placed at the top of the Magoffin Limestone which formed in a northeast trending marine embayment (Outerbridge, 1970).

In southeastern Kentucky, the top of the Pottsville Series is placed near the middle of the Catron Formation some distance above the Poplar Lick coal. In southwestern Virginia, the top of the Pottsville Series occurs in the upper part of the Wise Formation between the Phillips and Pardee Coals. In the Cumberland Plateau of Tennessee, Moore and others (1944) placed the Pottsville-Allegheny boundary within the Scott Formation a short distance above the Windrock coal and well below the Pilot Knob (Pilot Mountain ?) sandstone, so that it would be at about the base of the Vowell Mountain Group as used by Wilson, Jewell, and Luther (1956). Stearns and Mitchum (1962, p. 79) place the top of the Pottsville Series at the top of the Frozenhead Sandstone, at the very top of the Vowell Mountain Group and some 300 feet above the position picked by Moore and others (1944). The most recent attempt to place the boundary was a leaf flora study by Barlow (1970) who put the boundary at the base of the Rock Spring coal, about 90 feet below the top of the Vowell Mountain Group. The Cretaceous Tuscaloosa Formation unconformably overlies the Pottsville Formation in central Alabama.

Cropp (1963) studied the spore succession in Tennessee and recognized the probable early Allegheny age of the youngest coals, but was not specific in placing the Pottsville-Allegheny boundary. The position chosen by Barlow was used to prepare the isopachous map of Figure 15. Recall that to the southwest of northern Tennessee, the topmost Pottsville Series is not preserved, and only the Pottsville strata remaining are isopached.

The isopachous map of Figure 15 resembles closely the Pottsville isopach maps prepared by Stearns and Mitchum (1962, p. 85) and Branson (1962, p. 102). Branson showed an elongate trough of Pottsville deposition extending from Nicholas County, West Virginia (2, 000 feet thick) to Wise County, Virginia (5, 000 feet thick). Such a trough with thinning to the southeast is not evident in Figure 15, nor is thinning to the southeast from a trough axis indicated on the isopachous map of the New River-Pocahontas Group or Kanawha Group prepared by Arkle (1969, p. 80-81). Arkle (1969, p. 59) believed the Pottsville of southern West Virginia was deposited in a geosynclinal (trough) basin to the south of an epicontinental (platform) basin to the northwest, with a hinge line extending from Mingo County northeast to Randolph County separating the two areas of deposition. Neither the trough nor platform basin of Arkle shows isopach thinning on the flanks; instead there is a consistent regional thickening to the south as is also shown in Figure 15. Arkle's choice of the terms basin and trough is unfortunate; it would have been much clearer to designate them as a northern platform and a southern geosynclinal area of deposition. Isopach patterns show strong evidence of a continuation of clastic supply from the Virginia-Carolina delta to the south, as do the northward decrease of sandstones near the Pottsville-Allegheny boundary and cross-bed orientations in the Charleston Group (as used by Arkle, 1969, p. 83) and the appearance of more Pottsville marine zones toward the northwest in Ohio and western West Virginia.

The thickest Appalachian stratigraphic succession spanning the entire Pottsville Series is in Lee and Wise Counties, Virginia, although greater Pottsville thicknesses occur in Alabama where rocks correlating with the youngest Pottsville have been removed by erosion. Warrior Basin isopachs in Alabama are from the paper by Metzger (1965, p. 8), which is based on more data than was available to Stearns and Mitchum (1962). A southern (Ouachita) source is suggested for southern Alabama (Ferm and Erlich, 1967), but an eastern source probably was active also.

The outcrop trace of the top of the Pottsville Group is taken from the state geologic maps of West Virginia and Maryland, from county geologic reports in Virginia, from the Tennessee maps prepared by Wilson, Jewell, and Luther (1956) with appropriate adjustment for the stratigraphic boundary, and in Kentucky from the scores of geologic quadrangle maps published as part of the U. S. Geological Survey GQ series supplemented by generalized interpolation of unmapped quadrangles. Unfortunately, the published geologic map of Kentucky does not distinguish mapped units within the Pennsylvanian System.

A generalized southeastern source for Pottsville strata is indicated from Maryland to Alabama, based on isopach patterns and increasing coarseness and abundance of sandstones to the southeast, as well as introduction of more marine fossil zones to the west and northwest. Meckel (1970, p. 56) maps the invasion from the west of Pottsville marine faunas in southwestern Pennsylvania and adjacent West Virginia.

Clastic dispersal patterns based on Pennsylvanian System cross-beds are summarized for the United States by Wanless (1969, p. 326). A northwestward to westward transport from land located to the southeast or east can be detected from eastern Pennsylvania to Alabama. The Olean and Sharon Conglomerates of Pennsylvania and Ohio had a northern source, which probably supplied some of the Pottsville clastics to northwestern West Virginia. Meckel (1970, p. 57) shows a Pottsville current vector toward the west at the west border of Maryland. In West Virginia, Arkle (1969, p. 80-82) shows a rose diagram with transport toward the north or northwest for 14 cross-beds in his Charleston Group of strata spanning the Pottsville-Allegheny boundary, transport toward the west for his Kanawha Group, and toward the south or southwest for Pocahontas-New River strata. The Charleston Group pattern probably reflects the influence of the Virginia-Carolina delta centered in southwest Virginia. Pocahontas-New River patterns may result from an emergent craton at the time of the pre-Absaroka unconformity of Sloss (1963). Mitchum (1954) measured over a thousand cross-beds in Virginia, Kentucky, and Tennessee with a general transport toward the southwest with a shift toward due west in southern Tennessee. Tanner (1959) interpreted transport toward the west-northwest in Georgia and Alabama. Chen and Goodell (1960) reported transport toward the southwest in the Sewanee Sandstone at Lookout Mountain in Georgia and Alabama. Metzger (1965, p. 26) measured cross-beds in the Warrior Basin of Alabama and recorded sediment transport toward the southwest in the northeastern part of the Basin, with a transport toward the west in other parts of the Basin. Schlee (1963) also confirmed a similar transport pattern: toward the southwest in Tennessee, Georgia, and northeastern Alabama, as well as in the Coosa and Cahaba Basins of Alabama, but generally to the west in the Warrior Basin except for extreme western Alabama where cross-beds are inclined mostly toward the south. The Coosa and Cahaba Basin directions are especially interesting since Ferm and Erlich (1967) postulate a southern (Ouachita ?) source for Pottsville clastics in southern Alabama, based on decrease in quartz content of low-rank graywackes to the south, coupled with southward thickening along with increasing proportion of sandstone in the sedimentary sequence.

The following paragraphs discuss the Pottsville Group stratigraphy, sedimentology, and petrology for the area covered by Figure 15, moving from north to south.

Pottsville strata in Maryland are present in Garrett and Allegany Counties, where they are best described in the literature by Swartz (1922a, 1922b, 1922c), Toenges and others (1949), and by Toenges and others (1952).

In West Virginia outcrops of the Pottsville Group are described in geologic reports for the following counties: Mineral and Grant (Reger and Tucker, 1924), Pendleton (Tilton, Prouty, and Price, 1927; Heck, 1939), Tucker (Reger, Price, and Tucker, 1923), Preston (Hennen and Reger, 1914), Monongalia and Taylor (Hennen and Reger, 1913), Barbour and Upshur (Reger and Teets, 1918), Randolph (Reger and Teets, 1918; Reger, 1931a), Webster (Reger, Tucker, and Buchanan, 1920), Pocahontas (Price, 1929), Greenbrier (Price and Heck, 1939), Nicholas (Reger, Price, Tucker, and Sisler, 1921), Fayette (Hennen, Teets, Tucker, and Hagan, 1919), Summers and Mercer (Reger and Price, 1926), Raleigh (Krebs and Teets, 1916), Wyoming and McDowell (Hennen and Gawthrop, 1915), Logan and Mingo (Hennen, Reger, and Price, 1914), Wayne (Krebs and Teets, 1913), Boone (Krebs and Teets, 1915), and Kanawha (Krebs, Teets, and Price, 1914). The inlier at the crest of the Burning Springs anticline in Wood and Ritchie County has about 175 feet of Pottsville strata exposed along U. S. Route 50 (Cross and Schemel, 1956a, p. 71).

The standard reference section for the three divisions of the Pottsville Group is in southern West Virginia. The best summary stratigraphic column is by Hennen, Teets, Tucker, and Hagan (1919, p. 100-111) from which the following condensation is taken.

	Feet
Allegheny Group	
199. Coal, Clarion	0-3
Pottsville Group (3,850 feet)	
Kanawha Formation (2,100 feet)	
198. Sandstone, Homewood	75-95
197. Coal, Stockton "A"	0-5
196. Kanawha Black Flint, marine fossils	0-10
195. Coal, Stockton	0-10
194. Shale, sandy and fire clay	25-50
193. Sandstone, Upper Coalburg	50-80
192. Shale	5-10
191. Coal, Coalburg	2-10

		Feet
190.	Fire clay and shale	0-20
189.	Coal, Little Coalburg	0-3
188.	Fire clay, shale, and thin coals	0-22
187.	Sandstone, Lower Coalburg	20-40
186.	Shale, sandy	5-9
185.	Coal, Buffalo Creek	0-6
184.	Fire clay and shale	35-55
183.	Limestone, Buffalo Creek (Winifrede ?), marine fossils	0-2
182.	Sandstone, Upper Winifrede	20-30
181.	Shale	2-3
180.	Coal, Winifrede	1-10
179.	Fire clay and shale	0-20
178.	Coal, Lower Winifrede	0-2
177.	Sandstone, Lower Winifrede	10-23
176.	Shale	1-2
175.	Coal, Chilton "A"	0-3
174.	Fire clay and shale (Winifrede Limestone marine horizon ?)	10-18
173.	Sandstone, Upper Chilton	20-40
172.	Coal, Chilton "Rider"	0-4
171.	Fire clay shale	0-20
170.	Coal, Chilton	1-8
169.	Fire clay and shale	0-5
168.	Sandstone, Lower Chilton	0-30
167.	Coal, Lower Chilton	0-2
166.	Sandstone, Hernshaw	20-49
165.	Coal, Hernshaw	0-4
164.	Fire clay and shale	1-5
163.	Sandstone, Naugatuck	15-21
162.	Coal, Dingess	1-4
161.	Shale	1-5
160.	Sandstone, Williamson	5-20
159.	Shale	1-5
158.	Limestone, Dingess, marine fossils	0-2
157.	Shale, plant fossils	0-30
156.	Coal, Williamson	1-8
155.	Fire clay and shale	1-5
154.	Sandstone, Upper Cedar Grove	10-40
153.	Shale; locally with marine fossiliferous Seth Limestone near base	20-50
152.	Coal, Cedar Grove	2-5
151.	Fire clay and shale	0-10
150.	Sandstone, Middle Cedar Grove with thin coal	0-60
149.	Coal, Lower Cedar Grove	2-5
148.	Fire clay and shale	1-10

		Feet
147.	Sandstone, Peerless	20-30
146.	Coal, Alma "A"	0-1
145.	Shale, plant fossils, iron ore nodules	5-9
144.	Coal, Alma	2-5
143.	Fire clay and shale	0-5
142.	Sandstone, Monitor	20-40
141.	Shale, sandy	1-5
140.	Coal, Little Alma	0-3
139.	Sandstone, Lower Monitor	15-29
138.	Shale, sandy	1-5
137.	Limestone, Campbell Creek, siliceous	0-2
136.	Shale, plant fossils	10-20
135.	Coal, Campbell Creek	2-6
134.	Sandstone, Lower Campbell Creek	0-30
133.	Coal, Lower Campbell Creek	0-4
132.	Sandstone, Brownstown	10-17
131.	Coal Powellton "A"	0-1
130.	Shale, sandy	10-18
129.	Coal, Powellton	0-5
128.	Shale, dark	10-20
127.	Limestone, Stockton, siliceous, marine fossils	0-4
126.	Shale, dark, marine fossils	25-34
125.	Coal, Matewan	0-5
124.	Sandstone, Matewan	20-37
123.	Coal, Eagle "A"	0-2
122.	Sandstone, Eagle	20-37
121.	Shale, with fossil shells	5-10
120.	Coal, Eagle	1-6
119.	Fire clay and shale	0-5
118.	Sandstone, Bens Creek	0-27
117.	Coal, Bens Creek	0-3
116.	Fire clay and shale	0-10
115.	Sandstone, Decota	0-57
114.	Shale, marine and brackish fossils	0-9
113.	Coal, Little Eagle	1-4
112.	Sandstone, shaly	0-20
111.	Coal, Cedar	0-4
110.	Sandstone, Grapevine	25-30
109.	Shale, Eagle, marine fossils	15-20
108.	Limestone, Eagle, marine fossils	0-2
107.	Shale, Eagle, marine fossils	10-25
106.	Coal, Little Cedar	0-1
105.	Sandstone, Lower War Eagle	20-30
104.	Shale, black, with plant fossils	5-10
103.	Coal, Lower War Eagle	0-3

		Feet
102.	Shale	1-5
101.	Sandstone, Upper Gilbert	40-50
100.	Shale, siliceous, with lenticular Oceana Limestone (0-2 feet) near top	5-15
99.	Sandstone	5-15
98.	Coal, Glenalum Tunnel	0-15
97.	Sandstone, Lower Gilbert	50-79
96.	Coal, Gilbert "A"	0-1
95.	Shale, Gilbert, with marine fossils with Dorothy ? Limestone (0-2 feet) at top	5-40
94.	Coal, Gilbert	0-4
93.	Shale	0-6
92.	Sandstone, Dotson, locally conglomeratic	75-125
91.	Coal, Douglas "A"	0-1
90.	Shale, sandy	10-50
89.	Coal, Douglas	1-5
88.	Fire clay shale	0-5
87.	Sandstone, Lower Dotson, sometimes conglomeratic	50-100
86.	Shale, Douglas, marine and brackish fauna	5-15
85.	Coal, Lower Douglas	1-5
84.	Shale, sandy	1-5
New River Formation (1,030 feet)		
83.	Sandstone, Upper Nuttall, locally conglomeratic	50-100
82.	Shale, sandy	0-7
81.	Coal, Iaeger "B"	0-3
80.	Sandstone, Lower Nuttall ("Upper Iaeger")	30-50
79.	Coal, Iaeger "A"	0-1.6
78.	Shale, Upper Iaeger, with plant fossils	5-60
77.	Coal, Iaeger	1-5
76.	Shale, sandy	0-5
75.	Sandstone, Middle Iaeger	30-40
74.	Coal, Lower Iaeger	0-2
73.	Fire clay shale	0-3
72.	Sandstone, Lower Iaeger	20-30
71.	Shale, Lower Iaeger	20-35
70.	Sandstone, Harvey Conglomerate, conglomeratic	25-125
69.	Shale, Sandy Huff	5-40
68.	Coal, Castle	0-2
67.	Sandstone, Guyandot, locally conglomeratic	0-75
66.	Shale, sandy	0-5
65.	Coal, Sewell "B"	0-5
64.	Shale, sandy	10-24
63.	Coal, Sewell "A"	0-1
62.	Sandstone, Lower Guyandot	0-50

		Feet
61.	Shale, Hartridge, with plant fossils and fresh- or brackish-water fossils shells	0-5
60.	Coal, Sewell	0-10
59.	Shale, sandy	5-40
58.	Sandstone, Welch	0-50
57.	Shale, dark	0-5
56.	Coal, Welch	0-5
55.	Shale, sandy	0-5
54.	Sandstone, Upper Raleigh	50-75
53.	Coal, Little Raleigh "A"	0-3
52.	Shale, sandy	0-25
51.	Coal, Little Raleigh	2-4
50.	Shale, sandy	5-15
49.	Sandstone, Lower Raleigh	50-100
48.	Coal, Beckley "Rider"	0-2
47.	Shale, dark gray	0-17
46.	Coal, Beckley	0-10
45.	Sandstone, Quinnimont	0-66
44.	Shale, Quinnimont, siliceous to argillaceous	0-35
43.	Coal, Fire Creek	0-5
42.	Shale, sandy to sandstone	10-28
41.	Coal, Little Fire Creek	0-2
40.	Sandstone, Pineville	50-65
39.	Shale, sandy	0-5
38.	Coal, No. 9 Pocahontas	0-5
37.	Shale and sandstone mixed	0-28
36.	Coal, No. 8 Pocahontas	0-2
Pocahontas Formation (720 feet)		
35.	Sandstone, Flattop Mountain	20-50
34.	Shale, Rift, argillaceous and siliceous	17-30
33.	Coal, No. 7 Pocahontas	0-3
32.	Shale, gray and sandy	0-5
31.	Sandstone, Pierpont	40-60
30.	Shale and sandstone	0-35
29.	Shale, Royal, with fresh- and brackish-water fauna	0-5
28.	Coal, No. 6 Pocahontas	0-5
27.	Shale, sandy	0-5
26.	Sandstone, Eckman	40-67
25.	Coal, No. 5 Pocahontas	0-5
24.	Shale and sandstone, plant fossils	0-20
23.	Coal, No. 4 Pocahontas	0-8
22.	Shale, sandy	0-5
21.	Sandstone, Upper Pocahontas	25-55
20.	Coal, No. 3 Pocahontas "Rider"	0-2
19.	Shale, with plant fossils and fresh- or brackish-water fauna	0-10

		Feet
18.	Coal, No. 3 Pocahontas	0-15
17.	Shale, sandy	0-10
16.	Sandstone, Lower Pocahontas, locally shaly with 1.5-2.0 feet of No. 2 Pocahontas "A" coal near middle	0-50
15.	Shale, sandy	0-8
14.	Coal, No. 2 Pocahontas	0-2
13.	Shale, gray	0-5
12.	Sandstone, Vivian	0-29
11.	Coal, No. 1 Pocahontas	0-1
10.	Sandstone, Landgraff	0-20
9.	Coal, Landgraff	0-1
8.	Sandstone, Keystone	0-23
7.	Coal, Keystone	0-1
6.	Shale and sandstone	10-15
5.	Shale, North Fork, with fresh- or brackish-water fauna	5-10
4.	Coal, Simmons	0-1
3.	Shale and sandstone, alternating	0-122
2.	Coal, Squire Jim	0-2
1.	Shale and sandstone	0-50

Mauch Chunk Group (with red shales)

These Pottsville strata are principally fluvial and deltaic deposits of nonmarine origin, with numerous coals deposited in swamps, and with some shales containing iron ore (siderite ?) concretions suggestive of lacustrine deposits. Fourteen zones with probable marine fossils are recorded, yet the total thickness of strata with marine or brackish fauna comprises only three percent of the section. Several siliceous shales or siliceous limestones are indicated. The best-known is the Kanawha Black Flint (unit 196), which Cavaroc and Ferm (1968) interpret from detailed environmental mapping near Charleston to represent a spiculite deposit formed just seaward from a shoreline transgressing rapidly over a coal swamp which was receiving little or no detrital sediment. Proximity of desilicated ancient soils landward of main areas of silica precipitation indicates a potential source of silica-rich solutions. Such a model for the Kanawha Black Flint could probably be applied to the other siliceous zones noted in the Pottsville of southern West Virginia. The stratigraphic section just summarized characterizes the geosynclinal (trough) assemblage of Pottsville strata as postulated by Arkle (1969, p. 59). Although the sedimentation rate was so great that over ten times as much Pottsville accumulated as to the north, the strata of this rapidly subsiding basin are nearly all fluvial or deltaic in origin. Deposition rate exceeded subsidence, so clastics were carried northward and northwestward across the subsiding basin onto the platform, where conditions were more marine to the northwest. The cyclothems of the Pottsville of southern West Virginia (and elsewhere throughout the region mapped in Figure 15) are best characterized as the piedmont facies of cyclothem development (Wanless and Shepard, 1936, p. 1181-1182).

The Pottsville sandstones of southern West Virginia (and elsewhere in the region of Figure 15) show abundant evidence of channeling and wood fragments, both common in fluvial deposits. The sandstones are of the reduzate facies, however, with light gray to greenish gray color when unweathered. In the description of the detailed Pottsville section just presented for southern West Virginia, only the Dotson Sandstone (unit 92) and Lower Nuttall Sandstone (unit 80) are described with any colors suggestive of redbeds of the oxidizing facies. The Dotson Sandstone (Hennen, Teets, Tucker, and Hagan, 1919, p. 270) is described as brown or reddish-brown in color, often containing concretionary masses banded with iron ore streaks; this coloration would seem to result from surficial alteration of siderite cement or nodules deposited in a reduzate environment. In a quarry at Heberton, Fayette County, the Lower Nuttall Sandstone is described as six feet of reddish-brown sandstone overlying 10 feet of grayish white sandstone with reddish tinge (p. 298). It is not clear whether the red results from recent weathering or if the sandstone is a redbed. Certainly the Pottsville of West Virginia contains no significant amounts of redbed strata (no red shales are reported) which belong to the oxidizing facies. The sandstones are also probably too quartzose to serve as uranium protore.

The epicontinental (platform) aspect of the Pottsville in West Virginia is restricted to the northern and northwestern part of the State (Arkle, 1969, p. 59). The platform facies can be characterized from the following section compiled from Dennison (1955, p. 124-126 for the Keyser Quadrangle in Mineral County, West Virginia, and Allegany County, Maryland. West Virginia stratigraphic terminology (Reger and Tucker, 1924) is used, with differing Maryland nomenclature (Swartz, 1922) indicated in parentheses.

	Feet
Pottsville Group (about 360 feet)	
Kanawha Formation (260 feet)	
26. Sandstone, quartzose, medium to coarse, cross-bedded, weathers olive gray. Homewood sandstone.	65
25. Coal, shaly, lenticular. Tionesta coal.	0. 2-3. 0
24. Underclay, medium light gray. Mount Savage fire clay.	6
23. Coal, impure, lenticular. Upper Mercer coal; Stockton "A" coal of southern West Virginia.	2. 5
22. Shale, sandy. Horizon of Kanawha black flint and Mercer limestone	14
21. Coal, lenticular. Lower Mercer coal; Stockton coal of southern West Virginia.	0. 9

		Feet
20.	Shale, sandy.	8
19.	Sandstone, medium to coarse, conglomeratic in part, massive, weathers very light gray. Upper Connoquenessing sandstone.	90
18.	Shale, black, platy. Quakertown shale.	5
17.	Coal, impure, Quakertown coal.	1.5
16.	Shale, sandy.	5
15.	Sandstone, quartzose, medium-grained, cross-bedded, weathers light olive gray. Lower Connoquenessing sandstone.	35
14.	Shale, sandy.	25
New River Formation (100 feet)		
13.	Sandstone, quartzose, cross-bedded, channeled bottom, weathers yellowish gray. Nuttall sandstone.	29
12.	Shale, micaceous, platy, dark gray.	6
11.	Sandstone, quartzose, coarse, massive, cross-bedded, channeled bottom, contains plant fragments, weathers light brown. Guyandot sandstone.	9
10.	Underclay, carbonaceous, light gray. Sewell "A" or Sewell "B" coal horizon.	0.3
9.	Shale, silty, chippy, medium gray.	5
8.	Siderite lens, weathers light olive gray.	0.4-0.8
7.	Shale, dark gray, platy. Hartridge (Sharon) shale.	15
6.	Coal, blocky. Sewell (Sharon) coal.	0.8
5.	Shale, silty, micaceous, lumpy, dark gray.	4.5
4.	Sandstone, quartzose, micaceous, coarse, cross-bedded channeled bottom, weathers olive gray. Upper Raleigh (Sharon) sandstone.	21
3.	Shale, silty, micaceous, dark gray.	0.4-4.8
2.	Coal, lenticular, blocky. Fire Creek coal.	0.0-1.6
1.	Sandstone, quartzose, medium-grained, grayish black, weathers moderate reddish brown. Irregular bottom marks a disconformity with 5 feet of erosional relief at the base of Pennsylvanian System.	0.3-2.0

The Pottsville along the Maryland-West Virginia boundary is only one-tenth as thick as in southern West Virginia. The thinning apparently results from unconformable overstep and from stratigraphic convergence with omission of clastic cycles to the north away from the Virginia-Carolina delta southern clastic source. Probably the best correlation between these two Maryland and southern West Virginia sections is provided by the Kanawha Black Flint horizon, since the Mercer coals can be traced southwestward into the marine chert in Nicholas

County (Reger and Tucker, 1924, p. 261-262) and one coal test core at Henry, Mineral County, encountered two inches of black flint at the horizon of the Kanawha Black Flint. If correlations in the basal Pottsville are correst, the Fire Creek coal (unit 2) in Maryland corresponds to unit 43 in the southern West Virginia section, thereby demonstrating the magnitude of the unconformable overstep northeastward. The north limit of the Pocahontas Formation is in Greenbrier and Nicholas Counties, West Virginia (Figure 15). White (1913), Read (1947), and Read and Mamay (1964) have summarized the plant fossil zones of the Pottsville. Pocahontas-age floras are absent in the north (Gillespie, Latimer, and Clendening, 1966), indicating probable overstep (or facies change into the Mauch Chunk redbeds ?). Extensive leaf flora collections have been made by William J. Gillespie from numerous plant fossil horizons in West Virginia, but no results have been published to indicate how these collections document the Pottsville overstep to the north.

Read and Mamay (1964, p. K7) redefined the New River Formation to include the Quinnimont Shale Member (near the base), the Raleigh Sandstone Member, and the Sewell Member whose Nuttall Sandstone Bed is at the top. The formation overlies the Pocahontas Formation (redefined) and underlies the Kanawha Formation. This is not specified in terms of the detailed classification given by Hennen and others (1919), but apparently the redefined New River Formation includes units 44 through 83, shifting the basal boundary of the New River Formation upward some 100 feet.

Field examination suggests that the Pocahontas Formation contains more feldspathic sandstones than the sandstones of the overlying New River Formation.

The best exposures of the Pottsville are along the West Virginia Turnpike. A detailed description and road log have been prepared by Arkle and Latimer (1961).

The Pottsville strata of southwestern Virginia were mapped and divided into formations before the concept of cyclothems developed. Nevertheless, these old reports are the best account of specific outcrop data. The most useful of these early reports are by Campbell (1893), Butts (1914), Hinds (1916, 1918), Harnsberger (1919), Giles (1921, 1925), Wentworth (1922), and Eby, Campbell and Stose (1923). Outcrop and sedimentologic descriptions are meager, but the reports summarize numerous diamond drill holes in the Pottsville. Butts (1940a, p. 408-432) prepared a general description (which is summarized below) of the Pottsville of Virginia. Wanless began regional stratigraphic studies in order to obtain better correlations (Wanless, 1939) and later (Wanless, 1946) presented a regional interpretation of 37 stratigraphic sections of Pottsville strata in Virginia, Kentucky, Tennessee, and Georgia; that report is the starting point for most of the modern work in the region. Correlations among these states were linked by Wanless with the southern West Virginia coal fields to form the basis of the Pennsylvanian correlation chart for North America (Moore and others, 1944). Wanless' correlation for southwestern Virginia places the Pottsville-Allegheny contact in the upper part of the Wise Formation between the Phillips and Pardee coals. The following summary from Butts (1940a, p. 408-432) characterizes the Pottsville of Virginia.

POTTSVILLE GROUP (3,900-5,600 feet)

Wise Formation (2,100-2,300 feet; all but top 400 feet is Pottsville-age)

Shale, sandstone, 18 coal beds, underclays. No limestones noted in Pottsville portion, but fossiliferous sandstone occurs 60 feet below the Imboden coal. Over one-third of Wise Formation is sandstone, mostly arkosic so that decomposition of feldspar grains produces a white, speckled appearance. An exception is the Addington Sandstone which is hard and quartzose.

Gladeville Sandstone (50-150 feet)

Sandstone, quartzose to arkosic. Generally quartzose, changing to conglomeratic in western Wise County. In northern Wise, Dickenson, and Buchanan Counties, it is less quartzose and more arkosic and less persistent.

Norton Formation (825-1,500 feet, thinning markedly northwestward)

Shale, sandstone, and coal beds (nine minable) bounded by persistent, conspicuous Gladeville Sandstone above and "Bee Rock" sandstone (Harvey Conglomerate of West Virginia) at top of Lee Formation.

Lee Formation (800 feet in northwestern Dickenson and Wise Counties; 1,530-1,800 feet in southeastern outcrop in Wise to Tazewell Counties)

Prominent quartzose sandstones and conglomerates, with some shale and fine clay and at least 13 coal horizons. Known to intertongue with underlying Pennington Formation in Lee County (Englund, 1964).

No redbeds of an oxidizing facies are known in the Pottsville of Virginia. The upper Pottsville is more feldspathic than the lower portion, and feldspar content seems to increase toward the northeast in Virginia. Pottsville sandstones commonly contain wood fragments. The probability is small, but one of the two best chances for Pottsville uranium protore in the area of Figure 15 may be in Wise, Dickenson, and Buchanan Counties, Virginia, and adjacent counties in West Virginia and Kentucky. More detailed petrographic information is needed.

Early mapping of the coal fields in Kentucky resulted in much specific coal information around mining centers, each with numerous local stratigraphic terms. Unfortunately, no State geologic map of Kentucky breaks down the strata more specifically than Pennsylvanian System. The regional work of Wanless (1939) resulted in a better understanding of Pennsylvanian correlations, and the results were used to prepare the summary correlation chart (Moore and others, 1944).

McFarlan (1943, p. 99-106 has prepared the most recent summary of the Pottsville stratigraphy of Kentucky. The top of the Magoffin Limestone and marine shale forms a widely recognized marker zone used to delimit the top of the Pottsville. Eight marine zones are known in the Kentucky Pottsville (McFarlan, 1943, p. 104-106). The Lee Formation with prominent conglomerates forms the lower Pottsville throughout eastern Kentucky. The overlying Breathitt Formation occurs north of the Pine Mountain fault, and the Allegheny-Pottsville boundary occurs near the middle of the Breathitt. In the Middlesboro Syncline the Breathitt is mapped as a Group with a succession of formations in the Pottsville Series which can be summarized as follows from an important, modern geologic quadrangle study (Englund, Smith, Harris, and Stephens, 1963).

POTTSVILLE SERIES (about 4,000 feet)
- Breathitt Group
  - Catron Formation (ranges from base of Wallins Creek Coal to top of Jesse Sandstone Member; about 400 feet thick with roughly 200 feet assigned to Pottsville).
    - Sandstone, siltstone, shale, underclay, and coal.
  - Mingo Formation (ranges from base of Harlan Coal to base of Wallins Creek coal; 950 feet).
    - Sandstone, siltstone, shale, underclay, and coal. Contains marine fossils in shale at three horizons.
  - Hance Formation (ranges from top of Bee Rock Sandstone to base of Harlan Coal; 1,400 feet).
    - Shale, siltstone, sandstone, underclay, and coal.
- Lee Formation (ranges from greenish shale and sandstone of uppermost Pennington Formation to top of Bee Rock Sandstone; 1,500 feet).
  - Lee and Pennington Formations have intertonguing contact. Lee Formation is characterized by predominantly massive conglomeratic sandstone, with lesser amounts of fine to silty sandstone, siltstone, shale, and a few thin beds of coal and underclay.

The present program of geologic quadrangle mapping in Kentucky will add new information about Pottsville outcrop patterns; unfortunately not enough regional stratigraphic and sedimentologic work has been done to interpret the results of field mapping. New interpretations in field trip guidebooks suggest that the Kentucky Pottsville has more marine beds in it than had previously been suspected (Horne, Swinchat, and Ferm, 1971; Horne, Whaley, and Smith, 1971) and part of the Lee Formation may be a facies equivalent of the Newman Limestone.

The Pennsylvanian stratigraphy of the Cumberland Plateau of Tennessee has been summarized by Wilson, Jewell, and Luther (1956), who divide the Pennsylvanian into nine mapped groups. The Allegheny-Pottsville time boundary falls approximately at the base of the Rock Spring coal roughly 200 feet above the base of the Vowell Mountain group, according to the paleobotanical interpretation of Barlow (1970). The Pottsville of Tennessee is about 3,200 feet thick. The lower Pottsville (formerly called Lee Group) consists of massive sandstones with approximately equal amounts of shale (in modern classification consisting of Gizzard Group overlain by Crab Orchard Mountains Group). The upper Pottsville contains thinner sandstones and a larger percentage of shale, now assigned from base upward to the Crooked Fork, Slatestone, Indian Bluff, Graves Gap, Redoak Mountain and Vowell Mountain Groups. The type section of all five upper groups is at Cross Mountain, Tennessee. There are 48 coal horizons recognized in the Pennsylvanian of Tennessee, with 41 of these assigned to Pottsville age. The two most readily recognized horizons are the Windrock Coal underlain by a flint clay (the top of the Graves Gap Group is marked by top of Windrock Coal) and the next overlying coal (Big Mary coal in Redoak Mountain Group) that is overlain by a marine fossiliferous shale.

The Gizzard Group consists of three formations from base upward: Raccoon Mountain Formation, Warren Point Formation, and Signal Point Shale. These unconformably overstep from the east up onto the flank of the Nashville Dome.

Pottsville sandstones are of two categories. The lower Pottsville contains conspicuous massive, coarse-sandy to conglomeratic, high-silica, cross-bedded sandstones. Some of these qualify as potential economic deposits of glass sand (Hershey, 1960). The upper Pottsville contains a greater proportion of poorly sorted, silty to argillaceous sandstones with shale partings. Pottsville siltstones tend to be highly quartzose. Clay shales may form underclays or occur as fissile, dark shale sometimes associated with lenticular limestone or siderite beds a few inches thick.

Wilson and Stearns (1960) postulated that the cyclothems of Tennessee are not of the piedmont facies, but rather that they are composed of nearly all marine strata except for the coals and adjacent beds. Their interpretation has not been widely followed, yet they do record the presence of marine zones at several horizons in the Cumberland Plateau. They consider much of the sandstone in the Pottsville to be marine deposits. Ferm, Milici, and Eason (1972) favor even more marine deposition for the Pottsville of Tennessee, interpreting all strata except for the thick coals as marine or shoreline deposits.

The mineralogy of the Pottsville of Tennessee is probably too quartzose and too low in feldspar for the sandstones to be considered uranium protores. All the Pottsville strata belong to the reduzate facies. Coalified wood fragments are common in the sandstones; most of the coal beds are quite lenticular. Commercial coals occur mostly in the upper Pottsville. Additional details on Pottsville stratigraphy can be obtained from U. S. Bureau of Mines reports on coal test borings for Tennessee counties and from individual quadrangle geologic maps and mineral resources summaries issued by the Tennessee Division of Geology.

The Pennsylvanian strata of Georgia are restricted, from northwest to southeast, to Sand Mountain, Lookout Mountain, southern Pigeon Mountain, Little Sand Mountain, and an isolated patch in western Floyd County. All of the strata are Pottsville in age. The greatest thickness is in Lookout Mountain where 150-200 feet of mostly conglomeratic Lookout Sandstone is overlain by an estimated 930 feet of less massive and more shaly Walden Sandstone (Butts and Gildersleeve, 1948, p. 54-56). These correspond roughly to the Gizzard and Crab Orchard Mountains Groups of Tennessee. The few interbedded coals of Georgia and their associated stratigraphy have been described by McCallie (1904). Petrologic studies of sandstones in the Lookout Formation (Renshaw and Allen, 1953; Chen and Goodell, 1964) reveal a very high quartz content and high degree of sorting. Only one sample had as much as one percent feldspar noted, so the strata seem unlikely uranium protores, even though coalified wood fragments are common. Samples contain up to four percent rock fragments upon petrographic examination, chiefly low rank metamorphic types such as slate, phyllite, and fine-grained quartz schist. Chert comprises up to 2.5 percent of the detritus. These data suggest a sedimentary and low-rank metamorphic source terrane. Perhaps the quartz pebbles (in Sewanee Conglomerate) and sand came chiefly from weathered vein quartz in slate and phyllite terrane to the east or northeast in the Piedmont, with the clays generally winnowed and carried west or southwestward toward the Ouachita geosyncline.

Culbertson (1962b) restudied Pennsylvanian correlations in the Georgia coal fields and applied a Tennessee nomenclature to all the coal basins of Georgia. In about a thousand feet of strata he formally recognized, from base upward, the Gizzard Formation (Raccoon Mountain, Warren Point and Signal Point Members) and Crab Orchard Mountains Formation (Sewanee, Whitwell Shale, Newton Sandstone, and Vandever Members with the Rockcastle Conglomerate Member missing by erosion). The top of the Sewanee Member marks the boundary between the Lookout and Walden Sandstones of earlier classifications.

Pennsylvanian stratigraphy in Alabama has been best documented by a series of reports on individual coal fields, as follows: Cahaba (Squire and Smith, 1890; Smith, Squire, and Brewer, 1903; Butts, 1907, 1909), Plateau (McCalley and Gibson, 1891), Blount Mountain (Gibson, 1893), Coosa (Gibson, 1895; Prouty, 1912; Jones, 1929; Rothrock, 1949a, 1949b; Toenges, and others, 1949), and the Warrior Basin (McCalley, 1900; Metzger, 1965). In addition, U. S. Geological Survey folios contain important information on the following quadrangles: Birmingham (Butts, 1910), Bessemer and Vandiver (Butts, 1927), and Montevallo and Columbiana (Butts, 1940b). The stratigraphic work done prior to 1926 was briefly summarized in a single report (Butts, 1926, p. 208-217). Individual county geologic reports are usually not as helpful as these other references because Alabama county reports cover only fragments of coal basins and because most of the more recent reports were prepared by specialists in ground water geology.

The isopach patterns of Figure 15 suggest that the original Alabama accumulations of Pennsylvanian strata were deposited in a continuous geosynclinal basin deepening southward and southeastward, followed by folding and faulting forces from the southeast which produced the present Coosa, Cahaba, Blount Mountain and Warrior Basins, with the gently folded Plateau Coal Field extending northeastward toward Tennessee.

The Warrior Basin contains principally nonmarine fluvial or deltaic deposits, with the youngest outcropping beds preserved (probably early New River in age) in Tuscaloosa County where the total Pottsville thickness exceeds 4,000 feet. Drilled thickness beneath the Coastal Plain in Pickens County exceeds 6,000 feet. Metzger (1965) describes faunas from four thin marine zones, which are laterally persistent and thicken toward the west. Paleoslope apparently was generally to the west, because marine zones become more conspicuous to the west or southwest toward the marine Ouachita Geosyncline. At least 22 coals are present, some associated with underclays. A basal quartzose, conglomeratic sandstone is called the Boyles Sandstone. Metzger (1965) recognized seven stratigraphic intervals in the Pottsville and concluded that the Pottsville strata of the Warrior Basin thinned to the north by convergence rather than by overlap onto the Nashville Dome. Detailed measured sections are described by Metzer (1965).

The age of the youngest Pottsville in the Warrior Basin is controversial. Butts (1927, p. 13) gave the strata an upper New River age, as did Stearns and Mitchum (1962). Metzger (1965, p. 29-30) agreed, based on plants identified by C. B. Read from the youngest strata. Moore and others (1944) recognized some 500 feet of early Kanawha-age beds, from the Gwinn coal upward. Palynology work in the Warrior Basin by Upshaw (1967) verifies the presence of Pocahontas and New River ages of Pottsville strata, but contends absence of beds as young as the Kanawha Formation of West Virginia. Upshaw envisions slight overstepping and time transgression of Pottsville lithologic units to the northeast of Alabama, along with thinning by convergence.

The thickest Pottsville Group strata in the Appalachians occur in the Cahaba Basin where the preserved strata thicken from 5,100 feet in the north to 9,000 feet in the southeastern extremity, where are found the youngest Pennsylvanian strata in Alabama (correlative with Kanawha Formation). Some 35 coal seams are known in the Cahaba field, but only two marine zones. Two massive, quartzose sandstones in the lower Pottsville, from base upward, are called the Shades Sandstone (200 feet) and Pine Sandstone (250 feet) and are separated by 200 feet of more shaly beds. The commercial coal deposits are found above these massive sandstones. The Straven Conglomerate occurs high in the Pottsville in the Cahaba Basin, forming a zone 40 feet thick with quartzite and chert pebbles up to four inches in diameter. Pebbles diminish in abundance and size northward. The chert resembles that of the Cambrian Copper Ridge Formation, which Butts (1940b, p. 11) believes was exposed in the source area nearby to the east. The Straven Conglomerate is the basal bed of a group of conglomerates which occur throughout the uppermost 2,000 feet in the Cahaba field. No redbeds are reported in the Cahaba field stratigraphic descriptions. The base of the Kanawha-age strata is just above the Straven Conglomerate.

The Coosa Basin has a maximum preserved thickness of 5,450 feet of strata in the north and 7,400 feet in the south. Prouty (1912) divided the Coosa coal field into seven sub-basins bounded by synclines and faults. The youngest strata in this most eastern coal basin in Alabama occur near the north end in the Ragland, Fairview, and Coal City sub-basins (just to the left of the isopach numbers 5,000 and 6,000 in Figure 15) and in the Yellow Leaf sub-basin (just left of isopach number 8,000 in Figure 15). The Coosa Basin is unusual in that it contains the only important amounts of redbed strata (oxidizing facies) in the Pottsville group of the Appalachians. No marine zones are known in the Pottsville of the Coosa Basin. At least 23 coal horizons are present in the vertical succession.

In the northern Coosa Basin (Rothrock, 1949a) Shades Sandstone (190 feet) and overlying Pine Sandstone (210-250 feet) Members occur near the base of the Pottsville Group separated by 200-300 feet of claystone, siltstone, and sandstone. Above the Pine Sandstone is 2,800 feet of sandstone, siltstone, and claystone with three coal beds not of commercial thickness, in turn overlain by 1,980 feet of strata generally similar except for numerous coal beds including several of commercial quality. Twenty-four drill cores have been described in the northern part of the basin (Rothrock, 1949a; Toenges and others, 1949), but coloration details are not reported. In the northern Coosa basin, Jones (1929, p. 10-13) reports 20 feet of coarse, red sandstone overlying the Upper Chapman coal and 120 feet of sandstone and shale with red, gray and bluish colors beneath the Chapman coal.

In the Yellow Leaf sub-basin at the south end of the Coosa coal field, Butts (1927, p. 14) reports red shale zones 50-100 feet thick at two horizons located 1,000 and 1,500 feet below the top of the preserved Pottsville. These redbeds are New River in age and may correlate with the ones described farther north in the Coosa basin by Jones (1929).

These redbeds of the oxidizing facies occur in the midst of non-red (reduzate) facies sandstones. Carbonized wood and pyrite are common in Pottsville reduzate facies sandstones. Not much information is known concerning the petrography of sandstones in this part of the column, but they apparently are rather low in feldspar. The upper Pottsville of the Coosa Basin has more of the traits favoring uranium occurrence than any other portion of the Pottsville throughout the Appalachians. Additional investigation is needed. The structural setting of these redbeds favors ground water circulation down-dip, which could generate a uranium cell.

Throughout Alabama the Pottsville is reported to have one or two resistant conglomeratic quartzose sandstone (orthoquartzite) units at its base that contrast with the less resistant subgraywacke sandstone units in the rest of the Pottsville (Culbertson, 1962a). In the Cahaba and Coosa coal fields the two quartzose sandstone units are named the Shades and Pine Sandstone; in the Plateau coal field, McCalley (1891) called the two units the "Lower Conglomerate" and "Upper Conglomerate." In the Warrior coal field only one quartzose unit has been named, the Boyles Sandstone. Exposures along a new railroad cut revealed parts of the section not seen by earlier workers at Boyles Gap, where the redefined Boyles Sandstone (Culbertson, 1962a) rests unconformably on Mississippian Floyd Shale and consists of 114 feet of lower sandstone unit (quartzose, well-indurated, with quartz pebbles to one-half inch diameter), 33 feet of middle shale unit (shale, siltstone and some sandstone), and 86 feet of upper sandstone unit (quartzose, cross-bedded, well indurated). Only the lower sandstone unit was known to earlier workers. The lower and upper sandstone members of the redefined Boyles Sandstone are correlated with the Shades and Pine Sandstone, respectively (and with the Lower and Upper Conglomerate in the Plateau coal field). Culbertson (1962a, p. E49) redefines the top of the Parkwood Formation to be the widespread and conspicuous lithologic boundary at the base of the Shades Sandstone, rather than the Brock coal some 200 feet lower in the section as used by Butts (1926, p. 206). The base of the Pennsylvanian System may extend down into the marine Parkwood Formation as much as 500 feet below the Brock coal. If so, there are up to 700 feet of pre-Pottsville Formation Pennsylvanian-age strata in part of Alabama.

If Culbertson is correct in his correlations, the homotaxial succession of three distinctive units (shale tongue ? between two sandstones) in the lower Pottsville of every coal basin is an argument against significant northward overstep in Alabama by the basal Pottsville (as he redefines it). The basal Pennsylvanian does overstep to the north with omission of the lowest Pennsylvanian Parkwood Formation (Figure 15), but there is essentially an isochronous base of the Pottsville, within limits of time resolution in the present state of paleontologic and lithostratigraphic knowledge.

The interpretation has been vigorously expounded in recent years that the southern Pottsville of Alabama was derived from a southern or southwestern Ouachita source area (Erlich, 1964, 1965; Ferm and Erlich, 1967). Orthoquartzites occur principally in the lower Pottsville, and these sandstones pass upward into low-rank graywacke composed of 50-80 percent quartz with the remainder of the detritus being metamorphic rock fragments (chiefly chlorite schist) along with some volcanic detritus. The low-rank graywackes consist of varying proportions of metamorphic quartz and sodic feldspar along with a heavy mineral assemblage of staurolite, kyanite, epidote, garnet, muscovite, chlorite, tourmaline, and zircon. Associated clay shales contain illite with lesser kaolinite. Overall quartz content of the low-rank graywackes diminishes from north to south. This fact, coupled with southward thickening and increasing proportion of sandstone in the sedimentary sequence led Erlich (1965) to postulate a southern source area for the detritus. Such a Ouachita source area has also been recognized by Thomas (1967) for Mississippian clastics in Alabama.

This exciting evidence for a southern or southwestern source should not negate equally strong evidence for a southeastern, eastern, and northeastern source of detritus in the Alabama Pottsville. The Coosa, Cahaba, and Warrior basins probably simultaneously received clastics from both a Ouachita and Appalachia source area (analagous to the Canadian Shield and Appalachia source area for the Pottsville clastics of Pennsylvania). Evidence for an eastern clastic source in Alabama includes the following: 1) diminished thickness and number of marine zones across the Warrior and Cahaba basin, with none reported from the Coosa basin, 2) coarser and much thicker strata in generally equivalent beds to the east in the Coosa basin as compared to the Warrior and Cahaba basins, 3) the presence of significant amounts of redbeds in the Coosa basin, indicating proximity of shoreline, and 4) cross-bed evidence for Alabama which indicates a dominant transport direction toward the southwest and west. It would seem more reasonable to consider that both a Ouachita and Appalachia clastic source area was active in supplying clastics to Alabama during Pottsville time, with the Appalachia source being the more important one volumetrically and in terms of realm of geographic spread of detritus.

The total volume of nonmarine clastics in the Pottsville Group from Maryland to Alabama exceeds the volume of any other stratigraphic unit studied for this report on uranium potential. Plant debris and pyrite are common in the sandstones, which commonly are coarse enough to be permeable, and in fact, have yielded significant quantities of petroleum in West Virginia. Dips are gentle enough over broad areas to favor ground water circulation in uranium cells. Feldspar content is generally too low to make the Pottsville very promising as a uranium protore. There is indication from Maryland to Alabama that the lower Pottsville sandstones are orthoquartzitic, but pass upward into less mature sandstones of the low-rank graywacke variety. The Pottsville strata show evidence of occurring almost totally in the reduzate facies and being too highly quartzose for uranium, with two exceptions. Near the common juncture of West Virginia, Virginia, and Kentucky, the upper Pottsville may be more feldspathic than elsewhere, and at least one local occurrence of somewhat reddish sandstone has been noted in Fayette County, West Virginia. The Coosa basin of Alabama contains conspicuous redbeds, however. Redbeds are known from younger strata in the Pennsylvanian System of various parts of the Appalachians, but these are always shales and siltstones. The Coosa basin occurrence is the only reported reliable description of reddish sandstone (oxidizing facies) known from the Pottsville through Dunkard strata in the entire Appalachian region. More investigation of uranium potential in the Coosa basin is warranted. A palinspastic consideration of the stratigraphic setting may be helpful, with evaluation of the effects of possible rotation of the basins and paleocurrent vectors.

Allegheny Group

The Allegheny Group was named by H. D. Rogers (1840, p. 150) for a succession of coal-bearing strata exposed in the valley of the Allegheny River in western Pennsylvania. The Allegheny Group in its type region is also used for the standard reference section of the Allegheny Series as applied in a widely used time-stratigraphic scheme for division of the Pennsylvanian System. In the region mapped in Figure 16, the Allegheny Group includes the strata from the top of the Homewood Sandstone (or equivalent beds) to the top of the Upper Freeport coal (or the base of the Mahoning Sandstone where that coal is absent). In the region of this study the entire Allegheny Series is preserved only in West Virginia and a small part of adjacent Kentucky, in the area where isopachs are present in Figure 16. The upper part of the Allegheny Group is missing because of removal by recent erosion in the Cumberland Plateau of southeastern Kentucky and adjacent Virginia and Tennessee. For reasons explained in the treatment of the Pottsville Group, the base of the Allegheny Series in the southwest was placed at the top of the Magoffin Limestone, in southeastern Kentucky near the middle of the Catron Formation a short distance above the Poplar Lick coal, in southwestern Virginia in the upper part of the Wise Formation between the Phillips and Pardee coals, and in Tennessee within the Vowell Mountain Group at the base of the Rock Spring coal.

No significant unconformities are known at the top or bottom contact or within the Allegheny Group. Numerous diastems representing short time breaks occur at the base of sandstones, presumably representing ancient river channels which cut into the underlying sediments, causing local omission of underlying coal horizons. The Allegheny Group strata are distinctly cyclothemic, generally of the Piedmont facies (Wanless and Shepard, 1936) but changing toward the delta facies to the northwest along the Ohio River in northern West Virginia in the direction of more marine conditions and away from the clastic source area.

The isopachous map of the Allegheny Group (Figure 16) shows remarkably constant thickness. Control for northwestern West Virginia is inadequate because very few published well records specifically identify the strata closely enough to pick the Group boundaries. The most conspicuous feature is a thickened lobe caused by increased sandstone content, resulting in a 350 foot isopach in Fayette and Nicholas Counties, West Virginia. Regional thinning toward the Ohio River is significant in West Virginia. The thickened area with a 300 foot isopach in eastern Kentucky may result from variation in correlation. There is regional thickening, however, of preserved Allegheny strata from 200 feet to 250 feet across southwestern West Virginia to 300 feet in eastern

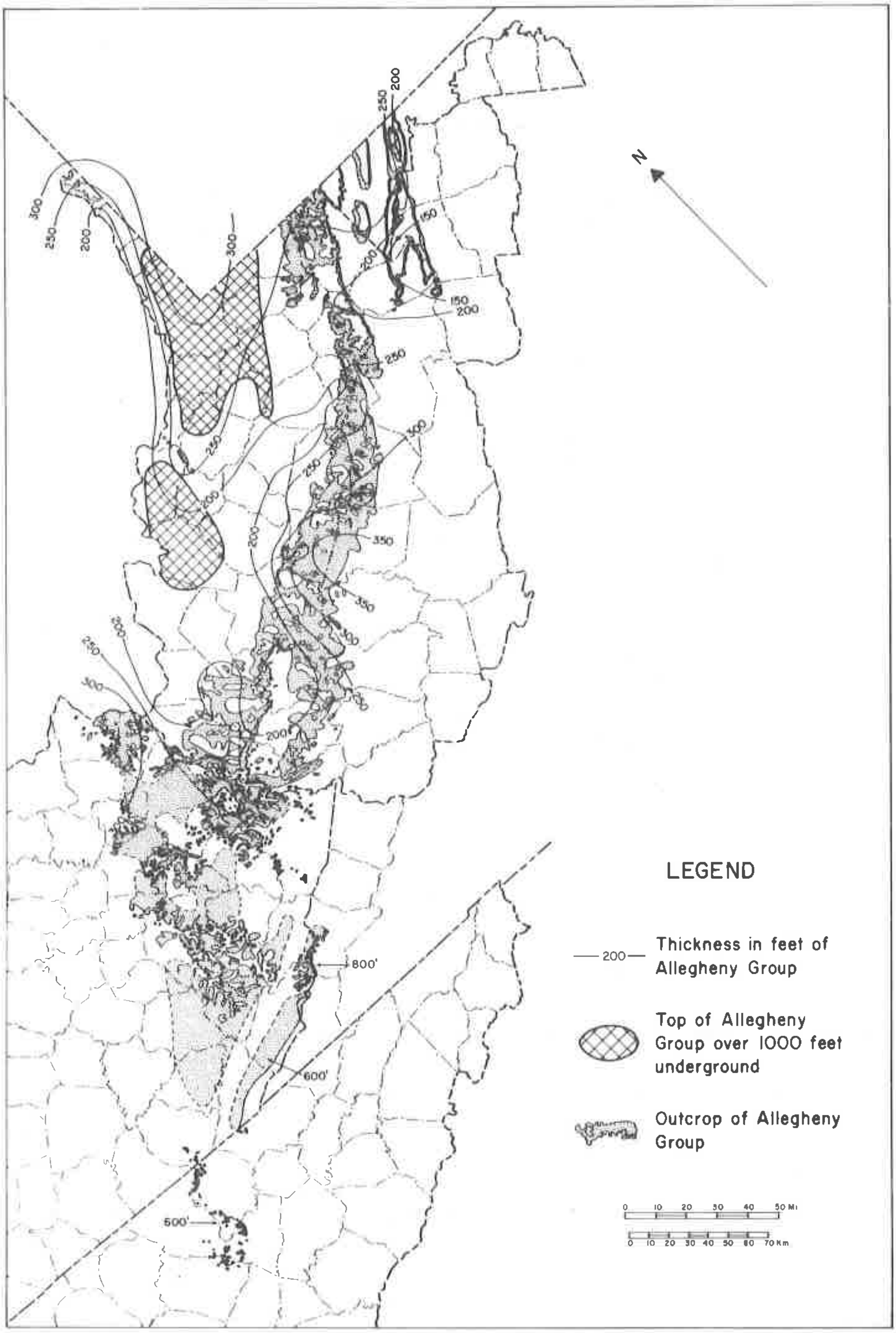


Figure 16. Outcrops and thickness of Allegheny Group.

Kentucky, along with a preserved thickness in Tennessee and in the Middlesboro syncline of Kentucky of 600 feet for only the lower Allegheny, with 800 feet in Wise County, Virginia. These facts suggest that another clastic wedge centered in extreme southwestern Virginia may have been present before partial removal of the Allegheny Series by the present cycle of erosion. The thinned area in Boone and Kanawha Counties may result partly from correlation problems in identifying the base of the Allegheny Series in that part of West Virginia.

The isopachous map of Figure 16 does not differ greatly from a generalized isopachous map of the Allegheny Group prepared by Branson (1962, p. 105) for Pennsylvania, Maryland, West Virginia, Ohio and Kentucky.

Specific paleocurrent information on the Allegheny strata is very limited, being restricted to a few observations by Arkle, 1969, p. 82, 85). The sandstones of the Charleston Group of Arkle, spanning the Pottsville-Allegheny boundary, have cross-beds with a vector mean slightly west of north. Two cross-beds recorded in the Allegheny Group of northern West Virginia indicate transport toward the north.

A northwestward paleoslope is also indicated by the facies patterns delimited by Baroffio (1964) in detailed environmental mapping of cyclothems within the Allegheny Series in West Virginia, Pennsylvania, Ohio and eastern Kentucky. A map from Baroffio's study has been utilized by Wanless (1969, p. 320) and by Wanless and others (1970, p. 240) showing the environments during East Lynn Sandstone time just before deposition of the Middle Kitanning coal in the upper portion of the Allegheny Group. In this map a piedmont alluvial facies persists from southwestern West Virginia northeast into Maryland; northwest of the piedmont, delta muds are crossed by river channel sands, with a large lacustrine area covering several counties near the base of the Northern Panhandle of West Virginia and parts of adjacent Ohio and Pennsylvania. Baroffio (1964) obtained a somewhat similar map pattern for West Virginia and Kentucky in the lower Allegheny during deposition of the Clarion Sandstone (map published in Wanless and others, 1970, p. 239). A barrier bar system and lagoon is recognized in eastern Kentucky.

Allegheny strata in Maryland are present in Garrett and Allegany Counties, where they are best described in the literature by Swartz (1922a, 1922b, 1922c), Toenges and others (1949), and by Toenges and others (1952).

The Allegheny Series of West Virginia crops out principally along a belt extending from the west edge of Maryland southwestward to eastern Kentucky, with smaller exposures in the Burning Springs anticlinal structure in Wirt, Ritchie, Wood, and Pleasants Counties and along the Ohio River valley in northern Hancock County. Summary columnar sections of the Allegheny Series are presented by Cross and Schemel (1956a) for Wayne, Wood, Upshur, and Hancock Counties, as well as diagramatic sections of specific exposures in Hancock County. The older county geologic reports covering the Ohio Valley area contain a little additional information, compiled before the recognition of cyclothems, however. Specific county geologic reports on the main outcrop belt extending from Maryland toward Kentucky are as follows: Mineral and Grant (Reger and Tucker, 1924), Tucker (Reger, Price, and Tucker, 1923), Preston (Hennen and Reger, 1914), Marion, Monongalia, and Taylor (Hennen and Reger, 1913), Barbour and Upshur (Reger and Teets, 1918), Randolph (Reger and Teets, 1918; Reger, 1931a), Webster (Reger, Tucker, and Buchanan, 1920), Nicholas (Reger, Price, Tucker, and Sisler, 1921), Braxton and Clay (Hennen and Gawthrop, 1917), Fayette (Hennen, Teets, Tucker, and Hagan, 1919), Kanawha (Krebs, Teets, and Price, 1914), Raleigh (Krebs and Teets, 1916), Boone (Krebs and Teets, 1915), Logan and Mingo (Hennen, Reger, and Price, 1914), and Cabell, Wayne, and Lincoln Counties (Krebs and Teets, 1913). A recent geologic map by Haught (1967) shows details of the Allegheny Series outcrop pattern in the vicinity of Charleston.

The following composite section for the Allegheny Group in the Keyser Quadrangle in Allegany County, Maryland and Mineral County, West Virginia, was compiled from several sources: Dennison (1955, p. 122-124), Swartz (1922c, p. 124-125), Reger and Tucker (1924, p. 154-159, 233-247), and Toenges and others (1949, drill hole 8-GC). West Virginia terminology is followed with differing Maryland terminology indicated in parentheses.

	Feet
Allegheny Group (about 260 feet)	
35. Coal, with 3 shale partings. Upper Freeport coal.	7
34. Siltstone, shaly, calcareous.	2
33. Limestone and limy claystone. Upper Freeport limestone.	3
32. Claystone, limy, silty. Bolivar clay.	9
31. Siltstone and sandstone. Upper Freeport sandstone.	5
30. Shale and siltstone.	2
29. Siltstone and fine sandstone.	33
28. Siltstone and carbonaceous shale.	2
27. Sandstone, fine to medium, with some silty and shaly partings. Lower Freeport (Montell) sandstone.	34
26. Silty claystone to shaly siltstone.	6
25. Coal, with 4 shale partings. Upper Kittanning coal.	7.0
24. Clay, silty, carbonaceous, and calcareous. Upper Kittanning fire clay.	4.7
23. Limestone, dark, crystalline. Johnstown (Mount Savage) limestone.	2.2
22. Siltstone and silty clay, dark. Hardman fire clay.	6

		Feet
21.	Sandstone, medium-grained, with 4 feet at top containing interbedded siltstone. Upper East Lynn sandstone.	24
20.	Siltstone to clay shale.	1.5
19.	Coal, with 2 shale partings. Middle Kittanning coal.	1.5
18.	Clay, carbonaceous, and silty. Middle Kittanning fire clay.	6
17.	Sandstone, fine, interbedded with shaly siltstone. East Lynn sandstone.	20
16.	Coal.	0.2
15.	Sandstone, interbedded with siltstone.	11
14.	Shale, gray, with pyrite.	2.5
13.	Clay, hard.	3
12.	Coal, with 2 shaly partings. Lower Kittanning coal.	3.1
11.	Clay, carbonaceous, silty to siltstone.	10
10.	Coal, with 4-inch shale parting. Lower Kittanning coal.	2.7
9.	Siltstone.	10
8.	Clay, hard, silty.	4
7.	Shale, carbonaceous.	4
6.	Clay, silty to sandy.	2
5.	Siltstone and sandstone.	3
4.	Shale, carbonaceous, with siltstone at base.	7
3.	Clay to claystone, silty.	10
2.	Siltstone.	4
1.	Shale, dark, silty.	7

No redbeds are present in this entire section, so it can be classified as reduzate facies.

The lithology of the thickest development of the Allegheny Series in West Virginia is indicated in this generalized section for Nicholas County (Reger, Price, Tucker, and Sisler, 1921, p. 191).

		Feet
Allegheny Series (350 feet)		
21.	Coal, usually multiple-bedded. Upper Freeport Coal.	0-2
20.	Fire clay. Bolivar Fire Clay.	0-6
19.	Limestone and iron ore, lenticular; usually represented by iron ore or sandy shale. Upper Freeport Limestone.	0-7
18.	Sandstone, massive, gray, usually conglomeratic. Upper Freeport Sandstone.	50-83
17.	Coal, lenticular. Lower Freeport Coal.	0-2
16.	Limestone and iron ore, 0-1 foot thick and interbedded in sandy shale. Lower Freeport Limestone.	10-15

		Feet
15.	Sandstone, massive, gray, coarse to pebbly. Lower Freeport Sandstone.	20-49
14.	Coal, seldom found. Upper Kittanning "Rider" coal.	0-1
13.	Shale, sandy.	0-25
12.	Coal, multiple-bedded. Upper Kittanning Coal.	2-5
11.	Fire clay, flinty; rarely present. Upper Kittanning Fire Clay.	0-5
10.	Shale, sandy.	5-10
9.	Sandstone, massive or current-bedded, grayish brown, locally pebbly. Upper East Lynn Sandstone.	30-50
8.	Coal, double-bedded. Middle Kittanning Coal.	2-5
7.	Sandstone, massive, gray or brown, locally pebbly. East Lynn Sandstone.	25-45
6.	Coal, multiple-bedded. Lower Kittanning Coal (No. 5 Block coal).	4-10
5.	Fire clay, seldom found. Lower Kittanning Fire Clay.	0-5
4.	Limestone, ferriferous; seldom found. Vanport Limestone.	0-5
3.	Sandstone, gray, massive; frequently absent. Kittanning Sandstone.	0-15
2.	Clarion Coal.	0-5
Pottsville Series		
1.	Sandstone. Homewood Sandstone.	

Sandstone is more prominent and coarser in Nicholas County than in the Keyser Quadrangle. The Nicholas County section probably represents Allegheny Group strata deposited somewhat farther up the alluvial plain toward the source area than does the section near Keyser. This may represent continuing influence of the Virginia-Carolina delta source which was first uplifted in early Mississippian time. Conglomeratic zones suggest nearness to source.

The Allegheny Series summary section for northeastern Wayne County (Cross and Schemel, 1956a, p. 56) is only 190 feet thick but contains about 90 percent sandstone. The sequence includes the Clarion, Lower Kittanning, and Upper Kittanning coals, with Lower Freeport limestone and Ruffner clay in stratigraphic succession overlain by lower Freeport coal and followed by Upper Freeport limestone and Bolivar clay overlain by the Upper Freeport coal at the top of the Allegheny Group. No conglomeratic zones are indicated.

The summary section for Upshur County (Cross and Schemel, 1956a, p. 56) is intermediate in lithology and thickness between the Keyser and Raleigh County section. No conglomeratic zones are indicated.

Average sedimentary or depositional strike probably trended a little east of a direct line from Wayne County to Keyser in Mineral County, so the Wayne and Raleigh County sections are very similar in proportion of sandstone, with more shaly beds in Upshur County and in the Keyser Quadrangle. The Wood County summary section for the Burning Springs anticline (Cross and Schemel, 1956a, p. 56) has much more silty and shaly strata, since it was located farther down the Allegheny Epoch alluvial plain system. The Hancock County sections (Cross and Schemel, 1956a, p. 56, 60) are likewise shaly with much more numerous limestone zones. In the Northern Panhandle of West Virginia, marine fossils are known from three zones: Vanport Limestone above the Clarion coal (attaining a maximum thickness of 2.5 feet of limestone in a core near Chester), the Hamden marine shale above the Lower Kittanning coal, and the Washingtonville marine zone above the Middle Kittanning coal. Fresh-water limestones occur below the Freeport coals in the Northern Panhandle, and they persist as far south as the Burning Springs anticline outcrop belt. The Hancock County outcrops are intermediate in character between the delta and piedmont facies of cyclothems (Wanless and Shepard, 1936), but all the other outcrop belts in West Virginia clearly belong to the piedmont facies. A marine zone associated with iron ore near Hubbardstown, Wayne County, may represent the southern extremity of the Vanport horizon. The entire Allegheny Group is characterized by an increase in sandstone and a decrease in shale toward the south and west in the Ohio Valley region.

Arkle (1969) separates the finer clastics of the Allegheny Group of northern West Virginia from the coarser clastics of a Charleston Group in the south. His Charleston Group spans the entire Allegheny Series in the south, ranging in age from the Stockton coals of the Kanawha Group, through the entire Allegheny and up to the base of the redbeds in the lower Conemaugh Group. Marker beds are difficult to trace in the sandstones which form the Charleston Group. The Charleston Group of Arkle contains over 70 percent sandstone of alluvial channel origin, often approaching 100 percent. Arkle states that the Charleston Group becomes more shaly to the southeast. He also postulates a disconformity at the top of the Charleston Group, representing a break in deposition in southern West Virginia during the accumulation of the Pottsville, Allegheny, and lower Conemaugh Groups of northern West Virginia, with the Charleston Group overlain unconformably by the middle Conemaugh. The present writer cannot envision how the southern clastic source area can be shut off, and instead favors an interpretation of Charleston Group as an upstream alluvial facies equivalent of the lower alluvial plain deposits (late Pottsville, Allegheny, and earliest Conemaugh) age in northern West Virginia.

Ferm and Cavaroc (1968) studied sediment distribution in about 400 measured sections and borehole records extending from the east edge of Kentucky northeastward along the main Allegheny Group outcrop belt to the south edge of Pennsylvania. Some of their conclusions are summarized below. Sandstone units in cross section are about 60 feet thick and 5 miles wide and are arranged in an en echelon manner within an anastomosing plexus of shale, coal, and seatrock (underclay). Sandstones presumably represent fluvial bar sands along the width of a meander swath, whereas shale, coal, and seatrock suggest various backswamp environments. The en echelon arrangement of bar sand units probably arises from major lateral shifting of channels into topographically lower backswamps. The sandstones locally coalesce to form vertically stacked bodies. Difference in proportional abundance and dimension of channel and backswamp elements suggest a transition from an alluviated upper delta plain in southern West Virginia outcrops to a partially inundated lower delta plain near the Pennsylvania boundary. The sandstones commonly show the basal disconformity and fining upward which is characteristic of alluvial deposits. Most of the sandstones are low rank graywacke (60 percent quartz, 10 percent feldspar, 30 percent micaceous rock fragments, with accessory tourmaline, zircon, garnet, and staurolite). The upper portion of some sandstones that are directly overlain by seatrock is distinctly orthoquartzitic (80-100 percent quartz); these represent abandoned channel bars that stood relatively high before being covered by the swamp, and therefore intense leaching reduced their complex feldspars and micaceous rock fragments to a simple mixture of quartz and clay. Removal of the clay by minor sheet wash would result in an orthoquartzite cap on some of the old bar complexes.

The strata of the Allegheny Group of West Virginia essentially all belong to the reduzate facies. The only mention of any reddish strata in all the literature examined was a few scattered reddish shale streaks in the uppermost Allegheny Series. In the Ohio Valley region there are no persistent redbeds in the sequence although occasionally some thin zones of grayish red shale are found below the Upper Freeport Coal (Cross and Schemel, 1956a, p. 69). Grimsley (1907, p. XIII) described a core at Glenova, Ohio County, in which the probable Bolivar fire clay horizon is 13 feet thick with 3 feet of limy, sandy beds in the middle with reddish color. At Fort Gay, Wayne County, the Upper Freeport Limestone zone is 12 feet thick, with the basal 3 feet consisting of red limy shale (Krebs and Teets, 1913, p. 76). Hennen and Gawthrop (1917, p. 126) note red to brown, sandy shale in the interval 60-100 feet below the top of the Allegheny Series (80-120 feet above Upper Kittanning Coal) in a section near Ivydale, Clay County. This zone could be in the basal Conemaugh and be incorrectly identified. These are the only records of any redbeds in the Allegheny Series of West Virginia, and there is no reddish sandstone.

Allegheny Series strata in Kentucky are described regionally by Wanless (1939, 1946) and by McFarlan (1943, p. 106-107, Plates XXI and XXIII). The East Lynn Sandstone is locally conglomeratic. The Vanport Limestone is the only marine horizon noted in the Allegheny Series of Kentucky, extending as far south as Elliott County (McFarlan, 1943, p. 107). In the recent geologic quadrangle mapping in eastern Kentucky, the term Breathitt Formation spans the entire range of rocks from the base of the Conemaugh Formation down through all of the Allegheny Series and upper part of the Pottsville Series to the top of the Lee Formation of Early Pottsville age. In the Breathitt Formation the top of the Magoffin Limestone marine zone marks the approximate base of the Allegheny Series. The upper part of the Allegheny Series is preserved only in Greenup, Boyd, Carter, and Lawrence Counties. Only three published geologic maps in the GQ series show for a single quadrangle strata spanning the entire Allegheny Series; these are the Ashland (GQ-196), Argillite (GQ-175), and the Rush (GQ-408) quadrangles.

The columnar section for the Rush Quadrangle (Carlson, 1965) can be used to describe the stratigraphic succession of the Allegheny Series in eastern Kentucky. The 0.5-1.0 foot Magoffin marine sandstone zone is the topmost layer of the Pottsville Series, with the lowest named bed in the Allegheny Series being the Princess No. 3 coal some 20-30 feet above the Magoffin. The named units in the Allegheny Series (with reported thickness in feet above the next named underlying unit) are Princess No. 3 coal (20-30), main block ore with limonite and marine fossils (Vanport Limestone ?) (21-40), Princess No. 4 coal (15-25), Princess No. 5 coal (40-50), Hutchins Clay bed and overlying Princess No. 6 coal (40-75), Princess No. 7 coal (36-40), Princess No. 8 coal (25-50) and upper Freeport coal (45-62). Silicified siltstone with marine fossils plus carbonaceous shale with silicified wood occur in interval 45-70 feet below Princess No. 6 coal. Gray marine shale and limestone in interval 0-45 feet below Princess No. 6 coal is probably equivalent to the Vanport Limestone, according to Carlson (1965). Non-marine nodular limestone zones with Spirorbis occur 10-15 feet above Princess No. 6 coal, 20-30 feet above Princess No. 7 coal, 15-20 feet above Princess No. 8 coal. The Allegheny Series strata are all greenish to gray except in the 45-62 foot interval between the Princess No. 8 and Upper Freeport coals, where there occurs some shale, light- to dark-gray and buff, with maroon mottling.

In the Middlesboro Syncline the thickened Breathitt is assigned Group status with several formations belonging to the Upper Pottsville and Allegheny Series. McFarlan (1943, Plate XXIII) suggests that beds as high as the very base of the Conemaugh Series occur in Harlan County; other workers do not consider the youngest strata in the Middlesboro syncline younger than middle Allegheny Epoch.

In the Ewing Quadrangle in Harlan County (Englund, Smith, Harris, and Stephens, 1963) the Allegheny Series strata include the upper half of the Catron Formation (400 feet thick) overlain by about 400 feet of Hignite Formation for a total thickness of some 800 feet of preserved Allegheny Series, with the top eroded from the highest mountains. The Catron Formation contains sandstone, siltstone, underclay, coal, and medium-gray shale; the Jesse Sandstone Member (60 feet thick) at the top of the Catron is the only sandstone in the Breathitt Group of the

Ewing Quadrangle coarse enough to contain quartz pebbles (up to one-half inch diameter). The Hignite Formation is predominantly fine- to medium-grained sandstone and medium-gray shale. Marine fossils in 8 feet of calcareous shale occurs 80 feet above the base of the Hignite and 3 feet of coal occurs 180 feet above the base of the Formation. The youngest named strata are 60-80 feet of Reynolds Sandstone Member about 250 feet above the base of the Hignite, and this in turn is capped by 80 feet of shale and sandstone.

Wanless (1946, p. 113) believed he identified the Magoffin marine zone within the Hignite Formation (110 feet below its top) in the Log Mountains, Bell County, Kentucky, with roughly 500 feet of Bryson Formation strata preserved on the highest peaks above the Hignite.

It therefore appears that the portion of Allegheny Series preserved from erosion in both Harlan and Bell Counties, Kentucky, in the Middlesboro Syncline is roughly 600 feet thick, with no redbeds (oxidizing facies) present.

In the Black Mountain coal field of Letcher County, Kentucky and Wise County, Virginia, the Allegheny Series strata include the upper 380 feet of the Wise Formation along with the overlying 500 feet of Harlan Formation, which contains the highest beds preserved from erosion. Wanless (1946, p. 115) in a detailed section, identifies the Magoffin marine zone 76 feet above the Pardee coal to give the thicknesses noted above. Moore and others (1944) place the Allegheny-Pottsville boundary shortly below the Pardee coal, so there is an inconsistency of about 100 feet in correlations. If these correlations are generally correct, then a minimum of 800-900 feet of Allegheny Series strata was deposited in Wise County. This rapid sedimentation continues into the Allegheny Epoch the site of the maximum rate of sedimentation known for the Pottsville Epoch in the Georgia to Pennsylvania portion of the Appalachian coal basin. No redbeds are noted in the section by Wanless (1946, p. 115-117). Virginia references on the Allegheny Series in the projection of the Middlesboro Basin into Lee and Wise Counties are as follows: Campbell (1893), Butts (1914), Eby, Campbell, and Stose (1923), and Giles (1925). The Allegheny Series strata in the Wise and Harlan Formation of Lee and Wise Counties consist of grayish sandstone, siltstone, and shale, with several zones of ironstone concretions, underclays, and coals. No marine horizons are known. The sandstones tend to be micaceous, and only the Harlan Sandstone is conglomeratic.

Nelson (1959, p. 1651) identified as bentonite 1.5 feet of tan silty clay separated by 2 inches of carbonaceous shale from the overlying 4.0 feet of Pardee Coal (or next lower local coal) 8 miles northwest of Wise in Wise County, Virginia. The reported bentonite gives an X-ray pattern with montmorillonite and a small proportion of kaolinite. Petrographically the bentonite contains quartz (some is euhedral), feldspar (probably sanidine), and euhedral apatite and zircon. This is the first identification by mineralogy of a bentonite zone in the

Pennsylvanian System of the Appalachians. A bentonite probably is not persistent in the piedmont cyclothem facies; it may be significant that the site of preservation is in the area of maximum rate of Pennsylvanian subsidence in the Appalachians, and thus there was less chance for destruction of the ash fall by reworking of the sediment after deposition. The bentonitic component of Pennsylvanian sediments is probably too small to have any significance in formation of uranium protore. This bentonite zone would be assigned to the basal Allegheny Series according to the correlations of Moore and others (1944), but would be assigned to the uppermost Pottsville Series if the identification of the Pardee coal below the Magoffin marine zone by Wanless (1946, p. 117) is correct.

If the base of the Allegheny Series is placed correctly at the base of the Rock Spring coal in Tennessee (Barlow, 1970), then some 600 feet of Allegheny Series strata are present in Tennessee, with the top part removed by erosion from the highest mountains in the Cumberland Plateau. Allegheny Series strata are preserved in Claiborne, Campbell, Scott, Anderson and Morgan Counties. The youngest strata occur at Cross Mountain, Campbell County, and the following section from Wilson, Jewell, and Luther (1956, p. 19) summarizes the Allegheny Series in Tennessee.

	Feet
Allegheny Series	
Cross Mountain Group (554 feet in type section)	
24. Sandstone and shale, and thin coals	50
23. Sandstone	20
22. Shale and thin sandstone with thin coals	74
21. Sandstone	26
20. Shale	40
19. Sandstone	22
18. Shale with thin coal	35
17. Sandstone (Tub Spring Sandstone)	50
16. Shale and thin sandstone with thin coals	76
15. Coal (Upper Wildcat coal)	
14. Shale	30
13. Coal (Lower Wildcat coal)	
12. Sandstone	20-40
11. Shale	30-70
10. Coal (Cold Gap coal)	
9. Sandstone (Low Gap Sandstone)	5-45
8. Shale and thin sandstone	50-100
7. Coal (Upper Grassy Spring coal)	
6. Shale and sandstone	30-45
5. Coal (Lower Grassy Spring coal)	
4. Shale	0-10

	Feet
Vowell Mountain Group (230-375 feet)	
3. Sandstone (Frozen Head Sandstone)	35-60
2. Shale	0-45
1. Coal (Rock Spring coal)	
Pottsville Series	
Vowell Mountain Group (lower portion)	

These authors do not list coal thickness because of extreme variability. Colors of strata in Tennessee are not specifically described, but there is no mention of redbeds.

The Allegheny Group has modest potential for uranium protore. Nearly all the sediments are alluvial, lacustrine, or paludal in origin. Only a few marine beds are known, and these increase toward the northwest. The rocks are essentially all reduzate facies. The only definite redbeds are impersistent shaly layers associated with the Upper Freeport Limestone in the highest Allegheny strata. Wood fragments and pyrite are both mentioned in descriptions of the clastic sediments. Coals are very abundant in the Allegheny Group, and uranium ores generally are not associated with major coal deposits. The sandstones contain a modest amount of feldspar. The Allegheny Group clastics coarsen from the north, northwest and southwest toward decidedly conglomeratic sandstones in the outcrop belt from Mingo to Webster County, West Virginia, centered on the continuing source of clastic supply known as the Virginia-Carolina delta. Probably the sandstones in the area from Mingo to Webster Counties have the best potential for uranium protore. Regional dip of these permeable beds to the north and northwest may favor setting up uranium cells, especially in the northwestern part of the outcrop area in these counties where the Allegheny Group dips northward beneath the Conemaugh strata toward the south edge of the Dunkard Basin. Lower Allegheny strata deeply dissected by dentritic erosion patterns from Tennessee across Kentucky could have produced ground water concentration of uranium in the beds dipping gently eastward off the Cincinnati Arch. The more steeply folded strata in the east edge of the Appalachian Plateau in West Virginia and adjacent Maryland are less promising, since ground water would have circulated a shorter distance through the rock. The Burning Springs anticline and the Hancock County areas of West Virginia are considered least promising because they represent less permeable sediments, are farther from clastic source, have fairly steep dips, and occur with more marine interbeds.

Conemaugh Group

The Conemaugh Group was named by Platt (1875, p. 8) for exposures along the Conemaugh River in Pennsylvania, where the Conemaugh Group ranges from the top of the Upper Freeport Coal to the base of the Pittsburgh Coal. These original stratigraphic boundaries are still followed, and can be easily applied in Maryland, West Virginia, and Kentucky, except that the Pittsburgh Coal locally is absent in the extreme southwestern outcrops of West Virginia, in Boyd and Lawrence Counties, Kentucky, and in Pleasants, Tyler, and Wetzel Counties, West Virginia. The Redstone Limestone near the base of the Monongahela Group is generally present in those areas where the Pittsburgh Coal is missing in West Virginia and serves as a clue to the top of the Conemaugh. The top contact of the Conemaugh is difficult to locate in Kentucky.

The Conemaugh Group in its type region is also used for the standard reference section of the Conemaugh Series as applied in a widely used time-stratigraphic scheme for division of the Pennsylvanian System.

The top and bottom contacts of the Conemaugh Series are conformable throughout the area of occurrence mapped in Figure 17. Diastems are locally present at the base of sandstones, presumably formed by stream channels.

The cyclothems of the Conemaugh Series contain more marine components than any other Series of the Pennsylvanian System in the Appalachians, but the cyclothems are still predominantly of the piedmont type. Northwestward toward the Northern Panhandle of West Virginia, certain cyclothems take on the characteristics of the delta facies rather than piedmont type of cyclothems described by Wanless and Shepard (1936).

The isopachous map of the Conemaugh Group in Figure 17 follows the one prepared by Arkle (1969, p. 86) for West Virginia. It shows only one major trend, thickening from 400 feet in Kentucky in an eastward direction to a maximum of 900 feet in the Georges Creek coal basin in Maryland. Conemaugh thickness is remarkably constant in the western half of the area, with thickness variation only slightly exceeding the variations possible as a result of measuring technique and correlation errors. The general north-south trend of the 600 to 900 feet isopachs with a steady increase to the east and loss of prominent marine strata in that direction suggest an eastern source of clastics in the latitude of Baltimore. Redbed facies patterns, to be described below, suggest that the Virginia-Carolina delta continued to be an active clastic source, but its influence is not apparent in the isopach pattern.

The isopachous map of Figure 17 resembles the Conemaugh Group isopachous map prepared by Branson (1962, p. 106), although his map has straighter isopach lines, perhaps as a result of more generalized thickness control.

Direct paleocurrent information from cross-beds is limited to the paper by Arkle (1969, p. 70, 86). Planar cross-beds of small to medium scale indicate generally northwesterly transport, although the Conemaugh rose-diagram shown by Arkle was based on only six measurements.

A detailed lithofacies and environmental map study of cyclothems

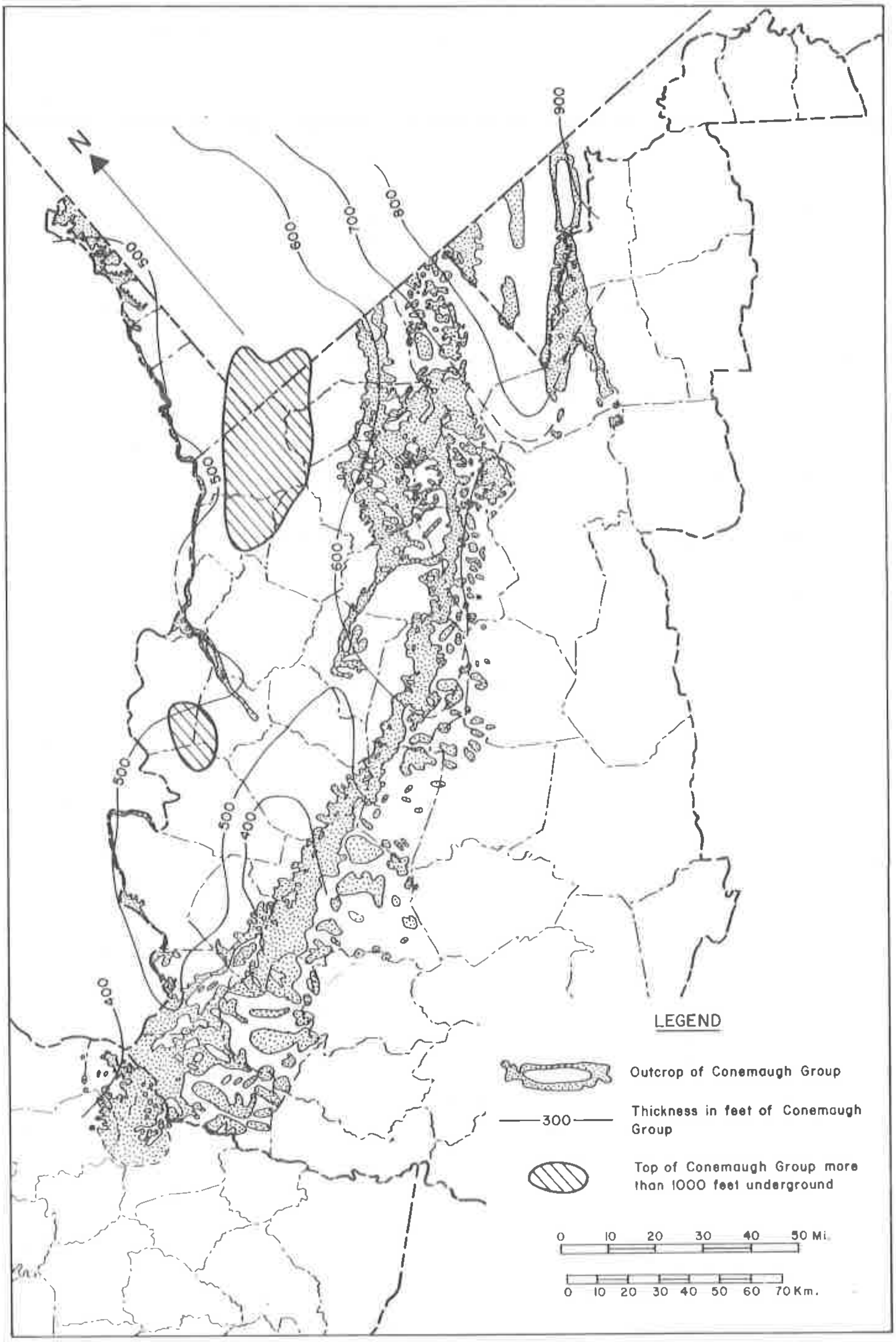


Figure 17. Outcrops and thickness of Conemaugh Group.

in the lower Conemaugh Group was done by Morris (1967) as a dissertation investigation. He envisioned southeastern and eastern clastic sources for most of West Virginia, with some clastics supplied to the Northern Panhandle from the north.

The Conemaugh Group was described in Braxton and Clay Counties, West Virginia by Hennen and Gawthrop (1917) near the middle of the region mapped in Figure 17. The following summary section from their report (p. 182-183) shows more redbeds than in most counties, but it can be otherwise cited as a rather characteristic expression of the Conemaugh Series for the entire region.

	Feet
Monongahela Group	
43. Coal, Pittsburgh	0-8
Conemaugh Group (635 feet)	
42. Fire clay and shale, sandy, brown	10-30
41. Sandstone, Lower Pittsburgh, massive, with quartz pebbles, gray	25-50
40. Coal, Little Pittsburgh	0-2
39. Shale, variegated, sandy	10-18
38. Sandstone, Connellsville, massive, medium-grained to coarse and pebbly, gray and brown	30-49
37. Coal, Little Clarksburg	0-1
36. Fire clay shale, Clarksburg	0-4
35. Limestone, Clarksburg	0-1
34. Sandstone, Lower Connellsville, massive, commonly pebbly, gray to brown	25-39
33. Coal, Normantown	0-1
32. Shale, Clarksburg Redbeds, red	20-30
31. Sandstone, Morgantown, massive, coarse, grayish brown	30-40
30. Shale, sandy	0-5
29. Limestone, Orlando, siliceous, shaly	2-3
28. Coal, Elk Lick	0-3
27. Fire clay and shale	0-4
26. Limestone, Elk Lick, shaly	0-4
25. Coal, West Milford	0-1
24. Shale, Birmingham, sandy reddish	20-29
23. Sandstone, Grafton, massive, coarse to pebbly, brown	25-40
22. Shale, Ames, dark green, contains marine fossils	0-5
21. Coal, Harlem	0-1
20. Fire clay shale	0-5
19. Limestone, Ewing, nodular, impure	0-5
18. Shale, Pittsburgh Redbeds, red with iron ore nuggets	15-20

		Feet
17.	Sandstone, Jane Lew, greenish-gray, lenticular	0-10
16.	Shale, Pittsburg Redbeds, red	5-15
15.	Sandstone, Saltsburg, massive, gray and brown; often replaced by red shale	20-30
14.	Coal, Bakerstown, multiple-bedded	0-5
13.	Fire clay shale and shale, sandy	0-5
12.	Sandstone, Buffalo, massive, gray; often almost entirely replaced by red sandy shale	50-59
11.	Shale, Brush Creek, with plant and marine fossils	0-5
10.	Coal, Brush Creek	0-1
9.	Fire clay shale	0-5
8.	Sandstone, Upper Mahoning, massive, coarse, pebbly, grayish brown	35-43
7.	Limestone, Sutton, yellowish gray, lenticular	0-2
6.	Shale, gray; sometimes carrying the lenticular Middle Mahoning Sandstone	0-10
5.	Coal, Mahoning, multiple bedded	0-2
4.	Fire clay, Thornton	0-5
3.	Sandstone, Lower Mahoning, massive, coarse, pebbly, grayish brown	35-43
2.	Shale, Uffington, dark-gray, sandy, with plant fossils	0-5
Allegheny Series		
1.	Coal, Upper Freeport, multiple-bedded	0-5

The only definite marine zones in this section are the Brush Creek Shale and Ames Shale, both of which grade into limestone farther to the north and northwest. All of the limestones in the preceding section are freshwater limestones between the basal sandstone and underclay members of the cyclothems.

The Conemaugh Group outcrops in West Virginia are described in the geologic reports for the following counties along the main northeast-southwest outcrop belts: Mineral and Grant (Reger and Tucker, 1924), Tucker (Reger, Price and Tucker, 1923), Randolph (Reger, 1931a), Preston (Hennen and Reger, 1914), Marion, Monongalia, and Taylor (Hennen and Reger, 1913), Harrison (Hennen, 1912), Barbour and Upshur (Reger and Teets, 1918), Lewis and Gilmer (Reger, 1916), Braxton and Clay (Hennen and Gawthrop, 1917), Webster (Reger, Tucker, and Buchanan, 1920), Nicholas (Reger, Price, Tucker, and Sisler, 1921), Roane (Hennen, 1911), Kanawha (Krebs, Teets, and Price, 1914), Boone (Krebs and Teets, 1915), and Cabell, Wayne, and Lincoln Counties (Krebs and Teets, 1913). The exposures in Mason County, at the Burning Springs anticline in Wood, Wirt, Ritchie, and Pleasants Counties, and along the Ohio River from Tyler to Hancock Counties are described generally in old county geologic reports, but the Conemaugh descriptions in the Ohio Valley summary volume by Cross and Schemel (1956a, p. 55-76) are much more detailed and reliable. They present summary columnar sections for the Conemaugh of Cabell, Wood, Gilmer and Hancock Counties, West Virginia, along with diagrams of specific outcrops.

The Conemaugh Group of Maryland is readily delimited by the thick Upper Freeport and Pittsburgh coals. The Upper Freeport is commonly 3-7 feet thick and the Pittsburg coal in Maryland ranges from 10 to a maximum thickness of 22 feet in the southern part of the Georges Creek coal basin. The Conemaugh stratigraphy of Maryland is described in reports by O'Hara (1900), Martin (1902a, 1902b), Clark and others (1905), Swartz (1922a, 1922b, and 1922c), Toenges and others (1949), Toenges and others (1952), and Amsden (1954, p. 53-65).

The Conemaugh Series is present in Greenup, Boyd, Carter, and Lawrence Counties, Kentucky, and possibly in the extreme eastern part of Elliott County on high hills. McFarlan (1943, p. 107-108, plate XXI) describes it briefly in a summary of the geology of Kentucky, regarding the Conemaugh Series as 450-600 feet thick in Kentucky. The Conemaugh is described in more detail in the summary stratigraphic column for three of the GQ series geologic quadrangle maps (Spencer, 1964; Carlson, 1965; and Sharps, 1967). The Upper Freeport coal clearly marks the top of the Allegheny Series in the Rush Quadrangle and is probably present in the Boltsfork Quadrangle, but in the Fallsburg Quadrangle the base of the Conemaugh Group is arbitrarily mapped at a yellowish gray, finely crystalline limestone midway between the Princess No. 8 and Brush Creek coals. The full thickness of the Conemaugh Series is preserved only in the Fallsburg, Prichard, Burnaugh, and Boltsfork Quadrangles. The top contact is placed at an underclay and fresh-water limestone which probably marks the Pittsburgh coal horizon. The Conemaugh Series in Kentucky is on the order of 410-480 feet thick (Sharps, 1967). Named members of the Conemaugh Series on these recently published geologic quadrangle maps are the Brush Creek Coal, Brush Creek Limestone, Ames Limestone, and Rough and Ready ore (limonite).

The Conemaugh Group strata consist of sandstone, siltstone, gray or redbed shale, fresh-water limestone, siderite nodules, marine limestone, and coal with varying amounts of associated marcasite. The rocks are arranged in a complex of laterally equivalent facies representing deposits on the alluvial plain, delta, tide-dominated shoreline, and bay deposits. The ordering of the vertical succession is slightly stronger than the persistence of lateral continuity at any time, so several approximate time surfaces can be identified, probably in response to major eustatic sea level shifts which resulted in nearly blanket deposits of certain coals and marine limestones and/or shales. The general stratigraphic column presented for the Conemaugh of Braxton and Clay Counties characterizes the succession of strata and can be used for time reference. In the following discussion stratigraphic horizons will be referred to in a time sense as approximately equivalent to some specific numbered unit in that summary column. The facies variation in that summary column is evident from the wide range of thickness of individual units, or even their total absence.

Different workers in the Appalachians have emphasized various aspects of the Conemaugh strata. Authors of the early county geologic reports were interested in geologic mapping and tracing coals and other marker beds as far as possible. Consequently they developed a multitude of names for marker beds and extended these names as far as possible, sometimes too far, as later work showed. The end result was a layer-cake stratigraphy which tended to make the rock units seem more persistent laterally than they actually are.

The cyclothem concept was first applied in the 1930's (Weller, 1930; Reger, 1931b; Wanless and Shepard, 1936; Wanless, 1947). The Pennsylvanian strata were shown to exhibit a remarkable vertical succession of stratigraphic units, with units present always in the same order, although certain units of the cyclothem may be locally missing. The Conemaugh Series shows the best development of marine and nonmarine components of all the Pennsylvanian strata in the Appalachians. A typical cycle averages about 70 feet thick. A given cycle can be divided into a lower regressed portion and an upper transgressive portion, frequently with a diastram at the base of the sandstone which marks the bottom of the cycle. Cause of this relative shift of sea level may be variable, including relative rates of sedimentation and subsidence of the basin, tectonic uplift pulses in a source area adjacent to a subsiding accumulation basin, or true eustatic sea level changes. Weller (1956) maintains that diastrophic control causes cyclothems. Wanless and Shepard (1936) first suggested that the pronounced development of cyclothems in Pennsylvanian strata resulted from sea level changes associated with expanding and receding polar ice caps during a late Paleozoic ice age. Such an interpretation is still attractive. The Conemaugh strata seem to show a much greater variation of sea level with more extensive shifts of shoreline than other Pennsylvanian strata in the Appalachians.

The tectonic factors which affected the accumulation basin were emphasized by Arkle (1969), who recognized a platform facies to the north of a geosynclinal facies; these reflected sediment accumulation thickness rather than water depth. He also emphasized a progressive northward shifting during the Pennsylvanian Period of the position of a marine embayment with deeper and more saline waters. Donaldson (1969a) showed that various tectonic lineaments and fractures recorded in the literature are related to the geometry of sedimentary patterns, so he concluded that those structural elements actively influenced the geometry of Pennsylvanian sedimentary bodies.

The latest approach has been to compare Recent Sedimentary environments with Pennsylvanian sediments, emphasizing the facies variation and its probable environmental cause. Studied by Morris (1967), Ferm and Cavaroc (1968), and Donaldson (1969a, 1969b) have stressed this approach in studying the Conemaugh Group in the region shown in Figure 17.

Paleontology has allowed some basis for separating time factors from environmental factors. A leaf flora zonation is generally established for the Pennsylvanian (Read and Mamay, 1964), with nine major floral zones in the Pennsylvanian (the zone of Neuropteris flexuosa spans the lower boundary of the Conemaugh and the zone of Lescuropteris spans the upper boundary). Palynologic analysis by the West Virginia Geological Survey scientists permits sufficient time resolution to distinguish most of the coal horizons in the Conemaugh Series. Paleocologic factors affecting Conemaugh spore or leaf assemblages have not been adequately studied. The marine fossil zones in the Conemaugh are not as distinctive as would be desired, since the waters generally were brackish and the number of genera present was limited. Fusulinids, which provide the most detailed marine zonation of the Pennsylvanian, are absent in the region of Figure 17. Insufficient study has been given to the ostracods and other invertebrates of the Conemaugh Group to permit reliable time zonation. Vertebrate fossils are too scarce to be useful in correlations within the region of Figure 17.

Each of these approaches has merits in understanding the true character of the Conemaugh Group. The following considerations relate certain lithologies to the search for potential uranium concentrations in the Conemaugh.

There were several advances of the interior sea over the region of Figure 17 during the Conemaugh Epoch. Marine inundations lasted longer, and were more frequent in the Northern Panhandle and Ohio River region than farther to the south, southeast, and east. The marine beds of the Brush Creek limestone and shale (unit 11 of summary Conemaugh column for Braxton and Clay Counties) and Ames limestone and shale (unit 22) extended farther south and east than the others, providing excellent time surfaces in the Conemaugh interval between the very persistent and essentially isochronous Upper Freeport and Pittsburgh coals. These coals probably represent invasion of swamp waters over a submerged delta plain, and the large areal extent of these two prominent coals probably formed at a time of moderate sea level rise causing the delta plain to be inundated by swampland. Other surfaces corresponding to times of sea level drop in excess of normal delta progradation are probably the Mahoning Sandstone group (units 3-8) which extend west into Ohio as massive sands beyond the usual westward limit of Conemaugh sands and the Clarksburg Redbeds (unit 32) and Pittsburgh Redbeds (units 16-18) which persist across the whole Appalachian basin, probably representing a time of general oxidation of exposed mudflats accompanying a eustatic lowering of sea level. Sea level fluctuations of lesser magnitude are represented by other less persistent, but regionally traceable coal horizons, marine limestones and shales, and redbed sequences. The eastward thickening of the Conemaugh Series is gradual between all these time marker horizons (Upper Freeport coal, Mahoning Sandstone group, Brush Creek marine zone, Pittsburgh Redbeds, Ames marine zone, Clarksburg Redbeds, and Pittsburgh coal), suggesting eastward thickening principally by facies change and introduction of coarser and thicker nonmarine clastic tongues rather than westward thinning by unconformable omission of strata.

The Mahoning and Buffalo Sandstones make a concentration of sand near the base of the Conemaugh, more similar to the sandstone abundance in the underlying Allegheny Group than to the overlying portions of the Conemaugh. Arkle (1969, p. 69) thinks that these lower Conemaugh sands may have formed principally in a southeastern depositional basin and that the basin center shifted northward in later Conemaugh time.

The sandstones of the Conemaugh are generally argillaceous and micaceous, but the Mahoning, Buffalo, and Saltsburg (units 3-8, 12, and 15) are locally quartzose and even pebbly, with their most quartzose development in Taylor and Preston Counties (Arkle, 1969, p. 70). The sandstones are probably chiefly low rank graywacke, although specific details on regional petrologic variation are not available. Individual sandstones vary in thickness, with common evidence of basal channeling, sometimes so deep as to merge with the next underlying sandstone (vertical stacking of channels). More commonly the channels are arranged in <u>en echelon</u> vertical order with offset stacking. Vertical stacking occurs in depositional areas with relatively rapid tectonic subsidence, while differential compaction in interchannel areas was the controlling factor in localizing offset stacking in areas with relatively slow tectonic subsidence (Donaldson, 1969a, p. 99). The northeast-trending shoreline probably shifted 125 miles northwest to southeast during marine transgressions and subsequent regression associated with delta progradation. The sandstone bodies of the Conemaugh probably represent alluvial channels and distributary channels (whose bottom was below the general level of the marine embayment, according to Donaldson, 1969a, p. 97). Paleostreams probably followed northwest and northeast fracture sets (Donaldson, 1969a). Conemaugh sandstone channels frequently contain reworked shale chips, limestone fragments and ironstone concretions and log or wood fragments in the basal portions. Quartz and feldspar pebbles sometimes are present. Conemaugh sandstones tend to be gray or greenish gray when unweathered; none are reddish in color (oxidizing facies).

The coals within the Conemaugh Group are not as persistent as the bounding Upper Freeport and Pittsburgh coals. The commercial Conemaugh coals (Mahoning, Bakerstown, Harlem, and Elk Lick) attain minable thickness only in or adjacent to the Allegheny Mountains, generally east of the 600 foot isopach in Figure 17. Minor coals are commonly lenticular deposits formed parallel to the distributaries during the constructive phase of delta growth; major and extensive coals form when there is a shift of a major river discharge to another location, resulting in an abandoned subdelta which subsided to permit a widespread coal swamp to grow on its surface (Donaldson, 1969a, p. 97). Higher sulfur content of the coal is probably concentrated in the swamp remote from the oxidizing waters of distributary channels.

Limestones in the Conemaugh Group may form some distance offshore accompanying marine transgressions, thereby having a diverse marine fauna; these grade landward into marine shales. Other limestones commonly are lenticular to nodular deposits associated with gray or reddish shales below underclay horizons formed in interdistributary lakes or in very brackish embayments; these commonly are algal or contain ostracods and Spirorbis, although lenticular limestones associated with the Birmingham and Pittsburgh Redbeds may contain rare marine fossils to the northwest in the Ohio Valley region.

Marine limestones are concentrated in three zones. The two most extensive are the Brush Creek Limestone (unit 11) and Ames Limestone (unit 22), but the Cambridge (Pine Creek) Limestone (at position of unit 13) is also rather extensive in northern West Virginia. Locally three distinct transgressive pulses of the Ames sea can be detected, producing three closely spaced marine limestone, known from base upward as the Ames, Gaysport and Skelly Limestones. The Skelly (at the position of unit 23) occurs between the Grafton and Upper Grafton Sandstone from Wayne to Pleasants County. There are also three different transgressive pulses associated with the Cambridge marine invasion: Lower and Upper Cambridge Limestones (both below the Bakerstown coal) and Portersville Limestone just above the Bakerstown coal. The Cambridge marine invasion is not as conspicuous in Maryland or adjacent West Virginia as the Brush Creek and Ames marine zones. Another possible marine invasion occurred associated with the Elk Lick coal (unit 28). The Orlando Limestone (unit 29) may be marine. Rare marine fossils in western counties are associated with the Birmingham Redbeds (position of unit 27). Marine fossils have been reported as rare in limestones associated with the Pittsburgh Redbeds (unit 16-18) in western counties, but this does not seem to represent a major change of sea level.

Other lenticular or concretionary limestones in the Conemaugh Group are probably fresh-water deposits, including the Sutton Limestone (unit 7), limestone nodules in the Pittsburgh Redbeds (unit 18), Ewing Limestone (unit 19), limestone nodules in the Birmingham Redbeds (unit 24), Elk Lick Limestone (unit 26), the Lower Clarksburg Limestone and limestone concretions associated with the Lower Clarksburg Redbeds (unit 32), the Upper Clarksburg (or Clarksburg) Limestone (unit 35) and Mona Limestone associated with the Upper Clarksburg Redbeds, the Lower Pittsburgh Limestone (position of unit 39) and the Upper Pittsburgh Limestone (position between units 40 and 41).

The Conemaugh Series is noted for being the oldest Pennsylvanian series containing important redbeds in the northern part of the

Appalachian basin. Redbeds occur in the Conemaugh Series at five horizons prominent enough to warrant special names: Mahoning Redbeds (about position of unit 6), Meyersdale Redbeds (unit 13), Pittsburgh Redbeds (unit 16-18), Birmingham Redbeds (unit 24), and Clarksburgh Redbeds (in two zones, units 32 and position just below unit 35). The Pittsburgh, Birmingham, and Clarksburg (both benches) redbeds are quite persistent over most of the area of Figure 17. The redbeds are always shale, commonly variegated, but with colors persisting deep into the subsurface. The Pittsburgh and Clarksburg Redbeds are commonly logged in sample studies of petroleum wells. The redbeds may grade laterally into or contain deposits of fresh-water limestone (Elk Lick and Ewing, units 26 and 19), probably accumulated in very shallow coastal waters, lagoons, or on broad delta plains which were occasionally submerged. The presence of ripple-marks, mud cracks, raindrop prints, and insect fossils indicates that the red muds were occasionally exposed to the air (Cross and Schemel, 1956a, p. 65). These reddish shales associated with nonmarine portions of cyclothems are the only oxidizing facies contained in the Conemaugh strata.

Conemaugh redbeds are more prominent in central and southern West Virginia than to the north and northeast, suggesting that they are less well developed in the deeper part of the basin. None of the sandstones is reddish, and none is even yellowish brown at depths beyond a few inches from the weathering surface; fresh sandstone is always greenish gray to gray.

The uranium protore potential of the Conemaugh Group is moderate, perhaps slightly better than the Allegheny and Pottsville Groups. The sandstones tend to be low rank graywacke rather than arkosic or orthoquartzitic. Carbonaceous material is present in channel sands, but coals are not as abundant as in the Allegheny and Monongahela Series. Oxidizing facies are present in at least five shale horizons, but all of the sandstones seem to be reduzate facies (greenish-gray to gray). The sandstones are permeable enough to yield petroleum in the subsurface, and gentle dips along outcrop belts could allow ground water circulation to establish uranium cells. No particularly favorable uranium areas can be established, except generally toward the south where oxidizing facies in the shales are more pronounced.

Monongahela Group

The Monongahela Group was named by H. D. Rogers (1840, p. 150) for a succession of coal-bearing strata exposed along the Monongahela River near Pittsburgh, Pennsylvania. Following separation of the Dunkard Group by I. C. White (1891, p. 20), the Monongahela Group was generally defined to include the strata from the base of the Pittsburgh coal to the top of the Waynesburg coal. Berryhill and Swanson (1962) modified this slightly by placing the top of the Monongahela at the base of the Waynesburg coal. These stratigraphic boundaries are easily recognized throughout the area shown in Figure 18, with the exception of parts of Pleasants, Ritchie, Tyler, and Wetzel Counties, West Virginia, where the Pittsburgh coal locally is absent. In those and adjacent areas the Redstone Limestone is well developed just above the Pittsburgh coal horizon.

The Monongahela Group in its type region is also used as the standard reference section of the Monongahela Series as applied in a widely used time-stratigraphic scheme for division of the Pennsylvanian System.

Berryhill and Swanson (1962) have divided the Monongahela Group into two formations in Washington County, Pennsylvania. These are the Pittsburgh Formation (base of Pittsburgh coal to the base of the Uniontown coal; 230-250 feet) overlain by the Uniontown Formation (base of Uniontown coal to base of Waynesburg coal; 55-70 feet). Roen (1969) has applied this nomenclature throughout the northern part of the Dunkard basin in Ohio, Pennsylvania, and West Virginia.

The complete range of Monongahela Group strata is present in Figure 18 only around and in the Dunkard basin, with the exception of the Georges Creek coal basin in Allegany County, Maryland. The exposures in Garrett County, Maryland, in Mineral, Grant, Preston, Lincoln, and Wayne Counties, West Virginia, and in Lawrence and Boyd Counties, Kentucky, all are outliers with only the basal Monongahela Group still remaining.

The top and bottom contacts of the Monongahela Group are conformable throughout the region mapped in Figure 18. The essentially isochronous nature of the Pittsburgh Coal is documented by two clay partings separated by 2-8 inches of coal which persist within the Pittsburgh coal bed over most of West Virginia, Ohio, Pennsylvania, and Maryland (Cross, 1954, p. 35-36). The only erosional breaks within the Monongahela Group are minor diastems locally present at the base of sandstones which may be channeled into the underlying beds.

The cyclothemic strata are of the piedmont facies (Wanless and Shepard, 1936), with no marine fossil zones known. Arkle (1959) recognized a general facies shift from a red facies in the south (red shales, non-red massive sandstones, thin or totally absent coals) to a gray facies in the north (gray shales, prominent fresh-water limestones, thin sandstones, thickest coals), with a geographically intermediate transitional facies (interlayered red and gray shales, thin limestones, thin coals, and non-red moderate development of sandstone). He envisioned northward drainage from an alluvial plain in the south across a delta toward fresh-water swamps and lakes in the vicinity of the Northern Panhandle of West Virginia.

The isopachous map of the Monongahela Group (Figure 18) follows one prepared by Arkle (1969, p. 87) for the Dunkard basin. In extreme western West Virginia, the Monongahela Group is about 250-300 feet thick. The section in Allegany County, Maryland, is 245 feet thick according to Swartz (1922c, p. 122), although Swartz (1922a, p.

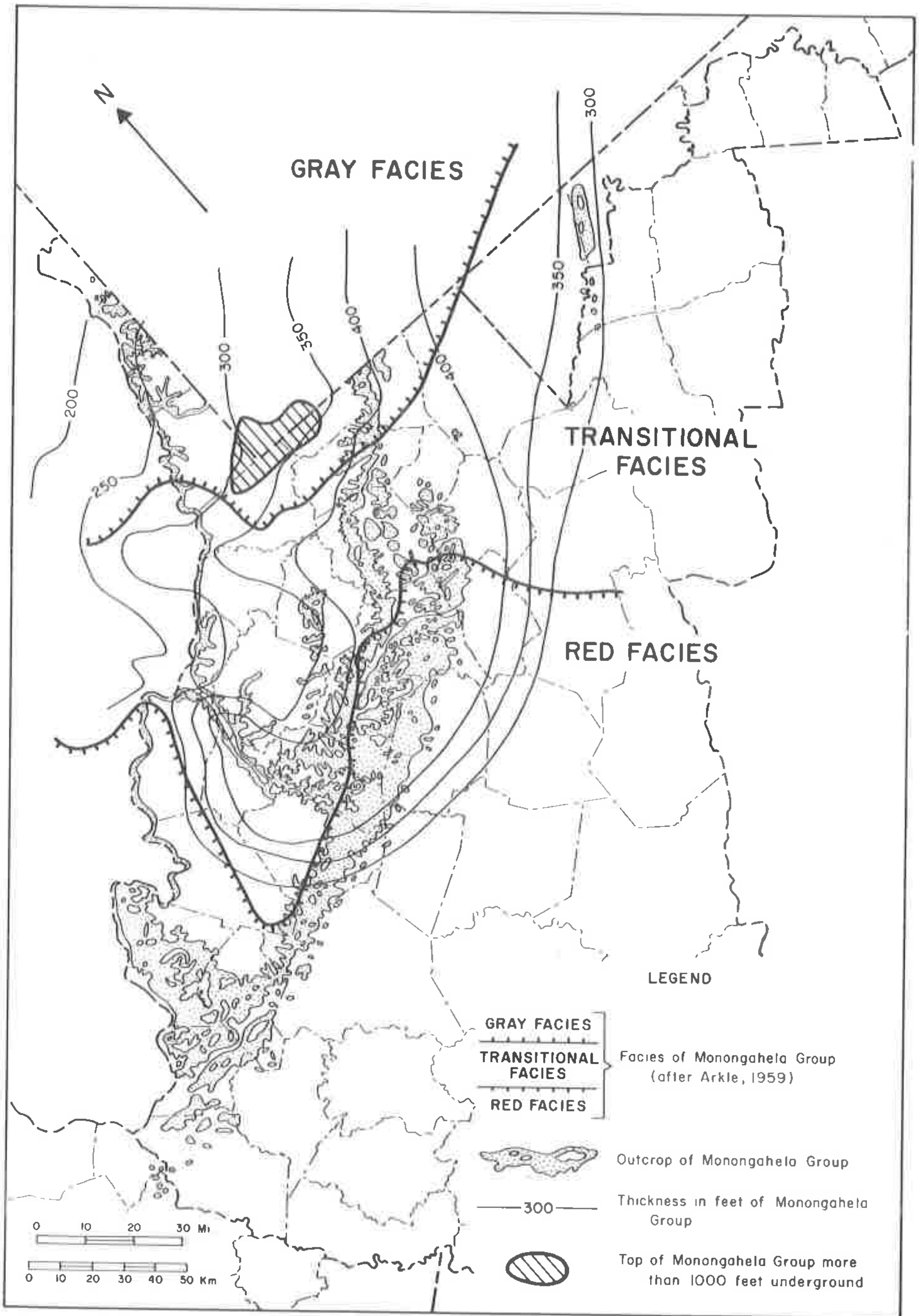


Figure 18. Outcrops and thickness of Monongahela Group.

71-72) questions whether the Waynesburg coal has been properly identified in Maryland so that the Monongahela Group may be thicker there. Arkle (1969, p. 71) favors a thinned Monongahela Series in Maryland. Berryhill and de Witt (1955) favor 336 feet for the Georges Creek coal basin in Maryland. A regional isopachous map of the Monongahela Group prepared by Branson (1962, p. 107) shows 400 feet thickness in Maryland, but otherwise seems to follow closely an earlier isopachous map for the northern Dunkard basin prepared by Arkle (1959, p. 124).

The isopach pattern of Figure 18 is quite simple, indicating a northeast-southwest axis of maximum thickness slightly southeast of the structural axis of the Dunkard basin and the axis of maximum preserved thickness of the Dunkard Group strata (Fig. 19). If the interpretation of eastward thinning of the Monongahela Series toward Maryland is correct, then the Monongahela Epoch was characterized by maximum tectonic downwarping along an axis trending southwest across West Virginia from Monongalia toward Roane County. Location of this tectonic axis considers not only thickness, but also the inferred elevation of a delta surface which sloped generally northward, causing a slight clockwise rotation of the tectonic axis from one envisioned using isopachs only. The surface of the Pittsburgh coal swamp was essentially level and just above sea level. This tectonic axis of maximum downwarping during the Monongahela Epoch is so similar in orientation to the structural axis of the Dunkard basin that one is led to conclude that the major downfold of the Dunkard basin was beginning to take shape as early as the Monongahela Epoch. Continued subsidence of the Dunkard basin during Dunkard Group deposition accentuated the earlier warping, and the entire basin was tectonically folded after Dunkard deposition by the Alleghany orogeny, which produced several minor anticlines in addition to the more pronounced fold of the Burning Springs anticline.

Monongahela Group strata in Maryland are preserved only in the Georges Creek and Upper Potomac synclinal basins where they have been described by O'Harra (1900), Martin (1902a, 1902b), Clark and others (1905), Swartz (1922a, 1922b, 1922c), Amsden (1954, p. 65), Berryhill and de Witt (1955).

The following summary stratigraphic section for the Georges Creek coal basin (after Swartz, 1922c, p. 121) probably can be best assigned to the transitional facies of Arkle (1959) because of the moderately prominent sandstone, plus significant thickness of coal and limestone, even though redbeds are not specifically mentioned in any of the Monongahela Group literature for Maryland.

	Feet
Dunkard Group	
30. Washington Coal	3.5
29. Concealed	10
28. Limestone	2
27. Concealed	40
26. Waynesburg "A" coal	2

		Feet
25.	Waynesburg Sandstone and shale	39
24.	Waynesburg Coal (Koontz coal)	4
Monongahela Group (241 feet)		
23.	Fire clay	5
22.	Waynesburg Limestone	9
21.	Shale and siliceous fire clay	12
20.	Uniontown Sandstone and shale	22.5
19.	Uniontown Coal	0.5
18.	Shale and sandstone	13
17.	Benwood Limestone, replaced locally by Upper Sewickley Sandstone	8
16.	Fire clay	7
15.	Upper Sewickley Sandstone	14
14.	Upper Sewickley Coal	5
13.	Fire clay and shale	5
12.	Lower Sewickley Sandstone and shale	20
11.	Lower Sewickley (Tyson) Coal, upper bench	2
10.	Sandstone and shale	15.5
9.	Lower Sewickley (Tyson) Coal, lower bench	2.5
8.	Fire clay and shale	10
7.	Sewickley Limestone	5
6.	Cedarville Sandstone and shale	20
5.	Redstone coal, with sandstone and shale parting	7
4.	Fire clay and shale	13
3.	Upper Pittsburgh Sandstone	15
2.	Pittsburgh Coal	10
Conemaugh Series		
1.	Shale	3

It is possible that the boundary between the gray and transitional facies should pass south of the Georges Creek coal basin. If so, it probably should pass through Tucker County, West Virginia, because the Mineral and Grant County exposures represent only the lower Monongahela Group, where redbeds are absent, as is common in most sections in northern West Virginia.

Berryhill and de Witt (1955) contend that Swartz (1922a, p. 72; 1922c, p. 121) misidentified the Uniontown, Waynesburg and Washington coals in this columnar section. Well-preserved plant fossils overlying the Koontz coal (bed 24) at Lonaconing, Allegany County, Maryland, contain Danaetites emersoni, Neuropteris scheuchzeri and several species of Pecopteris, all of which indicate a late Pennsylvanian age for the Koontz coal, not Permian (Dunkard Series). They would label unit 19 as an unnamed coal, call unit 24 the Uniontown coal and identify unit 30 as the Waynesburg coal. Such an interpretation would make the

Monongahela Series 336 feet thick in the Georges Creek coal basin, and produce only a slight eastward thinning in the isopach pattern in Figure 18. As early as 1903, I. C. White (1903, p. 145-146) favored an interpretation similar to Berryhill and de Witt (1955). Arkle (1969, p. 71) apparently preferred an older interpretation by White (1891, p. 56).

The Monongahela Group in West Virginia is described in geologic reports for the following counties: Mineral and Grant (Reger and Tucker, 1924), Tucker (Reger, Price, and Tucker, 1923), Monongalia and Marion (Hennen and Reger, 1913), Harrison and Doddridge (Hennen, 1912), Barbour and Upshur (Reger and Teets, 1918), Lewis and Gilmer (Reger, 1916), Braxton and Clay (Hennen and Gawthrop, 1917), Kanawha (Krebs, Teets, and Price, 1914), Cabell, Wayne, and Lincoln (Krebs and Teets, 1913), Jackson, Mason, and Putnam (Krebs, 1911), Wirt, Roane, and Calhoun (Hennen, 1911), Pleasants, Wood, and Ritchie (Grimsley, 1910), Marshall, Wetzel, and Tyler (Hennen, 1909), and Ohio, Brooke and Hancock Counties (Grimsley, 1907). Cross and Schemel (1956a, p. 54) show diagrammatic summary sections for the Monongahela Series in Ohio, Wood, Gilmer, and Putnam Counties, plus other stratigraphic sketches of the Monongahela Group (p. 62, 64, 66, 70, 75, and 76). Nearly continuous exposures of the Monongahela Group extend for several miles along the Ohio River valley near Wheeling, Ohio County, West Virginia. The Monongahela strata have been diagrammed in great detail in a series of stratigraphic cross sections by Streib and Donaldson (1969) to show the facies changes in the Wheeling 15-minute quadrangle.

The following is a summary section of the Monongahela Group in Braxton and Clay Counties (Hennen and Gawthrop, 1917, p. 44, 171). This is located well within the red facies of the Monongahela as delimited by Arkle (1959). Even though this is the red facies, note that redbeds are limited to shales at a few horizons; no redbeds are recorded at any other position in the several detailed sections measured in the two counties.

	Feet
Dunkard Group	
30. Coal, Waynesburg "A", trace	1
29. Sandstone, Waynesburg, massive, coarse, grayish brown	30
28. Coal, Waynesburg, not seen in covered interval	0-1?
Monongahela Group (400 feet)	
27. Shale, locally red	0-10
26. Sandstone, Gilboy	20-25
25. Shale	10-15
24. Sandstone, Uniontown, flaggy to massive, green to gray	30-40
23. Shale, Annabelle	5-8
22. Coal, Uniontown	0-2

		Feet
21.	Shale	2-4
20.	Limestone, Uniontown, shaly, impure	0-1
19.	Shale, red, with limestone nuggets	20-30
18.	Sandstone, Arnoldsburg, massive, coarse, locally pebbly gray	25-40
17.	Coal, Lower Uniontown	0-1
16.	Shale, red with limestone nuggets	20-24
15.	Sandstone, Sewickley, massive, coarse, very pebbly, gray	40-59
14.	Coal, Sewickley	0-1
13.	Shale	5
12.	Sandstone, Lower Sewickley, massive to flaggy, gray	20-30
11.	Limestone, Sewickley, ferriferous, shaly and impure, reddish	0-2
10.	Shale	5-7
9.	Sandstone, Cedarville, massive, medium-grained, gray	30-40
8.	Coal, Redstone	0-1
7.	Shale	0-5
6.	Sandstone, Weston, massive, gray	20-26
5.	Limestone, Redstone	0-5
4.	Shale, Weston	10-12
3.	Coal, Pittsburgh	0-8
Conemaugh Series		
2.	Fire clay and shale, sandy brown	10-30
1.	Sandstone, Lower Pittsburgh, massive, with quartz pebbles, gray	20-50

Coals and limestones are much thinner than to the north, and the sandstones are thicker and coarser.

No summary section is given for the Monongahela Series in the Kanawha County report but in detailed local sections (Krebs, Teets, and Price, 1914, p. 67-75, 109-111, 116-120) there is increased red-bed coloration of the shales to the southwest in Kanawha County as compared with Braxton and Clay Counties. In Kanawha County reddish shales are introduced or become thicker at the positions of units 27 and 26 and probably unit 10 in the Braxton and Clay County summary section just presented.

The same general character as in Kanawha County persists westward across Lincoln and Cabell to Wayne County; the redbeds are all shales or sandy shales (siltstone ?), coals are not recorded, some of the sandstones are conglomeratic, and the Pittsburgh coal thins and locally disappears, to be marked usually by a fire clay. The following section was measured three miles northeast of Milton, Cabell County (Krebs and Teets, 1913, p. 86-87).

	Feet
Dunkard Series	
14. Sandstone, buff, friable (Waynesburg)	31
13. Fire clay (Waynesburg coal)	1
Monongahela Series (239 feet)	
12. Dark red limy shale	3
11. Sandstone, fine grained, shaly (Gilboy)	20
10. Sandstone, friable (Gilboy)	40
9. Dark red shale	5
8. Sandy shale and sandstone (Uniontown)	30
7. Dark red shale	5
6. Sandy shale	12
5. Dark red shale	3
4. Sandstone, massive (Arnoldsburg)	45
3. Red and sandy shale	10
2. Sandstone, buff to gray, conglomeratic in middle part. (Pittsburgh Sandstone).	65
1. Fire clay (Pittsburgh coal horizon)	1

Some limestones or limy shales are reported associated with the redbed shales in nearby sections; coals are absent in all of the Monongahela Series sections described in Cabell Connty, although their position may be indicated by fire clays.

Northward along the Ohio River and Burning Springs anticline outcrop belts there is a gradual change (Figure 18) from the redbed facies to the transitional facies, and in the Northern Panhandle of West Virginia to the gray facies. No detailed written descriptions of measured sections of the gray facies in the Northern Panhandle of West Virginia occur in the literature. Cross and Schemel (1956a, p. 62) show an excellent detailed sketch of the Monongahela and lower Dunkard Group near Short Creek, Brooke County; no redbeds are indicated, the sandstones are all less than five feet thick except the 33 feet of interbedded sandstone, siltstone and shale labeled as the Lower Sewickley Sandstone. The following section at Wheeling, Ohio County, modified from Grimsley (1907, p. 39) is too old to show much detail, yet it is the most detailed one in the literature to convey the essential traits of the gray facies of the Monongahela Series.

	Feet
Dunkard Group	
20. Coal. Waynesburg Coal	2
Monongahela Group (262 feet)	
Uniontown Formation (48 feet)	
19. Shale, with black shale streak at base	6
18. Shale, buff	4
17. Sandstone, shaly	3
16. Shale, buff	3
15. Limestone, gray. Waynesburg Limestone.	2
14. Thin sandstone and shales	30

		Feet
13.	Coal blossom. Uniontown Coal horizon.	0.7
Pittsburgh Formation (214 feet)		
12.	Sandstone	0.5
11.	Shale, buff	6
10.	Limestone. Uniontown Limestone.	4
9.	Shale, buff and sandstone	41
8.	Shale, green	4
7.	Limestone and shale. Benwood Limestone.	86
6.	Coal. Sewickley Coal.	0.5
5.	Limestone. Sewickley Limestone.	33
4.	Coal. Redstone Coal.	0.7
3.	Shale	10
2.	Coal. Pittsburgh Coal.	7
Conemaugh Group		
1.	Sandstone	35+

The Monongahela Formation was first identified in Kentucky as a result of the recent geologic quadrangle mapping program. It is mapped in the Burnaugh (Spencer, 1964), Fallsburg and Prichard (Sharps, 1967) quadrangles and probably is present in the Rush quadrangle (Carlson, 1965). No named units are recognized within the Monongahela of Kentucky, so it is accorded the status of Formation. The maximum preserved thickness of the Monongahela Formation in Kentucky is about 140 feet in the Prichard quadrangle, with the upper beds of the Monongahela missing by erosion from the hilltops. Lithologies in the Monongahela Formation of the Prichard quadrangle include red, maroon, and gray shale; greenish-gray to brownish-gray siltstone; and gray to brown, fine- to medium-grained sandstone, calcareous in part. Reddish shale occurs within two units in the lower 95 feet of the Monongahela Formation. The base of the Monongahela in the Prichard quadrangle is placed at the top of an underclay which presumably marks the horizon of the Pittsburgh Coal.

Paleontologic correlations within the Monongahela Series are imprecise, and lithostratigraphic correlations are difficult because of facies changes. The Pittsburgh Coal, Redstone Coal, Benwood Limestone, Uniontown Coal, and Waynesburg Coal appear to approximate time surfaces, but the intervening clastics are complicated by facies changes. The coals can be recognized by spore assemblage. Two major leaf floral zones occur in the Monongahela Series (Read and Mamay, 1964); the Lescuropteris zone spans the upper Conemaugh and lower Monongahela Series, and the Danaeites flora distinguishes the upper Monongahela Series. Marine faunas are unknown, and the limited fresh-water invertebrate faunas have not been used for zonation. Vertebrate remains are too scarce to be useful for correlations within the Monongahela Series of the Appalachian basin.

The facies patterns delimited by Arkle (1959) suggest a regional paleoslope to the north during the Monongahela Epoch, with fluvial sandstones and red overbank mud deposits giving way to the north into chiefly swamp and lake deposits of gray shale, coal and fresh-water limestone which characterize the gray facies. Fourteen cross-bed measurements by Arkle (1969, p. 87) suggest a transport direction toward the north or northwest. Paleocurrent determination by ostracod orientation measurements in shale associated with the Redstone Limestone at Mill Fork, Ohio, adjacent to Pleasants County, West Virginia, also indicated northward moving currents (Jones and Clendening, 1968, 1969). Donaldson (1969a) indicates northward to northwestward paleoslope during the early Monongahela Epoch as indicated in a series of 15 paleogeographic maps of West Virginia, Ohio, and Pennsylvania, showing a series of shallow-water deltas (Guadalupe-type) forming in a very low salinity bay or lake.

Stratigraphic facies diagrams of the Monongahela Series extending northwest and northeast through Marion County, West Virginia, are presented by Arkle (1969, p. 88). Hoover, Malone, Eddy, and Donaldson (1969) present an east-west stratigraphic section through the same area, accompanied by regional isopachous maps of several coals and sandstones. Donaldson (1969a, p. 110) shows a detailed stratigraphic cross section extending northeastward across Ohio. Detailed stratigraphic variation within a limited area is described by Streib and Donaldson (1969) for the Wheeling 15-minute quadrangle in Ohio and West Virginia and by Donaldson, Kirr, Hughart, Nordeck, and Heffner (1969) for the Blacksville 15-minute quadrangle in West Virginia and Pennsylvania.

The sandstones of the Monongahela Group appear to be all fluvial channel sands deposited by northward to northwestward flowing rivers, passing from alluvial plains in the south and southeast to delta distributaries built out into a lake or bay with very low salinity to the north. Sandstones diminish in abundance and thickness toward the upper part of the Monongahela Group. Sandstones thicken and coarsen to the south; all are gray or greenish gray in color (reduzate facies) with no indication of redbed coloration in the sandstones. Petrographic details are not available, but the sandstones seem to be low rank graywackes. The Monongahela Group is not as sandy as the underlying Conemaugh Group. Donaldson (1969a, p. 101, 114) has shown that the Pittsburgh, Lower Sewickley, and (Upper) Sewickley sandstones of the Monongahela Group and the Waynesburg Sandstone of the basal Dunkard Group tend to be vertically stacked into three large "lobes" with offset stacking between successive individual sandstone belts within "lobes." Donaldson believes these probably represent the deposits of one large river which shifted periodically to form three major sites of subdelta accumulation centered in Mason, Pleasants, and Marion Counties, West Virginia.

Limestones in the Monongahela Group are all fresh- or very brackish-water. The worm Spirorbis, the branchiopod Estheria, some fresh-water pelecypods and ostracods are the only invertebrates. The

Benwood Limestone (and interbedded shale) is the thickest (as much as 86 feet) and most extensive limy zone, but other fresh-water limestones from base upward are the Redstone and Fishpot below the Benwood zone and the Uniontown and Elm Grove near the top of the Monongahela Group. In some places the sand-bearing river distributaries entered directly into the lakes, with only a thin belt of delta margin clastics separating the limestone from sandstone (Donaldson, 1969a). These marginal areas may be favorable spots for uranium concentration in sandy zones with associated organic debris adjacent to the limestones in the lakes. There is some resemblance of this setting to the Jurassic Todilto Limestone with its uranium ore in New Mexico (Gableman, 1956, p. 388-400).

The extensive coals of the Monongahela Series (Pittsburgh, Redstone, Sewickley, and Uniontown) probably represent approximate time surfaces related to sea-level changes or abandonment of active delta areas to form subsiding swamps. Minor coals probably formed in interdistributary swamps. Coals are best developed in the north near sea or lake level during the Monongahela Epoch, and coals disappear southward to become marked by underclay streaks in reddish shale or totally lost in the shale.

In the Dunkard basin the gray facies is characterized by a total absence of redbeds. Reddish coloration is present in a few shales in the intermediate facies and red shales exceed gray shales within the Monongahela Group in the red facies. Redbeds are seldom developed between the Redstone and Pittsburgh coal horizons, and seem to occur at that position only in Lincoln, Cabell, Wayne, Mason, Putnam, Jackson, Roane, and possibly Wirt and Calhoun Counties, West Virginia, and in Boyd and Lawrence Counties, Kentucky. The reddish shale which persists farthest north on the east edge of the Dunkard basin is in Marion County above the Benwood Limestone and below the Uniontown coal. In the Ohio River outcrop belt redbeds persist farthest north in the same horizon between the Benwood Limestone and Uniontown Coal in Tyler, Marshall, and Wetzel Counties, with an indication of redbeds above the Uniontown Coal horizon in one well in southern Marshall County (Hennen, 1909, p. 266). All the redbed coloration occurs in shale in the Monongahela Group clastics, with no indication of reddish sandstones.

Branson (1962, p. 106) has characterized an ideal Monongahela Group cyclothem as consisting of the following vertical sequence:

7. roof shale
6. coal
5. underclay
4. fresh-water limestone
3. red claystone
2. mudstone
1. sandstone

This sequence is best developed in cycles in the intermediate facies, with a total of 6 or 7 cycles in the Monongahela Series. Units 4 through 7 tend to drop out, from the top downward, as one proceeds farther south or southwest into the red facies, while units 1 through 3 become thicker in that direction. This may be partly because sandstones have channeled deeper in locations higher on the delta or alluvial plain, but it also is caused by the fact that extensive coal and limestones formed only in swampy or open water at elevations near sea level.

Cross and Schemel (1956a, p. 38) describe a characteristic cyclothem in the Monongahela Series with 11 members.

The Monongahela Group probably has only a modest potential as a uranium protore. The sandstones are not as coarse and massive as lower in the Pennsylvanian System. The sandstones are probably nearly all low rank graywacke, which is not feldspathic enough for good protore. Not enough petrographic work has been done to evaluate adequately the mineralogic content of the sandstones. The sandstones are all of the reduzate facies. Organic matter occurs as coals and coaly streaks in the Monongahela Group, but these disappear to the south as the strata become dominantly alluvial in character. Probably the greatest promise for uranium occurrence is in the area marked red facies in Figure 18, with less possibility in the intermediate facies, and very small possibility of commercial uranium in the gray facies. The detailed paleogeographic maps mentioned in preceding paragraphs should be helpful in locating the most favorable areas for uranium prospecting. The gentle dips of the Monongahela strata would favor ground water migration for long distances along sandstone channels. The channels trend north to northwest. Ground water circulation probably is inhibited in a direction perpendicular to sandstone channel trends.

Dunkard Group

The Dunkard Group was named by I. C. White (1891, p. 20, 22) for exposures along Dunkard Creek, Greene County, Pennsylvania, where a thickness of 1,162 feet is present from the top of the Waynesburg Coal to the youngest strata on the surrounding knobs. The Dunkard Group is the youngest sequence of Paleozoic strata in the Appalachians, with an age at the base approximating the Pennsylvanian-Permian boundary. Most authors believe that the younger beds almost certainly range up into the lower Wolfcampian of the Permian. The base of the Dunkard Group has usually been placed at the top of the Waynesburg Coal, but Berryhill and Swanson (1962) modified this procedure by defining the base of the Waynesburg Coal as the base of the Dunkard Series.

The Dunkard Group is comprised of two formations named for counties in southwestern Pennsylvania by Stevenson (1876, p. 34K-56K) fifteen years before the term Dunkard was proposed. Stevenson originally called them the Greene County Group and the Washington County Group, but through the years they came to be known as the Greene and

Washington Formations. The top of the Upper Washington Limestone separates the Greene Formation from the underlying Washington Formation. In 1962, Berryhill and Swanson restricted the definition of the Washington Formation in Washington County, Pennsylvania, so it now ranges from the base of the Washington Coal to the top of the Upper Washington Limestone (160-180 feet thick). For a new lowest formation in the Dunkard Group they proposed the name Waynesburg Formation (100-130 feet thick) ranging from the base of the Waynesburg Coal to the base of the Washington Coal. Roen (1969) has advocated that this tripartite division of the Dunkard Group into Waynesburg, Washington, and Greene Formations be applied throughout the northern part of the Dunkard basin in Ohio, Pennsylvania, and West Virginia. The most detailed summary column for the Dunkard Group in West Virginia was presented by Hennen and Reger (1913, p. 165-166, 216). It is reproduced below with the division of the Dunkard into formations as advocated by Roen (1969). Geographic names applied to members are indicated in parentheses.

	Feet
Dunkard Group (1,185 feet)	
Greene Formation (791 feet)	
71. Sandstone, flaggy (Upper Proctor)	40
70. Shale	15
69. Sandstone (Middle Proctor)	25
68. Shale	10
67. Sandstone, massive, green, micaceous (Lower Proctor)	25
66. Shale, red and variegated	35
65. Limestone (Windy Gap)	5
64. Sandstone, massive (St. Cloud)	20
63. Shale, sandy	4
62. Coal, slaty (Windy Gap)	0.2-1.0
61. Fire clay, shale, red, and variegated, with layers of limestones and sandstones	80
60. Sandstone, massive (Gilmore)	30
59. Coal (Gilmore)	1
58. Limestone (Gilmore)	1
57. Shale, variegated and red, with thin sandstones	93
56. Limestone (Upper Rockport)	5
55. Sandstone (Taylor)	30
54. Limestone (Middle Rockport)	5
53. Sandstone and shale, buff and red	29
52. Coal (Nineveh "A")	0.2-1.0
51. Limestone (Lower Rockport)	5
50. Shale, brown and variegated	15
49. Sandstone, massive, coarse and brown (Nineveh)	25

		Feet
48.	Shale	1-4
47.	Coal (Nineveh)	1
46.	Fire clay and limy shale	10
45.	Limestone (Nineveh)	5
44.	Shale, variegated and red	30
43.	Sandstone, massive (Burton)	29
42.	Coal (Hostetter)	1
41.	Shale, sandy, with thin sandstones	60
40.	Sandstone, massive (Fish Creek)	34
39.	Coal (Fish Creek)	1
38.	Fire clay shale (Fish Creek)	5
37.	Shale, sandy and red, with thin sandstones	29
36.	Sandstone, massive (Rush Run)	25
35.	Shale, sandy	5
34.	Coal (Dunkard)	1
33.	Fire clay and shale, red, sandy and variegated	29
32.	Sandstone (Jollytown)	20
31.	Coal (Jollytown)	1
30.	Fire clay	1
Washington Formation (239 feet)		
29.	Limestone (Upper Washington)	4
28.	Shale, limy	5
27.	Sandstone (Hundred)	34
26.	Coal (Hundred)	0.4-1.0
25.	Fire clay and red and variegated shale	34
24.	Sandstone (Upper Marietta)	50
23.	Coal (Washington "A")	1
22.	Shale, red (Creston)	60
21.	Limestone (Middle Washington)	5
20.	Sandstone (Lower Marietta)	40
19.	Limestone (Lower Washington)	2
18.	Coal (Washington)	3
Waynesburg Formation (155 feet)		
17.	Fire clay shale (Washington)	10
16.	Limestone (Bristol)	2
15.	Sandstone (Washington)	10
14.	Coal (Little Washington)	1
13.	Shale	7
12.	Sandstone (Mannington) (Waynesburg "B" coal horizon near middle)	45
11.	Shale	4
10.	Coal (Waynesburg "A")	1
9.	Fire clay and shale	3
8.	Limestone (Mt. Morris)	2

		Feet
	7. Shale	12
	6. Sandstone, coarse, brown and pebbly (Waynesburg)	45
	5. Limestone, dark flaggy (Elm Grove)	3
	4. Shale, dark, sandy with fossil plants (Cassville)	5
	3. Coal (Waynesburg)	5
Monongahela Group		
	2. Shale	10
	1. Sandstone (Gilboy)	35

Many of these named units are lenticular and commonly are locally absent, so the stratigraphy is not nearly so layer-cake as this nomenclature would suggest. There are also two types of violations to the formal Code of Stratigraphic Nomenclature: 1) the same geographic name is used for more than one lithologic unit of member rank, and 2) the same geographic name is applied to both members and formations. It is not the aim of this paper to offer solutions to these discrepancies.

Arkle (1959) has recognized a southern red facies (shales predominantly red, other beds non-red), a transition facies, and a northern gray facies (no redbeds; all shales are gray) within the Dunkard Group. He shows these facies boundaries for his Washington Formation (Waynesburg plus Washington Formation as used in the present paper) and for the Greene Formation; these boundaries shift progressively northward from the Monongahela Epoch through the lower Dunkard to the Greene Formation in the Upper Dunkard. Arkle's (1959) facies boundaries for the Greene Formation are reproduced in Figure 19 to show the maximum extent of this northward shift.

The thickness values isoplethed in Figure 19 show the preserved thickness of the remaining Dunkard Group; they reflect mainly the structural folding of the Dunkard basin, since the hilltops of the region are accordant and represent a peneplain dissected by a dendritic stream pattern into a region of mature relief with valleys 300-500 feet deep.

Berryhill (1967b) estimates an original maximum thickness of 3,500-4,000 feet of Dunkard strata, based on lithologic trends within the Dunkard Group and the rank of the Pittsburgh Coal. Erosion truncated the Dunkard to its preserved thickness.

Arkle (1959, p. 125-126) presents separate maps showing thickness of the Washington Series (base of Waynesburg Coal to top of Upper Washington Limestone) and the thickness from top of Upper Washington Limestone to the top of the Lower Rockport Limestone. Berryhill (1967a, plate 1; 1967b, plate 12) also presents isopachs of the Washington Formation (equals Waynesburg plus Washington Formations of Berryhill and Swanson, 1962).

The age of the Dunkard Group has been very controversial, ranging in estimate from totally Permian to totally Pennsylvanian, with the bulk of the recent literature suggesting that the Waynesburg

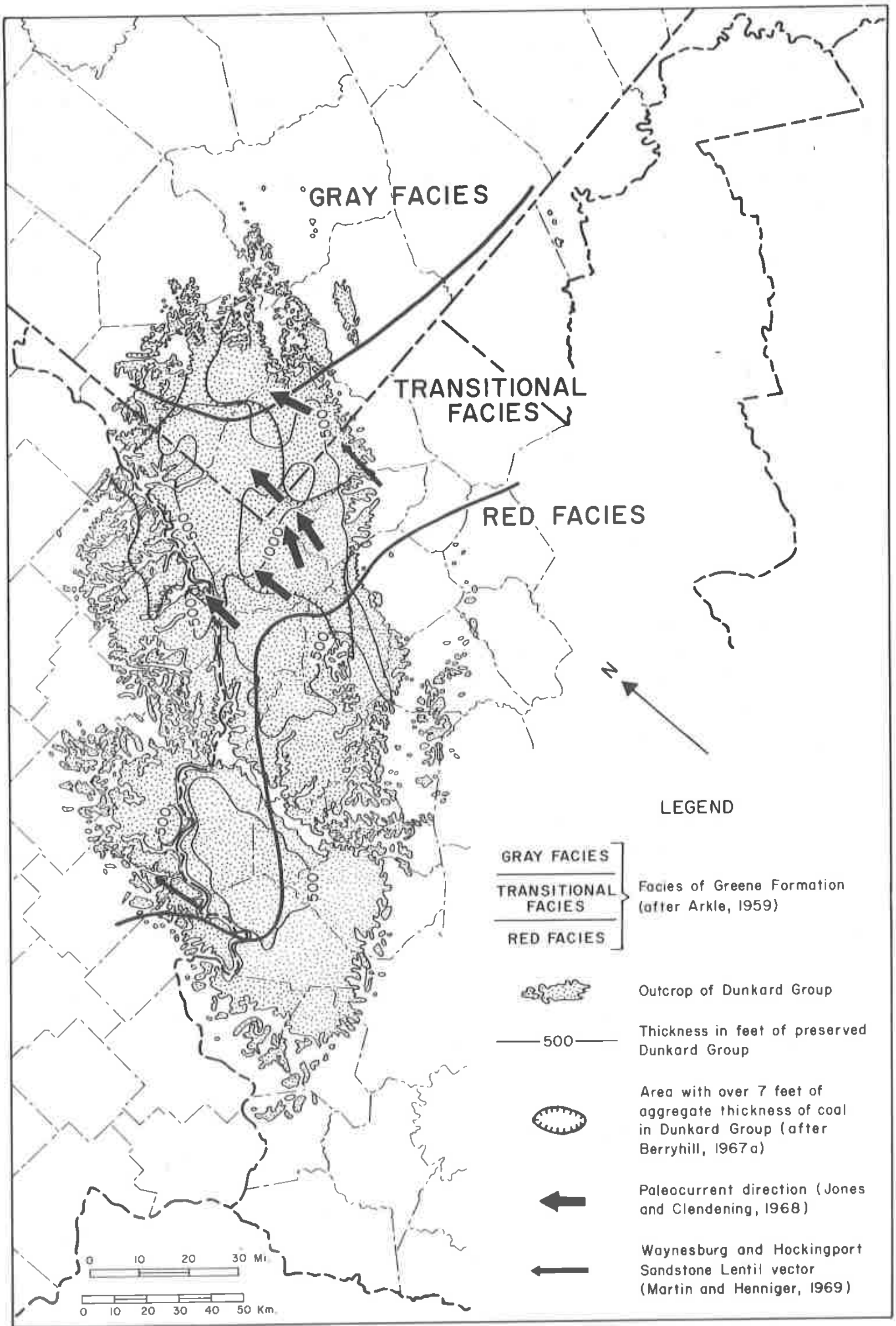


Figure 19. Outcrops and preserved thickness of Dunkard Group.

Formation is late Pennsylvanian and that the Washington Formation (restricted) and Greene Formation are Permian. The early West Virginia Geological Survey publications followed the dictates of I. C. White, who believed the entire Dunkard was Permian. Fontaine and White (1880) initially proposed that the Dunkard is entirely Permian. This is based on their reported discovery of Callipteris conferta in the Cassville Shale at its type locality in Monongalia County, West Virginia. Callipteris is considered by most specialists to be a reliable Permian index genus. Callipteris is not known below the Washington Coal at other localities, and the Cassville Shale type locality has failed to yield additional specimens to confirm Fontaine and White. The Callipteris zone of Permian age is recognized in the Upper Dunkard in the late Paleozoic floral zonation summary by Read and Mamay (1964). Good discussions of the early work on the age of the Dunkard are presented by White (1903, p. 119-123) and Grimsley (1907, p. 69-77). Berryhill (1967c) concludes that the base of the Permian operationally is best placed at the top of the Waynesburg Coal, with the Dunkard rocks below the Washington Coal as transitional, with age designated Pennsylvanian and Permian. Clendening (1969) reviews the Dunkard controversy and rejects the idea that Callipteris must be totally Permian; he envisions that the genus first appeared in the late Pennsylvanian. Clendening concludes that the entire Dunkard is Upper Pennsylvanian, based on his own spore work done for a dissertation at West Virginia University. Romer (1952) favors Lower Permian for both the Washington and Greene Formations. He notes that the Dunkard vertebrate fauna has more fish and tetrapods associated with pools and swamps than the drier Lower Permian fauna of Texas and Oklahoma. Eryops, the common layrinthodont amphibian of the Permian redbeds of Texas, is also the most common large amphibian in the Dunkard (Romer, 1952, p. 61). Beerbower (1963, p. 35-36) regarded the Dunkard as very late Stephanian or early Autunian in age based on his studies of the fossil amphibian Diploceraspsis. The Dunkard may bridge the Stephanian-Autunian boundary; the vertebrates of the middle part of the Greene Formation suggest an early Autunian age. In the Permian correlation chart for North America (Dunbar and others, 1960) both the Washington and Greene Formations are interpreted as Wolfcampian. Berryhill and Swanson (1962) consider their Waynesburg Formation Pennsylvanian or Permian, but their restricted Washington Formation is Permian.

The Dunkard Group in West Virginia is described in geologic reports for the following counties: Monongalia and Marion (Hennen and Reger, 1913), Doddridge and Harrison (Hennen, 1912), Barbour and Upshur (Reger and Teets, 1918), Lewis and Gilmer (Reger, 1916), Braxton (Hennen and Gawthrop, 1917), Kanawha (Krebs, Teets, and Price, 1914), Cabell (Krebs and Teets, 1913), Jackson, Mason, and Putnam (Krebs, 1911), Wirt, Roane, and Calhoun (Hennen, 1911), Pleasants, Wood, and Ritchie (Grimsley, 1910), Marshall, Wetzel, and Tyler (Hennen, 1909), and Ohio and Brook Counties (Grimsley, 1907).

The Dunkard Group stratigraphy is summarized by Cross and Schemel (1956a, p. 51-57), who present summary stratigraphic columns for the Greene Formation in Jackson and Wetzel Counties and for their Washington Formation (equals Waynesburg plus Washington Formations of Berryhill and Swanson, 1962) in Jackson, Ritchie and Marshall Counties. Cross and Schemel (1956a, p. 62, 64, 68, 70, 72-72) present detailed diagrams of specific outcrops. Cross and Schemel (1956b, p. 93-101) also give summary descriptions and locations of 114 Dunkard outcrops in the Ohio Valley drainage area of West Virginia.

The Dunkard outcrop pattern in Figure 19 is divided into two subbasins by the north-trending Burning Springs anticline. This fold has dips exceeding 20 degrees and is much steeper than the very gentle dips of the other folds in the region which trend generally northeastward. The most important of these gentle folds is the Parkersburg syncline in the south and the Nineveh and Robinson synclines in the north (Cardwell, Erwin, and Woodward, 1968). The valley of the Ohio River has incised through the Dunkard down into the Monongahela Group all along its course except in parts of Marshall, Wetzel, Wood and Jackson Counties.

The Greene Formation is present only in the deepest portion of each subbasin in the Dunkard basin. It has never been mapped separately in any published map for West Virginia, but measured section descriptions indicate that the Greene Formation is probaly restricted to Putnam, Jackson, Wirt and Wood Counties in the southern subbasin and to Ohio, Marshall, Wetzel, Tyler, Monongalia, Marion, Doddridge, Lewis, Gilmer, and Harrison Counties in the northern subbasin. The youngest Dunkard Group strata in the Appalachian basin is the Proctor Sandstone group (units 67-71 of Dunkard summary section). These sandstones occur on hill summits in the Nineveh syncline in Wetzel and probably Marshall County, on hill tops near the axis of the Robinson syncline in Harrison, Doddridge, Marion, Monongalia, and Wetzel Counties, and probably on a few summits along the axis of the Waynesburg syncline in Monongalia and Marion Counties. In the southern subbasin the youngest Dunkard stratum preserved is the Gilmore Sandstone (unit 60 of summary section) on a summit near Rockport, Wood County, close to the common junction of Wood, Wirt, and Jackson Conntíes (Krebs, 1911, p. 58-60, 101-102). It also caps a few knobs in northeastern Jackson County. A nearby section at Limestone Hill at the Wirt-Wood County boundary contains beds as high as the Gilmore Coal (Hennen, 1911, p. 48; Cross and Schemel, 1956a, p. 72).

Dunkard Group strata in Maryland are restricted to the summits of a few knobs near the axis of the Georges Creek syncline and probably occur only in Allegany County, although there is a slight possibility of Dunkard beds on top of one or two hills in Garrett County. Significant descriptions of the Dunkard Group in Maryland are by Martin (1902a, p. 142, 144-145), White (1903, p. 145), Clark and others (1905, p. 258), Swartz (1922a, p. 77-79; 1922c, p. 121), and Berryhill and de Witt

(1955). The Georges Creek basin summary section from Swartz (1922c, p. 121) is reproduced below with unit numbers corresponding to the summary section for the Monongahela Group at the same location, presented elsewhere in the present paper.

	Feet
Dunkard Group (393 feet)	
Greene Formation (94 feet)	
42. Unnamed sandstone	10
41. Concealed	25
40. Shale, limestone and concealed	37
39. Jollytown Coal	2
38. Concealed	20
Washington Formation (299 feet)	
37. Upper Washington Limestone	4
36. Concealed	80
35. Unnamed limestone	2
34. Concealed	110
33. Shale	1
32. Unnamed limestone	1
31. Black shale	0.5
30. Washington Coal	3.5
29. Concealed	10
28. Limestone	2
27. Concealed	40
26. Waynesburg "A" coal	2
25. Waynesburg Sandstone and shale	39
24. Waynesburg Coal (Koontz coal)	4
Monongahela Group	
23. Fire clay	5
22. Waynesburg Limestone	9

Berryhill and de Witt (1955) maintain that the Waynesburg Coal is misidentified in this section and that plant fossils overlying the Koontz coal indicate it is Pennsylvanian in age. They identify unit 24 as the Uniontown Coal, and call unit 30 the true Waynesburg Coal, the base of which marks the bottom of the Dunkard Group. If Berryhill and de Witt are correct, the Dunkard of the Georges Creek basin could be as thin as 296 feet in this section. The total remaining thickness of the Dunkard may be as thin as 225 feet in Maryland, according to Berryhill and de Witt (1955, p. 2090). They report that the coal of unit 30 is overlain by a massive, conglomeratic sandstone, which is a trait common in the Waynesburg Sandstone all along the east edge of the Dunkard basin (White, 1891, p. 40). If unit 30 really is the Waynesburg Coal then unit 39 may be the Washington Coal, and probably no strata belonging to the Greene Formation remain preserved from erosion in Maryland. This upward shift in basal boundary of the Dunkard reduces the size of outcrop area mapped by Swartz (1922c) to a much smaller area restricted to Allegany County (Berryhill, Colton, de Witt and Johnston, 1956). Redbeds are scarce in the Dunkard of Maryland (Berryhill, 1967a, p. 4), so the Dunkard there should be classified as transitional facies.

Several papers consider regional aspects of the Dunkard stratigraphy and contribute to an understanding of the sedimentologic and tectonic framework during deposition. These include White (1891), White (1903), Cross and Schemel (1956a), Arkle (1959), Beerbower (1961), Branson (1962), Berryhill (1967a), Arkle (1969), and Beerbower (1969). Various aspects of the Dunkard will be considered separately, drawing from these sources.

Sandstones in the Dunkard Group are consistently gray to greenish gray (reduzate facies) with no indication of reddish coloration of fresh sandstones; the sandstones weather brown to buff on outcrop. Reddish shale may be interbedded with sandstone. The sandstones commonly are argillaceous and silty, ranging from massive sand beds 1-2 feet thick to silt-sand laminae. Both biotite and muscovite mica are present. The massive beds are typically lensing, and some show local scour at their base, or more rarely are conformable at the base and convex upward in barlike form. The poor sorting and irregular lensing character of these massive sandstones suggest rapid deposition in river channels or in bars at the end of delta distributaries. The laminated siltstones and very fine sandstones may represent levee, channel, or delta-platform deposits. Where interbedded with a continuous sequence of limestones, coals, and finely laminated shales, they are almost certainly of lacustrine or delta-distributary origin (Beerbower, 1961, p. 1034).

The sandstone in the channel fills is the coarsest sediment in the Dunkard, usually fine- to medium-grained but occasionally including conglomeratic lenses in the basal portion. The pebbles consist of mud galls, limestone and ironstone nodules, carbonized plant fragments, and rarely quartz, chert, and feldspar. Sandstones become coarser and more abundant to the south and southeast, suggesting a source in that direction. It would appear that the Dunkard clastics came from the south and southeast, probably from the Virginia-Carolina delta source area which first appeared in lower Mississippian time (Price Formation). The sandstone character is consistent with an interpretation of Dunkard-age alluvial plains located southward from Tyler and Doddridge Counties (West Virginia) and Monroe County (Ohio), with sandstone channels in swamps north of there to Washington County (Pennsylvania), Ohio County (West Virginia), and Belmont County (Ohio), beyond which lacustrine areas extend to the north to the extreme limit of preservation of Dunkard deposits. Such an environmental map is shown by Berryhill (1967a, plate 1; 1967b, plate 12). The more landward facies gradually encroached northward during Dunkard deposition, with alluvial clastics filling in former swamp areas and the swamps displacing the lakes northward. Cyclothemic depositional patterns were superimposed on this progressive infilling of the basin.

The coarsest sandstones occur in the lower Dunkard. The Waynesburg Sandstone (unit 6 of summary Dunkard section) is fairly consistently pebbly along the southeast and east edge of the Dunkard outcrop belt. The Marietta Sandstone (units 20 and 24) is conglomeratic in Gilmer and Ritchie Counties, West Virginia (White, 1903, p. 112). Berryhill (1967a, plate 1; 1967b, plate 12) maps the areal extent of coarse locally conglomeratic sandstones in the Dunkard, showing it in Allegany County (Maryland), Fayette County (Pennsylvania), Lewis, Gilmer, and Calhoun Counties (West Virginia) and occuring in two north-south trends, one extending from Belmont (Ohio) to Calhoun (West Virginia) Counties and the other extending from Morgan (Ohio) to Putnam, Jackson, and Roane (West Virginia) Counties. These two north-south coarse belts probably represent two meander belts of major northward flowing rivers in Waynesburg Sandstone (unit 6) time.

The Waynesburg Sandstone (unit 6) is the most conspicuous coarse clastic unit in the Dunkard. In a formal nomenclature sense, the unit has no valid name since Berryhill and Swanson (1962) elevated the term Waynesburg to Formation rank and redefined the Waynesburg Formation to span those beds from the base of the Waynesburg coal up to the base of the Washington Coal. (It would have been far better to use some other geographic name for this new formation rather than confuse the literature for decades to come with a double meaning of Washington Formation and Waynesburg Sandstone or Formation before and after 1962). Donaldson (1969a, p. 114) and Hoover, Malone, Eddy, and Donaldson (1969, p. 188) map the Waynesburg Sandstone as almost a uniform blanket over the northern Dunkard basin, with thickened channels trending north or northwest. Martin and Henniger (1969) do not consider the Waynesburg Sandstone as a continuous member, and they reject the name Waynesburg Sandstone since Berryhill and Swanson (1962) applied the name Waynesburg to a Formation. Martin and Henniger (1969) studied two thickened, northward-elongated sandstone masses which they consider homotaxial units, to which they apply the names Hockingport Sandstone Lentil (Athens, Washington, and Meigs Counties, Ohio) and Mather Sandstone Lentil (Marion and Monongalia Counties in West Virginia and Greene, Washington, and Fayette Counties in Pennsylvania). The vector mean of cross-bedding orientation in the Mather is N5°E and in the Hockingport it is N8°W, confirming a regional sand distribution pattern suggesting northward flowing streams. The best petrographic data on Dunkard sandstones concerns these two lentils. Both are subgraywackes, but the Mather is locally conglomeratic and contains a higher percentage of framework constituents and less matrix than the Hockingport. Feldspar (untwinned feldspar, microcline, and plagioclase) comprises 4-5 percent of the rock. Muscovite exceeds biotite, and together they make up 3-5 percent of the rock. Detrital heavy minerals include ilmenite, magnetite, zircon, brown tourmaline, and garnet, and traces of apatite, anatase, and monazite. Authigenic pyrite occurs sparingly in both sandstones, and barite occurs as a minor cement component. Matrix comprises 19 percent of the Mather and 23 percent of the Hockingport. Detrital rock fragments include slate, phyllite, chert, traces of volcanic rock, and locally derived siltstone. Plant fragments and macerals are common, with the largest plant fragment noted being a piece of Calamites a foot long. The ultimate provenance of the sandstones probably was a low-rank metamorphic source (Piedmont of Virginia and North Carolina ?), but the immediate source was probably slightly reworked sediments containing an abundance of labile constituents. The greatest recorded thickness for any sandstone in the Dunkard Group is 165 feet of Gilmore Sandstone (unit 60 of summary section) at Jacksonburg, Wetzel County, West Virginia (Hennen, 1909, p. 174).

Shales in the Dunkard Group range from all gray with some grayish black in the north to nearly all red in the south, determining the gray, intermediate, and red facies described by Arkle (1959). The volume of Dunkard redbeds exceeds 30 percent in two areas (Berryhill, 1967a, plate 1; 1967b, plate 12); one trends nearly east-west in Washington County (Ohio) and Ritchie, Tyler, and Pleasants Counties (West Virginia) and the other occurs in Meigs County (Ohio) and Mason, Jackson, Putnam, Cabell, and Roane Counties (West Virginia). The oxidized coloration of the redbeds indicates deposition on a floodplain (in an environment equivalent to the present Mississippi River back swamps, according to Beerbower, 1961, p. 1035), and the progressive loss of red coloration northward in any given cyclothem indicates a regional paleoslope to the north. Successively higher cyclothems tend to have their redbeds encroach farther north to displace the swamp and lake environment. The farthest north partly red shales described in the West Virginia literature are 203-238 feet above the Washington Coal (therefore in the lower Greene Formation) at Ladley Run, Ohio County (Grimsley, 1907, p. 53) so that Arkle (1959, p. 126; see also Fig. 19 of the present report) mapped the transition facies extending as far north in West Virginia as Dunkard sediments occur. The Creston Redbeds (unit 22 of summary Dunkard section) are an especially bright and thick unit (20-62 feet) which is the most readily recognizable of the Dunkard redbed shales.

Jones and Clendening (1968, 1969) measured orientation of ostracods in gray shales at several horizons in the Dunkard and concluded that the general paleocurrent direction was approximately toward due north. The tips of the black arrows shown in Figure 19 mark their sample sites. Their results are consistent with the basal Dunkard cross-bed measurements by Martin and Henniger (1969).

The only reported definite marine fossil site in the Dunkard of West Virginia is a dark shale parting containing Lingula in the Washington Coal (unit 18 of summary section) in Wetzel and Marshall Counties, indicating a momentary invasion of the peat swamp by brackish water (Cross and Schemel, 1956a, p. 51).

Coals in the Dunkard Group are best developed in the north, in swamps marginal to the lake. The area with over 7 feet of aggregate thickness of Dunkard coal was mapped by Berryhill (1967a, plate 1; 1967b, plate 12) and is shown in Figure 19. The Waynesburg and Washington coals are used to mark the boundaries of the Waynesburg Formation, and the top boundary of the Washington Formation is indicated by the Jollytown Coal in places where the less persistent Upper Washington Limestone is absent. All of the coals in the Dunkard thin and locally disappear to the south at higher elevations on the alluvial plain. The more lenticular coals probably represent local peat developments in back swamps on the alluvial plain, but the thicker and more persistent coals are probably related to water level changes marginal to the large lake or very brackish bay in the north. The Washington and Waynesburg coals are locally thick enough to mine in Brooke, Ohio, Marshall and Wetzel Counties, West Virginia, and adjacent Washington and Greene Counties, Pennsylvania (Cross and Schemel, 1956b, p. 6). The Washington Coal is the coal bed which persists farthest south in the Dunkard basin (White, 1903, p. 101).

Limestones in the Dunkard are most abundant in the north. Definite marine fossils are absent, but ostracods and the branchiopod Estheria are present along with the worm Spirorbis. Berryhill (1967a, p. 5) suggests that Spirorbis may indicate very brackish marine water. The thicker and more persistent limestones form good marker beds in Washington and Greene Counties of Pennsylvania, and in the Northern Panhandle of West Virginia; these apparently represent deposits in a large lake or very brackish bay which was located in the northern part of the Dunkard basin. Farther south the limestones become impersistent. The Nineveh Limestone (unit 45 of summary section) is the one which persists farthest south into Jackson County (White, 1891, p. 21). These lenticular limestones probably formed in scattered lakes on the floodplain. In the extreme south the limestone occurs as nodules in the red shales. These may represent accumulations in local ponds, or in extreme cases, may be a sort of caliche deposit formed by ground water circulation in a temporarily arid floodplain where the muds were oxidizing to red colors (Beerbower, 1961, p. 1035).

Periods of aridity are indicated by the local occurrence of gypsum in the Dunkard Group. White (1903, p. 101) states that the Dunkard is slightly gypsiferous throughout, although no accumulations have taken place. Apparently he means no bedded gypsum is present. Beerbower (1961, p. 1040) states that a few gypsiferous claystones occur on the southern end of the flood plain and indicate local aridity, possibly not more than seasonal.

The Dunkard sediments are definitely cyclothemic; all belong to the piedmont facies of Wanless and Shepard (1936), although to the north they merge into a limestone-rich cycle which could be described as a fresh-water delta facies, as contrasted with the typical delta facies of Wanless and Shepard (1936) which contains marine interbeds. Cycles average 40-50 feet in thickness. The number of Dunkard cyclothems has been estimated from 10 (Branson, 1962) to 40 (Beerbower, 1961, p. 1040). Some cycles are local in occurrence and represent local incursions of clastic material superimposed on other cyclothems, thereby causing intercalation of discontinuous cyclothems into more extensive cycles which persist over most or all of the Dunkard basin. Weller (1956) argues strongly that cyclothems are controlled by diastrophism. Beerbower (1961) presents an excellent evaluation of mechanisms which could cause cyclothems and concludes that the major cyclothems in the Dunkard Group probably are related to climatic cycles, supporting the association of cyclothems in the United States with cycles of glaciation during the late Paleozoic in the Southern Hemisphere (Wanless and Shepard, 1936). Martin and Henniger (1969, p. 295) agree with Beerbower's climatic interpretation.

Branson (1962, p. 109) described the following vertical sequence in Dunkard cyclothems:

6. roof shale
5. coal
4. underclay
3. fresh water limestone
2. red shale with limestone nodules
1. sandstone and shale

Cross and Schemel (1956a, p. 38-41) characterize the Dunkard cyclothems in more detail and illustrate regional variations. Beerbower (1961) presents a very detailed treatment of each of the 11 members which he envisions in a typical Dunkard cyclothem. Maximum number of members occurs in the intermediate facies, with the red shale (unit 2 of Branson) disappearing to the north toward the ancient lake or bay, and units 6, 5, 4, and 3 of Branson disappearing to the south (generally from the top downward) higher on the alluvial plain. Beerbower (1961) concluded that most or all of the cyclothems in the Dunkard Group were probably related to climatic cycles. Beerbower (1969) studied the excellent exposures of cyclothems in the red facies of the Dunkard cropping out in cuts along Interstate Highway 77 in Jackson County, West Virginia. These are typical alluvial fining-upward cycles. He concluded that these cycles are of local (autocyclic) origin generated primarily by infrequent diversion of the main channel belt and secondarily by periodic crevassing and lateral migration of the channel belt. No evidence appears in these southern outcrops for external (allocyclic) generation of cyclicity by eustatic, tectonic, or climatic mechanisms. It would seem then that detailed correlations over several counties in the southern part of the Dunkard basin is virtually impossible, using the nomenclature of the summary Dunkard section presented on previous pages. The persistent characteristics of cyclothems in the intermediate and gray facies of the Dunkard Group lead Beerbower (1969) to maintain his 1961 position that those facies cyclothems probably are caused by climatic events.

Paleocurrent and regional facies information seem to indicate clearly that the regional paleoslope during deposition of the Dunkard strata was from south to north and that essentially all of the clastics came from the southern Virginia-Carolina delta source. In the past there has been a tendency to assume that the Dunkard clastics came from an eastern or southeastern source where most of the Paleozoic clastics had been derived from Middle Ordovician through Middle Pennsylvanian time. Beerbower (1961, p. 1039) indicated the presence of a probable eastern, southeastern or southern Dunkard source area. Berryhill (1967a, p. 5) considered the principal source area to have been to the southeast, with a drainage of the Dunkard basin toward the northeast. Berryhill (1967a, p. 5) considered that a secondary source of clastics apparently lay to the north, probably as a continuation of the Canadian shield source area from Pennsylvanian Pottsville through Monongahela time. No specific lithologic evidence supporting this postulated northern source area is given. The present writer suggests, therefore, that by Dunkard time the basin's topographic bottom was displaced so far to the north that none of the preserved clastics came from the north, and that virtually all of the Dunkard clastics originated from the Virginia-Carolina delta source to the south.

The Dunkard strata have considerable potential in uranium exploration because there is a clear indication of oxidizing facies (red shales) mixed with reducing facies (coals, greenish to gray sandstone, gray shales). The sandstone channels seem to trend northward to slightly northwestward, and organic debris is common in the fluvial sandstones. Limited petrographic data suggest that the sandstones are lower in feldspar content than is desirable for uranium protore. The Dunkard Group probably contains the rocks most favorable for uranium prospecting of all of the Pennsylvanian and Permian strata in the Appalachians. Within the mapped area of Figure 19, the best areas for prospecting are in the red facies and along the southern margin of the intermediate facies.

Newark Group

The major Triassic basins in the area under consideration are the Culpeper Basin of Virginia, the Richmond Basin of Virginia, the Dan River Basin of Virginia and North Carolina and the Deep River Basin of North Carolina (Figure 20). Other very minor basins exist in Virginia and there are several Triassic basins under the Coastal Plain of the Delmarva Peninsula, the Carolinas, Georgia, and the Panhandle of Florida. Of these buried basins, only two are under sufficiently little sedimentary cover to warrent mention: the buried Triassic basin near Florence, South Carolina, and a newly reported buried basin near Aiken, South Carolina (Marine and Siple, 1971).

Three important modern studies in the area have been done by Reinemund (1955) on the Sanford Basin portion of the Deep River Basin and by Meyertons (1963) and Thayer (1970) on the Dan River Basin. The

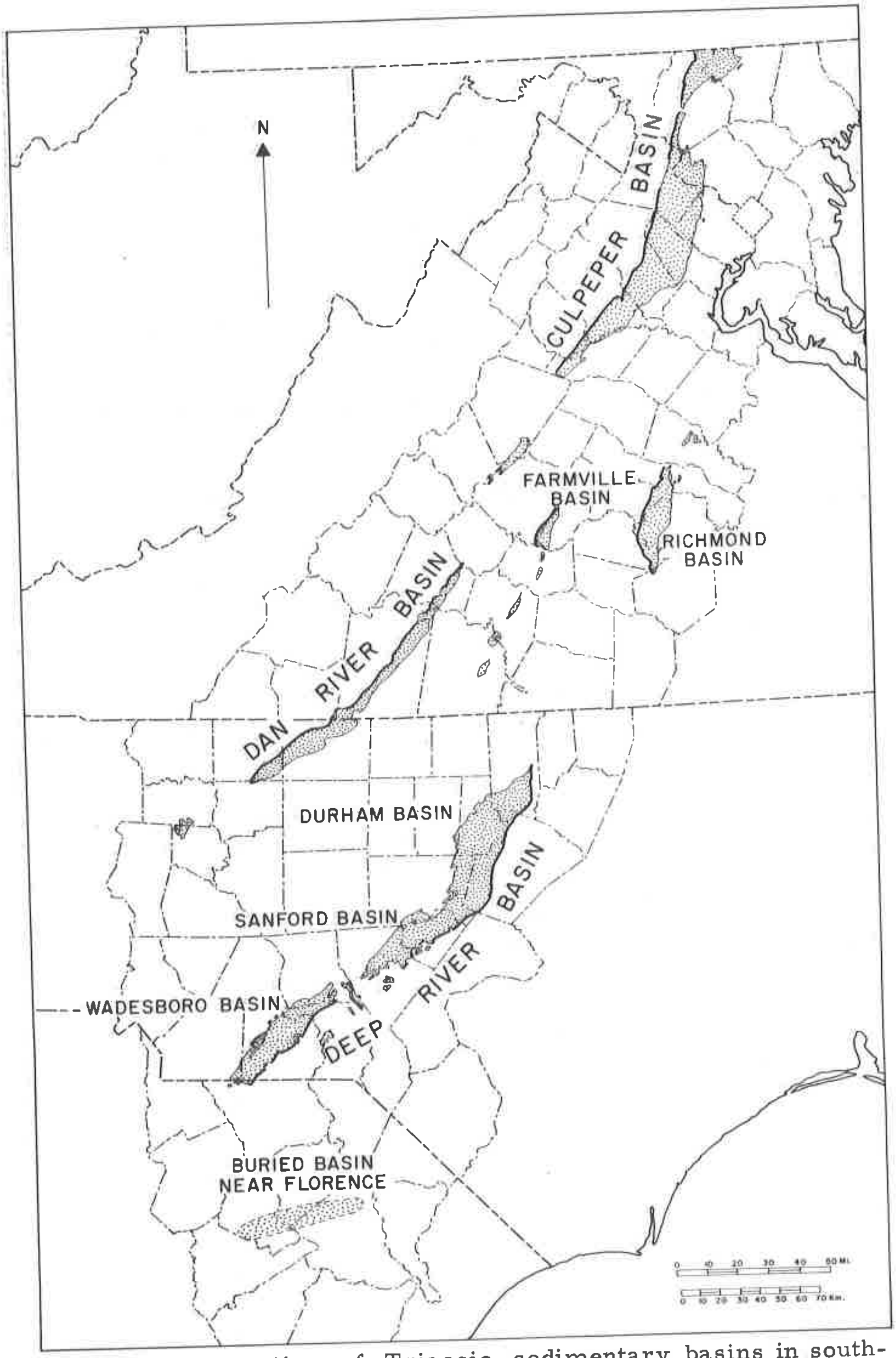


Figure 20. Location of Triassic sedimentary basins in southeastern United States.

general work on the Triassic basins of Virginia by Roberts (1928) is detailed in some aspects, but is somewhat outdated.

The Triassic sedimentary rocks of these basins consist mainly of siltstone, sandstones, conglomerates and fanglomerates. They are characterized by abrupt lateral changes in texture and composition. The source is the nearby igneous and metamorphic rocks of the crystalline Piedmont except in the northern part of Culpeper Basin where there are coarse clastic carbonate pebbles derived from eroded Lower Paleozoic limestone and dolomite terranes to the northwest.

The vertical thickness of the strata in these basins is poorly known. The best estimates are: Deep River Basin--maximum of 8,000 feet (Mann and Zablocki, 1961), Dan River Basin--5,000 feet (Geddes and Thayer, 1971), and Richmond Basin--2,000 plus feet (McKee and others, 1959, p. 12 and Pl. IV). The first two are based on geophysical data. With other statements of thickness, it may be difficult to tell whether the author is discussing stratigraphic thickness or the vertical distance to the base of the Triassic. These difficulties are summarized well by Roberts (1928, p. 90-91).

Many of the sands are arkosic, although few contain enough feldspar to be a true arkose (Reinemund, 1955, p. 26). The sands and conglomerates tend to be more arkosic opposite granite outcrops and less so adjacent to slate outcrops. The sands are commonly cross-bedded. An arkose conglomerate in the Wadesboro Basin is derived from the nearby Lilesville Granite Porphyry (Randazzo, Swe, and Wheeler, 1970, p. 1004).

Four of the basins contain coal and dark organic shales: Sanford Basin portion of the Deep River Basin, Richmond Basin, the Dan River Basin, and the small Farmville Basin which is somewhat of a northern outlier of the Dan River Basin. The first two have had commercial coal production.

By far, the most detailed study of any portion of the eastern Triassic Basins is that by Reinemund (1955) on the Deep River Coal Field, which is in the northern part of the Sanford Basin portion of the Deep River Basin.

The most useful terminology for the Deep River Basin would be to divide it into 3 sub-basins which are, from north to south, the Durham, Sanford, and Wadesboro Basins (see Figure 20).

In the Deep River Coal Field (Sanford Basin) the Triassic rocks are divided into a lower red Pekin Formation, a middle gray Cumnock Formation, and an upper red Sanford Formation.

The Cumnock Formation is 800 feet thick and contains two coal beds, the Gulf coal bed up to 2 feet thick, and the Cumnock coal bed up to 4 feet thick. The coal ranges from outcrop to several thousand feet in depth. The rest of the Cumnock Formation is gray and black shale, siltstone, and fine gray sandstone which is irregularly clacareous and carbonaceous.

The Cumnock grades laterally into redbeds in all directions.

Almost all of the mineable coal lies in a canoe-shaped post-depositional graben in the northwestern part of the Sanford Basin. Some ferruginous and carbonaceous shales contain some calcium phosphate and ammonium sulfate.

In the Durham Basin an interesting occurrence of nonmarine limestone and chert has a bearing on Triassic climate interpretations (Wheeler and Textoris, 1971). A 25 foot section of sandstone and mudstone contains several beds of impure limestone up to 9 inches thick, and chert up to 6 inches thick. The limestones are a dark laminated micrite, both algal and chemical in origin, and a void-filling calcite spar. The limestone was originally a calcareous tufa. The chert is of two types. One is a dark dense chert which "is an inorganic precipitate and is comparable to the silica gel being deposited in certain lakes in South Australia. The second is a light porous chert which has replaced some of the limestone." (Wheeler and Textoris, 1971). Thayer (1970, p. 15) has noted hopper-shapped crystal casts in the Dan River Basin.

The evidence of dry climate is consistent with evidence from other Triassic Basins to the north (Van Houten, 1965, and Glaeser, 1966, 1971) and inconsistent with the presence of coal. Perhaps the climate was such that the rainfall either was just sufficient to permit swamps or normal lakes in the basin centers and then was just small enough to result in the formation of playas, or perhaps the swamps were spring fed. But the evidence of dry climate from several of the Triassic basins is too strong to be denied.

The sands in all the basins are commonly strongly cross-bedded. One study in the Durham Basin (Custer, 1966) showed that the current flow was toward the northeast, that is to say, parallel to the strike of the basin. However, there is much variation which suggests meandering streams.

The coal of the Dan River Basin is only a few inches thick and occurs in discontinuous lenses. It is within the gray, thinly-bedded siltstones, claystones, and fine sands of the Cow Branch Formation. Also in the lower 200 feet of the Cow Branch Formation are abundant ironstone concretions, which contain abundant pyrite, vivianite, and macerated plant debris (Thayer, 1970, p. 13).

In his measured sections of the Cow Branch Formation as well as in the redbed units, Thayer (1970, p. 24-31) indicates many beds of arkose.

Thayer (1970) has used combinations of primary structures to determine original depositional environments. His work was in the Dan River Basin, but his conclusions are very pertinent to other basins where very similar lithologies exist but have not been as thoroughly studied. The coarse-grained, poorly sorted, crudely stratified conglomerates represent alluvial fan deposition along the basin margins. "Cross-bedded lenticular-sandstones in the formations are interpreted as channel deposits that accumulated on point and channel bars in low-to-high sinuosity streams. Finer-grained, reddish brown, uniformly thin- and medium-bedded siltstones, claystones, and shales were deposited on broad oxidizing flood plains, mudflats and possibly lakes adjacent to stream channels.

Fine-grained, dark-colored mudrocks of Cow Branch Formation were deposited in lakes that formed by damming the longitudinal drainage of the basin. The specific cause of the damming is unknown at this time. Rhythmic laminations, abundant pyrite, uniformly even stratification, graded bedding, and symmetrical ripply marks indicate that most of the Cow Branch accumulated below lacustrine wave base. Lenses of coal with autochthonous plant fragments, vivianite, and ironstone concretions along with lenticular sand bodies in the lower part of the Cow Branch suggest accumulation in swamps and deltas along the lake margins. The uppermost Cow Branch contains numerous tongues of reddish-brown siltstone that show abundant mud cracks, burrow casts, and few hopper-shaped crystal casts and raindrop imprints. These features are indicative of a regressive lacustrine deposit brought about by a waning of the lake, possibly caused by a change in climate regime." (Thayer, 1970, p. 15-16).

Coal was mined in the Richmond Basin for nearly 200 years; some mines went over 800 feet deep. The stratigraphic descriptions (Roberts, 1928) are not precise, but the sections show that green and black shales are associated with the coal. This is also true in the small Farmville basin.

All of the basins are tilted toward a major fault (Figure 20). For the Culpeper, Dan River, and Richmond basins the major fault is on the west side and the strata dip to the west. In the Deep River Basin the strata dip toward the major fault to the east. A heavy line on the map indicates the major fault bounding each basin.

Most of the Triassic sandstones are arkosic and red in color. Some of them qualify as true arkose. In North Carolina in the Sandhills area and near Sanford they are unconformably overlain by Cretaceous sands of the Middendorf Formation.

Deposition and tilting were simultaneous so that the oldest beds in the basin typically have the greatest dip. Dip also varies from basin to basin; in the Deep River Basin dips of 10 to 15 degrees are typical, whereas the Dan River Basin dips 32 degrees.

Although the arkosic redbeds and the pyrite-bearing organic shale and coal of these basins are an interesting possible uranium association, no authors have reported any uranium content. There is no indication that they examined for it. All the Triassic basin sediments were affected by much post-depositional transverse and longitudinal high-angle faulting. Many of the transverse faults and a few of the longitudinal faults are the sites of diabase dikes. Most of these faults of the Palisade Disturbance probably reflect movement of less than 100 feet. A few longitudinal faults do have a vertical displacement of as much as 2,200 feet (Reinemund, 1955, p. 69).

Of interest to the search for uranium associations are some of the diamond-drill records cited by Reinemund (1955, p. 127-156) in the Sanford Basin in North Carolina. The Sanford Formation (regarded as overwhelmingly red at the surface) has many beds which are described as "gray, variegated, arkosic" and some are even "oil saturated" or "tar-like." This is at a depth of only 465 feet in one core (Reinemund, 1955, p. 148). Of course, the Cumnock Formation is gray and organic at the surface and would be expected to be the same at depth. Several of the holes have hundreds of feet of Sanford Formation logged as gray, or dark gray. There is a strong suggestion of a reduzate facies at depth.

Tuscaloosa Group

Most of this discussion will deal with the truly non-marine portions of the Tuscaloosa equivalents from eastern Georgia to Maryland. However, it is easier to begin the discussion with the type Tuscaloosa in Alabama where the rocks are partially marine and work northward.

In the type area near Tuscaloosa and Eutaw, Alabama, there is a three-part division of the Group. Lower marine beds were termed the Eoline Formation. The next higher unit of apparent non-marine sand and clay was named the Coker Formation, and the overlying sequence of nonmarine gravelly sand and clay beds was named the Gordo Formation (Monroe, Conant, and Eargle, 1946, and Conant, 1967).

This interpretation was modified by Drennen (1953) who reduced the Eoline to a member of the Coker Formation. This classification of a lower Coker Formation (about 375 ft. thick) and an upper Gordo Formation (300 ft.) is widely accepted today. The Eoline (150 ft.) is the lower member of the Coker Formation. The unnamed upper member is 225 ft. thick.

Drennen (1953, p. 528) has presented the view that all formations of the Tuscaloosa Group in Alabama are, "for the most part, of shallow marine origin, for locally they contain glauconite or borings resembling those of the marine organism [Ophiomorpha]." The Eoline Member does contain some carbonaceous clay, but otherwise it seems to be marine. The line on Figure 21 separating "non-marine" to the east of central Georgia from "mainly marine" to the west into Alabama is based on Drennen's ideas. However, his evidence for the marine nature of the Gordo Formation is very tenuous.

The marine Eoline member "consists chiefly of stratified and cross-stratified fine sand interbedded with carbonaceous and lignitic clay. At many places fine- and very fine-grained sands are interlaminated with carbonaceous and lignitic clay" (Conant, 1967, p. 7). Fine-grained glauconite is common and a few mollusks have been found.

The unnamed upper member of the Coker Formation is highly variable, but mainly a micaceous sand with red-mottled gray clay. Drennen (1953) regarded this member as marine because of some thinly laminated Eoline-like sand and clay beds and some sparse glauconite.

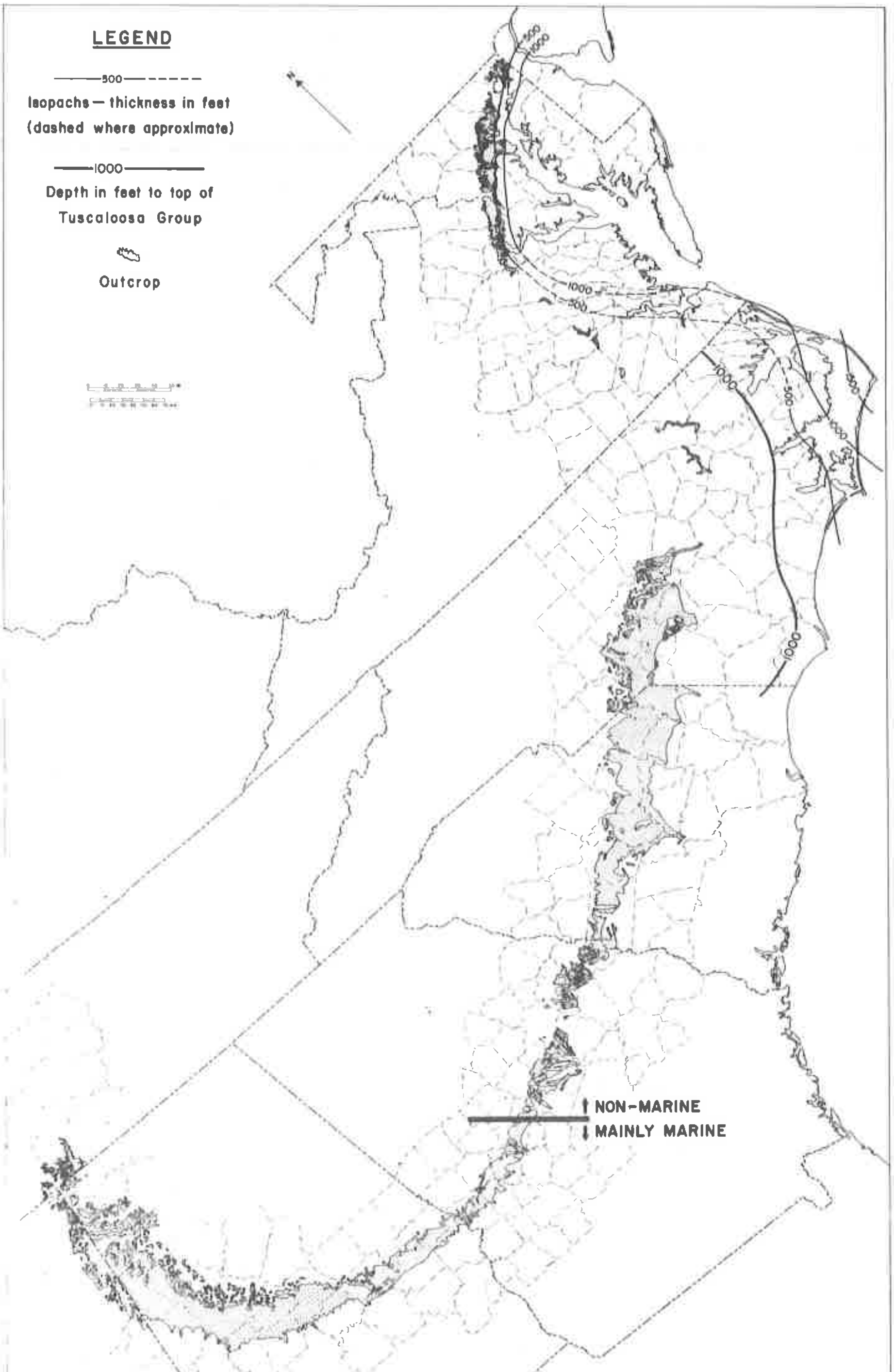


Figure 21. Occurrence and thickness of Tuscaloosa and Potomac Groups.

Conant (1967, p. 7) regards the virtual absence of glauconite; marine fossils, and Ophiomorpha borings as of "apparent non-marine origin."

The Gordo Formation is separated from the underlying Coker Formation by a major unconformity. The lower 130 feet of the Gordo is the main gravel-bearing part of the Tuscaloosa Group. The upper 170 feet has lenticular beds of clay and cross-bedded sands that are locally gravelly. Conant regards the Gordo Formation as deposited on an alluvial plain close to sea level (1967, p. 8-9).

The Lower (?) Creteceous Vick Formation shouldbe noted at this point. This unit has a very limited outcrop and underlies the Tuscaloosa Group. Four miles east of Centerville, Alabama, are many scattered exposures of clay and sandstone unlike that which is characteristic of the Upper Cretaceous and utterly unlike the underlying Paleozoic (Conant, 1946). This is the Vick Formation which contains in the outcrop area about 65 feet of semi-indurated cross-bedded sandstone, grading up through 20 feet fine-grained sand, silt, and clay into 12 feet of clay. Conant (1964) reported on drill hole through the Vick Formation 40 miles east-southeast of Tuscaloosa where there was 104 feet of the unit. He regards it as essentially a subsurface unit almost completely overlapped by the Tuscaloosa. The Vick Formation has a nonmarine environment (Conant, 1964, p. 97).

In Georgia, the Coker and Gordo cannot be identified and the Tuscaloosa is classified as a formation. It consists of coarse to gravelly sand with lesser beds of clay and silt. The gravel consists mostly of quartz pebbles and the sands have abundant grains of partially altered feldspar. Concretionary ironstone is common (Eargle, 1955). At Columbus, on the Chattahoochee River in western Georgia, the outcropping Tuscaloosa is 250 feet thick. Only 25 feet of Tuscaloosa is exposed in the higher hills around Macon in central Georgia. However Eargle (1955, p. 7) says that the "strata formerly called Tuscaloosa in eastern and central Georgia actually are equivalent to most of the Upper Cretaceous sequence (Tuscaloosa Formation through Providence Sand) exposed in the Chattahoochee River Valley. The Tuscaloosa proper is confined to a thin basal unit impracticable to map separately."

One important lithologic feature is that in western Alabama the Tuscaloosa beds contain cherty sands and the gravels consist chiefly of chert pebbles derived from weathering of the cratonal Paleozoic strata. In eastern Alabama and Georgia the coarser Tuscaloosa beds are arkosic and the gravels consist chiefly of quartz pebbles (Eargle, 1955, p. 10).

Although the terminology of today is different, some of the older works have helpful amounts of outcrop-by-outcrop detail. In Georgia these include Veatch and Stephenson (1911), and Cooke (1943); in South Carolina Cooke (1936); and in North Carolina, Stephenson (1923).

The outcropping, basal upper Cretaceous sands, clay, and gravels north from the Ocmulgee River (central Georgia) to Lynches River (South Carolina) should be referred to the Middendorf Formation and not to the Tuscaloosa Group. These sediments are very similar to the type Middendorf Formation in northern South Carolina and not at all like the type Tuscaloosa in western Alabama. This portion of the Middendorf Formation has no Ophiomorpha, no glauconite, and no chert pebbles. (Snipes, 1965, p. 105-106).

Before continuing with the Middendorf discussion a brief account should be made of the Cape Fear Formation. The Cape Fear Formation in the Fayetteville, North Carolina, area underlies the Middendorf Formation with distinct unconformity and with notable differences in lithology (Heron and Wheeler, 1964; Heron, Swift, and Dill, 1968; and Swift and Heron, 1969). However, it has been included in the Tuscaloosa Group in the past, and still is by some workers. For this reason a brief discussion of this marine (?) formation is added.

The Cape Fear Formation is a sandstone with intercalated layers of mudstone. The sandstones are quartz wackes. The very thick-bedded stratification is characteristic with sand layers ranging from 3 to 15 feet thick and having considerable lateral extent (Heron and Wheeler, 1964, p. 12-14). The stratification is cyclic with muddy sand - sandy mud couplets. The Cape Fear strata have graded bedding and other characteristics that point to turbidity current deposition (Heron, Swift, and Dill, 1968, p. 48). These authors picture the environment of deposition as an embayed coast with fluviomarine turbidites in estuaries that could be nearly flushed out by fresh water.

This formation may be correlative with the Patuxent Formation of Virginia and Maryland and with Lower Cretaceous sediments of the sub-surface.

In North Carolina, South Carolina, and northeastern Georgia (as far southwest as the Ocmulgee River) these basal Cretaceous sediments are overwhelmingly non-marine. The Middendorf Formation consists of loose to poorly indurated muddy sands, which in cross-section are clearly channel sands with both basal and clay-ball conglomerates. The clays, whether as impurities in the sands or as pure white beds, are kaolin. The upper part of Middendorf Formation grades seaward (southeastward) into the lower part of the Black Creek Formation (Swift and Heron, 1969, and Brett and Wheeler, 1961). The accessible and very typical Middendorf outcrop on the railroad cut at Spring Lake, North Carolina is illustrated in a section in Heron and Wheeler (1964, p. 36).

Most Middendorf sands are quartz wackes; that is, they have too much mud matrix (over 15 percent) to be either protoquartzites, subgraywackes or arkoses. The color is tan to yellowish orange. According to Swift and Heron (1969, p. 215), "part of the oxidation of the Middendorf sediments is post-depositional, but a large part represents deposition in an oxidizing environment." Many of the coarse Middendorf sands contain numerous small white blebs of clay, many of which are weathered feldspar grains. Several authors seem to use the word "arkose" rather loosely when speaking of sediments of the Tuscaloosa or Middendorf. It is quite possible that some beds contained the requisite 20 percent feldspar prior to weathering, but, if so, they also contained too much mud matrix to be a good or typical arkose. Because of the high mud content many of the Middendorf sands probably have low permeability although locally near Fayetteville, North Carolina, the Middendorf is an aquifer for groundwater supply.

In South Carolina and north-central Georgia, the quartz wackes consist of a framework of "quartz (26-50 percent), muscovite (3-10 percent), potash feldspar (0-6 percent) and heavy minerals (1 percent or less). The matrix consists of detrital kaolinite plus fine shreds of mica (34-58 percent), authigenic kaolinite (1-18 percent) and a trace of iron oxide." (Snipes, 1965, p. vi). Very pure clay lenses occur and reach their maximum purity between the Ocmulgee River, Georgia and the Aiken, South Carolina area. The regional dip of the cross-beds in South Carolina is southeasterly. Cross-beds in the Middendorf in North Carolina have been examined by Ibrahim (1973). The paucity of rock fragments and feldspar in the Middendorf sediments is consistent with a deeply weathered source. The sands are angular to very angular indicating only one cycle of erosion and deposition (Snipes, 1965, p. 107).

Despite its nonmarine character, the Middendorf sands are usually too muddy for extensive groundwater circulation, are not typically arkosic, do not contain organic material, and are not known to be reddish.

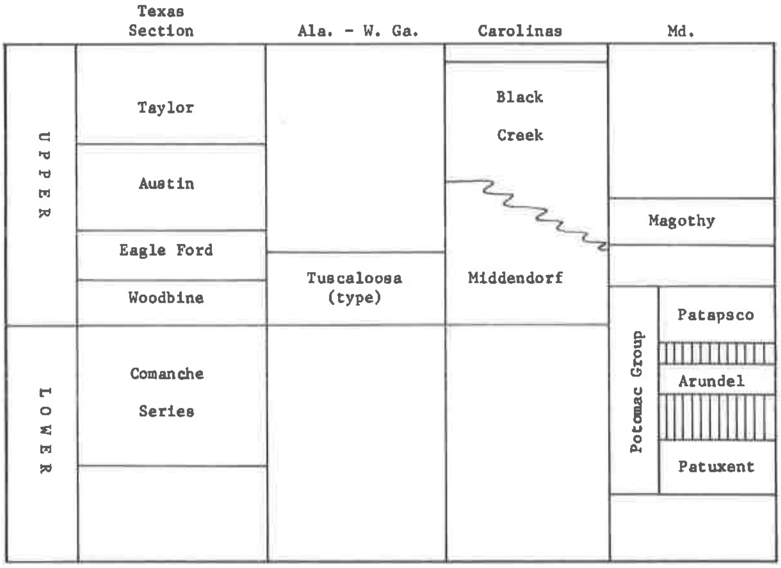
The Middendorf Formation is unconformably overlapped and hidden from outcrop by Cenozoic sediments in northern North Carolina and southern Virginia (Figure 21). Cretaceous outcrops appear again as the Potomac Group in Maryland and adjacent parts of Virginia where the basal Cretaceous unit is called the Patuxent Formation (Clark and others, 1911, and Clark, 1916). The Potomac Group is divided into the Patuxent, Arundel and Patapsco Formations (Table 5). The Patuxent Formation is made of quartzose sands and gravels interbedded with clays and greatly resembles the Middendorf. The Arundel is a dark gray to maroon massive clay with abundant lignitic and sideritic concretions. The Patapsco resembles the Patuxent. Where the Arundel clays are absent, the Patapsco is differentiated only by its fossil flora.

The Potomac Group is a thick sequence in the subsurface of eastern Maryland, but is too deep for economic consideration. At Salisbury the top of the Potomac Group is at 2300 feet below sea level (Anderson, 1948).

According to Groot (1955, p. 9) the pre-Magothy Cretaceous of Delaware (Potomac Group plus Raritan Formation) cannot be subdivided because of lithologic similarity. However, he notes that the Patuxent "zone" has a staurolite-kyanite-tourmaline heavy mineral suite, whereas the Patapsco-Raritan "zone" has a tourmaline-zircon-rutile suite. The Magothy heavy-mineral suite is dominated by staurolite.

These non-marine Cretaceous sediments were all derived from

Table 5. Chart to show relation of Cretaceous units discussed to each other and to the generalized Cretaceous section of Texas. Formations of Potomac Group highly generalized (their stratigraphic horizon is known only in a general way). Other units not shown.



essentially the same source area, the nearby Piedmont Province and the adjacent Folded Appalachians. The younger Cretaceous marine units also received material from an epidote-rich terrane to the south (Groot, 1955, p. 9).

There are several good arkoses in the Potomac Group. Glaser (1969, p. 53) lists several samples of arenites of both the Patuxent and Patapsco Formations as having 22 to 48 percent feldspar. Furthermore, the clays of the Arundel Formation have considerable organic matter and locally are maroon in color. The thickest section of Arundel clay is in the southwest portion of the outcrop belt in Ann Arundel and Prince Georges Counties (Washington and Baltimore). The combination of reddish oxidized color and organic content and proximity to permeable sandy strata above and below the Arundel Formation is an interesting combination in terms of uranium possibilities.

In Delaware the Potomac Group is undivided and is a very important source of ground water. The sand bodies are shoestring channels (Spoljaric, 1967, p. 1). The group consists of variegated silts and clays with interbedded sands of varying textures.

Spoljaric (1967) suggests that the Potomac sediments form a piedmont accumulation which is lithologically similar to the marine deposits near the mobile rim of a geosyncline. He cites the 3,700 foot thickness in the subsurface at Salisbury Maryland, in backing up his suggestion that the deposition and burial were rapid. "The uppermost part of the Potomac sequence seems to have been removed by erosion [as shown by] the anomalous pattern of the isopach map" (Spoljaric, 1967, p. 23).

From Maryland to Alabama, the Tuscaloosa equivalents become thicker and change to a marine facies both southward and eastward. However, this usually happens under a cover in the deep subsurface of Cenozoic sediments well over 1,000 feet in thickness. The landward edge of the Cretaceous sedimentary prism thins to zero and may or may not be unconformably overlain by Cenozoic strata. The primary dip of these strata was negligible, and in the outcrop belt is still less than one degree. Dips of even a few degrees exist only in the deeper subsurface near the coastline, as a result solely of the tilting of the edge of the continent under the sedimentary load. The source area for the sediments was the crystalline Piedmont to the west, a large part of which has outcrops of feldspar-rich granite or gneiss. An arkose could result if the resulting sediments were not too mature.

The summary works of LeGrand (1961) and Richards (1967) were helpful. Thickness data were assembled from Spangler (1950), Spangler and Peterson (1950), Snipes (1965), and Maher (1965 and 1971). The immense work of Brown, Miller and Swain (1973) arrived when this work was all but in press. Their biostratigraphy and thickness data will be basic for decades to come. It is difficult to match non-marine lithostratigraphy with their mainly marine chronostratigraphy.

Black Creek Formation

The Black Creek Formation of North Carolina and South Carolina is one of the most intriguing formations in the southeast from the point of view of uranium potential. It is a good aquifer and has a notable organic and pyrite content. It is an exemplary fluvio-marine unit and should not be overlooked because some of its aspects are marine.

"The Black Creek Formation is a mosaic of estuarine and lagoonal lithosomes, capped by lenses of littoral and nearshore sand" (Swift and Heron, 1967). The formation consists of laminated, medium dark gray to dark gray clay interlaminated with gray to yellow orange sands. It is remarkably heterogeneous with no well-defined lithic or faunal zones. Recurring associations of primary structures and sediment types are present.

There are several environments of deposition: estuarine, lagoonal, and littoral. The estuarine sediments contain clean sands and dark clays. The sands are clean with over 95 percent quartz plus glauconite, phosphorite, lignitized wood, shell material, and iron oxide or iron sulphide aggregates, with trace amounts of amber, ostracods and foraminifera. The dark gray clays are up to 98 percent sand-free.

The phosphate pieces range up to gravel size. They include some actual bone material but are mainly replacements of calcareous matter. Both limonite and pyrite aggregates are common. Many joint planes, bedding places and sand beds are stained yellow or orange, but not red. There is a very striking stratification that is both rhythmic and complex. Clayey strata sets consist of thin clay beds with sand laminae; sandy strata sets consist of thin sand beds separated by films of clay. Medium scale cross-lamination of sands is very common. The cross-strata sets are very distinct and contain both sand and clay laminae. Large scale, planar cross-stratification also may occur.

The origin of this estuarine facies of the Black Creek Formation is by tidal currents, as Swift and Heron (1967) have shown by analogy with deposits in the Netherlands. However, many deposits in the updip portion of the outcrop belt may be channel fillings which represent an eastern tongue of a channel from the intertonguing fluvial Middendorf-type of environment.

In fact there is a facies change in the updip direction. Brett and Wheeler (1961, p. 114) state that "upstream towards Fayetteville, the rocks become more and more terrestrial, containing no fauna, no glauconite, and much woody material and pyrite, suggesting stagnant swamp conditions." However, Swift and Heron (1967) note that glauconite has been found toward the base of the formation in other areas and caution against overassurance as to the exact extent of the marine or nonmarine portions. They sum it up with, "It seems probable that both wave and river-generated currents have left their imprint on this lithosome, consequently it is referred to as estuarine."

The lagoonal environment contains some beds characterized by a flamboyant mottling and other beds that are merely irregularly laminated. Clay strata dominate. The mottles are true mottles of compositional difference and not mere color changes. Swift and Heron (1967, p. 276) state that these deposits bear a striking resemblance to the tide flat and lagoonal deposits of the modern Dutch Wadden Sea.

The sediments of the littoral environment consist of well-sorted sand lenses 20 to 60 meters thick. The sequence of alternating rippled and cross-bedded units is typical of a surf zone feature. The prominent mottling is typical of near-shore sands just seaward of a surf zone (Swift and Heron, 1967, p. 278).

Of particular interest is the large amount of lignitized wood, some so little altered as to appear to be almost recent. Such wood fragments are especially common in the estuarine sediments, up to about 75 percent by volume. The lignitized wood occurs as logs, aggregates of granule-size cylinders in the troughs of ripple marks, and as mats of flattened twigs. It is associated with considerable pyrite. The logs occur mainly in the updip portion of the formation. The fragments of lignitized wood are often riddled by Teredo borings, a marine mollusk ("shipworm"). The black pigment of the Black Creek clays appears to consist of finely comminuted organic matter (Heron and Wheeler, 1964; Swift and Heron, 1967).

The closest lithologic and stratigraphic equivalent to the Black Creek Formation to the northeast is the Magothy Formation of Maryland and New Jersey. It probably correlates with the older portions of the Black Creek Formation. The Magothy Formation of Maryland consists of fine to medium quartzose gravel and ferruginous conglomerate; loosely bedded, clean, white, cross-bedded sand with sharply angular quartz grains; and a scarcity of silt-clay impurity and clay. There is an abundance of sand-size lignite particles giving a salt-and-pepper appearance to the sand. There is also dark brown to black, carbonaceous silty clay. Lignitized and pyritized wood, and pyrite are common in such clays.

"The Magothy Formation exhibits considerably less lithologic complexity than the underlying Potomac; on the other hand lateral lithofacies variation is more pronounced" (Glaser, 1969, p. 42). As the thickness increases to the southeast, the sand and gravel abundance decreases. This confirms cross-bedding data showing that the current direction was to the southeast.

The Magothy Formation along the Chesapeake and Delaware Canal in Maryland can be arranged in three members. The lowermost is a fine yellow, micaceous, compact sand with patches of clay, some of the same color and some of black, strong clay. The middle member is a white sand and clay. The sand and clay may be admixed or distinctly laminated and sharply interbedded. This sand is coarse, sharp, "sugary," and largely pure quartz with a small content of mica. The clay of the upper member is dark blue to black and contains much lignitized plant material and some grains of amber. The lignite has associated marcasite (Carter, 1937, p. 248-249).

In Delaware the Magothy consists of white, lignitic sands and black clays with abundant carbonaceous matter (Groot, 1955, p. 26).

The Magothy Formation grades eastward and northeastward into a fluvial-estuarine-lagoonal facies with a dominant clastic contribution from the Piedmont (Glaser, 1969, p. 77). Feldspar is singularly absent from the sands of the Magothy. The Black Creek and Magothy Formations are very organic but are never arkosic or red. The source area was the crystalline Piedmont and probably reworked earlier Cretaceous and Triassic sediments to the west.

The map (Figure 22) is purposefully vague on the Magothy-Black Creek thickness in the subsurface of southern Virginia, because it was not known whether this absence was non-deposition or non-recognition. The work of Brown, Miller, and Swain (1973, pls. 12 and 13) shows that it was due to non-deposition or subsequent erosion.

The Black Creek equivalents in Georgia and Alabama are marine and are not included in this report.

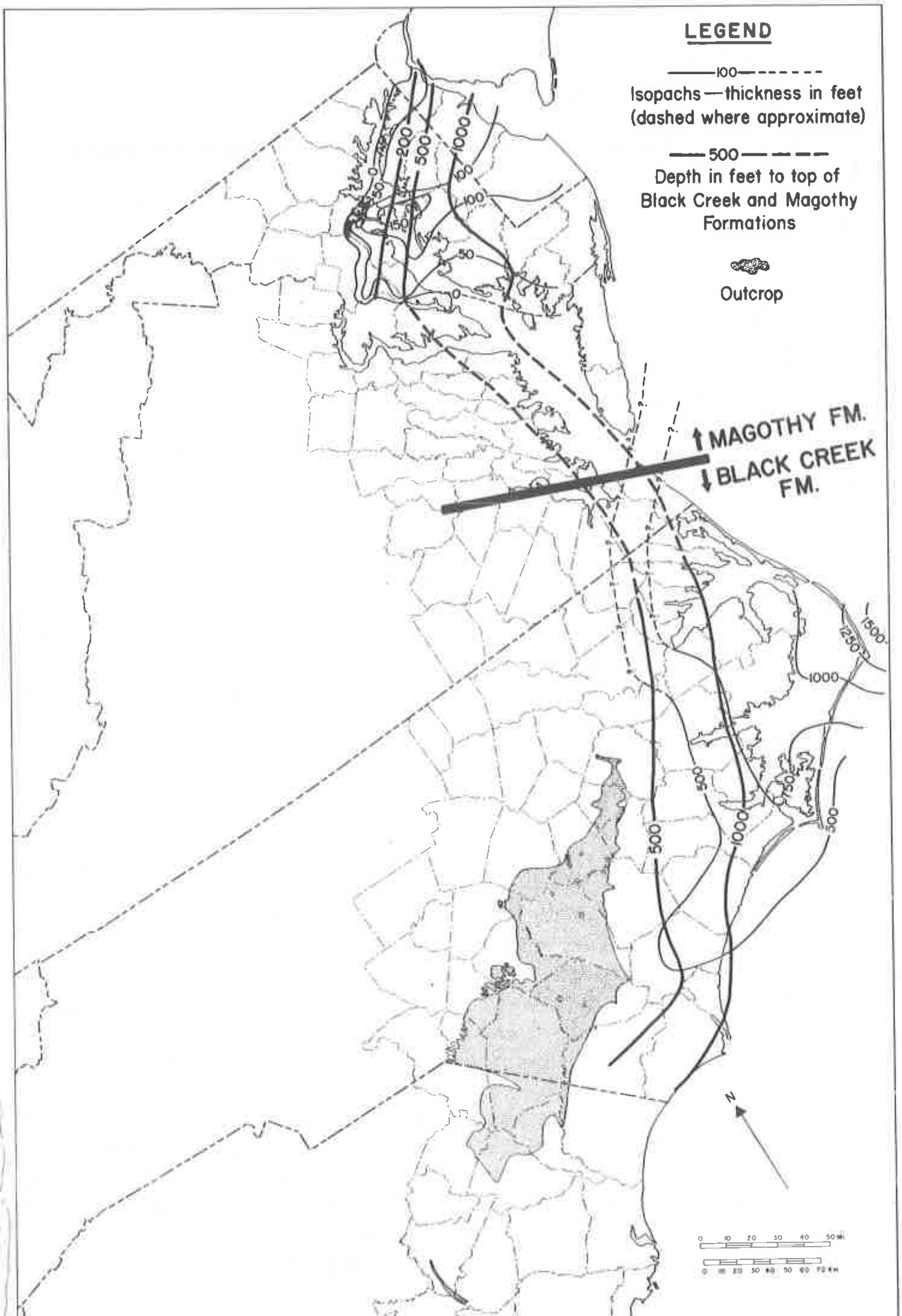


Figure 22. Occurrence and thickness of Black Creek and Magothy Formations in outcrop and subsurface.

CONCLUSIONS

The Southern Interstate Nuclear Board prepared a report (1969) for the United States Atomic Energy Commission on "Uranium in the Southern United States." That report points out that the most promising rocks for commercial uranium exploration are fluvial sediments, and in a very general way summarizes the principal occurrences of fluvial sediments in southern United States. Factors associated with uranium occurrence have been evaluated by Adler (1970) and incorporated by us into a model for uranium cell formation. We have specifically searched for favorable criteria in the Precambrian through Cretaceous rocks of southeastern United States, seeking first all formations of certain or possible fluvial or deltaic origin and then evaluating other uranium-favorable traits.

The following ranking of uranium protore potential is obtained, establishing those rocks most favorable for uranium prospecting:

<u>High potential</u>

- Black Creek Group (high to moderate)
- Newark Group
- Dunkard Group
- Pottsville Group (high to moderate)
- Mauch Chunk-Pennington Group
- Hampshire Formation

<u>Moderate potential</u>

- Tuscaloosa Group
- Monongahela Group
- Conemaugh Group
- Allegheny Group
- Maccrady-Stroubles Formations
- Pocono-Price Formations
- Juniata Formation
- Bays-Moccasin-Bowen Formations
- Rome Formation (moderate to low)

<u>Low Potential</u>

- Bloomsburg Formation
- Tuscarora-Clinch-Massanutten Sandstone
- Weisner Sandstone
- Erwin Formation
- Antietam Sandstone
- Cochran Formation
- Unicoi Formation
- Weverton Sandstone
- Mount Rogers Formation
- Swift Run Formation
- Ocoee Supergroup
- Other Precambrian quartzites

All of the high-potential stratigraphic units accumulated after the widespread appearance of land plants and contain significant amounts of fossilized or coalified wood disseminated in fluvial sands. The Black Creek Group contains much pyritized fossil wood in addition to lignitized material; it is the only one of the six high-potential units which totally lack any redbed coloration signifying oxidizing facies, so uranium accumulations would probably occur only at shallow depths near the ground surface. The only redbeds in the Pottsville Group are in the Coosa coal basin in Alabama

For each formation with high or moderate uranium cell potential, specific areas with more favorable situations are indicated in the text details.

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