THE HOCKINGPORT SANDSTONE (LATE CARBONIFEROUS) OF SOUTHEASTERN OHIO

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I hereby recommend that the thesis prepared under my supervision by Wayne Dudley Martin *entitled* The Hockingport Sandstone (Late Carboniferous) of Southeastern Ohio

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

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ABSTRACT

This paper presents the results of a study of a local sandstone of the Dunkard series herein termed the Hockingport sandstone. This sandstone is located in Washington, Athens and Meigs Counties of southeastern Ohio and adjacent parts of West Virginia.

The Hockingport sandstone has in the past been correlated with the Waynesburg sandstone of southwestern Pennsylvania and northern West Virginia. In the opinion of the writer, these widely-separated sandstones are not correlates.

The Hockingport sandstone is a fluvial deposit, whereas it is believed that the true Waynesburg sandstone is a near-shore accumulation of sand, formed as the result partly of current but predominantly of wave deposition in a shallow body of water.

Since the structure, lithology and fossil fauna of the rocks of the Upper Monongahela or Lower Dunkard series do not indicate the existence of a regional unconformity, the inferred Permian age of the Dunkard strata still rests on fossil flora associated with the coals of the Dunkard series.

INTRODUCTION

The object of this study is threefold: (1) to determine the environment of deposition of a sandstone body here named the Hockingport; (2) to determine whether or not this sandstone should be correlated with the Waynesburg sandstone of southwestern Pennsylvania and the adjacent area in northern West Virginia; and (3) to search for evidence indicating whether or not this and the Waynesburg sandstone are correlative basal sands above an unconformity separating the Pennsylvanian and Permian periods.

For more than 60 years the Waynesburg sandstone has been considered to be a more or less continuous deposit extending entirely across the Dunkard Basin. The writer believes that the true Waynesburg sandstone is restricted in areal extent to southwestern Pennsylvania and northern West Virginia. A relatively local sandstone occurring in parts of Washington, Athens and Meigs Counties, Ohio, and the adjacent part of West Virginia has previously been considered as a part of the Waynesburg sandstone, but in the opinion of the writer these sandstones are not correlates. The sandstone of southeastern Ohio is herein termed the Hockingport sandstone for the village of that name near where it is well developed.

The true Waynesburg sandstone was deposited in the nearshore area of a shallow body of water. The Hockingport sandstone is the result of fluvial deposition on a relatively broad plain.

The Dunkard series has been considered to be Permian in age on the basis of the fossil flora. The Permian age of the flora has been questioned (Cross, 1954a, 1954b). The existence of a regional unconformity is not indicated by either the structure, lithology, or fossil fauna of the rocks of the Dunkard series nor by the strata of the underlying Monongahela series, therefore these sandstones are not necessarily basal sandstones separating Permian from Pennsylvanian.

To the writer's knowledge, no previous detailed investigation of the Hockingport sandstone of southeastern Ohio has been made.

ACKNOWLEDGMENTS

The writer is especially indebted to his advisor, Dr. John L. Rich, Research Professor of Geology, University of Cincinnati, who visited the writer in the field, gave counsel during the study, criticized the manuscript and assisted in construction of some of the maps.

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Dr. Donald Baird, Assistant Curator of the Museum of Comparative Zoology, Harvard College, read and criticised parts of the manuscript, and furnished information on the vertebrate fossil footprints. Dr. Aureal T. Cross of the West Virginia University and Geological Survey, made available an unpublished manuscript and furnished additional information on the fossil flora of the Monongahela and Dunkard series.

Mrs. Elizabeth Dalvè is credited with the drafting of the plates and figures 1, 2 and 13. Special thanks and appreciation are due to Helen L. Martin, wife of the writer, for her wholehearted cooperation and assistance in the preparation of this paper and the typing of the manuscript. The writer expresses thanks to the many others, not mentioned here, for helpful suggestions and criticisms which aided materially in this work.

REGIONAL SETTING OF THE DUNKARD SERIES

Location, Topography and Structure

The strata of the Dunkard series occupy an area approximately elliptical in plan, (Fig. 1), located in Pennsylvania, West Virginia and Ohio. However, scattered outliers of the series occur as far east as Allegany County in Maryland. The outcrop area is about 8,000 square miles. In Pennsylvania, strata of the Dunkard series exist only in the southwestern part of the state, principally in Washington and Jefferson Counties. In West Virginia, Dunkard strata exist in a belt varying from 40 to 60 miles in width and occurring in the western part of the state. The Ohio portion is limited to a 1200-square-mile strip in the southeastern part of the state.

The region of Dunkard outcrop is a dissected plateau, most of which is in late youth or early maturity. The maximum relief is approximately 700 feet. The highest remnants rise to elevations of 1400 feet.

Over most of the region in which the Hockingport sandstone occurs, the relief ranges from 200 to 400 feet. Elevations in the region range from slightly less than 600 feet in valleys occupied by major streams to over 950 feet on

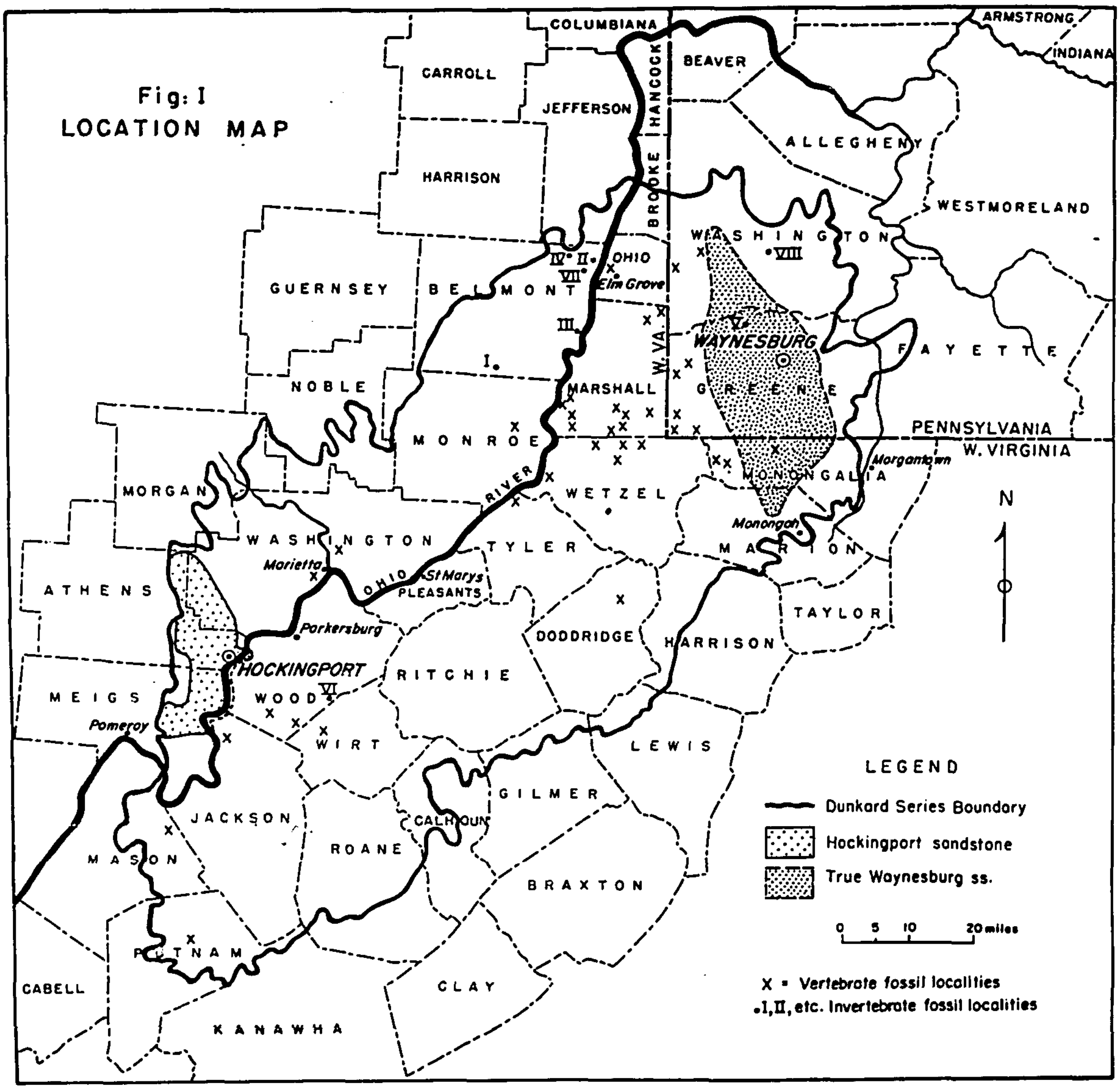
Fig: I
LOCATION MAP
COLUMBIANA
CARROLL
JEFFERSON
HANCOCK
BROOKE
BEAVER
ARMSTRONG
INDIANA
ALLEGHENY
WESTMORELAND
HARRISON
GUERNSEY
BELMONT
OHIO
Elm Grove
WASHINGTON
WAYNESBURG
GREENE
FAYETTE
W. VA.
NOBLE
MARSHALL
MONROE
PENNSYLVANIA
W. VIRGINIA
Morgantown
MONONGALIA
MORGAN
WETZEL
RIVER
OHIO
Monongah
MARION
WASHINGTON
Marietta
TYLER
St Marys
PLEASANTS
ATHENS
Parkersburg
TAYLOR
DODDRIDGE
HARRISON
HOCKINGPORT
RITCHIE
MEIGS
WOOD
Pomeroy
WIRT
LEWIS
GILMER
JACKSON
CALHOUN
ROANE
MASON
BRAXTON
PUTNAM
CABELL
CLAY
KANAWHA
N
LEGEND
Dunkard Series Boundary
Hockingport sandstone
True Waynesburg ss.
0 5 10 20 miles
X = Vertebrate fossil localities
•I, II, etc. Invertebrate fossil localities

many of the hills and ridges. The northern half of the region from Hockingport to Bartlett is less rugged than the southern half.

The gentler slopes are generally covered by a thick residual soil, but where thick sandstones crop out, steep cliffs of 100 feet or more are formed. For example, the Hockingport sandstone forms precipitous cliffs and slopes in the area along the Ohio River. From the top of the massive sandstone to the hilltops, however, the slopes are commonly gentle. A few miles distant from the Ohio River in the northern and western parts of the region, where the Hockingport sandstone has thinned and has been extensively weathered at the surface, the topography is less rugged than near the larger rivers.

At most of the valley heads, where the streams cross the sandstone, steep cliffs are formed with cresent-shaped reentrants that extend back under the sandstone for 20 feet or more. Along the sides of the valleys the less resistant shales below the sandstone have commonly been removed allowing huge blocks of the sandstone to tumble to the valley bottoms.

The region is drained by the Ohio River and its tributaries. The smaller streams have comparatively narrow flood plains with occasional terraces.

The rocks of the Dunkard series occur in what is essentially a structural basin whose longer axis trends roughly

N. 45° E. The regional dip of the rocks is in many places reversed by local sags, the trend of which is rudely parallel to the longer axis of the Dunkard Basin.

The Hockingport sandstone occurs in the southwestern part of the Dunkard Basin west of the axis, and the Waynesburg sandstone is located just east of this axis in the northern part of the basin.

Stratigraphy

The Dunkard series is a variable sequence of rocks, consisting of sandstones, siltstones, shales, limestones and coals, of which shale is the most abundant.

The limestones, coals and bluish-gray or dark-colored shales are generally restricted to the northern portion of the Dunkard Basin, being best developed in southwestern Pennsylvania and adjacent parts of Ohio and West Virginia. Southward from Pennsylvania, coarse clastics become increasingly abundant, and the shales attain greater thickness and are mostly red or buff in color. Coal and limestone are there practically non-existent.

The units of the Dunkard series are more lenticular in the southern part of the Basin than in the northern part. The sandstone units in particular are local and, when traced laterally, change abruptly to rocks of contrasting lithology. The shales seldom show distinct bedding or fissility and in general are quite silty. Not uncommonly, poorly-bedded fine sandstone and siltstone units are surrounded by non-bedded, silty shales. The coals are thin, of very poor quality and quite local. Limestone beds probably of fresh-water origin, which seldom attain a thickness of one foot, are similarly limited.

In the geological literature of Pennsylvania, Maryland and Ohio, the Dunkard series is divided into two formations, the Washington, below, and the Greene, above. The formations have been subdivided into smaller units which have been termed members or horizons. Some of the more persistent of these have been given names by H.D. Rogers, J.J. Stevenson, I.C. White, and geologists of the Ohio and West Virginia Geological Surveys.

The following list is simplified from the Ohio Geological Survey's "Generalized Section of Ohio" (1951?) and shows the principal members or horizons of the Monongahela and Dunkard series which exist in Ohio:

Dunkard series (White, I.C., 1891)

Greene formation (Stevenson, J.J., 1876)

Gilmore sandstone (Stevenson, J.J., 1876)
Gilmore limestone (White, I.C., 1891)
Nineveh sandstone (White, I.C., 1891)
Nineveh coal (White, I.C., 1891)
Nineveh limestone (White, I.C., 1891)
Fish Creek coal (Stevenson, J.J., 1876)
Fish Creek sandstone (Stevenson, J.J., 1876)
Dunkard coal (Stevenson, J.J., 1876)
Jollytown sandstone (d'Invilliers, E.V., 1895)
Jollytown "A" coal (Stauffer, C.R. & Schroyer, C., 1920)

Washington formation (Stevenson, J.J., 1876)

Upper Washington limestone (Stevenson, J.J., 1876)
Hundred sandstone (Hennen, R.V., 1909)
Upper Marietta sandstone (White, I.C., 1891)
Washington "A" coal (White, I.C., 1891)
Middle Washington limestone (Stevenson, J.J., 1876)
Lower Washington limestone (Stevenson, J.J., 1876)
Lower Marietta sandstone (White, I.C., 1903)
Washington coal (Stevenson, J.J., 1876)
Mannington sandstone (Hennen, R.V., 1909)
Waynesburg "A" coal (Stevenson, J.J., 1876)
Waynesburg sandstone (Stevenson, J.J., 1873)
Elm Grove limestone (Grimsley, G.P., 1906)
Cassville shale (White, I.C., 1891)

Monongahela series (Rogers, H.D., 1840)

Waynesburg coal (Stevenson, J.J., 1876)
Gilboy shale (White, I.C., 1891)
Little Waynesburg coal (Stevenson, J.J., 1876)
Waynesburg limestone (Stevenson, J.J., 1877)
Uniontown sandstone (White, I.C., 1891)
Uniontown No. 10 coal (White, I.C., 1891)
Uniontown shale (White, I.C., 1891)
Arnoldsburg sandstone (Hennen, R.V., 1911)
Arnoldsburg coal (Hennen, R.V., 1911)
Arnoldsburg limestone (Stout, W., 1929)
Fulton shale (Grimsley, G.P., 1906)
Benwood limestone (Campbell, M.R., 1903)
Upper Sewickley sandstone (White, I.C., 1891)
Meigs Creek No. 9 coal (?)
Lower Sewickley sandstone (White, I.C., 1891)
Fishpot coal (Stevenson, J.J., 1876)
Fishpot limestone (Stevenson, J.J., 1876)
Pomeroy sandstone (Lovejoy, E., 1888)
Pomeroy coal (Lovejoy, E., 1888)
Redstone limestone (Platt, F. & W.G., 1877)
Upper Pittsburgh sandstone (Rogers, H.D., 1858)
Pittsburgh coal (Rogers, H.D. (?), 1858)

Previous Work in the Area

The name Dunkard was introduced into the geological literature of Ohio by I.C. White in 1891 (pp. 100-123) in his report entitled "Stratigraphy of the Bituminous Coal Field of Pennsylvania, West Virginia and Ohio" for the United States Geological Survey.

The rocks included in the Dunkard series have been described under various names. H.D. Rogers (1858, p. 20) uses the name Newer Coal Shales, or Upper Barren Group, and points out that the group is distinctly recognized only in the southwestern corner of the state of Pennsylvania. In Ohio, Newberry (1874, p. 158) termed these strata the Barren Measures and included them in the Upper Coal Measures. Stevenson (1875, p.345) regarded these beds as the Upper Barren Measures, but considered the thickness so great, that for convenience he thought it well to divide the measures into two groups. The lower portion was designated the Washington County Group and included the strata from the top of the Waynesburg sandstone to the top of the Upper Washington limestone. The upper portion was named the Greene County Group and included the beds above the Upper Washington limestone.

E.B. Andrews (1873, pp. 247-313; 1874, pp. 441-587) did not separate the Upper Barren Measures from the coal-bearing strata of the Pennsylvanian in his discussion of the geology of southeastern Ohio. Orton (1884, p. 1) accepted the original classification of Rogers, but in 1888 (p. 3) referred to the Dunkard series as the Upper Barren Coal Measures. A few years later Orton, (1893, pp. 37, 55, 63) mentions that these rocks might possibly be Permian in age.

I. C. White (1891, p. 20) describes the Upper Barren Measures as the Permo-Carboniferous or Dunkard Creek series. In this report White named the strata the Dunkard Creek series, and extended the series down to include the Waynesburg sandstone and the roof shales of the Waynesburg coal. A few years later (O'Harra, 1900, pp. 128-130) the name was shortened to Dunkard series.

Stevenson (1907, pp. 96-97) later considered the Dunkard column divisible into two formations, the Washington and the Greene, thus replacing his original classification, the Washington and Greene County Groups. Stevenson also included the Waynesburg sandstone and the shales above the Waynesburg coal in the Washington formation, following the suggestion of I. C. White (1891, p. 20) that these strata should be included in the Dunkard.

Several folios of the United States Geological Survey (Stone, 1905, No. 121; Clapp, 1907, No. 144; Clapp, 1907, No. 146) covering portions of southwestern Pennsylvania use the term Dunkard group, recognize its Permian age and divide it into the Washington and Greene formations.

The Dunkard region of West Virginia has been studied by the Geological Survey of that state and the data have been published in the various "County Reports". The West Virginia

Geological Survey does not recognize the division of the Dunkard series into the Washington and Greene formations, but only the subdivision of these formations or members and horizons.

Prosser (1905, pp. 2, 5, 6, 7) in his "Revised Nomenclature of the Ohio Geological Formations" considered the Dunkard as a formation as had been the custom in the Maryland Geological Survey reports.

Stauffer and Schroyer (1920, p. 11) in their report on the Dunkard series for the Ohio Geological Survey, use the most recent classification of Stevenson (1907, pp. 96-7) and consider the rocks as a Permian series divisible into the Washington and Greene formations.

George W. White (1945) studied the rock sequence at Blaine Hill, Belmont County, Ohio. He also (1947) mapped the Waynesburg coal and revised the Dunkard boundary in Harrison and northern Belmont Counties, Ohio.

William H. Smith (1948) studied the geology of Newport Township, Washington County, Ohio.

Cross (1950, 1954a) has recently studied the stratigraphy and fossil flora of the northern part of the Dunkard Basin. Cross (1954a, 1954b) questions the Permian age of the Dunkard series.

THE HOCKINGPORT SANDSTONE DEFINED

Distribution, Attitude and Thickness

The Hockingport sandstone occurs over an area of approximately 225 square miles in southeastern Ohio and the adjacent part of western West Virginia (Fig. 1, Pl. 1). The sandstone forms a blanket deposit over the region delineated, except where it has been eroded from the stream valleys.

The present boundaries of outcrop, as shown on the map, do not truly report the original extent of the sandstone body because in the west and most of the north, the boundary is erosional. Along the northern half of the western boundary the sandstone is marked by considerable thinning before its horizon extends out over the hilltops. The slight thickness of the sandstone here suggests that this part of the boundary is near that of the original limit of the deposit. There are four areas along the western and northern borders where the sandstone exists at the hilltops and the thickness has been reduced by erosion. They are as follows: in sections 13 and 19 of Sutton Township, Meigs County, in the southwestern part of the region; in sections 16 and 17, Rome Township, Meigs County along the western border; between Broadwell and Sharpsburg in Athens County in the northwestern part of the region; and between Sharpsburg and Bartlett along the northern boundary.

Along the northeastern and eastern boundaries the sandstone is relatively thin, generally ranging from 10 to 30 feet in thickness before it disappears below drainage level. In the southeastern portion of the region the limits of the sand can be observed. Along the southern boundary of the sandstone the thickness is 20 feet or less where the deposit disappears under cover. The reduced thickness prior to disappearance of the sandstone along the northeastern, eastern and southern boundaries suggests that the observed boundary is near the original boundary of the deposit. The western and northern boundaries of the sandstone are the most irregular because here the northwestward rise of the strata brings the sandstone to the hilltops. The existence here of the outcrop is dependent upon elevation and the irregularities of the topography.

The area in which the sandstone outcrops is located on the west flank of the Parkersburg syncline. This structural feature is a local, shallow trough, the axis of which trends N. 20° E. extending from Jackson County, West Virginia, passing east of the city of Parkersburg, West Virginia, through the eastern edge of Marietta, Ohio, and disappearing a few miles to the north.

As indicated by the structure-contour map (Pl. 1) of the base of the sandstone, the strike of the deposit is approximately N. 20° E. The southeastward regional dip is variable from about 15 feet per mile in the southern, southeastern, and eastern part of the area, increasing to nearly 30 feet per mile in the northwestern part.

Cross sections of the Hockingport sandstone clearly indicate its lenticular nature (Fig. 2, Plates 2 and 3). Locally, however, there is considerable variation in its thickness (Pl. 2). In the southern part of the region, over most of eastern Chester, northern Lebanon, and southern Olive Townships, Meigs County, the thickness is from 40 to 60 feet. Adjacent to the Ohio River, from 2 miles south of Hockingport to 3 miles north of this village, the thickness ranges from 75 to 90 feet. Along a line through the central part of the outcrop area from Hockingport to Sharpsburg at the northwest, the deposit is from 40 to 60 feet thick with the thickness decreasing to the southwest and the northeast.

Weathering Characteristics

As a result of oxidation, the Hockingport sandstone has a buff color on all weathered outcrops. The fresh rock is a blue-gray color which can occasionally be noted in recent roadcuts where a large volume of rock has been removed and at the base of the deposit in the reentrants of the sandstone near the valley heads.

Case-hardening of the Hockingport sandstone is apparent on many outcrops. The natural moisture of the rock is drawn to the surface and evaporated, leaving behind in the

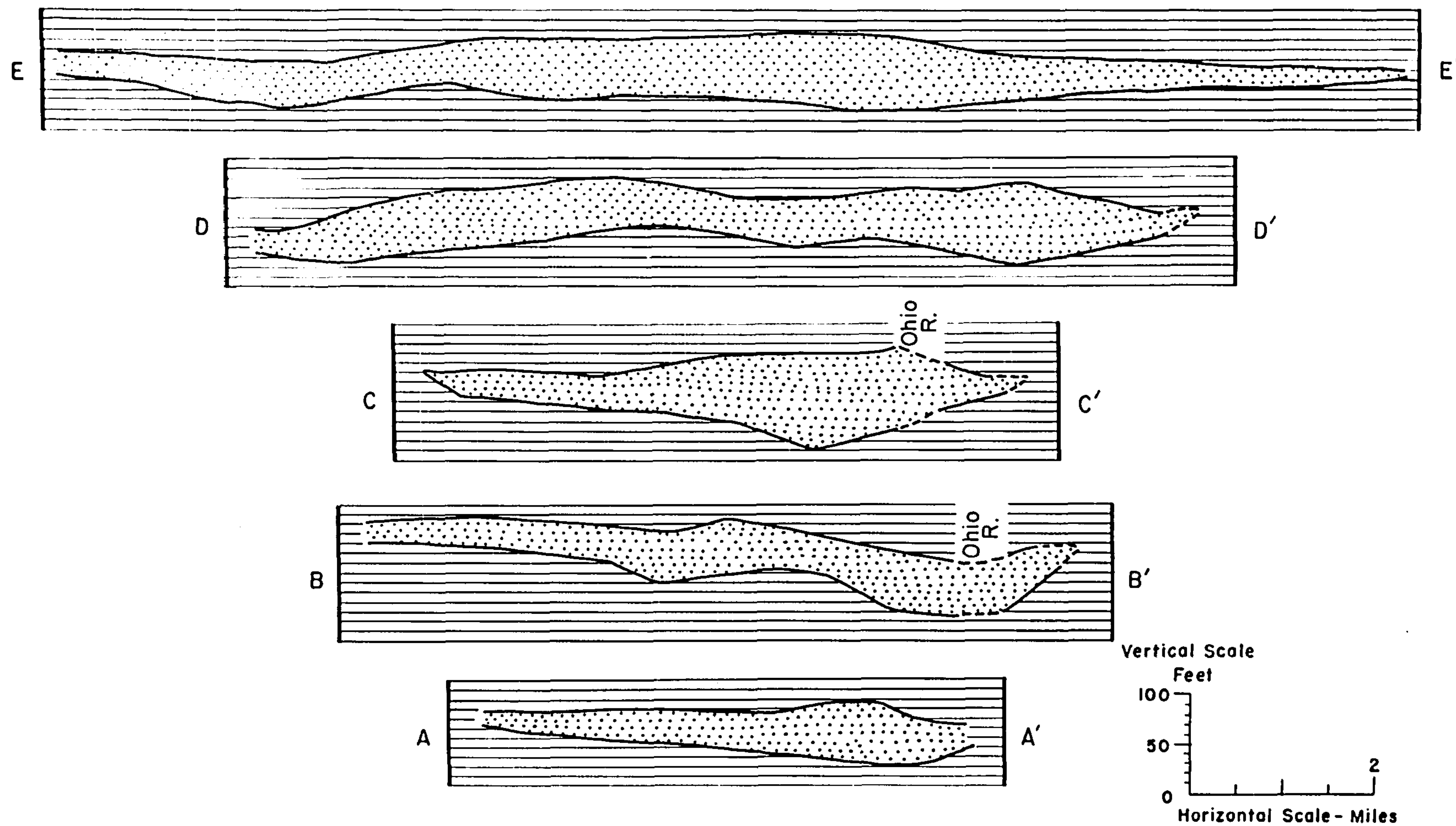

Fig. 2 Cross sections of the Hockingport sandstone.

near-surface interstices, a concentration of iron (Kiersch, 1950, p. 936). This is often concentrated along lamination planes which weather out as small ridges or in small circular areas that remain as knobby protuberances on the face of the outcrop.

This commonly results in a honey-combed or pitted surface (Fig. 3). Pitting of the surface of the rock occurs on both a large and a small scale. Some indentations extend as much as 6 feet into the sandstone from the face of the outcrop and may be 10 feet high and 12 feet wide (Fig. 20). In most cases, however, the pits are only 2 to 6 inches in all dimensions. It is believed that the irregular distribution of iron oxide at the surface of the sandstone and weathering are responsible for the honey-combed nature of the sandstone outcrop.

Fig. 3 -- Pitted surface of outcrop of Hockingport sandstone, .7 mi. northeast of Hockingport, Athens County, Ohio

Primary Structures and General Texture

Bedding

The Hockingport sandstone is characterized by great irregularity of bedding. Large parts of it are massive but other parts are intricately cross-bedded and the cross-beds vary from large size to very small. The lower half of the sandstone body tends to be cross-bedded to a greater extent than the upper part. The cross-bedding is of two distinct types, the foreset type and the cut and fill, resulting apparently from channeling and later filling (Figs. 4, 5, and 6). Sharp truncation of sets of cross-laminae caused by eroding currents and subsequent aggradation by currents flowing in other directions commonly produced a patchwork of sets of cross-laminae dipping in diverse directions and at different angles (Fig. 5). Regular, horizontal bedding is rare.

In general, the Hockingport sandstone is composed of a network of buried stream channel structures. Sandstone and conglomerate lenses rather than sandstone strata prevail. Cross-laminated channel structures occur in greatest abundance in the lower half of the sandstone with the upper portion being nearly structureless in some areas. In some cases, these channel fillings were almost completely removed by swift currents before subsequent aggradation occurred. Occasionally, complete examples of filled stream channels are preserved. The channel cross-sections are convex downward and are asymmetrical, but tend to be flat across the top (Fig. 7). The size of such lenticular units ranges from a width of 15 to 100 feet and a height of 3 to 35 feet.

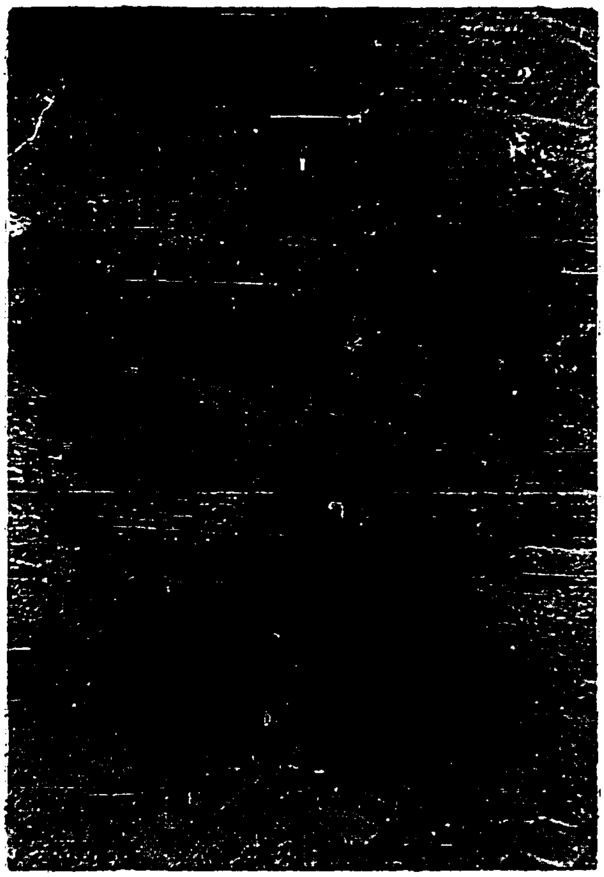

Fig. 4 -- Cut-and-fill structure and foreset cross-bedding in Hockingport sandstone, .7 mi. northeast of Hockingport, Athens County, Ohio.

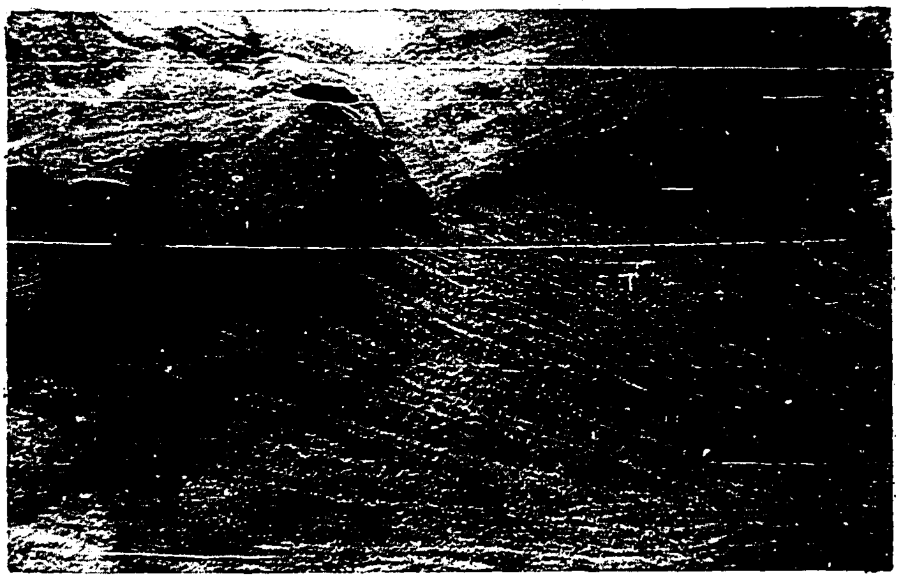

Fig. 5 -- Cut-and-fill structures and foreset cross-bedding in Hockingport sandstone, .7 mi. northeast of Hockingport, Ohio.

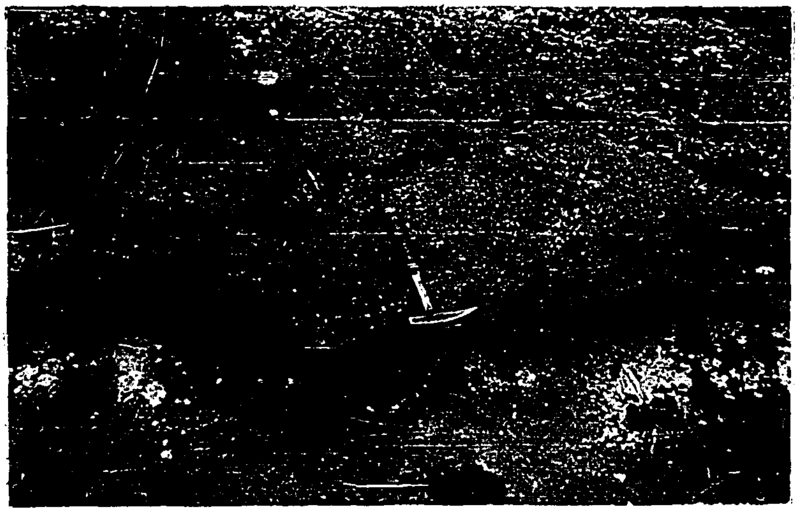

Fig. 6 -- Cut-and-fill structure in the Hockingport sandstone, 4 mi. south of Long Bottom, Meigs County, Ohio.

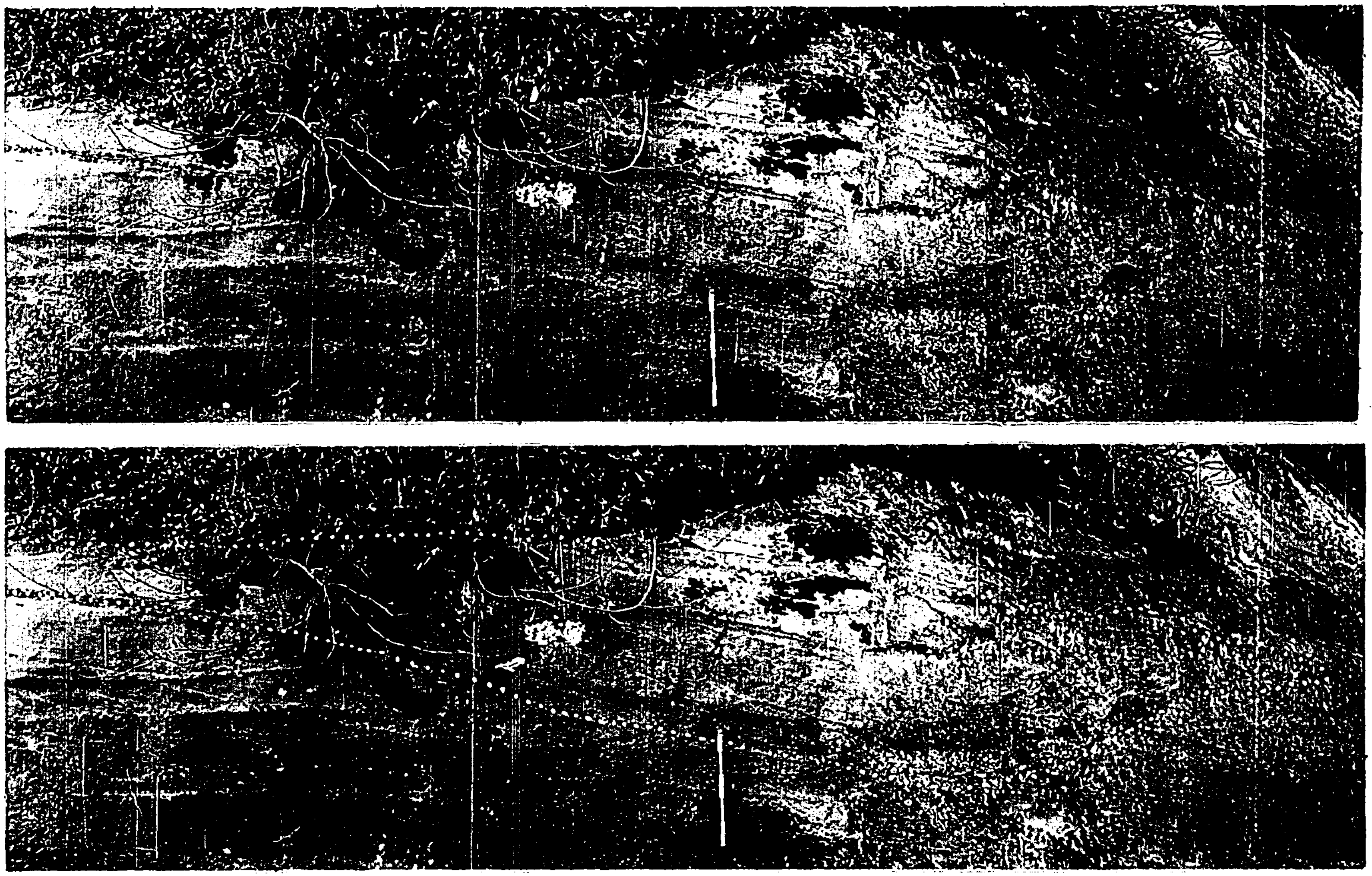

Fig. 7 -- Channel structure in the Hockingport sandstone, 1 mi. south of Hockingport, Athens County, Ohio.

Elongated lenses of sandstone and conglomerate can commonly be observed in the outcrop. These units are only a few feet thick but may be up to 165 feet in length. The units are flat on the top and bottom, and at the ends the top slopes down to intersect the base, or both top and bottom approach each other. Such structures are believed to be longitudinal sections of bars or of filled channels. The grain size of these deposits may be nearly the same throughout the width and length of the units, and the cross-laminae dip consistently in essentially the same direction and at approximately the same angle.

Cross-sections of structures believed to be buried bars have also been discovered. These structures vary from 4 to 6 feet in height and from 8 to 15 feet in width, the tops are convex upward and the bottoms are almost flat. In all cases noted, the grain size of the sand just above the bar is finer than the grain size within the bar structure. Cross-laminae in the sand above the structure dip in opposite directions from the crest, and at an average angle of about 15 degrees.

Grain Size Variation

The grain size of the Hockingport sandstone varies from pebbles an inch or more in diameter to fine sand or even silt and clay-size material, but the major portion is that of very coarse sand. Coarse conglomerate occurs in greatest abundance near the base of the member (Fig. 8). Some of the conglomeratic lenses are well-sorted into pebbles of nearly the same size, but lenses containing a mixture of argillaceous material, sand, granules and abundant scattered pebbles are more common. Very coarse sand is for the most part limited to the lower half of the sandstone deposit. Most of the remainder of the sandstone is composed of coarse sand but generally grading into medium and fine sand at the top. There is then, a gradation in grain size from the coarser material at or near the base of the sandstone to finer material at the top. However, many irregularities occur to this gradational sequence in the grain size of the deposit. Lenses of conglomerate occur 20 to 30 feet above the base, and thin lenses of fine sand, very fine sand, or siltstone occur at random within the deposit. It is not unusual to find a thin zone, or even a single row of pebbles occurring along a lamination plane, or scattered pebbles occurring in a matrix of granule conglomerate or very coarse sandstone.

The grain size of the deposit changes abruptly both laterally and vertically where the channel structures are best developed. Within any one channel the size gradation is generally from the coarser material at the bottom into progressively finer material toward the top. Commonly a lens of pebble conglomerate exists at or near the base of a channel structure.

Fig. 8 -- Part of a lens of conglomerate near base of Hockingport sandstone, .7 mi. northeast of Hockingport, Ohio.

General Composition

The Hockingport sandstone is a "muddy" sandstone, a subgraywacke. The deposit is made up of approximately 65 percent quartz, the remainder consisting mostly of rock fragments and argillaceous material. Argillaceous material seems to occur in greatest abundance in the more conglomeratic portions of the deposit, where with lesser amounts of silt and sand-size clastics, it composes the matrix of these lenses. Occasionally, lenses of shale are found within the Hockingport sandstone.

Along Burnett Run, about 1 1/2 miles southeast of Cutler in western Washington County, Ohio, the lower 12 feet of the sandstone contains numerous carbonaceous streaks 3/8 to 1 inch thick containing macerated woody material. Above and below these coaly layers several impressions of sticks can be observed in very coarse sandstone. At about 15 feet above the base of the sandstone is a 6-foot zone containing several molds of logs with a maximum diameter of 6 inches and stick impressions of Calamites and other fossil plants not readily determinable (Figs. 9 and 10).

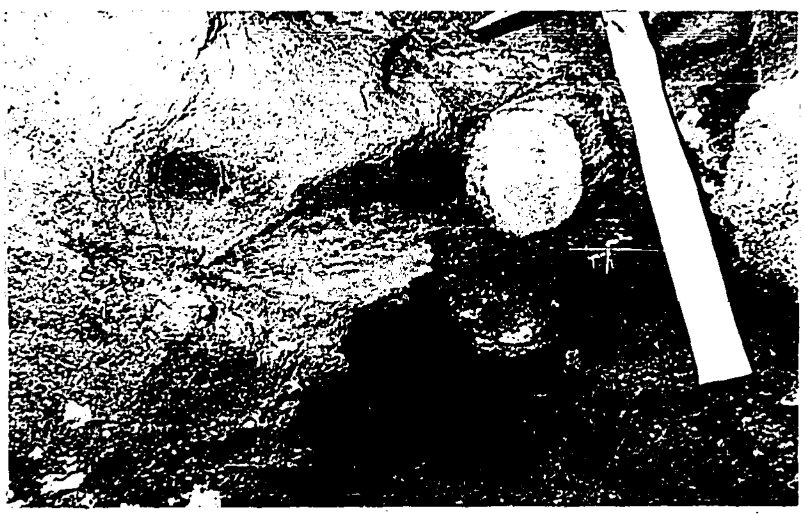

Fig. 9 -- Inner mold of a hollow log in Hockingport sandstone, 1.5 mi. southeast of Cutler, Washington County, Ohio.

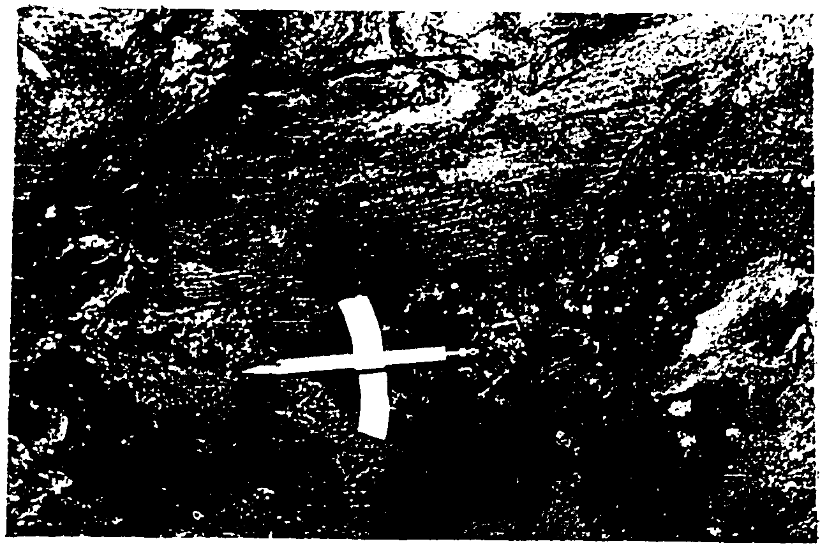

Fig. 10 -- Impression of Calamites in Hockingport sandstone, 1.5 miles southeast of Cutler, Ohio.

Near the base of the Hockingport sandstone in east-central section 20, Decatur Township, Washington County, impressions of fossil wood are also abundant. At this locality, in the lower part of the sandstone, a 1-foot zone occurs where 1-inch layers of very coarse sandstone alternate with layers of equal thickness containing alternating sand and carbonaceous laminae approximately 1/16 inch in thickness.

General Shape of Sand Body and Relation to Adjacent Sediments

The Hockingport sandstone is a lenticular deposit generally wedging-out laterally in all directions (Fig. 2). Along parts of the western and northern borders the thinning of the sandstone is due, at least in part, to erosion. Along other parts of the border of the sandstone, and especially in the east, southeast, and south, the termination of the deposit can be observed or predicted. The length of preserved outcrop of the sandstone in a north-south direction is about 28 miles, and in an east-west direction the width varies between 5 and 11 miles.

Along the southeast margin of the sandstone instances can be observed where, due to channeling into underlying deposits and later filling, the base of the deposit rises rapidly, and the thickness decreases until the sandstone lenses out. In some instances the contact of the sand with other rocks is very distinct. Below the contact, silty shales, siltstones and fine-textured sandstones occur exhibiting a fair degree of bedding. However, above the contact, the massive, coarse-textured sandstone may be practically structureless. The best example of the above condition has been noted about 4 miles south of Long Bottom, Ohio, near the point where Wells Run enters the Ohio River. Here the sandstone contact descends to the northwest at approximately 20 degrees (Fig. 11). In other instances, along the margins

Fig. 11 -- Base of Hockingport sandstone cutting down across bedded strata, 4 mi. south of Long Bottom, Meigs County, Ohio. Length of hoe, 30 inches.

of the deposit, the sandstone becomes interlaminated with, and finally grades into, red or buff argillaceous deposits.

The sediments immediately below the Hockingport sandstone are variable in lithology and structure, and in general, no single type occurs over a very large area. The sediment types most often found, in order of decreasing frequency, are red, buff, or gray silty shale; buff or gray siltstone; very fine sandstone, gray claystone; and coal. Most of the fine-grained, argillaceous deposits could aptly be termed mudstones since fissility is more often absent than present.

Several of the above types of sedimentary rocks, except coal, usually occur in successive horizons downward from the base of the Hockingport sandstone. Coal has been discovered immediately under the Hockingport sandstone in four localities. The coal is very thin, ranging from one to three inches in thickness; the other sedimentary units range from 1 to 10 feet thick with gray shale being the thinnest.

Specific occurrences of sedimentary rock types follow. Gray mudstone with abundant fossil plant fragments occurs locally under the Hockingport at the Washington-Athens County line along the Ohio River. Fossil plant fragments occur also in a 3-foot, red mudstone horizon beneath the sandstone about 1 mile west-northwest of the forks of the Little Hocking River and West Branch in southwestern Washington County, Ohio. Along McGill Run, .8 mile north of Hockingport, Troy Township, Athens County, a lens of conglomerate about 1-foot thick occurs at the base of the Hockingport sandstone. Below the conglomerate is about an inch of low-grade coal. The Hockingport sandstone rests on a 3-inch seam of coal in the bed of a small stream 3/4 mile northeast of Coolville in eastern Athens County.

Along Burnett Run, about 1 1/2 miles southeast of Cutler in western Washington County, Ohio, a 1-foot coal seam is exposed. This coal occurs 25 feet below the sandstone. Above the coal, and up to the base of the sandstone is a succession of gray claystone, buff and gray siltstone and red claystone.

In much of the northwestern part of the Hockingport outcrop, from southern Athens County northward to Sharpsburg, limestone occurs in the section at a level ranging from 75 to 100 feet below the base of the sandstone. The limestone may be in a single bed, or two or three beds may be separated by 2 to 3 feet of calcareous, gray shale or marl containing nodules of limestone. The limestone beds seldom exceed 1 foot in thickness, but locally they may attain a thickness of 2 feet. In the northern part of Decatur Township, Washington County, thin limestone beds commonly occur approximately 60 feet below the Hockingport sandstone.

The limestones are blue-gray, very hard and many appear to be somewhat brecciated or conglomeratic. Such textures are characteristic of many of the Monongahela and Dunkard series limestones in southeastern Ohio. Under the petrographic microscope, angular to rounded, nodule-like masses of dense, fine-grained, cloudy calcium carbonate appear to be held together by cloudy to clear carbonate and crossed by calcite-filled cracks. In the outcrop the angular to rounded masses are etched out by weathering giving the limestone the appearance of a breccia or a conglomerate (Fig. 12). Weller (1930, p. 129) in discussing this texture in the Pennsylvanian limestones says that it "is probably the result of wave action on the partially consolidated lime muds of the sea floor."

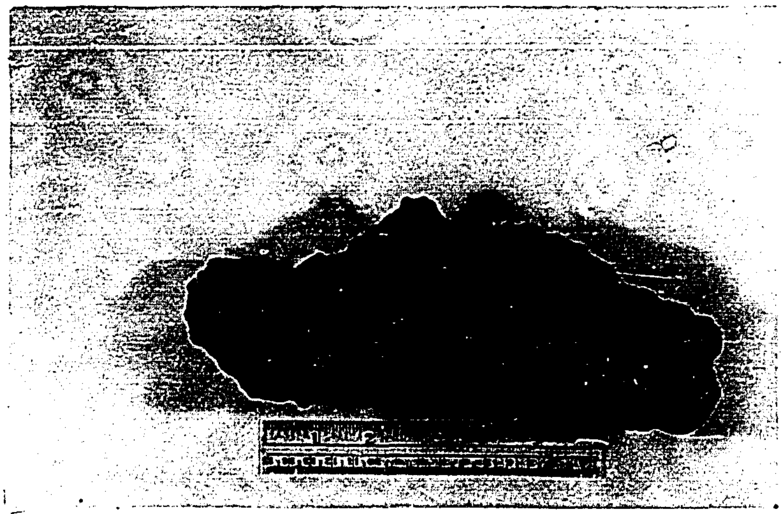

Fig. 12 -- Block of weathered Upper Pennsylvanian limestone, showing brecciation. From Carthage Township, Athens County, Ohio.

The structureless, massive, coarse-grained upper part of the Hockingport sandstone is generally overlain by a buff, silty shale, or fissile, or thin-bedded, buff siltstone. Occasionally, the massive upper portion of the Hockingport grades upward from coarse to medium sandstone with well-defined bedding. These sediments may there be succeeded by buff shale or buff siltstone. In a few localities the coarse sandstone gives way abruptly at the top to red, silty shale, and within a few feet upward this is succeeded by fine sandstone, siltstone or silty shales of a buff color. In any case, whether the sediments directly over the Hockingport sandstone are silty, red shale or buff sandstone, siltstone or shale, they are succeeded within a few feet by sediments of contrasting color, texture or both. There is then, in general, a succession of buff sediments followed by red beds or vice versa from the top of the Hockingport sandstone to the hilltops in all of the area studied. The red beds are not commonly well-bedded or fissile.

Sediments of the types referred to above seldom occur in units more than 10 feet thick. They are lenticular and limited in areal extent, one particular type occurring only locally at any one horizon. Lenticularity is more obvious in the sandstones than in the other sediment types. The sandstones are also more limited in extent. Many of the sandstones occurring well above the Hockingport appear to be sand-filled stream courses. They are generally linear in pattern and rarely are more than one or two hundred yards wide though they can be traced for several thousand yards in the direction in which the stream flowed. The sandstones are medium-grained and the bedding is not as distinct as that of the sandstones that occasionally occur directly over the Hockingport sandstone. These upper, channel sandstones have many characteristics similar to those of the Hockingport sandstone appearing, therefore, as small-scale counterparts of this larger sandstone deposit. Coal or limestone have not been observed in the strata preserved above the Hockingport sandstone.

Interpretation of Evidence

The characteristics of the Hockingport sandstone and adjacent deposits indicate a fluvial environment of deposition for these sediments. Other possible environments are those of the delta, littoral zone or beach, and the near-shore area of a shallow lake or sea.

A delta environment does not seem probable since there are no alternations nor dovetailing of relatively coarse channel sand with silt and clay deposits of quiet-water deposition. Such relationships would be expected as the main stream and its distributaries shift over the delta. The Hockingport sandstone generally varies from 40 to 80 feet in thickness, and contains only a relatively small proportion of bedded material finer than coarse sand. Gravel may be present in delta deposits, but it is not common unless the source is near. The Hockingport sandstone contains abundant conglomeratic zones, as well as scattered pebbles.

The conspicuous expression of the littoral environment is that of the beach. The nature of sorting, thickness and areal extent of the Hockingport sandstone tend to rule out the possibility of it being a beach deposit. Beach deposits commonly consist of well-sorted sand or gravel, free of much interstial material. Subgraywackes do form along beaches, however, where there is a large supply of clastics and subsidence of the coast. But commonly, fine detrital material is "winnowed-out" by the waves and currents and removed to offshore areas. In fluvial sandstones, sorting is generally poor. The Hockingport sandstone is in some places a heterogeneous accumulation of clastics which range in size from clay to large pebbles. Barrell (1906, p. 317), Twenhofel (1939, p. 95) and Kuenen (1950, p. 334) have pointed out that as a part of the geologic column, littoral deposits are relatively rare, and quantitatively unimportant. It is only under exceptional conditions that they can have a significant thickness. Presumably, this would be under conditions of a transgressing sea with continued subsidence. The chance for preservation of littoral sediments is slight and with regression of the sea, especially, deposits of the littoral zone tend to be destroyed. Barrell (1906, p. 438) states that:

> "taking the world as a whole the littoral zone does not average a mile in width and therefore comprises but a small fraction of the earth's surface compared with the great extent of marginal marine and even of continental deposits."

The Hockingport sandstone is a blanket deposit with a preserved outcrop area of approximately 225 square miles. It does not seem possible that a sandstone of this thickness and areal extent could represent deposition at the strand line.

There are many characteristics of the Hockingport sandstone and associated sediments which tend to rule out the possibility of their deposition in the near-shore area of a lake or inland sea. The most important of these characteristics are the nature of the bedding and cross-lamination, sorting and size of clastic material, shape and marginal relationships of the deposits, and lack of a marine, brackish or fresh water lacustrine fauna.

Bedding developed in clastics which are deposited in the zone of wave action in standing bodies of water tends to be more regular than that which is produced in coarse fluvial sediments. Barrell (1912) has compared the nature of bedding of the sediments of the marine and lake environment with that of fluvial deposits.

The transporting agents of marine sands, according to Barrell, are primarily waves and secondarily currents. He says: (1912, p. 430) "The waves and currents which they tend to generate are, however, in continual opposition, the one tending to fill up, the other to scour out." The result is a leveling effect, where, on flat shallow bottoms the sediments are spread in fairly regular sheets which produce flaggy bedding. Locally, where the waves drag on the bottom, coarse material may be piled up in the form of bars. Rich (1951, p. 10) has shown that sediments deposited in the zone of wave action should be expected to have moderately-thin, "wavy" bedding. In deeper water, below the zone of wave action of the heaviest storms, the finer sediments are characterized by very regular, even paper-thin, bedding. In streams, currents are the primary transporting agents and the effect of waves is slight. River currents tend to scour down into underlying deposits and concentrate sand and gravel into elongated discontinuous lenses. Barrell (1912, p. 433) states that although evenly-bedded, nearly structureless sands may be produced in both the sea and in rivers, the lenses of fluvial sands are convex down as well as up and show steep cross-bedding, whereas lenses of marine deposits tend to be convex up only and show flat cross-bedding.

Regular bedding is rare in the Hockingport sandstone since it is composed mostly of lenses of sandstone and conglomerate. Cross-bedding in the deposit is commonly steep, ranging from 15 to 30 degrees, the limits prescribed by Barrell (1912, p. 432) for fluvial sands. Good bedding or lamination does not characterize the sediments associated with the Hockingport sandstone, and they are thought to have been laid down principally in the flood-plain environment.

Although detrital material of all size grades can be found in the near-shore area of a sea, the association of much silt and clay with very coarse sand is not to be expected. With repeated agitation in the zone of wave action much of this finer material is thrown into suspension and removed by currents to deeper water where it may then be deposited. The conglomeratic lenses of the Hockingport sandstone, contain large amounts of argillaceous material. Therefore, it is not likely that they were laid down in a wave-worked shore environment.

The over-all shape of the Hockingport sandstone as well as its relations to adjacent sediments is most significant as to environment of deposition. Cross-sections of this sandstone body clearly show its lenticular nature. The cross-sections of the sandstone shown in Fig. 2 are remarkably similar to those drawn by Charles (1941, p. 47) for the sand body of the Bush City oil field of Anderson County, Kansas. Charles (p. 43) believes that this sandstone, which is 13 miles long and 1/4 mile wide, is a channel filling. The bottom of the Hockingport sandstone is much more irregular than the top. The undulatory nature of the lower contact of the sandstone, which is due to channeling into underlying deposits, is especially apparent in a detailed study of well-exposed outcrops.

It has been pointed out that along some margins of the outcrop the contact of the massive sandstone with the underlying bedded deposits, rises abruptly as the sand body lenses out, (Fig. 11). In other instances the sandstone becomes interlaminated with red or buff argillaceous deposits and finally grades into them. Barrell (1912, p. 431) has stated that this is to be expected on the concave sides of stream meanders, whereas, on the convex sides the sands of the abandoned channels cut across the bedding of the flood-plain deposits.

No invertebrate fossils of a marine, brackish or fresh water environment have been discovered in the Hockingport sandstone or associated sediments. Presumably, had these sediments been formed in a lake or shallow sea some evidence of existing invertebrate life would be in existence. Although, fresh water mollusks and other fauna may have lived in the stream channel, their structures may have been destroyed in the lithification of the sediments. Evidence of reptiles and amphibians has been found in the southern part of the Dunkard Basin. These fossils are discussed in more detail below.

Mudcracks, current ripple marks, and other sedimentary structures have been found in the Hockingport sandstone and associated deposits. Since these structures can be formed in other environments of deposition, they are not of significance in a determination of the nature of formation of these sediments.

In summation, it may be stated that the over-all nature of the Hockingport sandstone indicates deposition in a stream which meandered over a relatively flat plain. The environment and paleogeography of the sandstone are discussed further in other parts of this paper.

Petrography of the Hockingport Sandstone

The pebbles occurring in the Hockingport sandstone range up to 3/4 inch in intermediate diameter and up to 1 3/4 inch in maximum diameter. Most of the pebbles are rod-shaped or prolate, in that one diameter greatly exceeds the other two in length.

Most of the pebbles are composed of milky quartz. Tan or buff-colored chert is next in abundance. Dark-gray to nearly-black chert pebbles can be found. Most of the light-colored chert pebbles contain an abundance of sponge spicules. A few contain fragments of chertified brachiopods, and some of them contain dolomite. In one instance glauconite was discovered in a chert pebble. In addition to quartz and chert, well-rounded pebbles composed of fine sandstone or siltstone are common and dark-colored quartzite pebbles are not rare.

The major mineral constituents of the sand fractions of the Hockingport sandstone are quartz, feldspar, calcite, argillaceous material and chert. According to Pettijohn's criteria, (1949, p. 256) the sandstone would be classed as a subgraywacke. It contains approximately 65 percent quartz, 5 percent feldspar, 5 percent rock fragments, 10 percent argillaceous material, 5 percent chert, and 10 percent calcite.

The quartz grains range in roundness from subangular to rounded. Most of them are subangular.

The quartz has been grouped into six varieties on the basis of: their properties of extinction which are due to straining; the nature of their borders, whether sutured or not; granulation; elongation, caused by metamorphism of the source rocks; or in some cases, a combination of these properties. These varieties of quartz (Table 1) are similar to those which Krynine (1940) described in his analysis of the Third Bradford sand.

Authigenic quartz occurs as secondary overgrowths on some of the original detrital quartz grains, where "dust" rings separate the rounded quartz grains from the euhedral secondary outgrowths. Secondary silica exists to the greatest extent on unstrained and slightly-strained varieties of quartz.

The Hockingport sandstone contains varying amounts of calcite, which forms a crystalline mosaic between the grains. The manner in which the calcite is molded around the other grains suggests that it was deposited as a late, authigenic mineral cement.

Minor constituents of the Hockingport sandstone are the micas and the heavy mineral assemblage. The micas occur as aggregates of tiny flakes and as partially shredded larger grains. Muscovite predominates over biotite.

The heavy mineral suite of the sandstone is relatively simple, made up principally of the more persistent heavy mineral species. An exception, however, is barite, which probably occurs as an authigenic constituent of the cement of the sandstone.

The major and minor constituents of the sand fractions are listed in Tables 1 and 2, and are discussed further in other parts of this paper.

TABLE 1. Comparison of Major Constituents of the Sandstones

Constituents	Hockingport Sandstone Percentages		Waynesburg Sandstone Percentages	
Quartz				
Unstrained, with microlites, cavities and bubbles	10		4	
Slightly-strained, same as unstrained but with slight undulose extinction	26		23	
Highly-strained, well-developed undulatory extinction	9		15	
Strained with sutured borders, high degree of undulose extinction	5		11	
Granulated, fine-grained aggregates, sutured borders, highly-strained	9		12	
Schistoze, similar to granulated but with elongated grains	6		8	
Total		65		73
Feldspar				
Orthoclase	3		4	
Microcline	1		3	
Plagioclase	1		1	
Total		5		8
Micas			1	
Total				1
Rock Fragments				
Chert	3		1	
Shale	1		2	
Quartzite	1		4	
Total		5		7
Matrix				
Argillaceous material	10		5	
Chert	5		6	
Calcite	10		-	
Total		25		11
TOTAL		100		100

TABLE 2. Comparison of Heavy Mineral Assemblages

Constituents	Hockingport Sandstone Percentages	Waynesburg Sandstone Percentages
Ilmenite and Leucoxene	49	38
Tourmaline	7	10
Zircon	11	16
Garnet	9	2
Muscovite	5	1
Magnetite	3	0
Anatase	1	0
Rutile	0	1
Barite	15	19
Pyrite	0	13
TOTAL	100	100

Environment of Deposition and Paleogeography of the Hockingport Sandstone

Environment

The lithology, texture, and primary structures of the Hockingport sandstone and related sediments are indicative of a fluvial environment of deposition, with the source areas of the stream probably to the south or the southeast of the region studied in this investigation. It is thought that the stream entered southern Ohio from Mason County, West Virginia, and flowed generally northeast for a distance of 10 to 12 miles to Hockingport and thence generally north-northwest. This is indicated by the fact that the thickness as well as the grain size of the sandstone decreases to the north and northwest from the Hockingport area, and such evidence as could be found of directional trend of cross-lamination suggests that the source area of the sandstone was to the south or southeast of Ohio.

The degree and the direction of dip of sloping lamination surfaces were measured in cases noted where the true dip could be determined or computed from measurements of apparent dip. By use of a polar sheet, the individual readings of dip directions and the dip angles were plotted as dots. The degree of dip is represented by distance from the center, and the direction of dip, by orientation with respect to true north (Fig. 13).

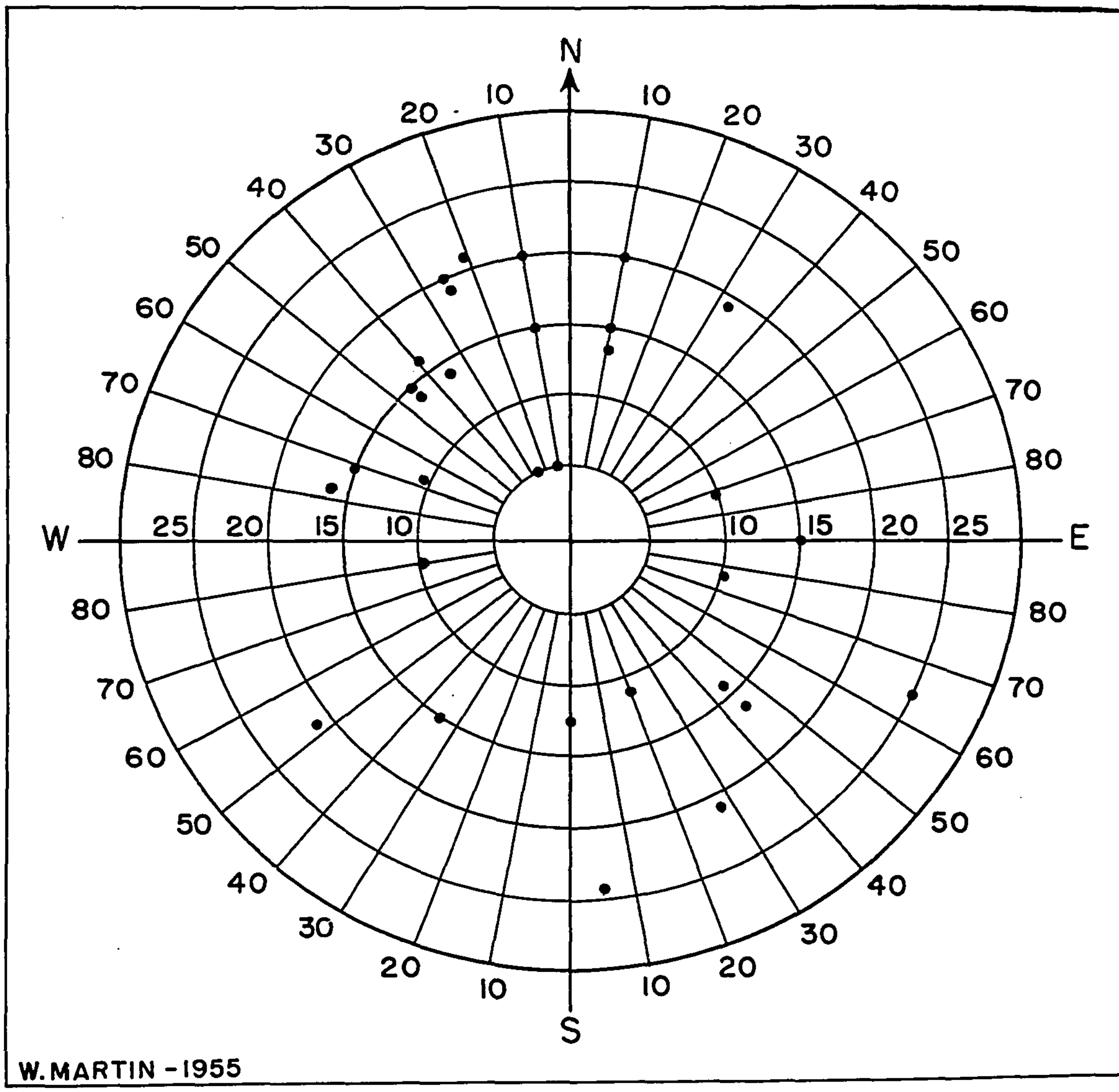

FIG. 13- Direction and amount of dip of cross-lamination in the Hockingport sandstone. Average dip is 15.5°.

The average dip angle was found to be 15.5°. There is a slight concentration of dip direction readings in the northwest quadrant and 58 percent of the readings occur within a 140° arc extending from 70° west of north to 70° east of north.

The sandstone is thickest along a line trending approximately north from Reedsville to Hockingport, Ohio, then N. 45° W., along the Hocking River to Frost, and finally N. 10° W. to Sharpsburg. The record of deposition beyond this latter point has been removed by erosion.

The stream became essentially an aggrading one during its course through western West Virginia and southeastern Ohio. This region was probably a relatively flat plain with numerous scattered swamps. The low gradient of the river resulted in the deposition of sand and gravel in the stream channel. A meander pattern, although probably not well-pronounced, may have been in existence. At times of increased velocity the currents cut laterally into the banks and scoured down into older flood-plain deposits. Deposition of material occurred on the concave sides of the meanders and in the shoal areas. As the river migrated across the floodplain, these deposits were in part carried downstream and the remainder buried under later fluvial sediments.

During times of flood, fine material was carried out onto the floodplain and deposited as a result of the decrease in the competency of the currents. Some of the deposits thus formed and not exposed at the surface were laminated. Other deposits were irregularly bedded. But it is likely that in the exposed floodplain deposits much of the lamination was destroyed by organisms, mudcracks and other surface agencies, or prevented by vegetation. Alternate wetting and drying and varying conditions for oxidation, coupled with irregularities in sedimentation, would produce the highly-variegated clays, siltstones and silty clays which prevail below, lateral to and above the coarse channel deposits.

Swamp deposits are represented in part by thin but well-developed local coals, a few of which underlie the channel sands, and by carbonaceous streaks with associated fine clay.

At some places, silicified logs, lignitized wood, and stick impressions are found in the Hockingport sandstone. The apparent localization of these occurrences would indicate a log jam or local collection of debris buried in the stream channel.

Marine, brackish water, or lacustrine invertebrate faunas have not been reported in the Dunkard strata of this area. Fossil evidence of reptiles has been discovered in a few localities in the southern part of the Dunkard Basin. These fossils are discussed in more detail in another part of this paper.

The climate of southeastern Ohio in Dunkard time was probably warm but drier and less humid than in earlier parts of the late Carboniferous. Red-bed deposition became more prominent and coal deposition was restricted to local, swampy, lowland areas. Possibly the fernlike plants were not as abundant as in early Monongahela time. Calamites and related flora probably flourished in the moist areas along the stream courses and near shallow ponds.

Source Areas

Probably the headwaters of the stream that transported the Hockingport sandstone lay in a highland area not very distant from southeastern Ohio, possibly only several hundreds of miles. The conglomeratic nature of the deposit, with pebbles nearly an inch in intermediate diameter, indicates that relatively strong currents were necessary to bring the material from the source area of the stream.

The relief of the source area may have been gradually decreased during the life history of the stream. This is indicated by decrease in the grain size of the sand from the bottom to the top which obtains throughout most of the sandstone. It is possible that the headwaters of the stream had reached late maturity or early old age before deposition of the Hockingport sandstone was completed. The coarseness of the channel sands observed above the Hockingport sandstone seldom exceeds that of medium sand.

The detailed lithology of the source area cannot be determined. It is probable that the clastic material was derived not only from sedimentary source areas but from igneous and metamorphic terranes as well.

Constituents from sedimentary rocks include the rock fragments and pebbles of chert, the rock fragments of shale, and the pebbles of fine sandstone and siltstone. However, some of this material could have been derived from the flood-plain deposits in which the channel was cut, and may have been moved only a short distance. It is possible that some of the more highly rounded grains of quartz are also second cycle sediments.

Krynine (1940) has pointed out that the unstrained quartz of the Third Bradford sand has been derived from igneous rocks. Although much of the unstrained quartz probably was derived from igneous rocks, it appears to the writer that some of the quartz could have been derived from quartz veins of thermally metamorphosed rocks which had not undergone appreciable deformation. Also, in many middle to high grade schists, quartz has recrystallized after the period of deformation and is essentially free from strain.

Although the granulated and schistoze quartz, and pebbles of milky quartz were probably ultimately derived from metamorphic rocks, it is impossible to determine whether these grains came directly from a metamorphic source area or are second cycle sediments.

The detrital grains of feldspar, although originally they may have been formed in igneous rocks, could have had their immediate source in gneissic metamorphic rocks.

THE TRUE WAYNESBURG SANDSTONE

Nature and Distribution

The northeastern portion of the area of Dunkard outcrop is located on the eastern limb and toward the northern extremity of a broad, flat, canoe-shaped trough — the Dunkard Basin. The gentle regional southwest dip of the strata is broken by numerous low parallel wrinkles or folds. The axes of these anticlines and synclines, and the axis of the Dunkard Basin, are in general alignment with the axes of the major Appalachian folds.

The type Waynesburg sandstone is named from the town of Waynesburg, Greene County, Pennsylvania, where the sandstone is well-developed and has conspicuous outcrops. The general area covered by the sandstone is as follows (Fig. 1): the irregular eastern boundary extends from north-central Washington County, Pennsylvania, to the southeast across eastern Washington, southwestern Westmoreland, western Fayette and eastern Greene Counties, and then south into Monongalia County of West Virginia to the west of Morgantown. Outcrops of the sandstone extend to the southwest of Morgantown possibly as far as Monongah, Marion County. From this locality the western boundary trends northwestward across Marion County, then north along the West Virginia-Pennsylvania line to north-central Washington County, Pennsylvania. It is not apparent that this sandstone forms a blanket deposit over the region outlined above. There are many localities within this region where it is poorly-developed or is non-existent.

Stauffer and Schroyer (1920, p.5) point out that along Dunkard Creek in Monongalia County, West Virginia, the Waynesburg sandstone is approximately 50 feet thick, is cross-bedded, and is mostly coarse in texture and contains quartz pebbles up to the size of a pea. In the Burgettstown and Carnegie quadrangles of north-central Washington County, the Waynesburg sandstone is reported to be thinly-laminated and in some places resembles shale (Shaw and Munn, 1911, p. 4). Just to the south, in the Claysville quadrangle, southwestern Washington County, the sandstone is locally massive but is generally very thin-bedded (Munn, 1912, p. 5). In many places the sandstone is absent and occurring in its place is a reddish, sandy shale. Over the western and northern parts of the Amity quadrangle, to the east, the Waynesburg interval is usually represented as shaly sandstone or is replaced by shale. The sandstone is prominent along several streams located in the southern part of the quadrangle.

The Waynesburg sandstone is well-developed along the west bank of the Monongahela River between California and West Brownsville, but is poorly-developed in most of the area to the north and east, in southwestern Westmoreland

and western Fayette Counties. According to Campbell (1903, p. 10), the sandstone is exposed at a few points in the Latrobe syncline and in the Port Royal syncline, but is poorly developed in the Uniontown syncline, the Pigeon Creek area, and in the Masontown-Uniontown quadrangles of southern Fayette County.

In the Rodgersville quadrangle, western Greene County, Pennsylvania (Clapp, 1907, p. 3), the Waynesburg sandstone occurs along Dunkard Fork and Crabapple Creek, tributaries of Wheeling Creek, but it is absent and is represented by shale on Enslow Fork. In the Waynesburg quadrangle of eastern Greene County (Stone, 1905, p. 6) the sandstone is exposed at many places along South Fork of Tenmile Creek between Waynesburg and Jefferson.

It is apparent, therefore, that the Waynesburg sandstone is best developed within a relatively narrow, north-south belt extending from north-central Greene County. Pennsylvania, into northern Marion County, West Virginia, a distance of approximately 30 miles (Fig. 1). Around the margins of this belt, especially on the west, the sandstone becomes very shaly and thinly-laminated, and is only locally a true sandstone. The author believes that here, east-west trending tongues of sandstone are intercalated into shaly, offshore facies, with narrow sandstone bodies wedging-out to the west.

In central Greene County, Pennsylvania, the Waynesburg sandstone is a coarse, flaggy to massive, gray to buff rock ranging from 30 to 40 feet in thickness. It occasionally exhibits irregular massive bedding, but in general the deposit is characterized by a flaggy type of bedding with units 2 to 12 inches thick.

Two miles east of Waynesburg, Greene County, Pennsylvania, representative, flaggy, Waynesburg sandstone can be observed overlying the Waynesburg coal and the roof shales of this deposit (Fig. 14). But within 50 yards along the outcrop the flaggy type of bedding changes to more massive units, the sandstone thickens considerably, and the base of the deposit cuts down into the underlying beds to below the horizon of the Waynesburg coal (Fig. 15). Within an interval of 10 yards from the above point, the base of the sandstone rises and the Waynesburg coal exists directly under the sandstone, the roof shales of the coal having been removed by eroding currents prior to the deposition of the sandstone. At this point the sandstone is somewhat massive but the thickness is very much reduced (Fig. 16). This rapid change from flaggy to a more massive type of bedding, local thickening of the sandstone, and a return to flaggy bedding and a thinner deposit can also be observed at other localities. A fine example of the above condition occurs along U.S. Route 19, .5 mile south of Mount Morris, Pennsylvania. Figure 17 shows the flaggy nature of the sandstone at this locality. This exposure of the sandstone occurs approximately 15 miles to the south of the outcrops shown in Figures 14 through 16.

Fig. 14 -- Flaggy Waynesburg sandstone. The Waynesburg coal (2 feet thick) occurs about 3 feet below hammer, the handle of which is at the sandstone-shale contact. Two miles east of Waynesburg, Pennsylvania.

Fig. 15 -- Massive Waynesburg sandstone, 50 yards along outcrop from Fig. 14. The Waynesburg coal has been cut out.

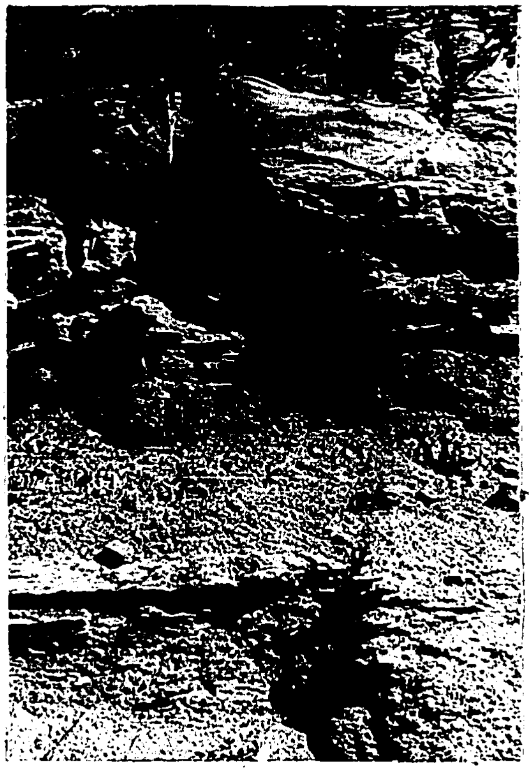

Fig. 16 -- Waynesburg sandstone occurring directly above the Waynesburg coal, the roof shales of the coal have been removed. Ten yards along outcrop from Fig. 15. Figures 14, 15, and 16 taken from about the same level, a railroad track.

Fig. 17 -- Flaggy Waynesburg sandstone, .5 mi. south of Mt. Morris, Pennsylvania. Twenty yards to the south the sandstone is massive as in Fig. 15.

The grain size varies from coarse sandstone near the base to medium or fine-grained sandstone near the top. Cross-bedding is discernable in some units but, in general, nearly horizontal lamination prevails.

To the south in Monongalia County, West Virginia, the sandstone thins considerably. In southern Greene County, Pennsylvania, and Monongalia County, West Virginia, it is generally coarse in grain size and almost universally exhibits a flaggy type of undulatory bedding (Fig. 18).

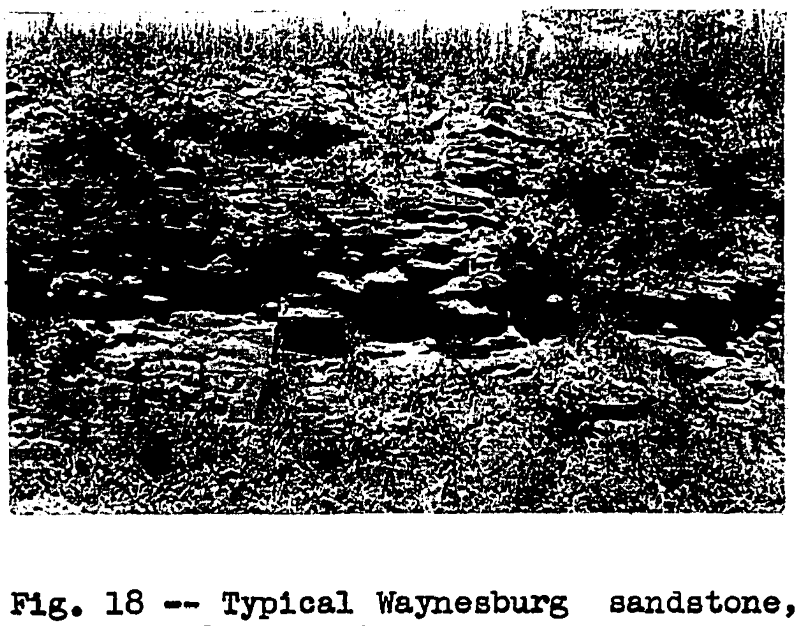

Fig. 18 -- Typical Waynesburg sandstone, U. S. Rt. 19, north of Arnettsville, Monongalia County, West Virginia. Striped hammer to right of center.

In many places in central Greene County, Pennsylvania, the Waynesburg sandstone rests directly on the rather extensive Waynesburg coal (Figs. 14 and 16). But generally, in the area to the south, in northern West Virginia, a bluish shale, the Cassville, occurs between the Waynesburg coal and the Waynesburg sandstone. This 5- to 15-foot shale (White, 1891, p. 41) is best developed in its type area near Cassville, Monongalia County, West Virginia; but it is reported to occur occasionally in Belmont and Monroe Counties of Ohio (Stauffer and Schroyer, 1920, pp. 37-112). In western Washington County, Pennsylvania (Munn, 1912, p. 5), the Cassville shale is described as a thin, dark or reddish shale with 8 inches to 1 foot of limestone in it. Shaw and Munn point out (1911, p. 4) that in some parts of Washington County this limestone occurs between the shale and the Waynesburg sandstone.

The Waynesburg sandstone is generally overlain by shales, termed argillaceous shales in some reports. The strata between its top and the top of the Dunkard series consists of alternating shales, sandstones, coals and limestones with shales and sandstones making up the greater part of the sequence.

Petrography of the Waynesburg Sandstone

The major constituents of the Waynesburg sandstone are quartz, feldspar, rock fragments and the matrix material. It would be classed as a subgraywacke since it contains approximately 73 percent quartz, 8 percent feldspar, 7 percent rock fragments, 5 percent argillaceous material and 6 percent chert which occurs in the matrix.

The varieties of quartz as well as most of the other constituents, which occur in the Waynesburg sandstone, are similar to those types making up the Hockingport sandstone. There is, however, a notable difference in the relative abundance of the various varieties of quartz in the two sandstone deposits.

A comparison of the constituents of the Hockingport and the Waynesburg sandstone is shown in Tables 1 and 2.

The most notable difference in the varieties of quartz in the two sandstones is to be found in the types which have possibly been derived from metamorphic rocks. The Waynesburg sandstone contains about 17 percent more highly-strained quartz than the Hockingport sandstone. Of the rock fragments of the Waynesburg sandstone, quartzite and shale fragments are abundant, but chert is practically non-existent.

The bonding material of the Waynesburg sandstone is mainly argillaceous matter and chert. Calcite has not been observed. The heavy mineral assemblage is similar to that of the Hockingport sandstone. A notable difference is in the abundance of pyrite of the Waynesburg sandstone. Since this mineral is authigenic in origin and occurs sporadically in the deposit, its presence may not be significant. Barite, an authigenic mineral cement, is not uniform in occurrence in either sandstone. Some samples do not contain this mineral, whereas in others, it may make up as much as 40 percent of the heavy mineral fraction.

Environment of Deposition of the Waynesburg Sandstone

The flaggy bedding which characterizes the Waynesburg sandstone is indicative of a shallow sea environment of deposition. The individual beds, which generally range from 2 to 6 inches in thickness are not persistent, but lens out within short distances. The grain size in most instances is almost uniform, being in general coarse-grained and containing but little argillaceous material. Bedding of this type, as well as texture, composition, and other features of the Waynesburg sandstone are the same as those characteristics which Rich (1951, p. 10) prescribes for sedimentary rocks of "unda" origin. According to Rich, the "unda" environment is "that part of the floor [of any body of standing water] which lies in the zone of wave action and in which, therefore, the bottom is repeatedly stirred and reworked by storm waves."

The constant reworking of the sediments in this environment by waves would tend to remove the fine material and spread the coarser clastics irregularly over the bottom.

The main characteristics listed by Rich (1951, p. 10) that occur here are relatively coarse texture, ranging from gravel to silt; composition, ranging from conglomerate through coarse silt and including fragmental limestone, oolite or coquenite; and moderately-thin, "wavy" bedding. Cross-bedding, flow-and-plunge structure, lenticularity of beds and ripple marks are also common in these strata.

Therefore, the Waynesburg sandstone is considered to be a near-shore accumulation of sand, the result of current, but predominantly wave deposition. These agencies spread the sand over the sea bottom and perhaps locally piled it up in the form of linear bars.

The instances referred to (page 55) where the sandstone thickens locally and the bedding changes from a flaggy to a more massive type and the bottom of the sand body cuts down below its general level (Figs. 14, 15 and 16), are thought to be deposits produced by scouring, and later filling, at tidal inlets. If they are such deposits, a detailed study of the sandstone, and adjacent strata, might indicate that they are aligned approximately at right angles to the strand of the Dunkard sea, or they might be parallel to it, depending on the amount of migration of the inlet.

The writer believes that the Waynesburg sandstone is not a blanket deposit but is represented by a series of relatively local accumulations of sand within the region previously delineated.

Source Areas of the Waynesburg Sandstone

The Waynesburg sandstone contains a greater percentage of highly-strained and granulated quartz, feldspar, and rock fragments of quartzite than does the Hockingport sandstone. Rock fragments of chert, however, are more abundant in the Hockingport sandstone.

These relations suggest that the source area of the Waynesburg sandstone contained a greater percentage of crystalline rocks as compared to sedimentary types than that of the Hockingport sandstone.

The results of a comparison of constituents of the two sandstone deposits would be of greater value if the environments of deposition had been the same.

Much of the evidence that sedimentary rocks existed in the source area of the Hockingport sandstone is the occurrence of chert pebbles and sand-size rock fragments of chert. Although these constituents may also have been present in the source area of the Waynesburg sandstone, they may have been separated from the sand fractions before the stream transporting the material reached the environment of deposition of this deposit.

It is thought on the basis of general geologic relations, but without any definite proof, that the clastic material which makes up both of the sandstone deposits was derived from different parts of the same linear orogenic belt. This belt probably existed as a northeast-southwest-trending highland to the east of the Dunkard Basin. The streams which transported the detrital material of the Waynesburg sandstone to the inland sea possibly headed farther to the north in this highland area than the stream which deposited the Hockingport sandstone.

EVIDENCE THAT THE HOCKINGPORT SANDSTONE IS NOT THE TRUE WAYNESBURG SANDSTONE

The coarse, massive sandstone deposit occurring mainly in eastern Athens, eastern Meigs and western Washington Counties of Ohio, and referred to in this paper as the Hockingport sandstone, should not be correlated with the true Waynesburg sandstone because of the following evidence:

1. The Hockingport sandstone of southeastern Ohio is limited in areal extent to the region outlined above. The Waynesburg sandstone of southwestern Pennsylvania cannot be traced from the type area to southeastern Ohio.

2. It is apparent that the environments of deposition of the Hockingport sandstone and true Waynesburg sandstone were substantially different. This is shown by (a) the comparison of the nature of the strata in the northern and southern parts of the Dunkard Basin; (b) by the comparison of fossil fauna in the northern and southern parts of the Dunkard Basin; and (c) the comparison of the primary structure and texture of the two sandstone deposits.

Areal Extent of the Sandstones

I. C. White (1903, p. 118) is quoted as follows:

"The Waynesburg sandstone has a very wide distribution, extending as a great, coarse deposit entirely across the state /West Virginia/. Being seldom less than 50 feet and often 75 feet in thickness it makes a line of rugged cliffs along its eastern outcrop from where it enters the state in Monongalia County, across Marion, Harrison, Lewis, Gilmer, Calhoun, Roane, Kanawha, Putnam, and Cabell to where it leaves the Appalachian trough in Wayne County near the Big Sandy. It is especially massive and pebbly where it rises from the bed of Poca River just below Walton /Roane County/ and for many miles down that stream, as well as in all the country to the southward where the southwestward rise of the strata carries it up into the hill tops before it disappears from the same a few miles west from Elk River. This same stratum comes out of the Ohio River along the Ohio shore in the vicinity of Blennerhassett Island, and its massive top is frequently visible at low water in the bed of the Ohio at many localities between Parkersburg and Letart."

The author is doubtful if the true Waynesburg sandstone can be traced farther south than Marion County along the eastern border of the Dunkard-covered area in West Virginia. Numerous sections south of Marion County in the eastern part of the area have been described in the West Virginia Geological Survey County Reports. The Waynesburg sandstone reportedly occurs in this area. A field study of these sections reveals that the sandstone described does not resemble the true Waynesburg sandstone of southwestern Pennsylvania or the Hockingport sandstone of southeastern Ohio. The sandstone to which White refers, near the southern end of Blennerhassett Island, is a local deposit extending for approximately 800 yards along the Baltimore and Ohio Railroad tracks where it then lenses out and where its horizon is occupied by red shales (Fig. 19). This highly

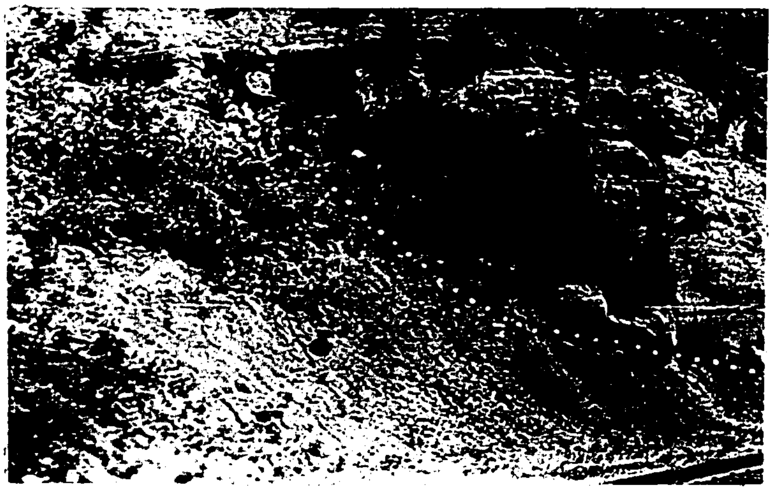

Fig. 19 -- Edge of a channel sandstone, red shale to left. Near southern end of Blennerhassett Island, Washington County, Ohio. Scale indicated by railroad track.

cross-bedded, local channel sandstone is much finer in grain size and is less massive than the Hockingport sandstone which crops out two miles to the southwest. The Hockingport sandstone extends along the Ohio River from Sec. 29 Belpre Township, Washington County, Ohio, to the northern part of Sec. 20, Lebanon Township, Meigs County, Ohio, but not as far south as Letart, as White has indicated.

The Hockingport sandstone lenses out to the south in Meigs County. To the west and north the deposit exists near, at, or above the hilltops due to the northwestward rise of the strata. In these areas the thickness has been, in some areas, reduced by erosion. To the northeast the sandstone thins rapidly and finally becomes non-existent, and to the east the thickness is reduced to about 15 feet where the deposit disappears below drainage. If the regional dip of the strata is projected to the southeast across the Ohio River into West Virginia, the sandstone is non-existent at the proper elevations, except in the area adjacent to the river between Newberry Island and Harris Ferry, opposite Hockingport, and to the southeast between Pond Creek and Muses Bottom in Jackson County.

Another massive sandstone having much the same primary structure as the Hockingport sandstone, but which is finer in grain size and averages approximately 30 feet in thickness, crops out in several localities in southern Sutton and Lebanon Townships of Meigs County, Ohio. This sandstone outcrops as far north as the central part of Sec. 12, Sutton Township and extends, not as a blanket deposit, but in scattered exposures, southward in Ohio to the Ohio River, and possibly extends under the river into West Virginia in the vicinity of Letart Falls, Ohio, and the village of Letart, West Virginia. This sandstone is a fluvial deposit. Cross-sections of the channel deposit measure approximately 1/2 mile in width. These cross-sections, as well as longitudinal sections of the sandstone are best exposed in the present stream valleys, especially those of Groundhog Creek, Oldtown Creek, Tanner Run and Johns Run. Although this sandstone resembles the Hockingport in types of primary structures, it differs considerably from the latter in texture, thickness, and areal extent. The sandstone is finer in grain size than the Hockingport. It is, in general, less than one-half as thick, and is so limited in areal extent that the general course of the stream can frequently be traced. Additional evidence that this sandstone is not the Hockingport is the fact that extending east-west across northern Sutton and central Lebanon Townships there is a two and one-half mile-wide strip in which no coarse, massive sandstone occurs. The stream responsible for this deposit meandered widely in Sutton and Lebanon Townships and may have been tributary to the larger stream which deposited the Hockingport sandstone.

According to White, the Hockingport sandstone, as well as the more local, stream-deposited sandstones to the north and to the south of the Hockingport, would be considered as one large blanket deposit extending along the Ohio River from southern Washington County to southern Meigs County. He would also extend this deposit into the area of the true Waynesburg sandstone in northern West Virginia and southwestern Pennsylvania, making it a great blanket deposit extending for a linear distance of about 100 miles.

A sandstone horizon, which Grimsley (1906, p. 68) refers to as being the Waynesburg sandstone occurs occasionally in the northern panhandle counties of West Virginia. This sandstone, or sandy horizon seems to exist from 18 to 45 feet above the Waynesburg coal. In one section, coarse, sandy shales and sandstones reach 100 feet in thickness. In most sections between Wheeling and Elm Grove this sandstone is replaced by sandy shales. This condition also occurs in Ohio County to the north of Wheeling. In the few instances where the sandstone is well developed, it is reported to be only 18 to 20 feet in thickness.

I.C. White (1891, p. 40) states:

> "Along the western border of the outcrop of this rock [Waynesburg sandstone] it dwindles down and changes its character entirely, being frequently represented in Washington County, Pennsylvania; Marshall and Ohio Counties, West Virginia; Belmont and Monroe Counties, of Ohio, by sandy shales and flaggy sandstones, and occasionally even a stratum of limestone may be found at this horizon."

Stevenson (1907, pp. 97-8) in his more recent discussion of the Waynesburg sandstone, may be quoted as follows:

> "In Maryland, Westmoreland, Fayette, eastern Washington and Greene [counties] of Pennsylvania, as well as southward to Harrison County of West Virginia, it is a sandstone, usually massive and often to some extent conglomerate. In the interior of Washington County [Pennsylvania], as well as in Allegheny County, it is apt to be shaly, but in the western part of the former county it is usually massive...... Along the western outcrop it is insignificant in Muskingum, but farther north, in western Belmont, in Harrison, and southern Jefferson [counties in Ohio], it is a well marked sandstone. The sandstone of this interval is insignificant and at times replaced by sand or even clayey shale within a large interior area embracing Ohio, western Marshall and Wetzel, Tyler, Pleasants, and Wood County of West Virginia as well as eastern Belmont, Monroe and most of Washington County of Ohio."

Therefore, these authors admit that within a large area which includes part of southwestern Pennsylvania, the northwestern counties of West Virginia, and the adjacent counties of Ohio, the Waynesburg sandstone is not well represented, and it is not a persistent sand. However, the authors still choose to correlate these limited, widely-separated sandstone deposits, because a sandstone regardless of its nature and lithology occasionally occurs at approximately the same horizon.

Stauffer and Schroyer (1920) point out that the Waynesburg sandstone appears about the margin of the Dunkard-covered region in Ohio to the southern limit of the region. They say (p. 18):

> "As a continuous sandstone, however, it seems to make its first appearance in Washington County [Ohio] in the Muskingum Valley, and from there it is more or less continuous into Athens and Meigs Counties, in the latter of which it rises to cap the hills north of Pomeroy and then disappears."

The author was unable to find a sandstone even remotely resembling the Hockingport around the western margin of the Dunkard-covered region in Ohio. The "continuous sandstone" to which Stauffer and Schroyer refer, is in part the deposit which is termed Hockingport sandstone in this paper. This sandstone does not, however, make its first appearance in the Muskingum Valley, Washington County, Ohio, but about 15 miles to the southwest in Sec. 27, Belpre Township.

Stauffer and Schroyer (1920) report the occurrence of the Waynesburg sandstone in only 10 widely separated sections out of 76 printed sections measured in Jefferson, Belmont, Monroe, Noble and eastern Washington Counties, Ohio. If the Waynesburg sandstone is a blanket deposit, it would presumably be recognized in nearly all of the sections. The Waynesburg sandstone is listed as occurring in two sections in Belmont County, six in Monroe, one in Noble and one in Washington County.

William H. Smith (1948) shows approximately 20 feet of the Waynesburg sandstone in six measured sections in Newport Township, northeastern Washington County, Ohio.
A field study of the above deposits reveal that they occur in general as beds of fine to very-fine, micaceous, gray sandstone, in units from 1 to 5 feet thick and alternate with beds of fissile, greenish-gray siltstone.

Cross (1950, pp. 49, 51, 68, 71) occasionally reports a sandstone, which he terms Waynesburg, in sections measured in Belmont and Monroe Counties of Ohio and Marshall County, West Virginia. In the sections by Cross, these deposits are described as shaly, irregularly-bedded sandstone, as massive sandstone, or as a shaly phase of the Waynesburg sandstone made up of 3 3/4 feet of siltstone. The thickness of these deposits ranges from 2 1/2 to 10 2/3 feet. These local occurrences of sandy material are certainly not indicative of a widespread blanket deposit such as the Waynesburg sandstone has been reported to be.

Diverse Environments of Deposition

Comparison of Strata in the Northern and Southern Parts of the Dunkard Basin

Stevenson (1907, p. 98) reports that limestone is persistent in the Cassville shale in western Washington County, Pennsylvania, but that the limestone does not occur in the Cassville shale in eastern Washington and Greene, nor in Westmoreland and Fayette Counties. It is thought that this is the limestone which is well-developed above the Waynesburg coal in the panhandle counties of West Virginia and the adjacent area of southeastern Ohio. The limestone of this region was named the Elm Grove by G.P. Grimsley (1906, p. 68), and he reports that it ranges from 2 1/2 to 10 feet in thickness. Grimsley (1906, p. 69) points out that the Elm Grove limestone is found with the Waynesburg coal in the northwestern part of Marshall County, and through most of Ohio and Brooke Counties in West Virginia. In some places it rests directly upon the Waynesburg coal, but more frequently it is separated from this coal by several feet of shales. Grimsley states that the shales are 5 to 8 feet thick.

According to Stauffer and Schroyer (1920, p. 17) the Elm Grove limestone occurs in the Ohio area, bordering the panhandle counties of West Virginia especially in Belmont County. Here it ranges from 1 1/2 to 5 feet in thickness and contains fish scales, coprolites, and teeth as well as worm tubes, pelecypods and ostracods. The Cassville shale is reported by Stauffer and Schroyer (1920) as occurring frequently in the Ohio region, and here, as well as in the type area, it contains an abundance of fossil plant remains.

In eastern Ohio, and adjacent areas of West Virginia, the sequence of the horizons in the lower Washington formation is reported to be Cassville shale, Elm Grove limestone, and Waynesburg sandstone. It has been pointed out that the Waynesburg sandstone is listed in only 10 of the 76 sections measured by Stauffer and Schroyer in this area of Ohio. The sandstone deposits reported do not resemble the Waynesburg sandstone or the Hockingport sandstone.

The author believes that the environment of deposition of the strata of the lower part of the Washington formation of the northeastern part of the outcrop of the Dunkard series differs considerably from the environmental conditions that existed in the southwestern part of the region in early Dunkard time. This is made apparent by the nature of the strata occurring at the Waynesburg sandstone horizon in Belmont and Monroe Counties of Ohio and adjacent areas of Pennsylvania and West Virginia. In this region the Elm Grove limestone frequently occurs at the horizon which is occupied by the Waynesburg sandstone in the type area of this stratum. This results in elevating the Waynesburg sandstone, stratigraphically, in a comparatively large area.

The deposition of a limestone as thick and as extensive as the Elm Grove is reported to be, would require a body of standing water. The strata occurring at the horizon of the Elm Grove where it is non-existent, are frequently gray, limy shales, or marls which could also be deposited under similar conditions. Likewise, the strata occupying the position of the Waynesburg sandstone where it does not occur above the Elm Grove limestone, are of such a nature that they also could have been formed in a shallow body of water. These strata, as reported by Stauffer and Schroyer (1920, pp. 37-113), are most frequently arenaceous, gray shales or alternations of arenaceous, gray shale with laminated fine-grained, gray, micaceous sandstones.

Therefore, the nature of the rocks deposited in the northeastern part of the Dunkard Basin during late Carboniferous time is substantially different than that of the massive conglomeratic Hockingport sandstone and the associated flood-plain deposits of the southwestern part of the region. But according to the literature they are not only contemporaneous, but, at least in part, correlative.

Comparison of Fossil Fauna

The fossil fauna provides additional evidence of different environmental conditions existing in the northern part of the Dunkard Basin as compared to the southern part in Dunkard time. Relatively few fossils have been discovered in the rocks of the Dunkard series. In the northern portion of the region, invertebrate fossils and remains of aquatic types of vertebrate animals have been found; whereas in the southern portion, the fossil evidence is mostly confined to amphibious reptiles and aquatic amphibians.

Many of the invertebrate fossils discovered in the Ohio portion of the area were new species and are briefly described and figured by Stauffer and Schroyer (1920):

Lingula permiana Stauffer and Schroyer has been found in the black shales associated with the Washington coal near Crabapple, Belmont County, Ohio (Fig. 1, Locality I). Two pelecypods, Plenrophorus (?) ohioensis Stauffer and Schroyer and Glossites (?) belmontensis Stauffer and Schroyer were collected in the Elm Grove limestone west of Martins Ferry, Belmont County (Locality II). Numerous small ostracods probably belonging to the genus Cythere (?) sp. also occur in the Elm Grove and other limestones along with slightly larger forms which no doubt represent several different genera.

Other pelecypods, Edmonia (?) washingtonensis Stauffer and Schroyer and Edmonia (?) minuta Stauffer and Schroyer were found respectively in the Cassville shale and the Lower Washington limestone at Shadyside, Ohio (Locality III). The following gastropods, Anthracopupa (?) dunkardana Stauffer and Schroyer, Loxonema (?) parva Stauffer and Schroyer, and Naticopsis (?) diminuta Stauffer and Schroyer occur in the shales at the base of the Lower Washington limestone, one-half mile south of Pleasant Grove, Belmont County, Ohio (Locality IV). Stauffer and Schroyer (1920, p. 145) point out that the pelecypods and gastropods are "probably all brackish or even fresh water forms".

A new genus, Whipplella, and several species of ostracods are described and figured by Holland (1934, pp. 343-50) from the Nineveh limestone of the Greene formation (Localities V and VI). According to Holland the fauna of the Nineveh limestone is composed entirely of fresh water forms.

Cross (1950, pp. 55, 59, 61, 82) reports ostracods at a number of the Dunkard horizons (in one instance an ostracod coquina, Locality VII), in Belmont County, Ohio, and in Washington County, Pennsylvania (Locality VIII). Pelecypods have also been found at Locality VIII.

Vertebrate fossils of the Dunkard region have been described and figured by Stauffer and Schroyer (1920), Tilton (1926, 1930, 1931), Whipple and Case (1930), Baird (1952), Moran and Romer (1952) and many others. The most complete listing and discussion of vertebrate fossils and collecting localities is to be found in Moran and Romer's (1952), mongraph entitled "Fossil Vertebrates of the Tri-State Area". These authors include in their publication a discussion of the significant vertebrate fossil discoveries up to 1937. Baird (1954) has reviewed the significance of the vertebrate fossil footprints of the rocks of the Monongahela and Dunkard series. These fossils are considered in more detail in another part of this paper.

Romer (1952, p. 102) in his discussion of the vertebrates of the Dunkard region concludes that they were predominantly aquatic or amphibious in nature. In discussing the faunal list, he says (p. 103):

> ".....an abundance of fishes, reasonably considered as inhabitants of the streams and lagoons of such an area, including predaceous pleuracanth sharks, lungfishes, palaeoniscoids and - rarer in numbers - crossopterygians and acanthodians; purely aquatic pool-dwelling amphibians such as the 'horned' Diplocerapis and the lysorophids; a more limited number of rhachitomes of amphibious habits, including Eryops and one or more obscure smaller types; of reptiles, an abundance of edaphosaurs which presumably fed on lush swamp vegetation, but few remains of other sorts."

Romer (p. 102) points out that reptiles are extremely rare in the Dunkard with only one type being well represented. This reptile is Edaphosaurus, a terrestrial type which fed on swamp plants.

Of the amphibians that have been discovered Romer (p. 102) indicates that 60 percent are of purely aquatic types such as Diploceraspis and the lysorophid group. Eryops, however, according to Romer, was a partially terrestrial amphibian type.

On the map accompanying their report, Moran and Romer (1952) list a total of 38 localities within the region of the Dunkard outcrop and in rocks of the Monongahela and Dunkard series at which vertebrate remains have been found. Vertebrate fossils have been found in the Monongahela series at only one locality. The fossil localities are shown by X's on Figure 1. With regard to distribution of these localities, 29 of them are north of an east-west line which extends along the northern boundary of Washington County, Ohio, and which divides the Dunkard area in two nearly equal parts. Of the 9 fossil discoveries in the southern part of the region, reptiles and pond-dwelling amphibians predominate practically to the exclusion of other animal life with the swamp-dwelling reptile Edaphosaurus occurring at 4 localities. It is interesting to note that most vertebrate fossil localities of the northern part of the Basin are concentrated in southern Marshall and northern Wetzel Counties of West Virginia with the boundary line of these counties passing near the center of the area of concentration. This line, extended eastward forms the southern boundary of Pennsylvania.

It is noted that nearly all of the vertebrate fossils collected in the northern part of the region were found in limestones or in shales associated with limestone deposits. While in the southern part, vertebrate fossils have been found in limestones in only 3 of the 9 localities cited.

There may be several explanations to this geographic localization of fossil discoveries and abundant occurrence of fossils in limestones and associated shales. It may be that the vertebrate fauna was not abundant in the southern part of the region because of environmental conditions unsuited to the mode of life of most inhabitants. Possibly the search for fossils has not been carried out to the same extent in the southern part of the Basin as compared to the northern part. The most logical explanation seems to be that environmental conditions were distinctly different in the two parts of the region. In the north, during much of Dunkard time, aquatic vertebrates and invertebrates lived for the most part in shallow, fresh water lakes and in streams.

Calcareous sediments were formed in these lakes and animal remains were entombed in the deposits. In the southern part of the region there are few limestones, and fossils of any kind are rare. Invertebrate fossils, other than ostracods have not been reported from the southern part of the Basin. Vertebrate fossils found here are either amphibious reptiles or amphibians which lived in shallow ponds or in swampy tracts along the streams. Vertebrate fossils are much rarer in the southern part of the Dunkard terrain than in the northern part. This may reflect a smaller proportion of terrestrial creatures and a less satisfactory environment for fossilization.

It seems, therefore, from the reported fossil evidence, that practically all of the marine, brackish or fresh water invertebrate forms of life of this time existed only in that part of the Dunkard Basin which lies to the north and northeast of Washington County, Ohio. The reptiles and amphibians which existed in the southern part of the Basin were adapted to a floodplain, swamp, and pond environment; whereas the invertebrates, and predominantly aquatic vertebrates of the northern portion, lived in environments which varied from a shallow inland sea to fresh water lakes, streams, swamps and ponds. Romer (1952) says:

> "The general impression of the Dunkard area gained from nonvertebrate evidence is thus that of a flat, well-watered coastal region with abundant swamps and lagoons; a region ecologically ideal for an abundant fauna of freshwater fishes and aquatic or swamp-dwelling tetrapods, but with relatively few dry land areas in which the more purely terrestrial types of amphibians and reptiles could flourish in any numbers."

The writer believes that on the basis of both the lithologic and faunal evidence, this description seems much more applicable to the northern part of the Dunkard Basin than to the southern part. The southern part of the region probably contained more dry land throughout Monongahela and Dunkard time than the northern part.

Comparison of Texture and Structure of the
Waynesburg Sandstone and the Hockingport Sandstone

The Waynesburg sandstone and the Hockingport sandstone are strikingly dissimilar deposits.

The Waynesburg sandstone is fairly uniform in texture, generally made up of coarse sand, but contains granules and pebbles up to the size of a pea. The Hockingport sandstone, although composed for the most part of very coarse sand, contains a large intermixture of granules, and pebbles up to an inch or more in diameter. Some parts of this clastic deposit are true conglomerate, and this condition is not local. Detrital material, larger than very coarse sand, can be found in all of the region in which the deposit occurs. Therefore, sorting is quite different in the two sandstone deposits, a characteristic which reflects the environmental conditions under which the respective deposits were formed.

The Waynesburg sandstone although occasionally somewhat massive, is characterized by flaggy bedding. The distance between the bedding planes is generally from 2 to 6 inches. The Hockingport sandstone on the contrary, is almost universally massive, and is characterized by sandstone and conglomerate courses rather than sandstone strata (Fig. 20).

Fig. 20 -- Hockingport sandstone, .7 mi. northeast of Hockingport, Athens County, Ohio. Compare with Figs. 14 through 18.

A flaggy, regular type of bedding is indicative of the action of waves with clastic material having been spread more or less uniformly over the shallow sea bottom. River currents, on the contrary tend to prevent regularity of bedding, and by scour-and-fill action give rise to a meshwork of discontinuous, highly-cross-bedded, sandstone lenses with gravel concentrated at the bottom. These are the channel structures that typically occur in the Hockingport sandstone. It has been pointed out that lenticular thickenings of marine sands normally should be convex upward and show flat cross-bedding, whereas channel sands, although convex on the upper surface, are more commonly convex at the bottom and show steep cross-bedding. The cross-bedding found in the Hockingport sandstone is commonly steep, whereas cross-bedding in the Waynesburg sandstone is normally flat within the more massive units of the deposit.

GEOLOGIC HISTORY

In early Paleozoic time sediments were being rapidly removed from "Appalachia" and deposited in the geosyncline which existed to the west of this highland area. Caster (1952, p. 504) has shown that as successive uplifts occurred in "Appalachia" during the Paleozoic, the axis of the subsiding depositional trough was shifted after each orogeny progressively westward. Orogeny along this highland area at the end of the Ordovician period folded, faulted and metamorphosed the sediments in the eastern part of the trough. These sediments had accumulated during the Cambrian and much of the Ordovician. During the Silurian, Devonian and the Mississippian periods, parts of the uplifted early Paleozoic strata were subjected to erosion. These sediments and meta-sediments, along with material derived from crystalline rocks, were distributed farther to the west in the shallow epeiric seas. At times, deltas were built in the eastward portions of these seas, and still farther to the east, nearer the source land, floodplain and alluvial fan conditions prevailed. Numerous unconformities were formed when through uplift or changes in sea level the shallow seas were drained from the land, erosion ensued, then, through subsidence or sea level changes, the seas again covered the lands.

At the beginning of the Pennsylvanian period, the central interior of the United States was a vast lowland, slightly above sea level, and hemmed in on the east and south by highland areas. Early in the period a seaway extended along the north side of Llanoria and into the Appalachian geosyncline as far north as New York. Deposition began on the westward slopes of "Appalachia" and in the geosynclinal areas, but later, deposition became more widespread over the eastern and central parts of the country. Uplift apparently in "Appalachia" occurred intermittently throughout the period while the interior of the continent was being subjected to slow regional subsidence at a variable rate. Large areas of land were repeatedly inundated by the shallow epeiric sea.

The influx of sediments from the highland areas at other times resulted in the filling of the seas, forcing the strand to the south and west, and a return to swamp and alluvial plain conditions of deposition. The Lee ("Pottsville") series or oldest Pennsylvanian, although for the most part made up of continental deposits, contains numerous fossiliferous marine horizons, especially to the west in eastern Ohio. As shown by David White (1904, pp. 267-82) the "Pottsville" attains the greatest thickness in Alabama, thins gradually and becomes finer in texture to the north and west. The southern "Pottsville" is characterized by vast thicknesses of sandstone and conglomerate with extensive coal deposits extending from Alabama to southern West Virginia. The overlying Allegheny beds are likewise partly marine and partly of continental origin. Sandstone and shale are predominant in the sequence; however, a few widely-distributed mineable coal beds, and a few thin but persistent marine limestones also occur. The Conemaugh sequence, in the lower portion, is characterized by several thin but very wide-spread marine limestones and some calcareous marine shales that alternate with continental deposits. The Ames limestone of the middle Conemaugh seems to be the youngest, truly marine horizon of the series. Deposition following the Ames and through the remainder of the series and in overlying Monongahela is almost entirely continental with shale in greatest abundance. This sequence also contains much fresh water limestone, a few local, and one extensive coal, the Pittsburgh, and local, lenticular sandy deposits.

According to Stevenson (1907, p. 157) Monongahela time begin with a long period of slow subsidence, and the greatest subsidence occurred in north-central West Virginia as shown by the thickness of the Monongahela and Dunkard series. The thickness of the sedimentary rocks decreases in all directions away from this area. In this basin the Benwood, Arnoldsburg and Uniontown limestones and the associated calcareous shales and thin coals were deposited. It is apparent that a shallow, fresh water lake environment alternated with swamp and possibly alluvial plain conditions with the lake environment being the most persistent. By late Monongahela time the basin was practically filled, and was converted shortly thereafter to an extensive swamp in which the peat was formed that later was changed to the Waynesburg coal.

During most of Monongahela time in the southwestern three-fourths of the Dunkard region, a broad, relatively flat plain must have existed. This plain probably contained numerous shallow lakes and swamps, and was crossed by a few meandering streams. In the scattered swamps relatively thin coals were formed, and in the shallow lakes calcareous deposits accumulated. The stream channel deposits are probably represented by the Pomeroy sandstone and numerous other lenticular, and more local, sandstones. The red, gray and buff, silty, poorly-bedded shales are the flood-plain deposits of these streams. These types of strata make up the major part of the sedimentary sequence of the Monongahela series in this region. Near the end of Monongahela time this placid scene may have been briefly changed, when, through subsidence or a rise in sea level, a relatively narrow and shallow sea extended into the region, reaching well into southwestern Pennsylvania.

There is, however, no positive evidence that truly marine conditions ever existed in the Dunkard Basin. If a sea extended into this region, the evidence of marine deposits may have been removed during the regression of the sea. It is also possible that extreme shallowness, stagnation of the water, turbidity, or the influx of fresh water into the sea prevented the establishment of a truly marine fauna.

If a sea existed in the region, it must have receded within a relatively short period of time converting most of this area again into a broad, swampy plain, but leaving in the northern part of the Dunkard region, a shallow, isolated, body of water that was gradually changed into a brackish-water marsh.

Whether a cut-off-arm of the sea, or a fresh water lake, a shallow body of water was more or less persistently in existence in the northern part of the Dunkard Basin from middle Monongahela time through the time of deposition of the Washington formation and most of the Greene formation. This is evidenced by the numerous limestone and calcareous shale deposits which contain either a marine, brackish or fresh water fauna.

Around the northeastern border of the basin the plant-bearing Cassville shale was deposited. Over the Cassville, but covering a smaller area, the relatively coarse clastics of the Waynesburg sandstone were distributed. In the off-shore areas of the basin, the Elm Grove limestone, marls and calcareous, silty shales were deposited. Over the Elm Grove and associated deposits, silty and fine sandy material was distributed in the shallowing waters.

It is apparent that influx of sediments increased relative to subsidence of the basin, so that the depth of water was gradually decreased as the basin shrank in size. The Linguloid brachiopods, found in the shales associated with the Washington coal, were probably the last of the marine or brackish water invertebrate fauna to exist in the basin. From this time on the environment of deposition was likely that of local fresh-water lakes, swamps, and generally westward-flowing streams with broad flood plains.

In the area to the southwest an alluvial plain environment probably existed throughout most of Dunkard time. The Hockingport sandstone and the associated floodplain deposits represent the early sediments of this area. The sequence extending from the Hockingport sandstone to the hilltops is principally made up of similar materials suggesting floodplain environment. These are red or buff, silty shales with red beds more predominant, thin, lenticular siltstones and very fine to medium sandstones. Coal and limestone are practically non-existent. To the northeast, at least as far as Monroe County, Ohio, the strata similarly bear evidence of the alluvial plain environment.

Sometime during the Late Permian or Early Triassic periods, the sediments of the Dunkard Basin were gently folded. This deformation occurred during the Appalachian Revolution.

It is impossible to determine when deposition ceased in the region or to determine the thickness of Permian rocks that have been removed by erosion.

THE AGE OF THE DUNKARD SERIES

In many parts of the world, there seems to be no significant stratigraphic break between the Pennsylvanian and the Permian systems. The Pennsylvanian-Permian boundary has been, and is currently, a subject of much controversy. Most of the controversial issues involve a placement of the boundary on the basis either of fossil plants such as Callipteris and Gigantopteris, or of invertebrate fossils, principally the fusulinids, and the boundary chosen, in many cases, depends on which are used.

The Permo-Carboniferous controversy in America dates back to 1857-58 (Grimsley, 1906) when Hawn made a collection of fossils in Kansas which was identified by Meek as Permian in age. In 1889-91 the strata near Nebraska City, Nebraska, were assigned to the Permo-Carboniferous by Tschernyschew and Waagen. In 1890 the Permian of Texas was divided into the Wichita, Clear Fork and Double Mountain beds by Cummins. At about the same time, I.C. White identified the fossil flora of the Wichita as similar to the flora above the Waynesburg coal in Pennsylvania and West Virginia, and Waagen correlated the Wichita with the Zechstein (Upper Permian) in western Europe.

The existence of Permian rocks in the mid-continent and western parts of the United States has been well established, yet there has been much debate and shifting of the Pennsylvanian-Permian boundary (Moore, 1940).

The evidence that the Dunkard series is Permian in age is not convincing. I.C. White, Fontaine, and David White have been largely responsible for assigning the Dunkard series to the Permian. Their evidence is mainly in fossil plants, collected principally from the roof shales of the Waynesburg, Washington and Dunkard coals. Fontaine and I.C. White (1880, p. 111) point out that 28 out of 107 fossil plants found in the Dunkard occur also in the Permian of Europe. Of the 28 species, 12 have not been found in the Carboniferous of the United States. David White (1903) after studying the Pennsylvanian and Dunkard flora, considered that the Dunkard strata above the Lower Washington limestone could be assigned to the Permian. White's conclusions were based on the presence of typical Rothliegende plants such as Callipteris conferta, Callipteridium, and Equisetites rugosus. The Dunkard strata below the Lower Washington limestone, according to White, contained a transitional flora.

For more than twenty years David White (1926, p. 1053) held the opinion that the lower part of the Dunkard series was not definitely Permian in age. In 1936, however, he believed that the Permian boundary could safely be drawn at the top of the Waynesburg coal. He (1936, p. 681) points out that the flora of the Dunkard series is specifically distinct from that of the Allegheny series and to a marked degree from that of the Conemaugh series. He states (1936, p. 681):

> "The contrast with the Monongahela, which immediately preceded the Dunkard (basal Permian) is less evident, though besides representatives of the genera Callipteris, Taeniopteris, Saportea, and Baiera, the Dunkard carries a number of distinctive species, hardly separable from forms characteristic of the Permian of Europe. A striking illustration is seen in a giant-toothed Equisetites."

Darrah (1934, p. 451; 1937, p. 128) on the basis of the fossil flora of the Dunkard series places the base of the Permian of the Appalachian region at the top of the Washington formation.

Cross (1954a) has questioned the value of certain plants, namely Callipteris, Walchia, and Taeniopteris, as used by Darrah and by I.C. White as being conclusive in identifying the Dunkard strata as Permian in age. Cross also believes that many of the new plant species which are given by Fontaine and I.C. White (1880) are merely forms of some of the better known species.

Cross (1954a) has compared his collections of Dunkard flora with those made by Bell (1938, 1940, 1943), Miklausen (1950), Arnold (1949) and Read (1947), which are from Pennsylvanian strata with an overall range in age from upper Allegheny through Monongahela. The collections were made in Nova Scotia, Pennsylvania, Michigan and Kansas respectively. Cross has found that most of the fossil plants listed by these authors from Pennsylvanian strata also occur in the Dunkard rocks.

Cross (1954b, personal communication, September 15) says:

> "At the moment I do not see how, on the basis of the flora, the Dunkard can be considered Permian in age. The flora is distinctly a dying remnant of the upper Pennsylvanian and may in fact be Permian in age but not in composition, i.e., it may be a relict flora which existed on into Permian times in a steadily dwindling area where conditions remained virtually constant from mid-Conemaugh to the end of the deposition which remains for us to study. There was a steady decline in the number of genera and species represented and extremely few new ones introduced."

Cross (1954b) also points out that the plant microfossils show the same general trends as the macrofossils. "There is a steady decline in abundance of genera and species. No new forms appear which are interpreted as being of significance."

Romer (1935, p. 1632) in considering the vertebrate fossil evidence says: "The Dunkard seems to be nearly equivalent to the Wichita and Wolfcamp [beds of Texas], the Lower Dunkard to the Council Grove, the Upper to the Chase and possibly the Sumner [groups of Kansas]." Romer (1952, pp. 99-100) accepts the Permian age of the Dunkard and states: "We may reasonably conclude that the Dunkard as a whole, is essentially comparable to the Wichita group of Texas and compare the faunas on that basis."

Vertebrate footprints known from the Dunkard are not diagnostic as to late Pennsylvanian versus early Permian age. The evidence has been analyzed for this report by Donald Baird (personal communication, November 9, 1954) as follows:

"Three genera of reptile and amphibian footprints are known from the Dunkard series of West Virginia. The largest of these, found near the base of the Waynesburg sandstone near Berea, Ritchie County, was described as Dimetrodon berea by Tilton (1931) and is now the type species of Dimetropus Romer and Price (1940). Other footprints of this type occur in the upper Pennsylvanian of Center Township, Morgan County, Ohio, in a flaggy calcareous sandstone underlying the Benwood limestone of the Monongahela series. The foot structure of this undescribed Dimetropus appears more primitive than that of D. berea. In morphology and in distribution these tracks correlate with the fin-backed reptile Edaphosaurus, an herbivorous pelycosaur which is common in the Dunkard and the Clear Fork of Texas and has been found as low as the Conemaugh in the Pittsburgh area. In Europe, basically similar footprints known as Herpetichnium occur in lower Permian exposures near Birmingham, England, and in central Germany (particularly the upper Rotliegende of Tambach, Thüringia); these tracks probably represent another genus of pelycosaur.

"Blunt-toed footprints redescribed by Baird (1952) as Limnopus waynesburgensis (Tilton, 1931) have been found 19 1/2 feet below the top of the Waynesburg sandstone near West Union, Doddridge County. Another specimen was found by Happ and Alexander (1934) in a sandstone tentatively correlated with the Lower Marietta sandstone at Sherman, Jackson County. This species is similar to but distinct from L. littoralis (Marsh) from the upper Pennsylvanian (Howard limestone, Virgil series) of eastern Kansas, and L. (Thenaropus) heterodactylus (King, 1845) from the upper Conemaugh series of Westmoreland County, Pennsylvania. These footprints are logically correlated with large rhachitomous amphibians of the Eryops type, remains of which occur from the Conemaugh through the Dunkard and in the upper Pennsylvanian and lower and middle Permian of Texas.

"Happ and Alexander's specimen of the third Dunkard genus has been lost, and I could find no further specimens in the millstone quarries at Sherman. Unfortunately the exact nature and affinities of this form cannot be determined from the published description and figure.

"In sum, the fossil footprints of the Dunkard are permo-carboniferous in the original sense of Meek and Hayden (1859), i.e., transitional in nature, showing affinities with both Pennsylvanian and Permian forms."

The fossil evidence of vertebrate footprints found in Dunkard rocks is not of value in placing the Permian boundary since footprints of the three genera occur also in rocks of Pennsylvanian age. The Dunkard flora, seemingly, is largely a Pennsylvanian flora but with a few Permian types.

The physical evidence will now be considered. The following is quoted from I.C. White (1903, p. 100):

> "Under the name, Dunkard series, the writer has included all of the beds above the Waynesburg coal of the Monongahela series. The dividing line is drawn where Permian plants have first been observed in the fossil flora. Hence, although there is no observable unconformity between the top of the Monongahela series and the base of the Dunkard as now defined, yet the existence of a thick, coarse, conglomeratic sandstone of wide distribution, just above the Waynesburg coal horizon, denotes a very great change in physical conditions. It is also quite probable that considerable erosion took place in some portions of the Appalachian field during the deposition of this basal conglomerate of the Dunkard series, and hence, although there is no appreciable unconformity in the dip of the beds, there can be no doubt that the currents which brought in the great deposit of coarse sand and gravel just after the epoch of the Waynesburg coal, also transported the elements of a new flora, several species of which are found only in the Permian beds of Europe, while others are even near relatives of Triassic types."

The thick sandstone to which White refers includes the Waynesburg sandstone, the Hockingport sandstone and numerous other local sandstones scattered about the Dunkard Basin, all of which appear to occur at approximately the same stratigraphic level. He believed that these local sandstones were part of an almost continuous deposit extending over nearly all of the Dunkard Basin. White also thought that this sandstone was a basal "conglomerate" thus indicating a major change in physical conditions. With this evidence, plus the evidence of fossil flora, White termed the Dunkard a Permian series.

It has here been shown that the Waynesburg sandstone, the Hockingport sandstone, and the other local sandstones, occurring just to the north and south of the Hockingport sandstone, are not parts of a continuous deposit. Although these deposits may be nearly contemporaneous, it is evident that environmental conditions of deposition differed over the region of accumulation.

During Monongahela and Lower Dunkard time, fluvial deposition prevailed in the southern portion of the region and a lake environment alternating with swamps and fluvial conditions prevailed in the northern portion. The lake environment was predominant. White reasoned that the upper member of the Monongahela series, the Waynesburg coal, was also a continuous deposit over the Dunkard region. After deposition of the coal, according to White, a major physical change occurred, and the Waynesburg sandstone was deposited.

The Waynesburg coal cannot be traced into the southern half of the Dunkard Basin. The writer believes that this coal was never deposited there. I.C. White (1903, p. 117) was of the opinion that it was deposited and later removed by erosion.

It is not apparent that a major physical change took place over the entire Dunkard Basin at the end of Monongahela time. There may be many minor unconformities developed in the rock sequence, but they are quite local and not of the magnitude to divide periods of geologic time and systems of rocks.

SUMMARY AND CONCLUSIONS

It is believed that the Hockingport sandstone should not be correlated with the Waynesburg sandstone because of several lines of evidence.

The respective deposits are relatively local and cannot be traced beyond their type areas which are more than 100 miles apart.

The primary structures and texture of the two sandstone deposits, and the lithology and the fossil fauna of strata adjacent to each of the deposits are indicative of different environments of deposition for the two sandstones.

The Hockingport sandstone and the associated deposits are the results of fluvial deposition on a relatively broad plain. The stream which transported the clastic material originated in source areas of predominately sedimentary and metamorphic rocks probably located to the south or southeast.

The Waynesburg sandstone was deposited in the near-shore area of a shallow body of water. The clastic material of this deposit was possibly derived from a different part of the same highland area which furnished the sediments of the Hockingport sandstone.

No evidence was discovered indicating that a major unconformity exists at the base of the Dunkard series.

The basis for assigning these strata to the Permian period still rests on the fossil flora of the shales associated with the coals of the series.

The Dunkard sediments of the northern portion of the Dunkard Basin represent lateral and vertical facies changes from the borders of the basin into the deeper water of the central part. Particular deposits are thus considered to be local and representative only in the type area.

With the concept of "layer-cake" stratigraphy in mind, the early students of the strata of the Monongahela series and the Dunkard series correlated deposits from place to place on the basis of somewhat similar lithology, position in sequence and elevation above sea level. The apparent similarity of certain deposits which are locally developed at nearly the same position in the sequence in several parts of the region probably led to many long range correlations which in many instances were erroneous.

A complete, detailed restudy of the rocks of the Monongahela and Dunkard series is sorely needed.

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