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SHORT, MICHAEL RAY

PETROLOGY OF THE PENNINGTON AND LEE FORMATIONS OF NORTHEASTERN KENTUCKY AND THE SHARON CONGLOMERATE OF SOUTHEASTERN OHIO.

UNIVERSITY OF CINCINNATI, PH.D., 1978

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PETROLOGY OF THE PENNINGTON AND LEE FORMATIONS OF NORTHEASTERN KENTUCKY AND THE SHARON CONGLOMERATE OF SOUTHEASTERN OHIO

A dissertation submitted to the

Division of Graduate Studies
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

in the Department of Geological Sciences
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1978

by

Michael R. Short

B. S. University of Kentucky, 1970
M. S. University of Kentucky, 1973

UNIVERSITY OF CINCINNATI

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I hereby recommend that the thesis prepared under my supervision by Michael R. Short

entitled Petrology of the Pennington and Lee Formations of Northeastern Kentucky and the Sharon Conglomerate of Southeastern Ohio

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

Approved by:

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INTRODUCTION

General Statement

Late Mississippian and Early Pennsylvanian sediments in the Appalachian Basin are representative of a time of transition from the dominantly marine conditions represented by the carbonates of the Mississippian Greenbrier Group, to a nonmarine or marginal setting represented by the Early Pennsylvanian clastics of the coal-bearing Breathitt Formation. Much attention has been focused on the economically attractive, coal-associated sediments, but little attention has been given to these sediments which represent this time of change.

The purpose of this investigation is to examine these transitional sediments in outcrop in northeastern Kentucky and southeastern Ohio to determine their depositional environment and history. This, in turn, will be related to structural activity just prior to, and possibly during deposition of the sediments. If this environmental setting can be properly ascertained, it will improve the understanding of the problematic Mississippian-Pennsylvanian boundary in this area.

The sediments to be considered are the Pennington and Lee Formations. The former has generally been considered Late Mississippian in age while the latter has been termed Early Pennsylvanian.

Location

The study area (Fig. 1), located in northeastern Kentucky and southeastern Ohio, is approximately 60 to 80 kilometers (37 to 50 miles)

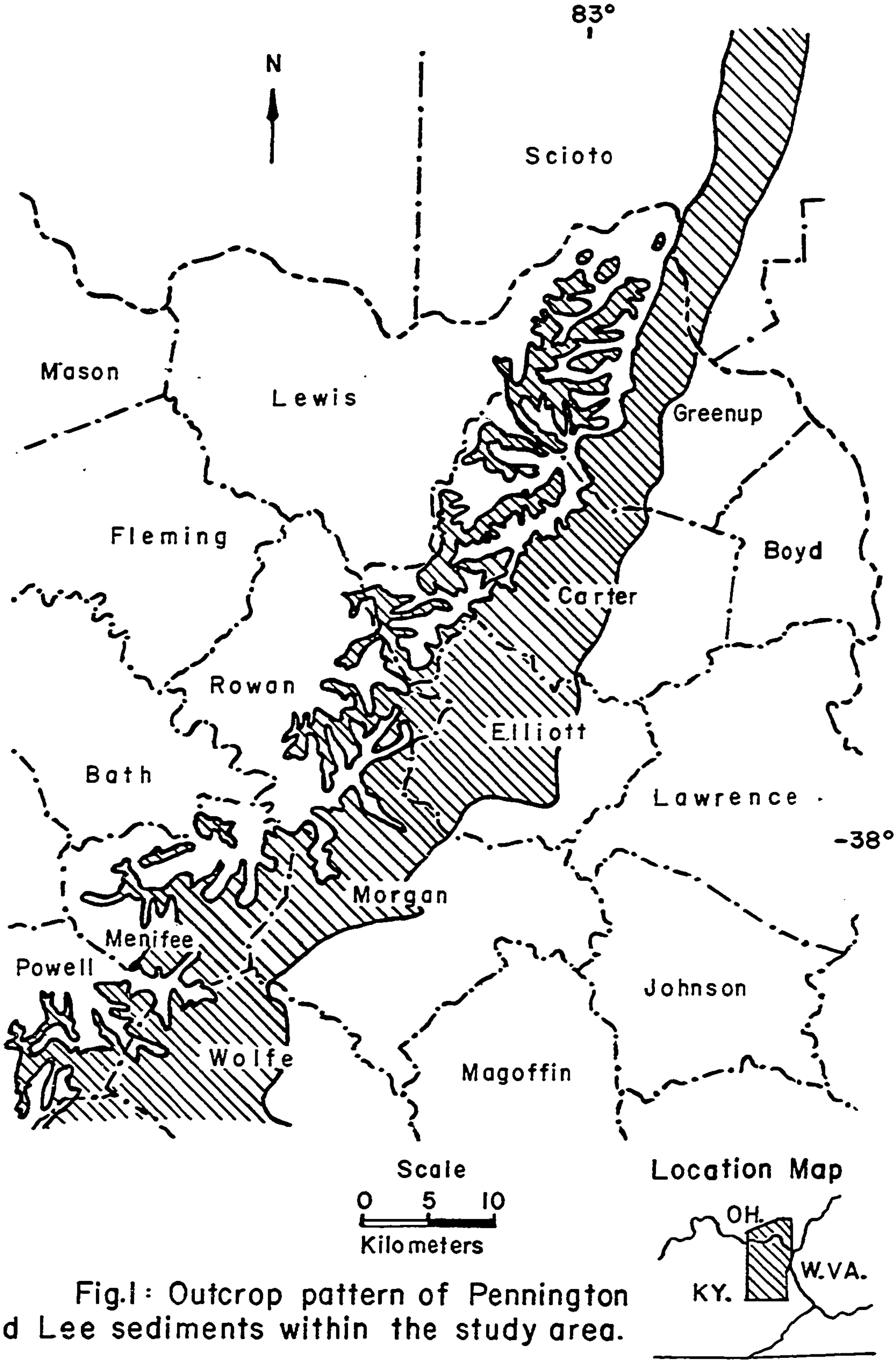


Fig.1: Outcrop pattern of Pennington and Lee sediments within the study area.

east of the Cincinnati Arch, on the western edge of the Appalachian Foreland. The outcrop belt, which is 5 to 10 kilometers (3 to 6 miles) wide, trends northeast-southwest, following the outcrop pattern of the Pottsville Escarpment.

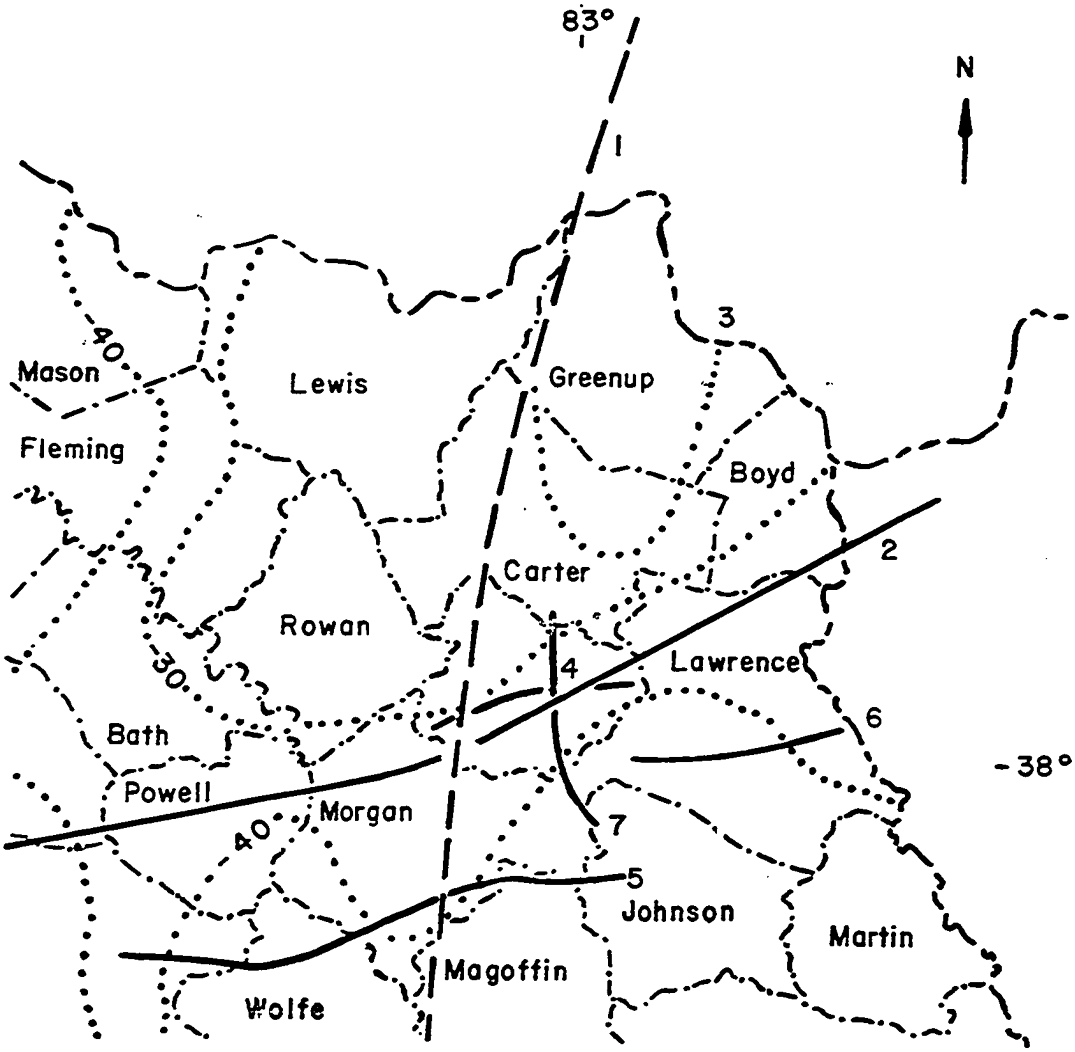
South of a line which runs from east-central Rowan County to west-central Elliott County, then northeast through central Carter County, the interval consists of massive, resistant, cliff-forming sandstones (Plate 1) and underlying black and gray shales. To the north of this line the interval is largely shale and siltstone with interspersed linear sand bodies. The topography in this area is that of low, rounded hills (Plate 2) which are unfavorable for good outcrops. However, the Olive Hill Clay Bed of Crider (1913) has been extensively stripped in the area and man-made outcrops provide adequate exposures for study.

Structure

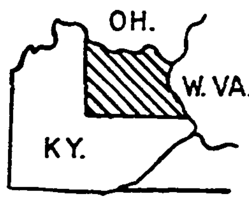
Late Mississippian and Early Pennsylvanian sediments within the study area lie east of the Cincinnati Arch and exhibit east-southeast dips ranging from 4 to 10 meters per kilometer (20 to 50 feet per mile; McFarlan, 1943, Patterson and Hosterman, 1961). The principal structural features in the study area incude a broad gravity anomaly, the Waverly Arch, numerous surface faults, and two basement fault zones which have surface expressions in the Irvine-Paint Creek Fault System and a system first proposed by Woodward (1961) and now considered part of the Kentucky River Fault System (Haney, 1976). These structures are outlined in Figure 2.

Plate 1. View of the cliff-forming sandstones of the Corbin Sandstone Member of the Lee Formation in Menifee County, Kentucky, Carter Coordinates 8-R-71.

Plate 2. View of typical type of topography which dominates the northern half of the study area. This area is located in Greenup County, Kentucky, at Station 110, Carter Coordinates 1-Y-78.



1 Proposed axis of Waverly Arch (Woodward, 1961)
2 Postulated basement fault (Woodward, 1961; Silberman, 1972)
3 Bouguer gravity contours (Watkins, 1963)
4 Little Sandy Fault
5 Irvine- Paint Creek Fault system
6 Blaine Creek Fault (McGuire and Howell, 1963; Englund and Delaney, 1966)
7 Axis of Paint Creek uplift (Dohm, 1963)



Index Map

Scale
0 5 10
Kilometers

Fig. 2: Structural features within the study area.

The first evidence of basement faulting in the area was presented by Thomas (1960) in a study of deep drill holes from which he documented the presence of an uplifted basement platform over which Cambrian sediments thinned. This positive feature was later verified by gravity measurements which show an anomaly north of the southern bounding basement fault (McGuire and Howell, 1963; Watkins, 1963; Rudman et al, 1965). This southern bounding fault was first described by Woodward (1961) in Cambro-Ordovician sediments and termed a coastal declivity. Later the feature was described as a Precambrian or Cambrian fault scarp (Summerson, 1962; Webb, 1969; Silberman, 1972), or a possible Cambrian hingeline (McGuire and Howell, 1963). The exact location of this fault has been rather uncertain probably because the structure is not a single fault but a wide zone of faulting. Ettensohn (1975) suggests the presence of one basement fault trending from the area where Menifee, Rowan, and Morgan counties meet to the northeast; however, gravity data (Watkins, 1963; Ammerman, 1976) and Woodward's work (1961) indicate that the major basement fault is farther south in central Menifee County and then is deflected northeastward into northern Morgan County (Fig. 2). These two proposed faults may better actually present the northern and southern limits of the easterly trending Kentucky River Fault System (Haney, 1976). Haney (1976) and Keller et al. (1976) have shown that this fault system marks the northern boundary of the Rome Trough. Ettensohn (1975) has reported synsedimentary tectonic activity along this fault system during the late Mississippian.

The Irvine-Paint Creek Fault System is located approximately 20 kilometers (32 miles) south of the Kentucky River Fault System and also trends east-northeast. Haney et al. (1975) and Haney and Hester (1976) have reported effects of Late Mississippian and Early Pennsylvanian synsedimentary tectonic activity on this system in the form of subaerial exposure phenomena and variation in the thickness and distribution of clastic rocks. This fault system marks the extreme southern boundary of the study area.

Repeated normal and strike-slip movement has been reported on the surface expressions of these fault systems (Jolly and Heyl, 1964; Heyl, 1972). Heyl (1972) has suggested right lateral movement on the Kentucky River System; however, Black and Haney (1975) have indicated that left lateral movement was prevalent on some western segments. These lateral movements appear to be pre-Late Mississippian, because upper Newman depositional trends cross the structure with no apparent lateral offset (Ettensohn, 1975). Late Mississippian synsedimentary effects in the zone appear to be related to normal basement growth faulting.

The Waverly Arch, which trends north-south through the study area, was first described by Woodward (1961) from deep drill holes as a broad, low arch within Cambro-Ordovician sediments. Kearby (1971) was the first to postulate activity during the later Paleozoic based on sedimentation patterns within the Mississippian Borden Formation. More recently much stratigraphic evidence has been gathered from surficial Late Mississippian units which support the presence of the structure and its synsedimentary influence (Englund, 1972; Dever, 1973; Dever and MacQuown, 1974; Ettensohn and Dever, 1975; Ettensohn, 1975, 1976).

The remaining surface faults, the Little Sandy Fault and the Blaine Creek Fault, appear to be post-Pennsylvanian features, because Pennsylvanian depositional trends are not offset vertically in all instances where they cross these faults. Because these structures were not active during the Late Mississippian-Early Pennsylvanian, they will not be considered further in this investigation.

Stratigraphic Interval

The sediments under consideration here encompass that part of the section present between the underlying Late Mississippian Newman Limestone or Borden Formation where the Newman is absent, and the overlying Early Pennsylvanian Breathitt Formation. This interval includes the Pennington Formation and the overlying Lee Formation (Fig. 3).

The Borden Formation represents clastic deposition from a westerly prograding deltaic system which originated to the east and northeast of the study area, perhaps as a result of the continuation of tectonic activity in the northern Appalachians (Pepper et al., 1954; Moore and Clarke, 1970). The expected normal deltaic sequence, from distal sediments to upper delta plain sediments, are not represented within the study area, however. In place of upper delta plain sediments, which apparently never reached this area (Kearby, 1971), are shallow water shelf and intertidal or supratidal sediments of the Nada and Renfro Members. Kearby has suggested that uplift on the Waverly Arch provided shallow water conditions on a broad, uplifted platform and diverted the major deltaic influx elsewhere.

Following the uplift, which ended Borden sedimentation in the area, renewed transgression ensued, represented by shallow water, subtidal sediments of the St. Louis Limestone Member of the Newman Limestone

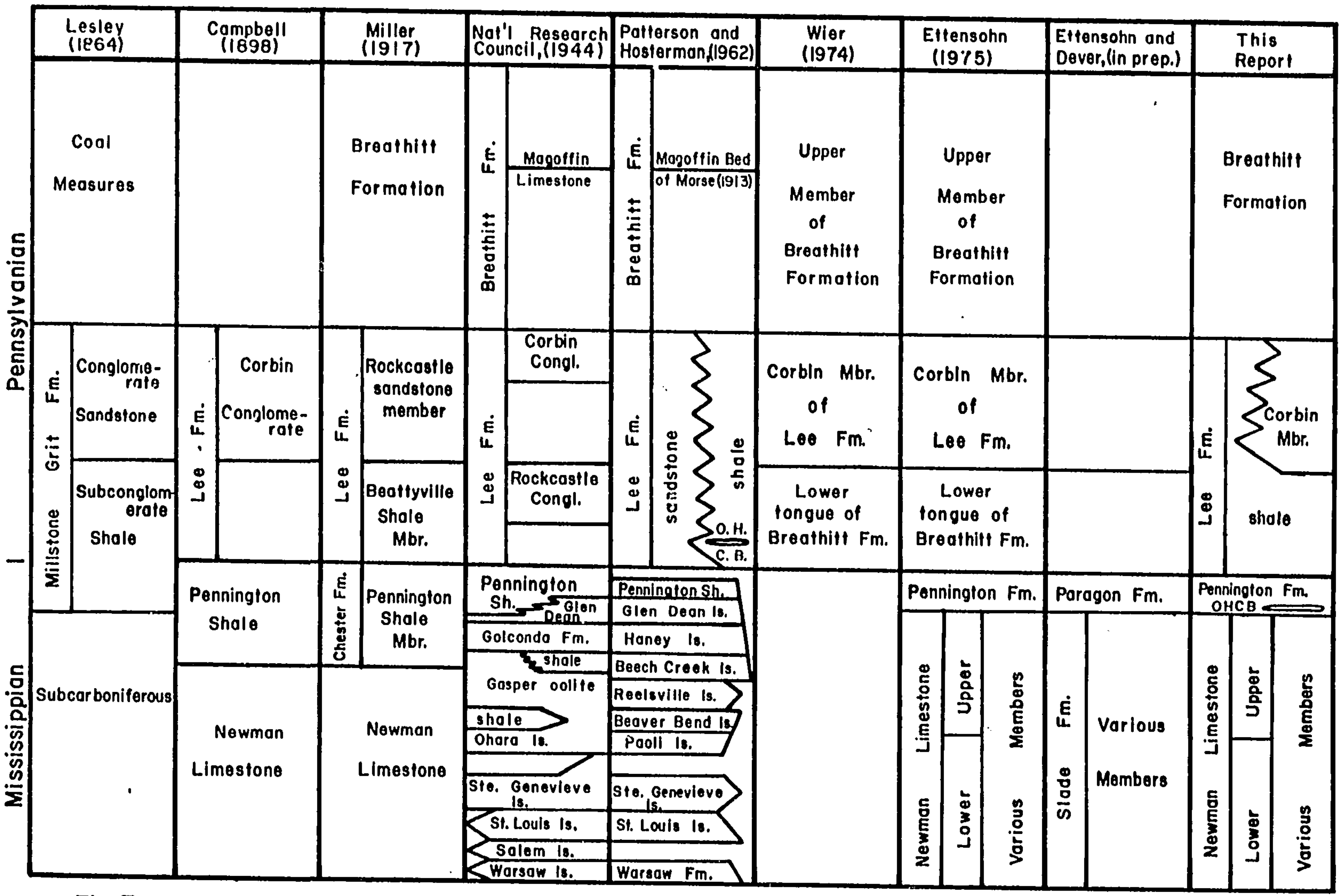


Fig. 3.: Stratigraphic nomenclature, Late Mississippian-Early Pennsylvanian, N.E. Kentucky.

(Dever, 1973). Intertonguing relations between the Borden and lower Newman west of the study area indicate that transgression began before Borden sedimentation ended. Subsequent shallow marine deposition, indicated in the Newman sediments, was characterized by a series of transgressive and regressive, or progradational, events, some of which were halted by synsedimentary tectonic activity on the Waverly Arch and Kentucky River Fault System (Ettensohn, 1975). This activity is represented by several erosional or subaerially exposed surfaces which are indicated by brecciation, mircokarst, subaerial exposure crusts, caliche, and slumping (Philley, 1970; Swinchatt, 1970; Ettensohn, 1975). The patchy distribution of the units on the northern, uplifted side of the Kentucky River Fault System and the thinning or pinching across the axis of the Waverly Arch also attest to the probable tectonic control of the areal distribution of these units during their deposition. The upper part of the Newman Limestone contains abundant detrital quartz and argillaceous material (Klekamp, 1971), apparently representing a transitional environment between the underlying shallow marine carbonates and the overlying Pennington clastics and carbonates.

Locally overlying the Newman Limestone is the Pennington Formation which consists of sandstones, siltstones, red, green, and gray shales, thin carbonates and coals. Local correlations of this unit within the study area have been uncertain, and regional mapping by the U. S. Geological Survey and the Kentucky Geological Survey shows only a patchy distribution in the study area (Sheppard, 1964; Delaney and Englund, 1973; Englund, 1975; Englund and Windolph, 1975; Philley, Hylbert and Hoge, 1975). Ettensohn (1975, 1976) has divided the Pennington into four informal units based on lithology and environment of deposition. These include a lower dark shale unit, an overlying clastic member which is interpreted to be equivalent to the Carter Caves sandstone, a thin limestone and shale member, and an upper shale member (Fig. 4).

The separation of the Pennington clastic units from the overlying Lee Formation has proven to be quite confusing, because the carbonates which might aid in the division are rarely present and the clastic units closely resemble the overlying Lee clastics. The presence of coals in the Pennington has made differentiation even more of an enigma. Historically, the presence of coals within the Pennington-Lee interval suggested an Early Pennsylvanian age, and therefore placement in the Lee Formation. This practice seems to date back to the work of Lesley (1861) who identified the shales and coals below the conglomerate phase of the Lee Formation as the Subconglomerate Shale Member of the Millstone Grit Formation (Fig. 3). Miller (1971) renamed these shales the Beattyville Member of the Lee Formation, distinguishing the unit from the underlying Pennington on the basis of the presence of coals and fireclay and the absence of red and green shales. Wier (1974 a, b) has recently redefined these coal-bearing shales which lie south of the Kentucky River Fault System as the lower tongue of the Breathitt Formation. Wier has shown that the Lee sandstones consist of lenticular bodies and localized sheet sandstones and that in the intervals between the sandstone bodies, the underlying shale is transitional into the overlying Breathitt Formation. Peppers (pers. comm.) has dated several of the coals in this interval as Mississippian and Pennsylvanian and concludes that the presence of coal can no longer be used as an indicator of Pennsylvanian age.

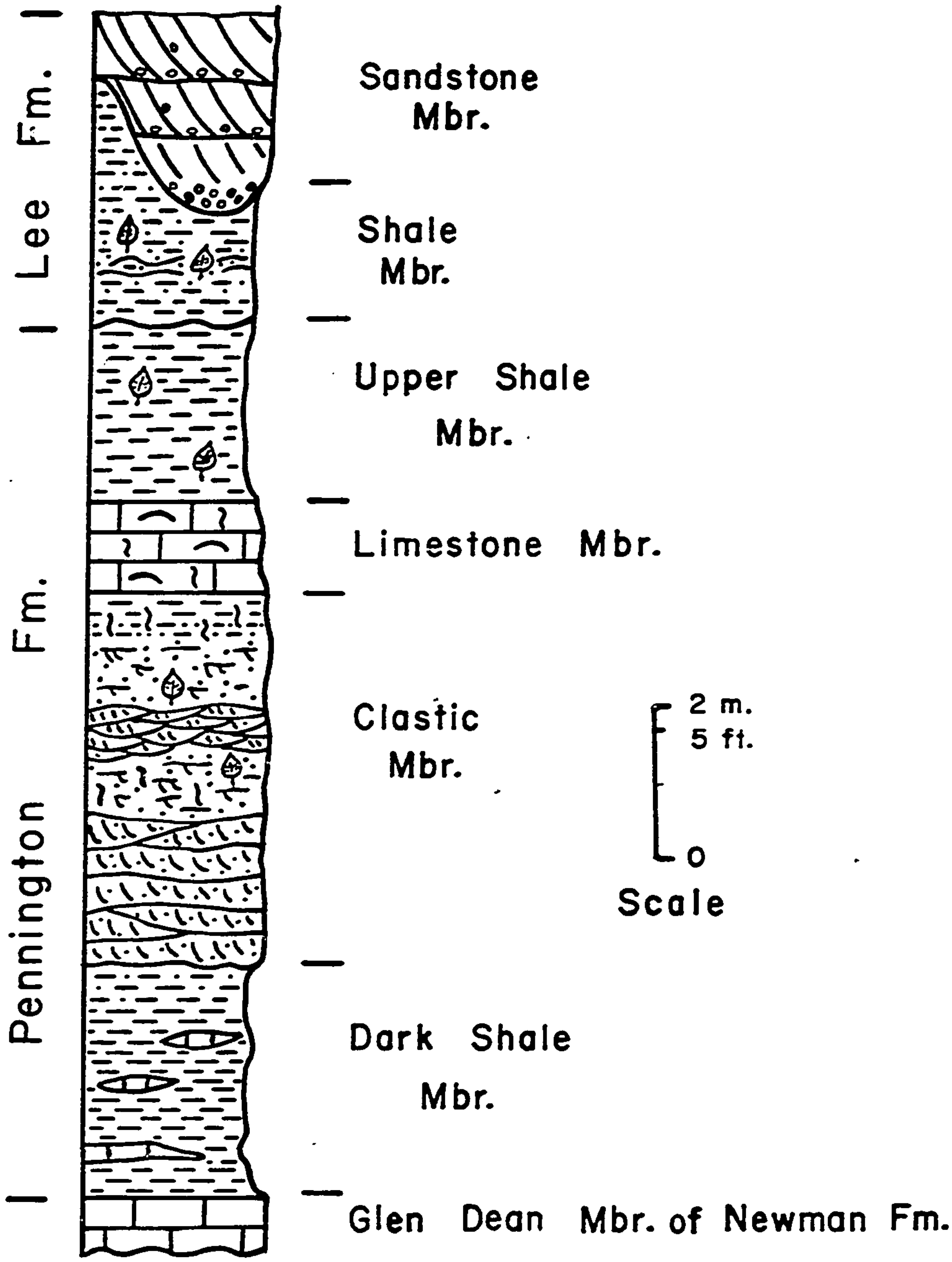


Fig. 4: Informal division of Pennington Formation. Adapted from Ettensohn, (1975).

Overlying the Pennington-Lee shale zone, and frequently cutting through these units into the underlying Newman and Borden formations, are the massive, crossbedded, locally conglomeratic sandstones of the Lee Formation. This unit reaches a maximum thickness in excess of 70 meters (230 feet) in the southern part of the study area, but thins to the north and south. The sandstone is gradational into overlying sandstones, siltstones, and shales of the Breathitt Formation. In the northern part of the study area, the sandstone is replaced by a much thinner sequence of fine-grained sandstones, siltstones and shales which also appear to be gradational with the overlying sediments.

Stratigraphic studies of the Pennsylvanian of the Appalachian Basin have been quite numerous, particularly in Kentucky, because of the large coal reserves contained in these formations. Unfortunately, most investigations have been directed to units younger than the Pennington-Lee strata because the coal contained in these latter formations is not of economic value. Some studies, however, have included these lower units (Stevenson, 1904; Wanless, 1946; Mitchum, 1954) and some have concentrated specifically on these units (Kilburn, 1956; Wood et al., 1956). Workers in Kentucky have made many advances in defining the stratigraphy of the Mississippian and Pennsylvanian with the geologic mapping program, and the stratigraphic boundaries of the Pennington and Lee have been well defined in most areas. However, few studies, other than the maps themselves, have resulted. Englund (1964, 1966) reported on the stratigraphy of the Lee Formation in southeastern Kentucky and pointed out the intertonguing relationship between the Lee and Pennington in northwestern Virginia. Currently, efforts are under way to redefine the stratigraphy of the Newman and Pennington formations in northeastern and east-central Kentucky.

Regional Correlation

The units which are the object of this study and those that are immediately associated are not local occurrences, but extend over most of the Appalachian Basin, varying slightly in lithologic properties and thickness.

The Newman Limestone, which often occurs at the base of the study interval, thickens appreciably to the west, south and east of the study area. To the north, in Ohio, the interval has been termed the Maxville Limestone, while in West Virginia it becomes the much thicker Greenbrier Group. The upper Newman, which has been described by Ettensohn (1974, 1975, 1976) in eastern Kentucky and divided into formal members, loses its identity deeper into the basin and becomes indistinguishable from the thicker Greenbrier Group. According to regional treatments of the Paleozoic section in the Appalachian Basin, it seems likely that much of the Newman is time-equivalent with the Pocono clastics which were deposited to the northeast in Pennsylvania and New York (Meckel, 1970).

The Pennington Formation is part of the more extensive Mauch Chunk Formation of New York, Pennsylvania, and West Virginia. Further south in southwest Virginia, eastern Kentucky, eastern Tennessee and northern Alabama the unit retains the name Pennington Formation, but in northwest Georgia it becomes the Pennington Shale (Culbertson, 1963)..

Nomenclature of the overlying Lee Formation becomes somewhat more confusing because of its variable lithology and depositional nature.

Campbell (1899) was the first to suggest that the Lee Formation is not everywhere the same age, implying that the Lee of Tennessee is largely older than that of Kentucky. Englund and Delaney (1966) have since shown that the Lee is indeed a time-transgressive unit which originated along the axis of the Appalachian Basin and prograded northwestward with time. The particular part of the Lee present in the southern part of the study area has been termed the Corbin Sandstone Member of the Lee . Formation (Wier, 1974), and appears to be present along the outcrop belt throughout eastern Kentucky and northern Tennessee, but disappears before reaching southern Tennessee (Wanless, 1946). The Corbin can be identified from wells located slightly south and east of the study area, but has not been identified in outcrop in West Virginia or Virginia. In southeastern Kentucky, in the vicinity of London, the Corbin rises stratigraphically and several conglomerate, sandstone, and shale units appear below. Two of these units have been formally identified, the highest of the two has been termed the Rockcastle Conglomerate by Campbell (1898 a) and the lower the Livingston Conglomerate by Miller (1910). These units, together with the Corbin member and various shale and siltstone horizons, constitute the Lee Formation in south-central and southern Kentucky.

In southeastern Kentucky in the vicinity of Cumberland Gap, these units cannot be identified, but the U. S. Geological Survey has mapped five separate sandstone bodies which collectively form the Lee Formation (Englund et al., 1964). Wanless 1946) has correlated this sequence with the Pocahontas and New River Groups of Virginia and West Virginia.

Farther south in Georgia, the Lee Formation is termed the Crab Orchard Mountains Formation, and in Tennessee it is raised in status to the Crab Orchard Mountains Group.

The northern, or southeastern Ohio, exposures of the conglomeratic sandstones are termed the Sharon Conglomerate and can be traced more or less continuously into northeastern Ohio. Morningstar (1922, p. 10), while studying the Pottsville fauna of eastern Ohio, noted that the Sharon "although patchy in appearance, can be found everywhere in the deepest troughs eroded in pre-Pottsville times". Fuller (1955) has suggested that the Sharon is partially separated from the Pottsville sediments (Olean Conglomerate) of western Pennsylvania by a Mississippian "highland". Meckel (1967), however, has interpreted the thinning of the unit in this area as depositional. Meckel correlated the Sharon of Ohio, which is the lowermost part of the Pottsville Group in the northern part of the Allegheny Plateau, to the middle part of the Pottsville sequence of the anthracite district of Pennsylvania. This would correspond roughly to the middle of the Schuylkill Member of the Pottsville Formation of Pennsylvania.

Within the study area, the northern and southern exposures of the conglomeratic sandstones do not appear to be physically connected, and it appears that these two bodies might not be equivalent. This concept will be treated more fully later.

Previous Work

Historically, geologic interest in the Late Mississippian and Early Pennsylvanian of southeastern Ohio and northeastern Kentucky has been little more than academic. The major impetus of geologic study, that of economic mineral accumulation, is for the most part lacking except for the Olive Hill Clay Bed of Crider (1913), small, shallow oil accumulations and thin coal beds. The major stimulus of study in recent time has proven to be the initiation of the U. S. Geological Survey and Kentucky Geological Survey cooperative mapping program. Earlier studies within the area have been sparse, but include Stout's (1916) report on the general geology of southeastern Ohio, Morningstar's (1922) investigation of the Pottsville fauna of Ohio, and the early, more generalized observations by the Kentucky Geological Survey (Lesley et al., 1853; Crandall, 1884; Campbell, 1900; Stevenson, 1904; Miller, 1908, 1910). McFarlan (1953) also discussed these units in his treatment of the geology of Kentucky.

Both the Pennington and Lee Formations were named outside the study area and correlations have been carried from the type sections into the area under investigation. Campbell (1893; p. 28, 37) applied the name Pennington to a thickness of strata between the Newman Limestone and the Lee conglomerates in Lee County, Virginia. Although he did not cite a type section, Campbell did measure a reference section at Big Stone Gap, Wise County, Virginia. This section has been most recently described by Butts (1940, p. 394-395) with little deviation from the original description. The Pennington consists mostly of sandstone, red and green shale, some calcareous shale, and thin coals near the top of the interval. At the type locality of the Mauch Chunk, which is generally equivalent to the Pennington, in Carbon County, Pennsylvania, redbeds rest on the Pocono Formation and are conformably overlain by the Pottsville Group (Dennison and Wheeler, 1975).

The Pennington of eastern Tennessee has been summarized by Rodgers (1953) who described it as a heterogeneous mixture of red, purple, and green shale, pink, red, and brown calcareous sandstone, and minor amounts of silty, fossiliferous limestone. Rodgers placed the upper contact of the unit at the base of a thick, pebbly, white sandstone of the Lee Formation where this latter unit was present. In other areas, he drew the contact in a transitional zone between red, clay shale which contained scattered fossiliferous limestone beds, and gray or brown sandy and silty shale with scattered coal beds. Rodgers noted that this contact may mark a change from marine to nonmarine deposition.

This thickest accumulation of Pennington-Mauch Chunk strata occurs in southern West Virginia and has been correlated to a continuing clastic influx from the Virginia-Carolina deltaic system (Dennison and Wheeler, 1975). These authors atrribute the thinning of the unit away from this depositional maximum to stratigraphic convergence rather than unconformable relations. In certain areas of eastern Kentucky and in the subsurface of West Virginia, the Pennington is only partly preserved.

No apparent directional properties have been reported from the Pennington except for general thickness trends, which may be misleading due to later erosional patterns, and a general loss of redbeds and the appearance of interbedded limestone and dolomite to the west and southwest in Tennessee and Alabama (Dennison and Wheeler, 1975). Meckel (1970) reported a mean direction of N 54° W for 39 Mauch Chunk crossbed dip directions in the central Appalachians of Pennsylvania and Maryland, and BeMent (1976) has reported southwest dip directions in southeastern Kentucky. In addition, Meckel interpreted fining-upwards cycles in the body as characteristic of fluvial deposition.

Reger (1931, p. 277-316) reported the presence of well-developed coals within the Mauch Chunk of southern West Virginia and Dennison and Wheeler (1975, p. 102) point out the presence of coals in southwestern Virginia and Tennessee. Looking at the Mauch Chunk-Pennington intervl in a generalized perspective, Dennison and Wheeler described the strata as "true fluvial deposits.....in northeastern West Virginia and Maryland outcrops, with coal-bearing deltaic deposits in southern West Virginia and Tazewell to Wise Counties, Virginia, and dominantly marine deposits with some marine mudflat accumulations farther southwest toward Tennessee and west toward Kentucky". BeMent (1976) has interpreted the Pennington in southeastern Kentucky as marine, shoreface, and tidal deposits.

Pennington strata within the study area has been reported on several U. S. Geological Survey quadrangle maps as patchy, generally thin accumulations (Sheppard, 1964; Delaney and Englund, 1973; Englund and Windolph, 1975; Philley et al., 1975; Englund, 1976). Sheppard and Dobrovalny (1962) have reported on the Carter Caves sandstone and placed this unit within the Pennington on the basis of faunal remains taken from an overlying limestone zone. Formerly, this unit had been considered as part of the Pennsylvanian Lee Formation, but Mississippian ages on these fossils warranted the movement of the systemic boundary upwards. Englund and Windolph (1971) expounded upon this work using additional data collected during the mapping of the area and showed an intertonguing relation between the Carter Caves sandstone and the underlying Newman Limestone. The authors concluded the origin of the sandstone body to be that of a marine offshore bar which received detritus from the positive Cincinnati Arch to the west. Earlier Englund (1966) had demonstrated a similar intertonguing between the Pennington and Lee Formations in northwest Virginia.

Patterson and Hosterman (1960, 1962, 1963), while studying the Olive Hill clay bed, noted that the Pennington is only sparsely present in the Wrigley and Haldeman quadrangles of Kentucky. This patchy distribution was attributed to pre-Pennsylvanian removal by erosion.

The majority of work done in northeastern Kentucky was in association with the U. S. Geological Survey and the Kentucky Geological Survey mapping program. The opening of U. S. Highway 64 in late 1960's provided the best exposures of Late Mississippian and Early Pennsylvanian strata there, and with it came a new period of geologic interest, most notably those studies involving the Early Pennsylvanian Lee Formation.

The Lee Formation was named by Campbell (1893, p. 28, 36) in Lee County, Virginia, as a part of the larger Pottsville Group. At this location, the Lee consists largely of conglomerate and sandstone with lesser amounts of shale and coal. The thickest accumulation of the entire Pottsville Series of the Appalachian Basin occurs in Lee and Wise Counties, Virginia; however, thicker accumulations occurred in Alabama where the youngest Pottsville strata have been removed by erosion.

Initial studies of the Lee Formation were conducted by the Tennessee Division of Geology and established the internal stratigraphy of the body in that state (Butts and Nelson, 1925; Glenn, 1925; Nelson, 1925; Wilson et al., 1956). Briggs (1957), while mapping the structural geology of Lee County, Kentucky, defined the Lee Formation as all of the Pennsylvanian rocks from the Mississippian-Pennsylvanian contact to the base of the Zachariah coal bed.

Apparent uninterrupted deposition occurred between Mississippian and Pennsylvanian time in the region southeast of Greenbrier County, West Virginia (Dennison and Wheeler, 1975). Geologic mapping in the Cumberland Plateau of Tennesee has also emphasized the gradational nature of the lower contact in the southeastern part of that area. Ferm and Erlich (1967) have suggested that the lower Pottsville (Lee equivalent), Parkwood, Floyd, and Pennington formations are all time equivalent in the Warrior Basin of Alabama. Colton (1970) notes that an unconformable lower boundary is well-documented in the northern part of the Appalachian Basin (Fig. 5) and McGrain (1954) shows the commonly held interpretation of the boundary within the study area, that of Pennsylvanian sandstones resting unconformably on Mississippian limestones. Breganback and Wilson (1961) have shown through detailed drill core analysis that a Pennsylvanian overstep occurs westward onto the Cincinnati Arch in Tennessee and Kentucky, and Wilson (1970) has presented subsurface data in Carter and Boyd Counties, Kentucky, which supports westward beveling of the Pennington Formation. Flowers (1956) also described a northwest beveling of the Mauch Chunk and locally the Greenbrier Limestone in West Virginia.

A generalized southeastern source with west and northwest dispersal patterns has been proposed for the entire Pottsville Group from Pennsylvania to Alabama based on isopach patterns and the increasing coarseness and abundance of sandstones to the southeast (Stearns and Mitchum, 1962; Dennison and Wheeler, 1975). Several studies involving paleocurrent analysis of lower Pottsville sediments indicate a dominantly southwest transport direction from Virginia through Kentucky and Tennessee into

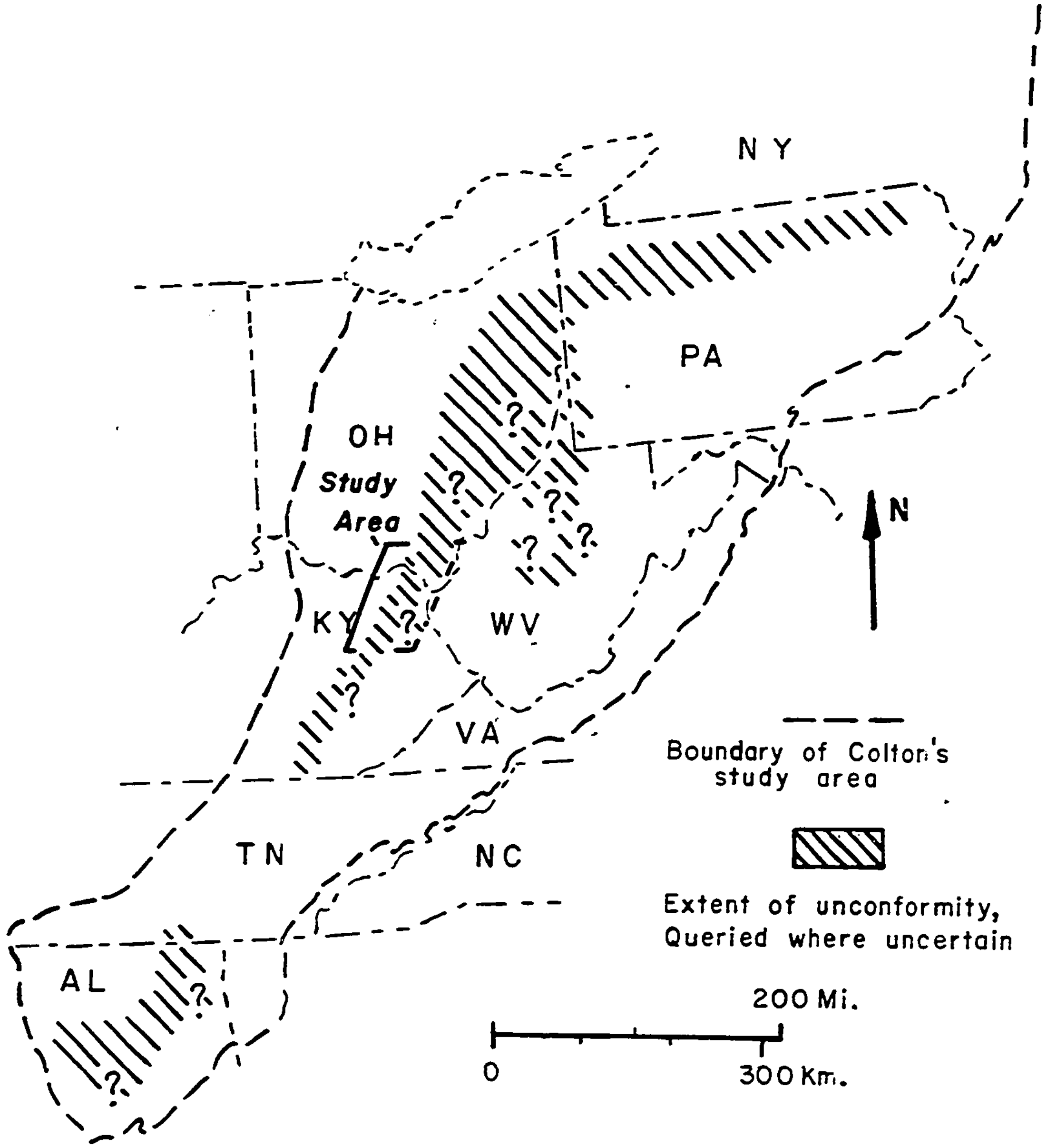


Fig. 5: Extent of Mississippian-Pennsylvanian unconformity within the Appalachian Basin. Adapted from Colton, (1970, p. 16).

Georgia with a slight shift to the west occurring in Alabama (Mitchum, 1954; Tanner, 1959; Chen and Goodell, 1960; Schlee, 1963; Metzger, 1965; BeMent, 1975). Clastic disperal patterns for the basal Pottsville (Lee Formation, Sharon and Olean Conglomerates) of Pennsylvania and Ohio indicate a northwestly transport direction across Pennsylvania and southerly transport direction in Ohio (Fuller, 1955; Meckel, 1967, 1970; Mrakovitch and Coogan, 1975).

Arkle (1969, p. 59) believed that the Pottsville of southern West Virginia was deposited in a trough to the south of an epicontinental basin to the northwest with a hinge line extending northeast-southwest. Dennison and Wheeler (1975) support this hypothesis, but prefer the terms geosynclinal basin and platform to trough and epicontinental basin. Meckel (1967, 1970) also proposed the presence of a flexure zone in this area which separated a platform area to the northwest from a trough area in southern and eastern Pennsylvania.

Based on the standard reference section for the three divisions of the Pottsville Group in southern West Virginia (Hennen et al., 1919) Dennison and Wheeler have interpreted the Pottsville to be principally fluvial and deltaic deposits of nonmarine origin. Meckel (1967, 1970), Fuller (1955), and Mrakovitch and Coogan (1975) have interpreted the lower Pottsville Lee and Sharon equivalents of Pennsylvania and northeastern Ohio as alluvial and possibly deltaic channel deposits based on physical properties and depositional trends. BeMent (1976) studied the Pennington-Lee interval in southeastern Kentucky along Pine Mountain and concluded a shoreface, tital, and fluvial origin for the sediments. Wilson and Stearns (1960) postulated a marine origin for the whole

Pottsville except the coals and adjacent beds in Tennessee, and Ferm et al. (1972) and Miller (1974) favor an even more marine setting for the Lee equivalents of Tennessee and Virginia. These authors interpret all strata except the thick coals as marine or shoreline deposits. These interpretations are similar to those made by Hobday (1969) for the Pennsylvanian of Alabama.

Within the study area, the Lee Formation, which is considered to consist of conglomerate, sandstone, shale and the Olive Hill clay bed, is much thinner than in adjacent parts of the Appalachian Basin. Patterson and Hosterman (1960, 1962, 1963) noted the discontinuous nature of the Olive Hill clay bed and proposed a marginal marine setting for its formation, visualizing its origin by acid leaching of fine-grained Pennsylvanian sediments in coastal swamps.

Ferm and others (1971), using the aforementioned U. S. Highway 64 roadcuts, proposed a depositional model for the rock units ranging from the top of the Mississippian Borden Formation into the Lower Pennsylvanian Breathitt Formation. These authors postulated that lithologic and faunal differences between these units (i.e. the Newman, Pennington, Lee and Breathitt Formations) could be attributed to depositional environments and no unconformity need be inferred in the area. According to this model, the Pennington is interpreted as shallow marine and the proposed "Lee" sandstones are beach barrier deposits. This work, in essence, laid the foundation for subsequent investigations finding both supporters and opponents for the concept (Ettensohn, 1974, 1975, 1976; Ferm, 1974; Horn et al., 1974; Philley, 1974; Swinchatt, 1974; Wilson, 1974; Martin, 1975).

Dever (1973) offered the first alternative hypothesis for the deposition of the lower Newman, using synsedimentary tectonic activity on the Waverly Arch and Kentucky River Fault System to explain the distribution patterns of the individual members. Ettensohn (1974, 1975, 1976), extending this concept into overlying strata of the upper Newman and Pennington formations, reported the existence of an "apical island" which was atop the Waverly Arch and on the north side of the fault block. According to Ettensohn's model, this positive feature and movement on the fault system controlled the distribution and thickness of the various members of the Newman and Pennington formations. Ettensohn recorded a series of easterly progradations and regressions and has interpreted deposition in environments ranging from shallow marine to tidal flat or tidal channel. Martin (1975) also inferred structural control from the Waverly Arch on the deposition of the Carter Caves sandstone, which he interpreted as a tidal channel deposit.

Systemic Boundary

The position of the Mississippian-Pennsylvanian boundary in the Appalachian Basin, and particularly within the study area, has proven to be more of a question than was initially envisioned by early workers. The boundary has historically been placed at the base of the massive, crossbedded, often conglomeratic sandstones of the lower Pottsville (Lee Formation), or at the base of the associated black, carbonaceous shales. This practice appears to have started in order to separate the upper coal-bearing sediments from the lower barren sediments. The presence of an unconformity between these lithologies in eastern Ohio and northern

Pennsylvania also accentuated the importance of this boundary. As has been previously pointed out, however, the boundary is not everywhere unconformable, and where a gradational relation exists, it is often difficult to ascertain the exact location of the systemic contact.

The possibility of synsedimentary tectonic influence within the study area opens the door for even more complicated relations between the Mississippian and Pennsylvanian sediments. As pointed out by Merrill (1973, p. 1122), age determinations for particular units in northeastern Kentucky have been based mostly on assumptions and have relied heavily on lithologic distinctions for separation of the two Paleozoic systems. It is hoped that stratigraphic relations and age determinations included herein will aid in resolving this.

DATA

Method of Study

Data for this study was collected during the period from the summer of 1975 through the fall of 1976. A total of 85 sections were measured, described, and sampled and 52 outcrop exposures were described and sampled. Fifteen sets of well cuttings from the Kentucky Geological Survey core library were examined by binocular microscope and logged for use in correlations. Additional information was taken from the studies conducted by Patterson and Hosterman (1960, 1962, 1963), Martin (1975) and published U. S. Geological Survey geologic quadrangle maps. The locations of the data collected during the study are shown in Figure 6.

Physical characteristics noted during the collection of data included information on lithology, sedimentary structures, bedding, grain size, trace and body fossils, and paleocurrent data. Special care was taken to note any trends in grain size and bedding thickness. These data, combined with information from thin-section analyses, isopachs, cross-sections, plots of areal distributions of particular units, x-radiographs and x-ray diffractograms form the basis for the identification of the facies described and their relation to local structural features. This composite picture will then be compared to results of previous studies to reconstruct a regional picture for the time of deposition of the units under consideration.

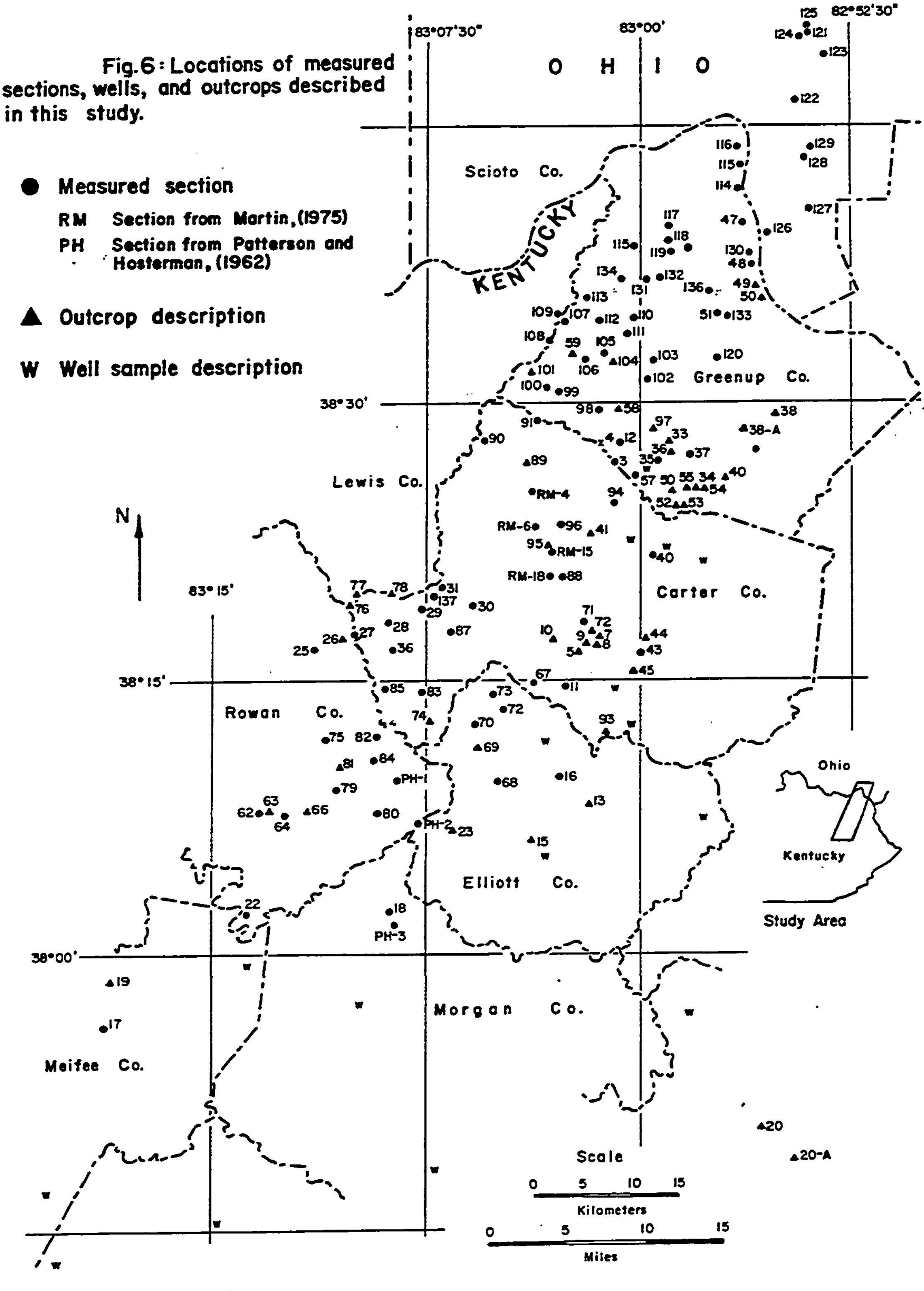


Fig.6: Locations of measured sections, wells, and outcrops described in this study.

Facies Description

Eight distinct facies have been defined on the basis of properties observes in the sediments and previously outlined. Inasmuch as only one of these facies has been formally named, and to minimize confusion for the reader, each of the facies will be assigned a letter which will be used in all discussions concerning that facies. Where it is possible, the formal stratigraphic terminology will supplement the letter designation.

Facies A

Facies A is formally termed the Corbin Sandstone Member of the Lee Formation in Kentucky and the Sharon Conglomerate in southeastern Ohio. The unit consists of fine- to coarse-grained, white to brown to red, quartzose sandstone which contains abundant quartz pebbles and lesser amounts of chert and limestone pebbles. The pebbles range in size from granules to cobbles and occur in zones which are best developed near the base of the unit, where it is a true conglomerate, although they persist in lesser quantity throughout the facies.

Bedding ranges from thin to massive and, in general, does not appear to exhibit any ordered, vertical variation in thickness except at the top of the body where thickness decreases as the unit begins to interbed with siltstones and shales of the Breathitt Formation. Figure 7 is a plot of bed thickness versus vertical distance from the base of the unit at Station 43 near Leon, Kentucky, where the sandstone is 21 meters (69 feet) thick.

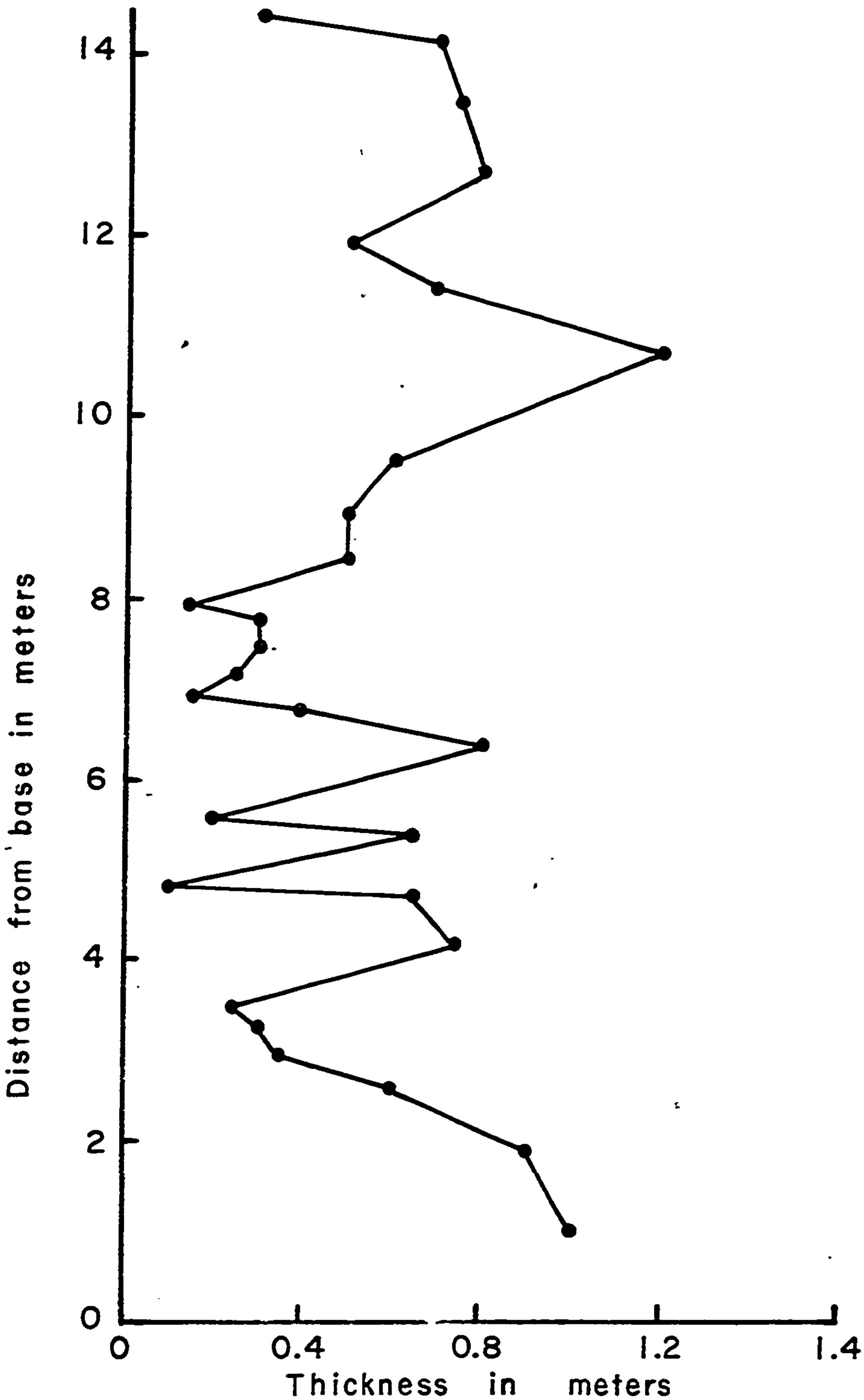


Fig.7: Vertical variation in bed thickness in facies A, Station 43, Leon, Kentucky.

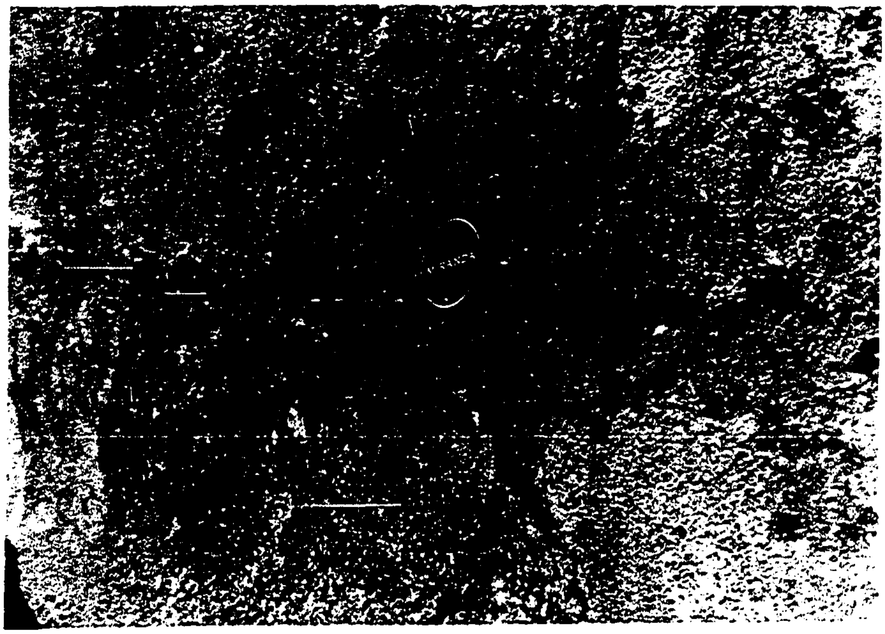
Planar and trough cross-stratification, omikron and pi types respectively in Allen's (1963) classification, and horizontal beds are the dominant bedding types occurring within this facies. Planar cross-bedding is the most abundant, and horizontal beds are volumetrically minor, being best developed in the conglomerate zones. Planar sets are commonly underlain by nearly planar ercsional surfaces which, on occasion, contain lag pebble concentrates only one pebble thick (Plate 3). In conglomerate zones, these crossbeds may be graded with decreasing grain size to the top of the set and in the upcurrent direction (Plate 4). Overturned cross-stratification and convolute bedding are also present in some areas.

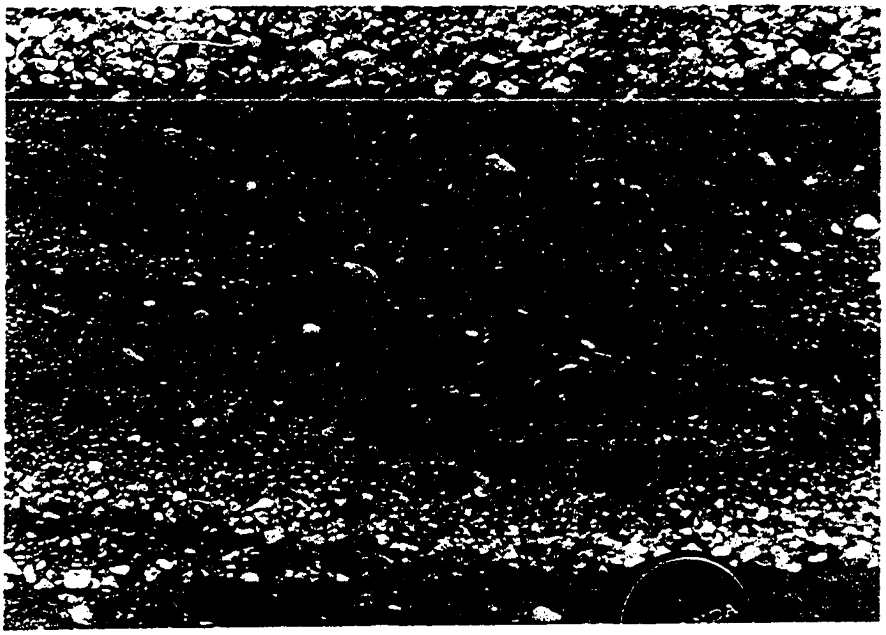
Near Station 73 in the northern Ault quadrangle, a large, channel-shaped accumulation of massively bedded, sparsely conglomerate sandstone nearly 4 meters (13 feet) thick and 8-10 meters (26-33 feet) wide is enclosed in planar and cross-bedded sandstones. The configuration suggests erosion of facies A sandstones and subsequent filling by the sparsely conglomeratic sandstones.

Remains of woody material are very common within this facies. Hylbert and Philley (1971) have reported local occurrences of the plant fossils Sigillaria and Stigmaria as casts and molds. These, plus examples of Calamites, Lepidodendron and other undeterminable species which occur as logs 15-20 centimeters (6-8 inches) in diameter and 3-4 meters (10-13 feet) long, are commonly observable (Plate 5). Abundant plant materials usually occur in the basal portion of the facies; however, smaller accumulations can be found throughout. The unit is devoid of any other fossil remains.

Plate 3. Pebble lag concentrate in facies A sandstones. The line of pebbles represents an erosional surface on which pebbles accumulated. Location is Station 19, Menifee County, Kentucky, Carter Coordinates 19-R-71. Camera lens cover for scale.

Plate 4. Grading of pebbles on the forests of planar crossbeds in facies A sandstones. Pebble size decreases toward the top of the bed and in the upcurrent direction (to the left). Location is Station 19, Menifee County, Kentucky, Carter Coordinates 19-R-71. Camera lens cover for scale.





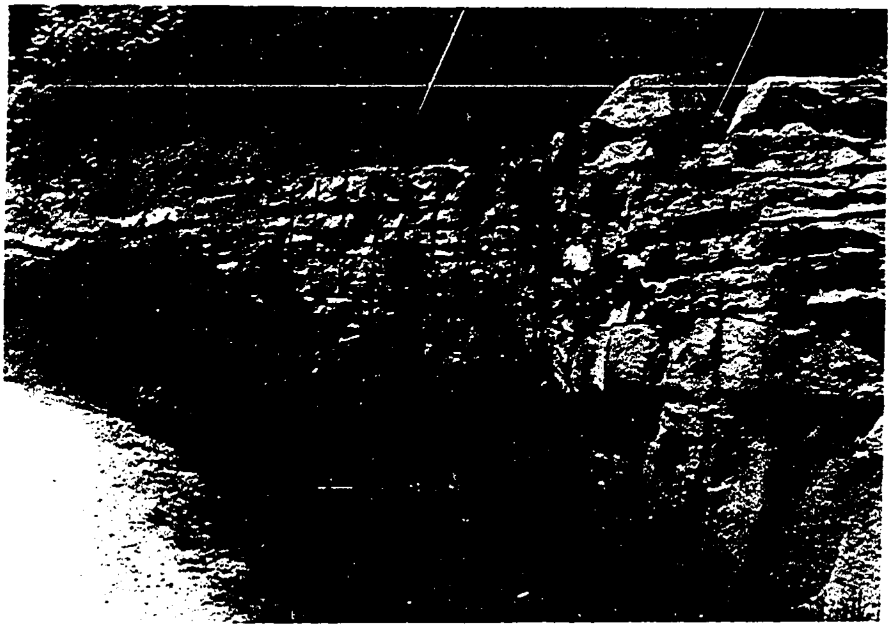
The basal contact of this facies is always found to be very sharp and often undulatory with minor relief up to 1-2 meters (3-6 feet) in a single exposure. The sandstones and conglomerates rest on a variety of lithologies ranging from Borden siltstones and shales, Newman limestones, or black shales assigned to the lower tongue of the Breathitt (Wier, 1974; Wier and Richards, 1974) in the southern exposures to gray and green shales and bioturbated sandstones in the northern exposures. This represents a stratigraphic rise in the position of the contact and will be better illustrated later in cross-sections.

The upper contact, where it is visible as at Station 13, is gradational with overlying siltstones and shales of the Breathitt Formation. Bedding thins and the grain size decreases across this contact as the sandstone begins to interbed with the overlying lithologies (Plate 6). Eventually the sandstones are replaced by shales and siltstones.

Facies A is present in the study area in two separate, distinct locations, one south of a line extending norteast-southwest through central Rowan and Carter Counties, Kentucky, and the second in the northern part of the study area in Scioto County, Ohio (Fig. 8). The southern exposures, where fully developed, attain thicknesses up to 60-70 meters (197-230 feet), but thin rapidly to the north and northwest. Data from measured sections, well cuttings, and U. S. Geological Survey geologic quadrangle maps were used to construct an isopach of this unit (Fig. 9). Note the relatively thick accumulation of sediment near the center of the map that trends slightly northeast-southwest. This zone of greatest thickness occurs along the same trend as that of the Kentucky River Fault Zone and thinning of the body begins on the upthrown, or

Plate 5. Abundant plant material present in the basal portion of facies A sandstones. Location is at Station 65, Rowan County, Kentucky, Carter Coordinates 15-T-74. Hammer is for scale.

Plate 6 View of the upper contact of facies A sandstones (Corbin Sandstone Member of the Lee Formation) at Station 13, Elliott County, Kentucky, Carter Coordinates 7-T-78. The outcrop is approximately 3 meters thick.



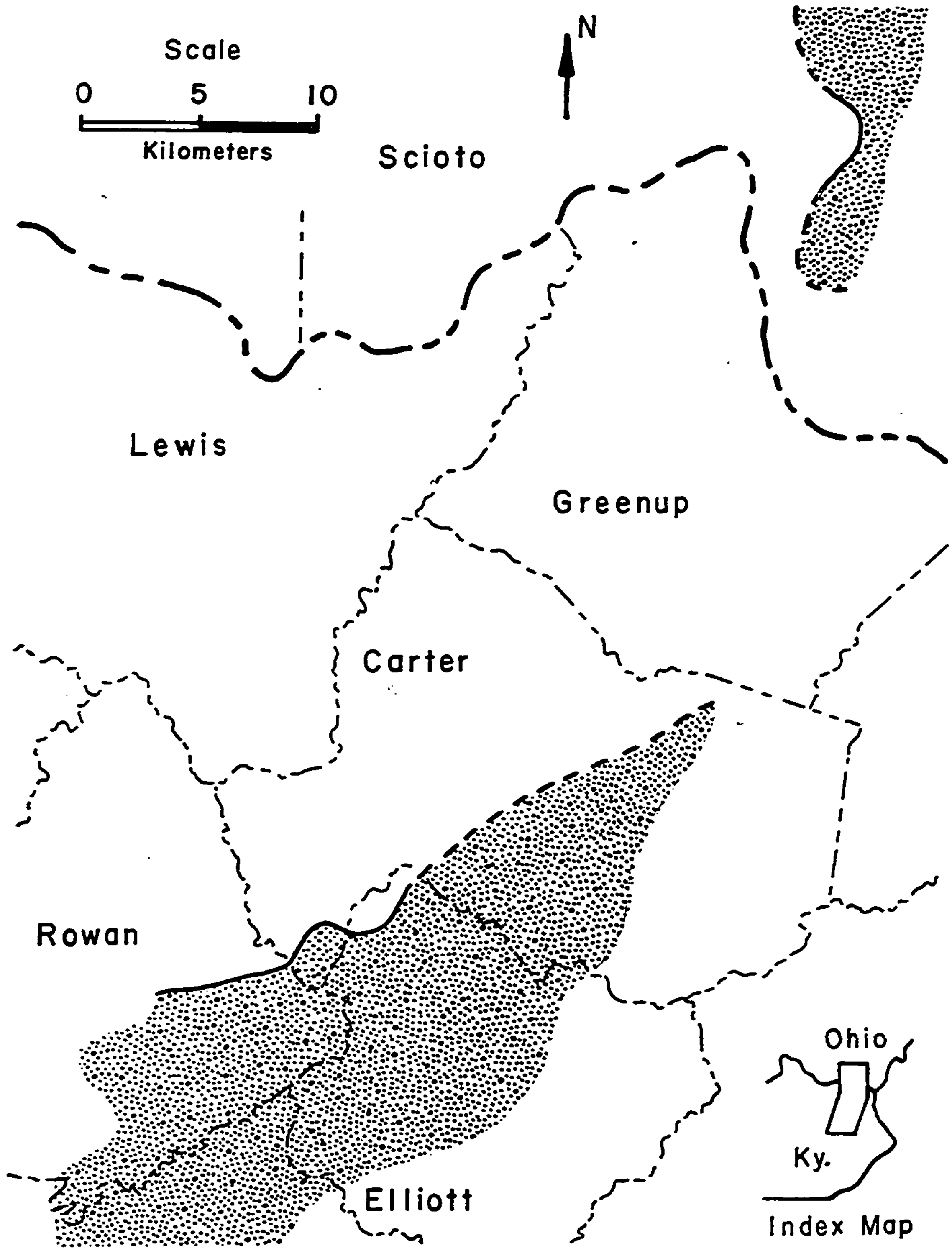


Fig. 8 : Areal distribution of facies A sediments. The northern and southern exposures are not connected in outcrop.

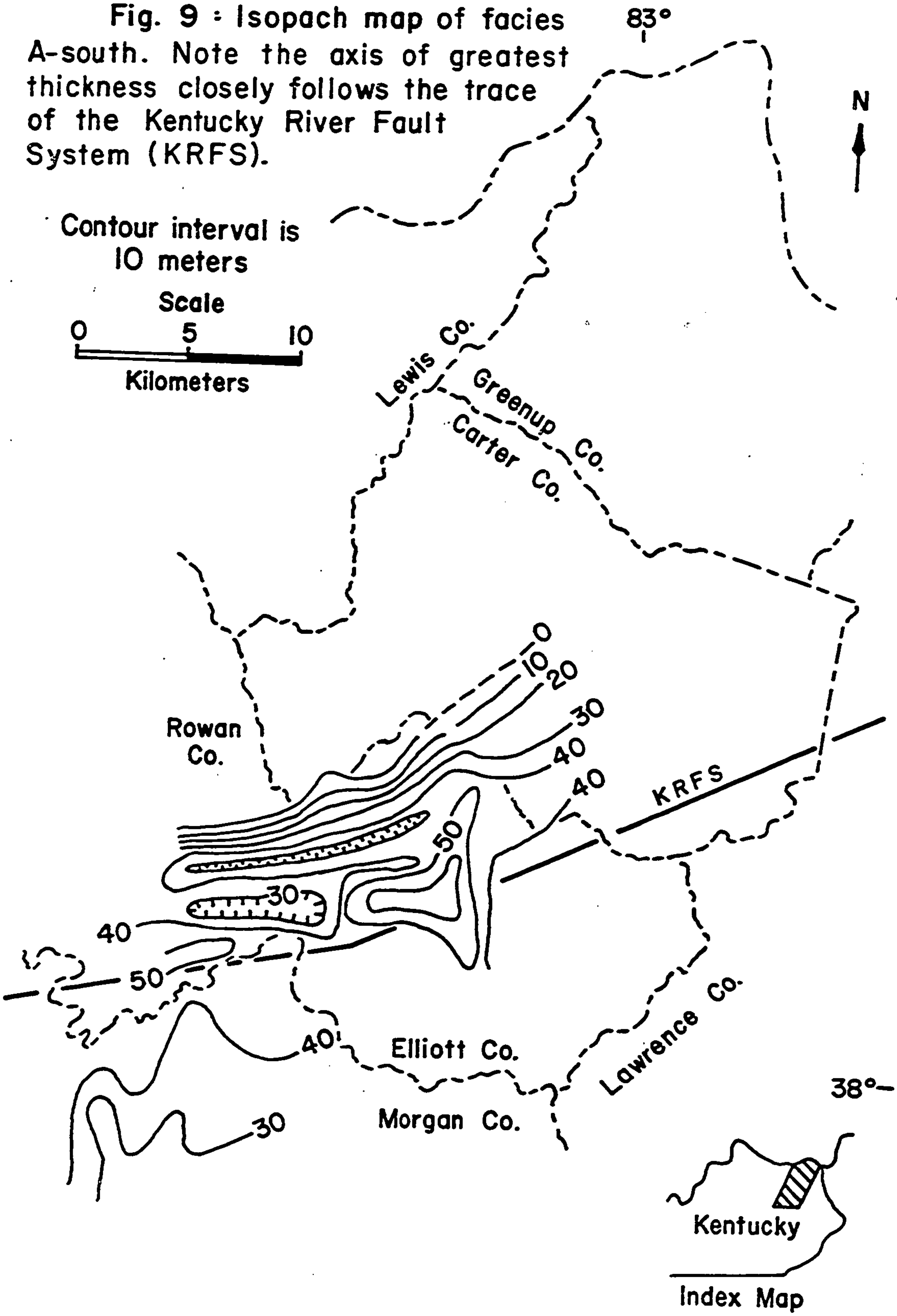


Fig. 9 : Isopach map of facies A-south. Note the axis of greatest thickness closely follows the trace of the Kentucky River Fault System (KRFS).

northern side of the fault system. The calculated rate of thinning in this area is on the order of 8 meters per kilometer (44 feet per mile). The unit also begins to thin to the south, although no thicknesses less than 20 meters (65 feet) were measured in this area. Wier (1974) and Wier and Richards (1974) have mapped this sandstone body to the south in the Stanton and Pomroyton quadrangles as lenticular, channel-like bodies and localized sheet sands with the intervals between the sandstone bodies occupied by the underlying shale which is transitional into the overlying Breathitt Formation.

Facies A of southeastern Ohio is lithologically identical to that of Kentucky except that graded pebble accumulations and convolute bedding were not observed, possibly because of poor exposures. For this same reason, data were insufficient for the construction of isopach maps. The thickest occurrence of this unit found reported in southern Ohio is nearly 60 meters (200 feet) in Liberty and Washington townships, Jackson County, Ohio (Stout, 1916, p. 29). The thickest accumulation found within the study area is approximately 10 meters (33 feet) at Station 121.

The upper contact within this particular area is rarely visible, but when observable is relatively sharp with black, carbonaceous, coaly shales (Station 127). The basal contact is always found to be sharp, sometimes with relief of 1-2 meters (3-6 feet) into the underlying Borden Formation (Logan Formation of Ohio). On occasion, rocks of this facies were found resting sharply on carbonaceous, sparsely bioturbated, black shales (Station 127); however, in these instances, the facies consists of thinner accumulations of sandstone, lacking the well-defined pebble-rich zones characteristic of the better developed areas. In no instance in these northern exposures was facies A found resting on limestone.

Facies A in the northern exposures terminates under cover to the south near the Ohio River, drops below drainage to the east, and rises above drainage to the west. It has been reported to extend into northeastern Ohio in nearly continuous exposures (Morningstar, 1922, p. 10).

Facies B

Facies B is a fine- to medium-grained sandstone occurring in thin to massive beds and containing abundant bioturbation structures. The trace fossils comprising the bioturbation are not treated here but are discussed extensively in conjunction with other biota encountered during the study (see Fossil Content, Trace Fossils). Ripples are the dominant sedimentary structure present with types ranging from straight crested, symmetrical wave ripples (Plate 7) to linquoid or rhomboid, asymmetrical, small current ripples (Plate 8). The ripples are often contorted or completely destroyed by bioturbation which occurs mostly as horizontal and vertical tubes and tracks. Bioturbation is also responsible for the massive nature of many of the beds (Plate 9).

In areas where bioturbation has not destroyed bedding, individual beds characteristically pinch and swell, corresponding to ripple troughs and crests, and are discontinuous, rarely being traceable throughout any particular outcrop (Plate 10). Flaser, wavy, and lenticular bedding are the dominant types present and these are commonly interbedded with carbonaceous or coaly shales.

Plate 7. Symmetrical wave-type ripples in the facies B sandstones. Note the vertical and horizontal bioturbation structures present on the surface. Location is at Station 82, Rowan County, Kentucky, Carter Coordinates 17-U-75. The scale is divided into 10 centimeter intervals.

Plate 8 Asymmetrical, rhomboid current ripples in facies B sandstones. Current was from upper right to lower left. The scale is 0.5 meters long. Location is at Station 65, Rowan County, Kentucky, Carter Coordinates 15-T-74.

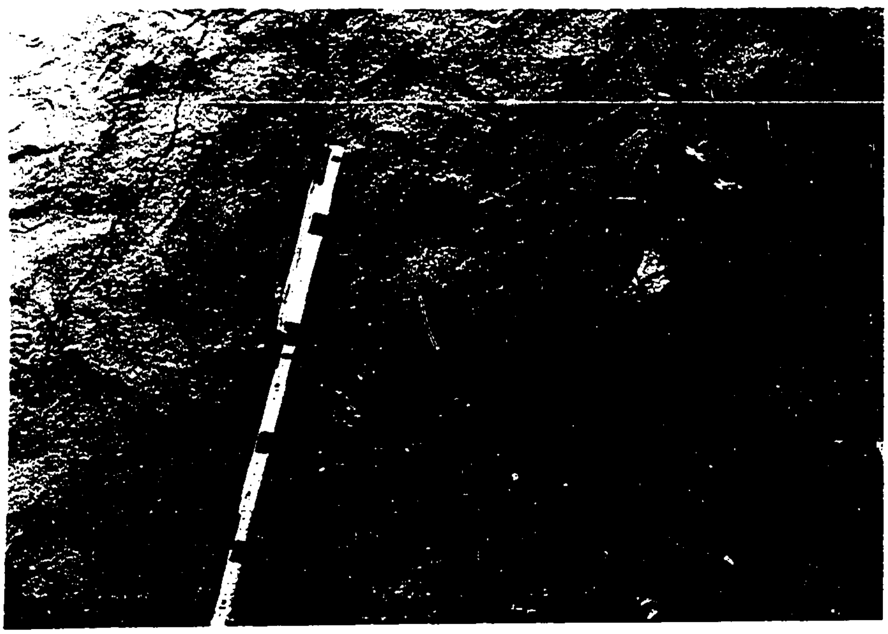
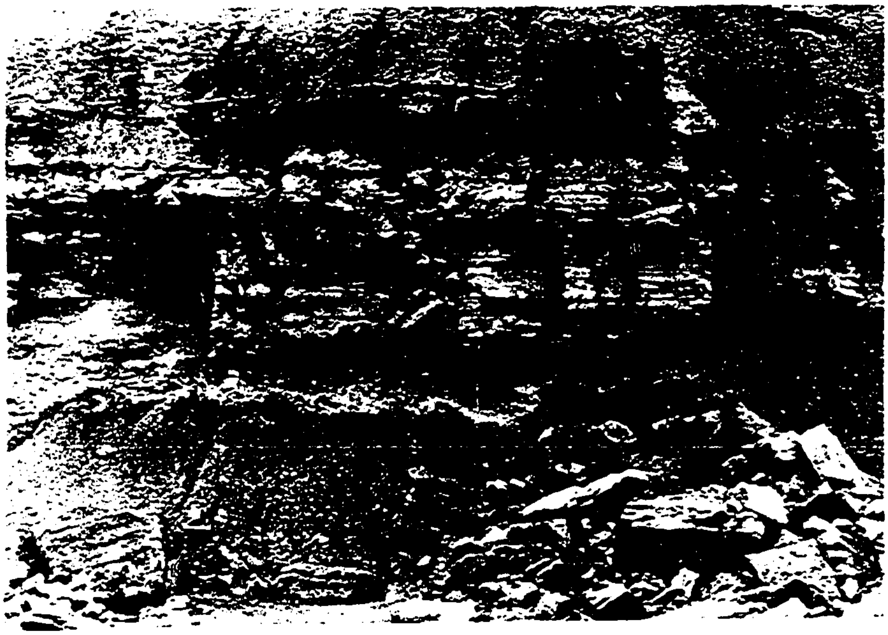
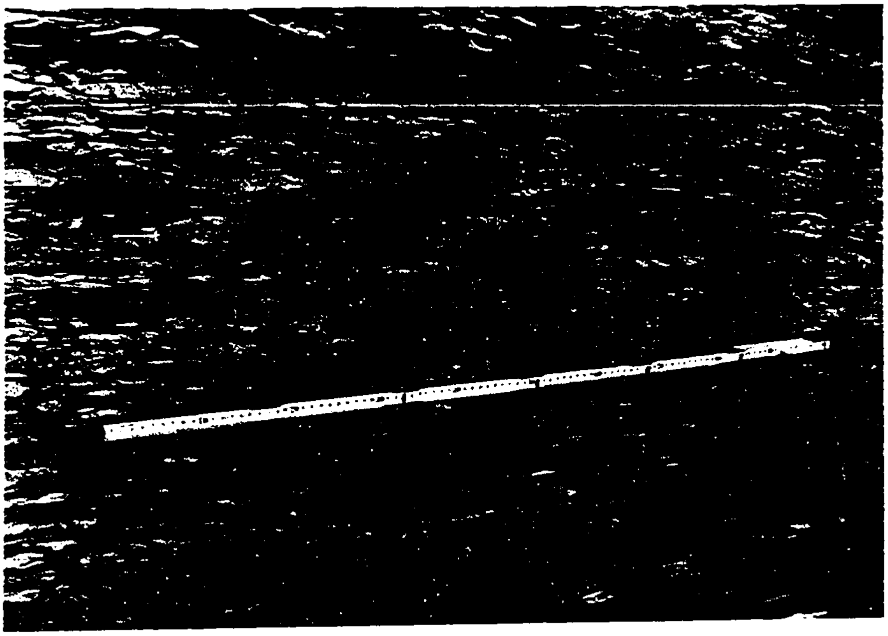


Plate 9. Outcrop exposure of facies B sandstones. Note the gradation from massive bedding at the base to thinner bedding in the upper portions. A 15-centimeter coal is present near the top of the outcrop. The bed above the coal is dolomite. Location is at Station 82, Rowan County, Kentucky, Carter Coordinates 17-U-75. The scale is one meter long.

Plate 10. Flaser bedding present in facies B sandstones. Note the pinch and swell corresponding to ripple troughs and crests. Location is at Station 48, Greenup County, Kentucky, Carter Coordinates 12-Z-80. The scale is one meter long.





The upper and lower boundaries of this facies are difficult to observe because of poor exposures in its outcrop area. When the contacts are exposed, they display only slight variation from place to place. In southern and eastern Roan County, Kentucky, the lower contact is exposed in clay strip pits and appears as part of a gradational sequence from underlying green and gray shales. The basal sandstone at Station 82 consists of a single, massive bed 1.5 meters (5 feet) thick and intensely bioturbated. This unit grades upward into more shaly sediments with characteristics described above. At Station 119 in northern Greenup County, Kentucky, the lower contact is gradational from black, silty, bioturbated shales (Facies E_2), with small sandstone lenses and eventually sandstone beds replacing the shale vertically (Fig. 35). No massive sandstone occurs at the base here.

The upper contact is even more difficult to observe, but has been seen at Station 82 where it occurs as a fairly sharp boundary with a 60 centimeter (2 feet) black shale zone which contains a 15-centimeter (6-inch) coal bed (Plate 9). At Station 65 in the southeast Morehead quadrangle, the same contact occurs as a gradational sequence with black, silty shales which also contains a 15-centimeter (6-inch) coal.

Facies B is confined largely to a north-south elongate area in eastern Rowan County and western Carter County, Kentucky (Fig. 10). This area is situated north of the Kentucky River Fault System and sits atop the axis of the Waverly Arch as it was proposed by Ettensohn (1975). Facies B is separated from the Newman in this area by several meters of gray to green shale (Facies F) and the Olive Hill Clay Bed of Crider (1913).

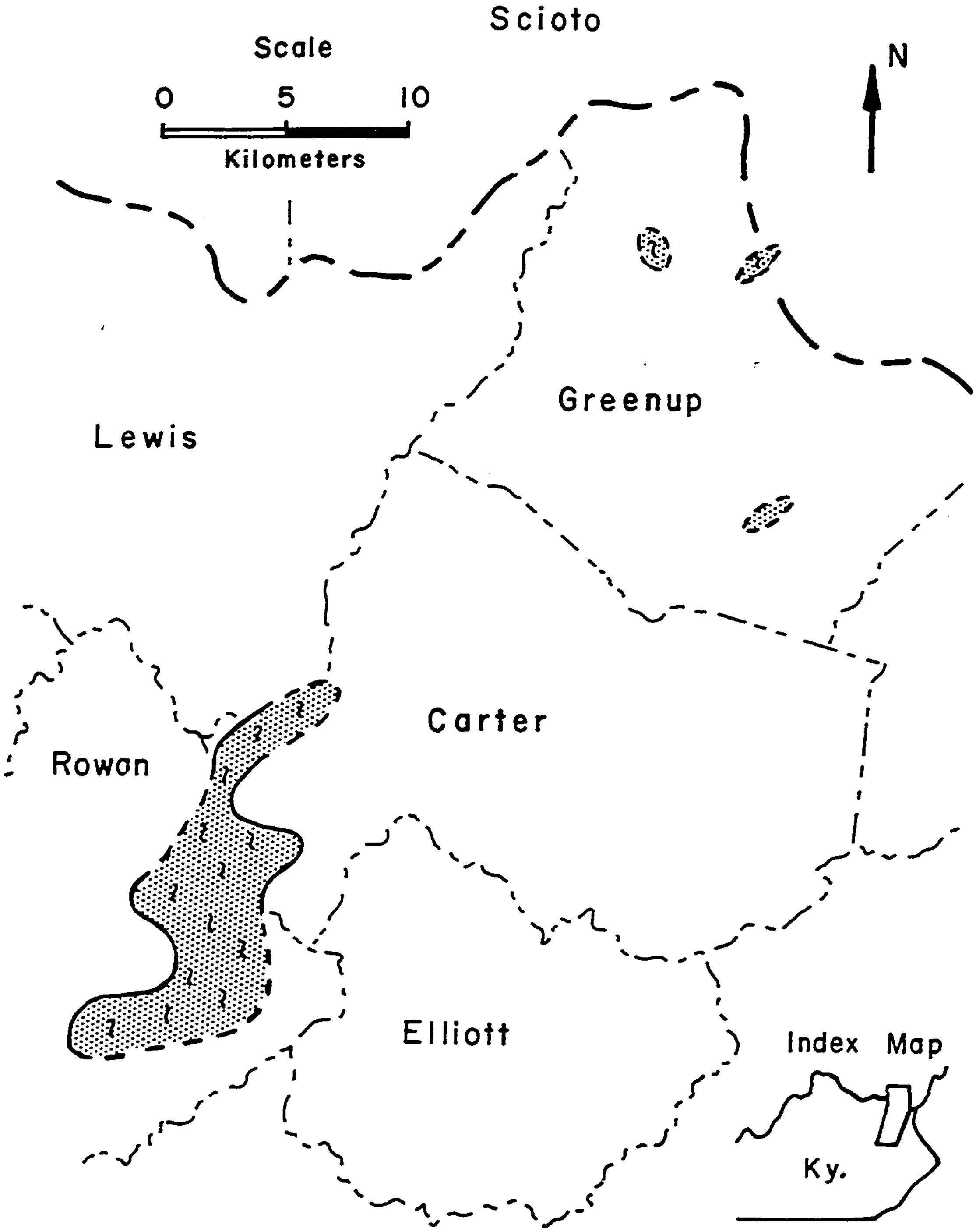


Fig. 10: Areal distribution of facies B sandstones. The large area in eastern Rowan County sits atop the north-south trending Waverly Arch.

Rocks characteristic of this facies are also present in isolated patches in the northern part of the study area (Fig. 9). These exposures have lithologic properties which are nearly identical to those just described except for the degree and typs of bioturbation, which is much less pronounce here, and the absence of straight crested, symmetrical wave ripples. The nature of the adjacent facies is also different in these smaller exposures; these lateral associations will be treated extensively during analyses of the cross-sections.

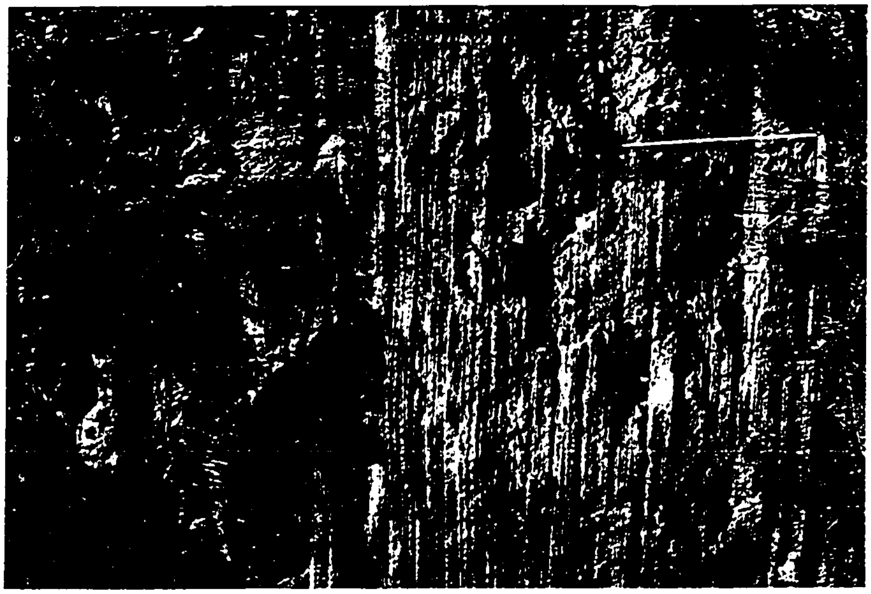
The maximum observed thickness of this facies is approximately 5 meters (16 feet) at Station 82 near the center of its outcrop area. Bioturbation decreases in importance towards the margins and away from this depositional maximum. The unit rises above drainage to the west and is in facies relation with other units of this study to the north, south, and east.

Facies C

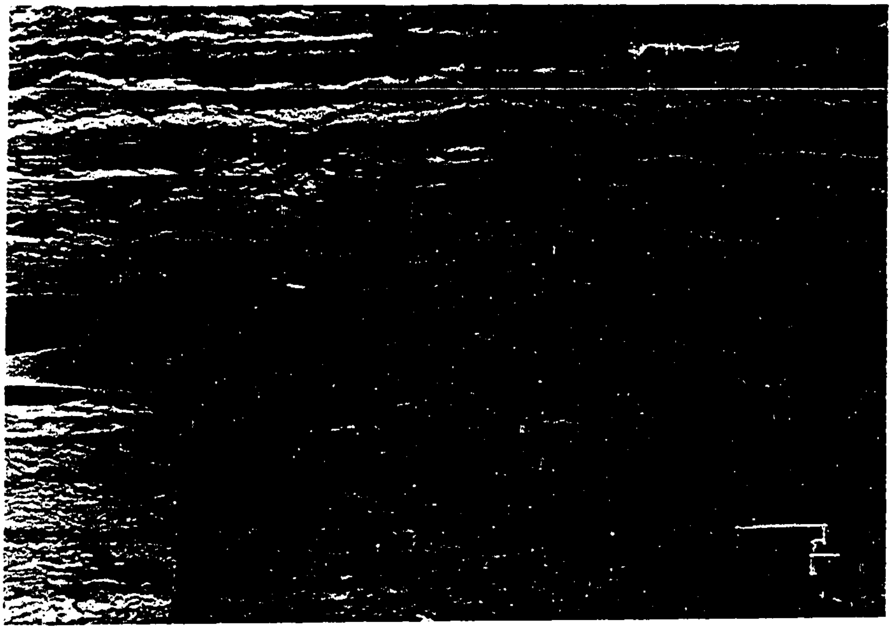
Facies C consists of coarse quartzose siltstone to fine-grained, quartzose sandstone which occurs in thin, lenticular, horizontal beds and laminae. Carbonaceous and shaly laminae normally occur as interbeds (Plates 11 and 12). Bioturbation is locally abundant as horizontal and vertical tubes and tracks which are concentrated along the organic-rich interbeds. Iron oxide and iron carbonate nodules and lenses are also common, often as infillings of burrow structures. One siderite nodule measured 25 centimeters (10 inches) in diameter. Scour and fill structures are also observable, although not commonly. These structures are generally 4-6 centimeters (1.5-2 inches) deep and 10-15 centimeters (4-6 inches) across.

Plate 11. Outcrop exposure of facies C sandstones. Note the horizontal nature of the beds. Location is at Station 57, southern Greenup County, Kentucky, Carter Coordinates 20-X-78.

Plate 12. View of the bedding style characteristic of facies C sandstones. Notice the thin laminae and the interbedded carbonaceous material. Bioturbation is minimal at this locality. Location is at Station 57, southern Greenup County, Kentucky, Carter Coordinates 20-X-78. Scale is in centimeters.



up

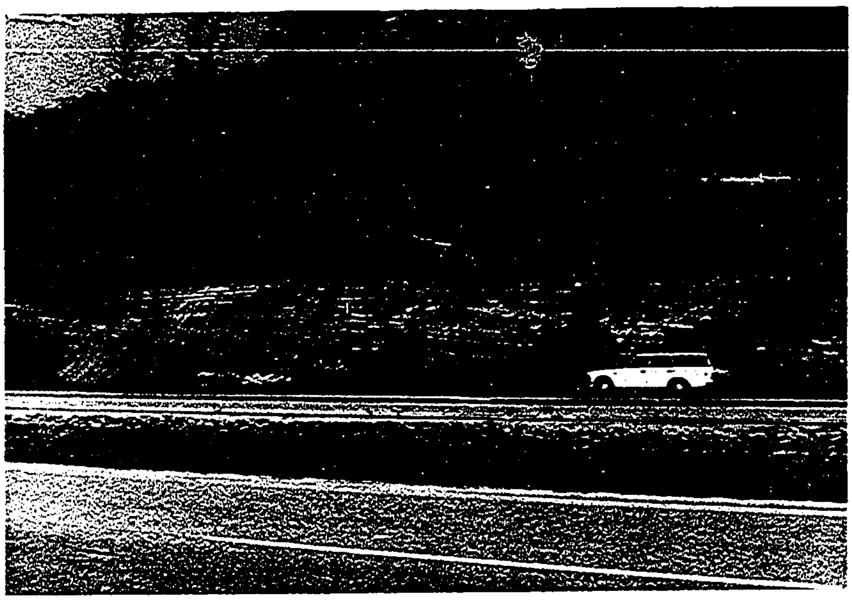


Bedding thicknesses range from several millimeters to nearly 0.7 meters (2.2 feet) and generally decreases upwards. This unit often caps hills and the upper parts are often removed or not exposed. However, at Station 27, located along U. S. Highway 64 roadcuts near the Rowan and Carter County line, a nearly complete section is observable. Here the fine-grained sandstone beds are replaced vertically by black, silty shales (Plate 13). The sandstone beds often exhibit internal graded bedding from coarse to fine upwards, and are separated by thin (less than 1 centimeter) shale partings. These beds show abundant internal ripples and bioturbation; however, individual structures do not cross bedding planes. The normal bedding sequence is interrupted at this locality by a channel-shaped feature which has removed much of the upper part of the unit and has been infilled by siltstones and carbonaceous shales. A thin coal occurs along the base of the channel (Plate 13).

At Station 88, also along U. S. Highway 64 but in central Carter County, the upper contact is also visible and appears gradational into gray and black shales of the Breathitt Formation (Englund, 1976). The lower contact at this locality (Plate 14), in contrast, is fairly sharp and has 3-4 meters (10-13 feet) of relief into underlying gray and black, silty shales (facies E_1). Lower beds appear to converge on the sides of the channel-shaped deposit, while the upper beds are horizontal to the edge of the outcrop. At Stations 3 and 57 in southern Greenup County, Kentucky, the lower boundary is gradational with black and gray, silty, slightly bioturbated shales (facies E_2).

Plate 13. Outcrop exposure of facies C along U. S. Highway 64 at the Carter and Rowan County line. Note the channel-shaped feature which cuts into this unit. The facies grades into overlying shale at this locality. Carter Coordinates, 15-V-75.

Plate 14. Outcrop exposure of facies C sandstones along U. S. Highway 64 in central Carter County, Kentucky. Note the channel-like geometry of the unit here. Carter Coordinates, 25-W-77.



At Station 61 in the southern Portsmouth quadrangle, this facies appears to rest direcely on siltstones and shales of the Borden Formation (Sheppard, 1964). Vertically the unit grades into silty shales and is ultimately overlain by conglomeratic sandstones similar to facies A.

There appears to be a general trend in the overall nature of the bedding from north to south within this facies. In the northern exposures, the unit is characteristically laminar bedded with abundant carbonaceous laminae as interbeds; however, in the southern exposures along U. S. Highway 64, the beds are much thicker and lack carbonaceous laminae, these being replaced by shaly interbeds. Bioturbation also appears to increase to the south within the unit.

Facies C is generally restricted to the northern part of the study area, north of the Kentucky River Fault System. The largest single exposure occurs at Station 27 on U. S. Highway 64 where it attains its maximum observable thickness of 20 meters (67 feet). The geometry of the unit is generally of a sheet-type deposit being thickest near the middle and thinning towards the edges with a flat base and top. The actual distribution is uncertain because of poor exposures. The unit disappears to the north and south, being in facies relation with other unit of this study, and goes into the subsurface to the east. Areal distribution of the facies is shown in Figure 11.

Facies D

Facies D consists of coarse-grained siltstone to medium-grained, quartzose sandstone and occasionally, in the northern part of its outcrop area, contains chert, limestone and quartz pebbles as basal lag

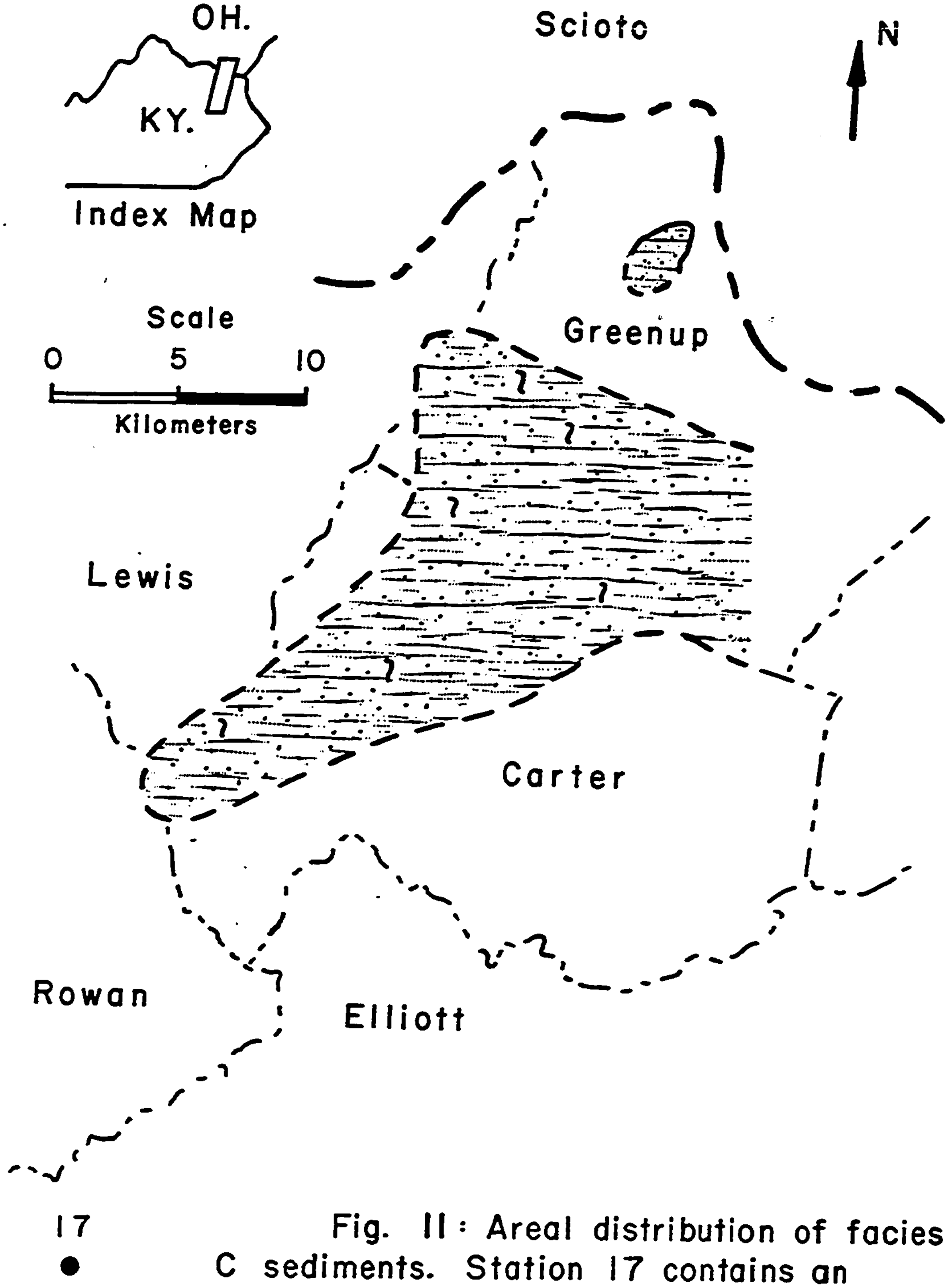


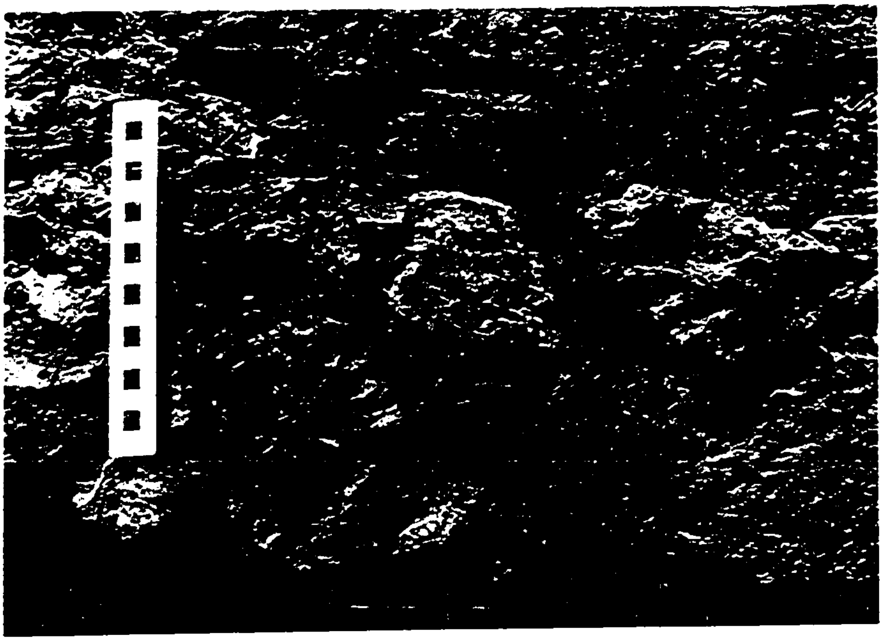
Fig. 11: Areal distribution of facies C sediments. Station 17 contains an exposure of this lithology which appears to be isolated from northern outcrops.

deposits (Plate 15). Most of the chert pebbles are angular to subround and average 2-3 centimeters (0.8-1.2 inches) in diameter, while the quartz pebbles are much smaller, 1-2 centimeters (0.4-0.8 inches) or less, and are well-rounded. In the extreme southern exposures of this unit, the chert is not present and the quartz only in small amounts; however, these may be replaced in the lag deposits by plant material such as Annularia or Calamites, some attaining lengths of 40-50 centimeters (16-20 inches) and diameters of 5-6 centimeters (2-2.5 inches), and clay clasts. Other plant material is found sporadically throughout the unit, but is most commonly preserved in the basal portion.

Trough and planar cross-stratification, pi and omikron of Allen's (1963) classification, and horizontal beds are the dominant bedding types within the unit with trough cross-stratification by far the most abundant (Plate 16). Individual cross-stratification sets range in thickness from over 2 meters (6.5 feet) to several centimeters and generally appear to thin upwards, although in no well-ordered manner. Horizontal beds also occur throughout the facies; however, Martin (1975) reports that these are most common in the upper half of the body. Thickness of these beds range from several centimeters to more than 1 meter (3.3 feet), the latter measured by Martin at Echo Canyon (Station 32) in the northern Grahn quadrangle. Reactivation surfaces are common and contacts between the cross-strata are usually erosional. Asymmetrical ripples ranging from nearly straight crested to linquoid are common, occurring on the upper surfaces of the cross-stratification sets (Plate 17). Overturned crossbeds and convolute bedding occur in minor amounts.

Plate 15. Angular and rounded chert pebbles which are present as basal lag deposits in the sandstones of facies D. The scale her is 15 centimeters long and divided into 1-centimeter intervals. Location is at Station 115, northeastern Greenup County, Carter Coordinates, 13-80-AA.

Plate 16. Trough crossbeds present in facies D sandstones. The troughs are inclined perpendicular to the plane of the page. Hammer at lower center for scale. Location is at Station 55, southern Greenup County, Kentucky, Carter Coordinates, 22-X-79.



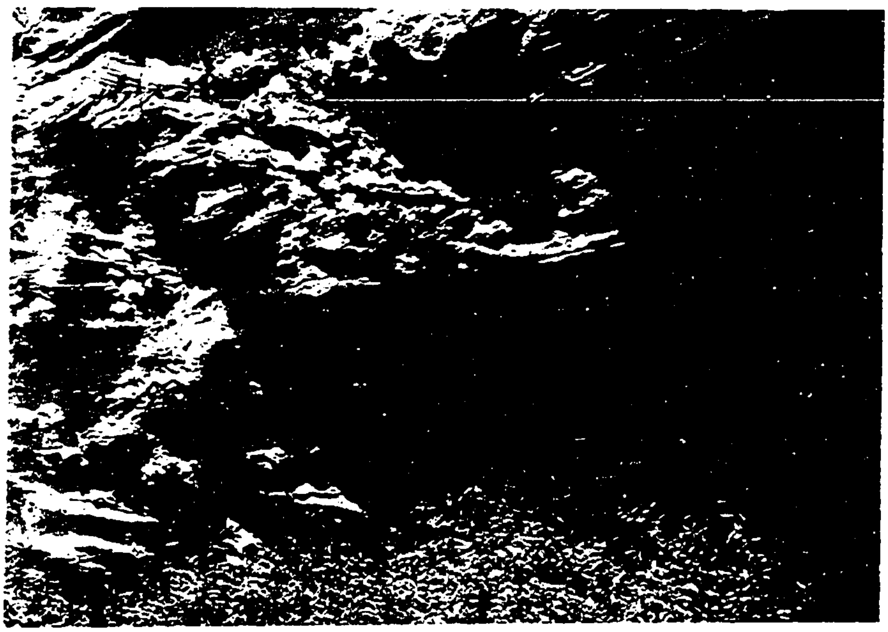
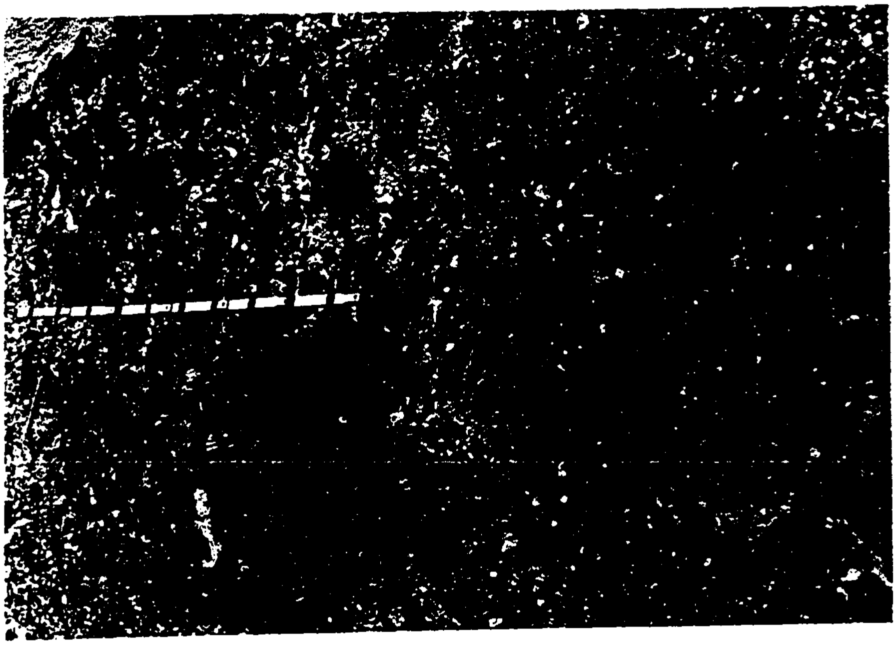
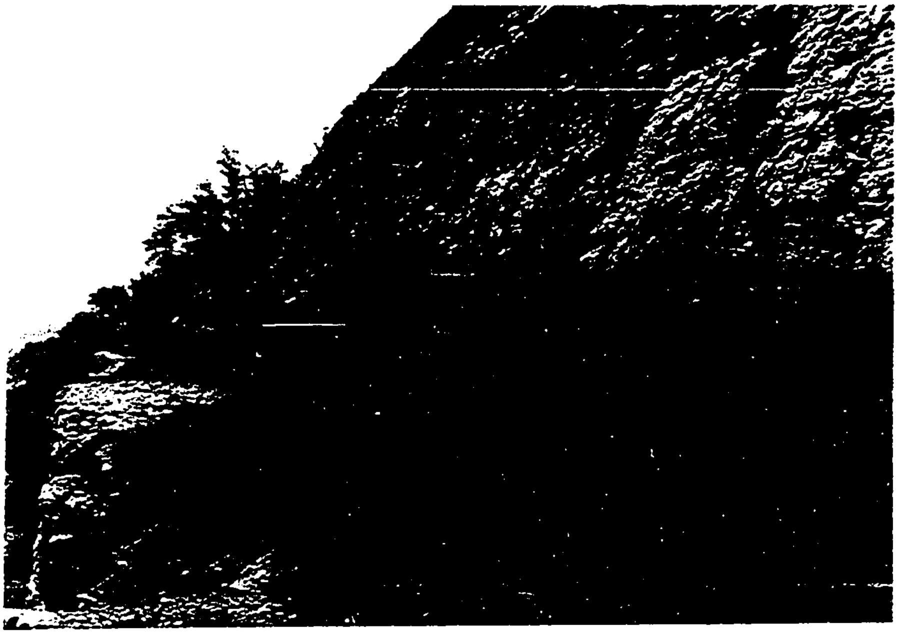


Plate 17. Asymmetrical straight crested to linquoid ripples on the upper surfaces of cross-stratification sets in facies D sandstones. Location is at Station 115, northern Greenup County, Kentucky, Carter Coordinates, 13-80-AA. The scale is one meter long.

Plate 18. Basal contact of facies D sandstones at Station 115. The chert conglomerate of Plate 15 is present where the scale is located. The unit rests on green shales which are filling solution cavities in the underlying Newman Limestone (lower left). Note the gradational upper contact of the facies D sandstone with black shales of facies E_1.



← up



Bioturbation is not a common feature within the sandstone body itself, and that which is observable is in the form of small, horizontal trails. These marks are usually on beds where ripples are present. Martin (1975, p. 45) reported the presence of the trace fossil Scalarituba on the undersides of some beds, but these were not observed in this unit during this study.

The basal contact of this facies is always found to be quite sharp, and wherever exposures are favorable, such as at Station 115, relief of up to 1-2 meters (3.3-6.5 feet) is observable (Plate 18). The underlying lithologies are variable. In southern exposures, such as Stations 88 and 96, the sandstone may lie on limestones or green shales assigned to the Newman Limestone (Sheppard, 1964; Englund, 1976); however, because of the patchy distribution of the Newman in the northern exposures of the study area, these sandstones most commonly lie on siltstones and shales of the Borden Formation or black, silty, carbonaceous shales of facies E. The upper surface of the Borden in these areas appears deeply weathered and in some instances, such as at Station 130, the formation is overlain by a rubble zone of angular chert and limestone pebbles containing abundant coaly stringers and cemented by iron oxide. At Station 115, the sandstone rests sharply on green, clayey shales which have filled solution cavities in the underlying Newman limestones. This locality is shown in Plate 18.

The upper contact of facies D is always found to be gradational into siltstones and shales (Plate 18); however, the characteristics and lithologies of these overlying sediments vary from north to south. In the northern extremities of the outcrop area, the overlying shales are dominantly gray to black, silty and contain abundant plant material and occasional thin coals. At Station 114, three thin coal beds are present in these overlying shales. In the southern exposures of facies D sandstones, particularly in central Carter County, the overlying sediments consist of green to gray, clayey to silty shales which contain numerous small, fossiliferous limestone and dolomite beds and nodules. These shale units will be discussed individually under subsequent headings of Facies E and F, respectively.

Facies D is present only in the northern part of the study area, north of the Kentucky River Fault System and east of the Waverly Arch. The areal distribution of this facies, which is reconstructed from field observations and U. S. Geological Survey geologic quadrangle maps, is as elongate, channel-shaped networks which are oriented north-south in the southern exposures and northeast-southwest in the northern exposures (Fig. 12). Laterally these channels grade into sandstones, siltstones, and shales while to the south they appear in facies relation with other units described in this study. To the north and northeast, the unit disappears under cover and into the subsurface.

Portions of this facies in central and northern Carter County have been previously referred to as the Carter Caves sandstone and have been mapped accordingly (Delaney and Englund, 1973; Englund and Windolph, 1975; Philley et al., 1975; Englund, 1976). This study, however, extends the previously defined limits of the body northward and recognizes several other similar bodies which are possible lateral equivalents but not part of the same channel.

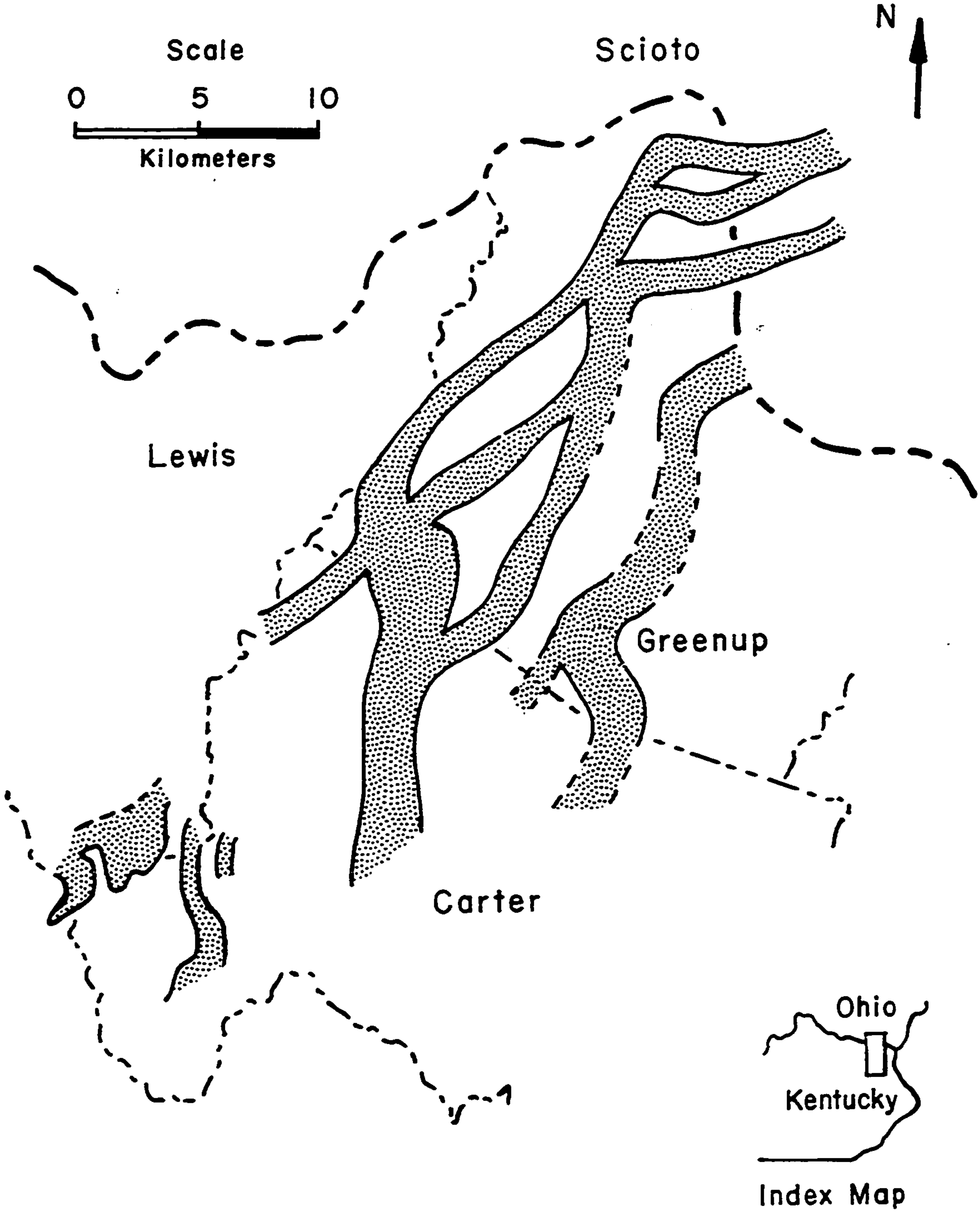


Fig. 12: Areal distribution of facies D sandstones. Note the channel-like geometry of the bodies.

Facies E

Facies E consists of gray to black, clayey to sandy shale occurring in laminae to thin beds. Lithologically this unit is quite variable, ranging from barren to coaly or cabonaceous to fossiliferous depending on the areal location and the stratigraphic position. On the basis of this variability, and to aid in later environmental interpretations, this facies will be subdivided into four units.

Subfacies E_1: Black to gray, clayey to silty shale containing abundant plant remains as carbonaceous impressions is present in many localities in the northern part of the study area and in isolated localities to the south. In many instances, these shales contain thin coals up to 20 centimeters (8 inches) thick. Siderite nodules or lenses are also common features. These shales commonly overlie or are laterally marginal to sandstones of facies D in that facies' northern exposures (Greenup County), and generally are gradational with that unit. At Station 27 in eastern Rowan County where the shale overlies facies C, and at Station 114 in northeastern Greenup County where the shale overlies facies D sandstones, this subfacies can be seen filling channel-shaped depressions. At each of these localities, a small coal lies at the base of the channel form. Shales of this subfacies are also present in limited exposures at Stations 65 and 82 in eastern Rowan County, there overlying sandstones of facies B and also containing thin coal beds (Plate 9).

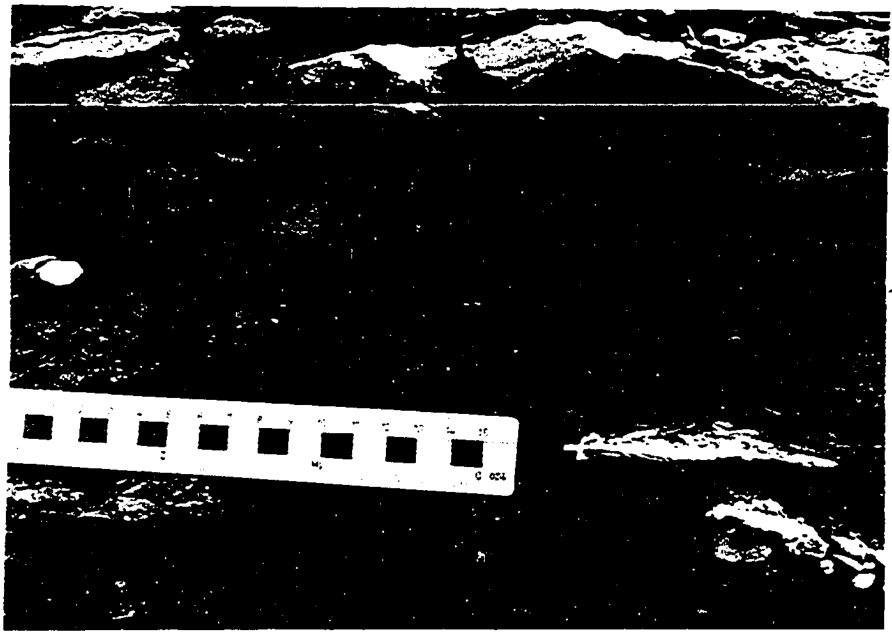
Subfacies E_2: Black to gray, slightly carbonaceous shales containing abundant trace fossils are present in several exposures in Carter and Greenup Counties, Kentucky. The trace fossils consist largely of horizontal and vertical "worm" tubes which are locally so abundant that all primary bedding is destroyed. These shales usually grade from a clayey texture in the basal exposures to a very silty or sandy variety in the upper portions, eventually grading to sandstone and siltstone above. The shales are often found as the lowermost exposures in many of the clay pits in the area; however, their relation to the underlying Olive Hill clay bed is always obscured. At Station 119 in northern Greenup County, these shales are gradational into overlying sandstones of facies B, and at Stations 3 and 57 in southern Greenup County shales suspected of belonging to this subfacies overlie facies D sandstones and are gradational into overlying sandstones of facies C.

At Station 28 along U. S. Highway 64 in western Carter County, shales of this variety can be seen interbedded with quartzose sandstones (Plates 19 and 20). Here the shales rest on the Olive Hill clay bed, interbed to the west with the quartzose sandstones, and are capped by thin sandstone, coals, seat rocks, and siderite beds (Ferm et al., 1971, p. 27). To the east, the sandstones are less abundant and the shales dominate the section. Ferm et al. (1971) have interpreted this exposure as a barrier overwash deposit which intertongues with bay silts and clays.

Subfacies E_3: Shales that are characterized by their barren and brittle nature are common near the southern limits of facies D sandstone distribution. These shales are thin bedded and often contain small, fine-grained sandstone pods or lenses. At Station 27, these shales can be seen in limited outcrop overlying the sandstones of facies D and underlying sandstones and siltstones of facies C. At no time during

Plate 19. Outcrop exposure of interbedded quartzose sandstones and subfacies E_2 shales at Station 28 in western Carter County. Notice how the sandstone dies out to the east (right) and is replaced by the shale. Ferm et al. (1971) have interpreted this as a barrier overwash deposit.

Plate 20. Closeup view of the bioturbated shales of subfacies E_2 at Station 28. Not the abundant horizontal worm tubes. Carter Coordinates, 8-V-75. The scale is in centimeters.



this investigation were the upper or lower contacts of this unit observed.

Subfacies E_4: Black and gray shales which contain body fossils of marine organisms are observable near the southern limit of the study area along State Highway 1274 in Menifee County, Kentucky. The shale is calcareous and may contain thin calcilutite lenses. Fenestrate bryozoa, crinoids, and brachiopods are especially abundant in these exposures. Ettensohn (1975) has reported an intertonguing relation between these shales and the underlying Glen Dean Member of the Newman Limestone and both disconformable and conformable relations with the overlying sandstones (facies G). This particular subfacies was not observed at any other location within the study area.

The shales of facies E are, volumetrically, the most abundant sediments within the study interval. North of the outcrop limit of the southern exposures of facies A these sediments generally encompass most other facies described in this study. The exact nature of the lateral and vertical relationships between the subfacies is not easily discernible; however, a general trend within the facies is apparent from north to south. Subfacies E_1 is most prevalent in northern exposures while E_2 is present only in northern and central exposures. Subfacies E_3 is present mainly in the central portion of the study area and E_4 is present only near the southern boundary. Disregarding the stratigraphic location of these units, this represents a gradation from seemingly nonmarine deposits in the north to more marine influenced deposition in the south.

The thickest observed accumulation of this facies is at Station 86 in western Rowan County. At this location, 25 meters (82 feet) of black shale containing several thin coals and a single thin limestone overlies the Olive Hill clay bed, which is 1.15 meters (3.7 feet) thick. The shale zone is capped by 3 meters (10 feet) of trough cross-bedded sandstone of facies D. No doubt, thicker accumulations of this facies exist in the study area; however, the nonresistant nature of the sediments make exposures difficult to find.

Facies F

Facies F consists of a sequence of gray, green, and red, clayey to silty shale, argillaceous limestone and dolomite. The shales are laminar to thin bedded and locally contain sparse accumulations of carbonaceous plant remains, although not nearly as abundant as that contained in facies E. Green and gray shales dominate the section and these are, for the most part, unfossiliferous except where they are adjacent to limestone or dolomite beds. In these areas, the shale may contain body fossils of marine organisms. Several samples of the shale were dissolved in Stoddard solvent and subsequently examined for microfossils; however, all samples were found to be barren. Exposures of red shale were seen at Stations 3 and 90. At these localities, the shale is clayey and contains sparse carbonaceous plant impressions and small nodules of limestone. In both of the exposures, the shale lies within 0.7 meters (2 feet) of the Newman Limestone.

Locally contained within the green shale sequence are beds and nodules of gray, argillaceous limestone and nodules or thin beds of dolomite. The thickness of these beds ranges from several centimeters to 70-80 centimeters (2.3-2.6 feet); however, most appear to be less than 0.5 meters (1.6 feet). The limestones are fossiliferous, containing well-preserved specimens of brachiopods, pelecypods, ectoprocts, and ostracods. These fossils have been previously reported by Sheppard and Dobrovalny (1963) and Englund and Windolph (1971), and a list of the positively identified species is given in Appendix A. The dolomites are fine crystalline, dense, and seemingly unfossiliferous in hand specimen.

This facies appears to rest everywhere conformably on underlying sandstones and shales. At Station 88, green shales overlie sandstones of facies D; however, the actual contact is obscured. At Stations 65 and 82 in eastern Rowan County, a thin, 30-40 centimeter (12-16 inch), dolomite bed which appears to be correlative to other exposures of this facies, overlies a 0.6-1.2 meter (1.9-3.0 feet) shale of facies E_1 which contains a 15-centimeter (6-inch) coal bed. At both localities, the shale overlies sandstones of facies B and the dolomite is overlain by silty, sideritic shales of facies E_1. At Station 88, the contact is very sharp between the overlying black and underlying green shales. At Station 86, the facies is represented by 0.8-meter (2.6 feet) limestone bed which contains abundant quartz grains. At this location, the facies is completely encompassed by shales of facies E_1.

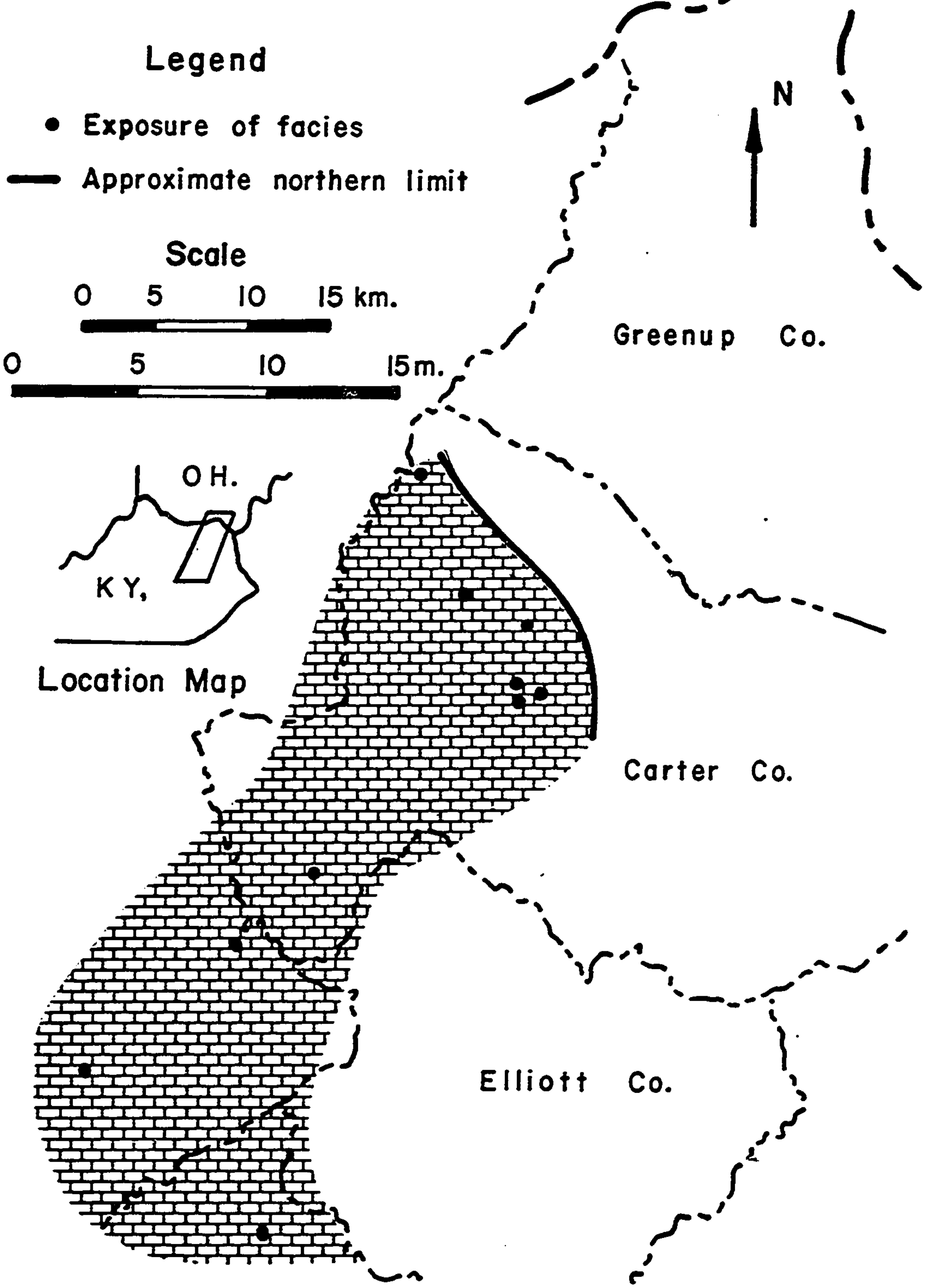
The thickest observed accumulation of this facies occurs at Station 88 where the unit is approximately 15.2 meters (50 feet) thick. To the west of this exposure at Stations 65, 82, and 86, the facies is represented by a single dolomite or limestone bed 30-80 centimeters (1.0-2.6 feet) thick. The associated green shale is absent at these localities; however, a complete section similar to that at Station 88 has been described by Patterson and Hosterman (1962, p. F25) near Liesure, Kentucky, in the Wrigley quadrangle. The thickness of the facies at this outcrop is reported to be 4.27 meters (14 feet). The thinning of the facies at Stations 65, 82, and 86 is coincident with the axis of the Waverly Arch and the distribution of facies B (see Figures 2 and 10).

Facies F is confined to the central and southern portions of the study area and has not been observed anywhere to the north in Greenup County (Fig. 13). The northernmost occurrence observed is at Station 32 near Echo Canyon in the northern Grahn quadrangle; however, an exposure has been reported near the junction of State Highways 180 and 2 in the southwest Wesleyville quadrangle (Englund and Delaney, 1971). The unit appears to thin to the north and west from its thickest occurrence at Station 88 and disappears into the subsurface to the east. Ettensohn (1975) reports well-developed exposures of this lithology south of the study area, and in Rockcastle County, Kentucky, he reports 3 meters (10 feet) of dark marine shale overlain by 26 meters (85 feet) of red and green shale with thin, dolomitic mudstone layers interbedded. If this outcrop is contiguous with the exposures in the study area, it would seem that the best development of the facies was to the south in central and southern Kentucky.

Facies G

Facies G consists of carbonate cemented, fine-grained sandstone and sandy carbonates. Locally, in the extreme southern exposures in the study area along State Highway 1274, the unit is fossiliferous containing abundant remains of echinoderms, ectoprocts, and brachiopods similar to the overlying carbonates of facies F. To the north at Station 67, the unit consists of carbonate cemented sandstone which has been extensively

Fig. 13: Distribution of facies F shales and carbonates.



bioturbated; however, no body fossils are preserved. Woody fragments are common in these sandstones and these are observable in outcrop at Station 67 but are visible only in thin-section in the southern, fossiliferous exposures. Shale clasts up to 3 centimeters (1.2 inches) in diameter are also locally present.

Bedding is generally thin to massive with tangential and cross-stratification, omikron and pi of Allen's classification, locally abundant in sets 40-50 centimeters (16-20 inches) thick. Trough cross-bedding is observable at Station 74 in relatively uncemented, unfossiliferous sandstone while the tangential cross-stratification is more common in the carbonate cemented, fossiliferous sandstone along State Highway 1274. Asymmetrical ripples are also common in the carbonate cemented units and are best developed in the thinner beds.

The areal distribution of facies G is not presently well established; however, the unit appears to be confined to areas south of the channel systems of facies D and east of the sandstones of facies B (Fig. 14). Laterally, the unit appears to be in facies relation with the previously described units, while to the east it disappears below drainage. To the south, the extent is unknown. The thickest accumulation observed in the study area is 3.6 meters (12 feet) at Station 22.

Facies H

Facies H is comprised of the Olive Hill Clay Bed of Crider (1913). The unit is only occasionally visible in the study area because of its discontinuous nature and relatively small thickness. There are numerous strip pits where the bed has been extracted; however, the faces of these

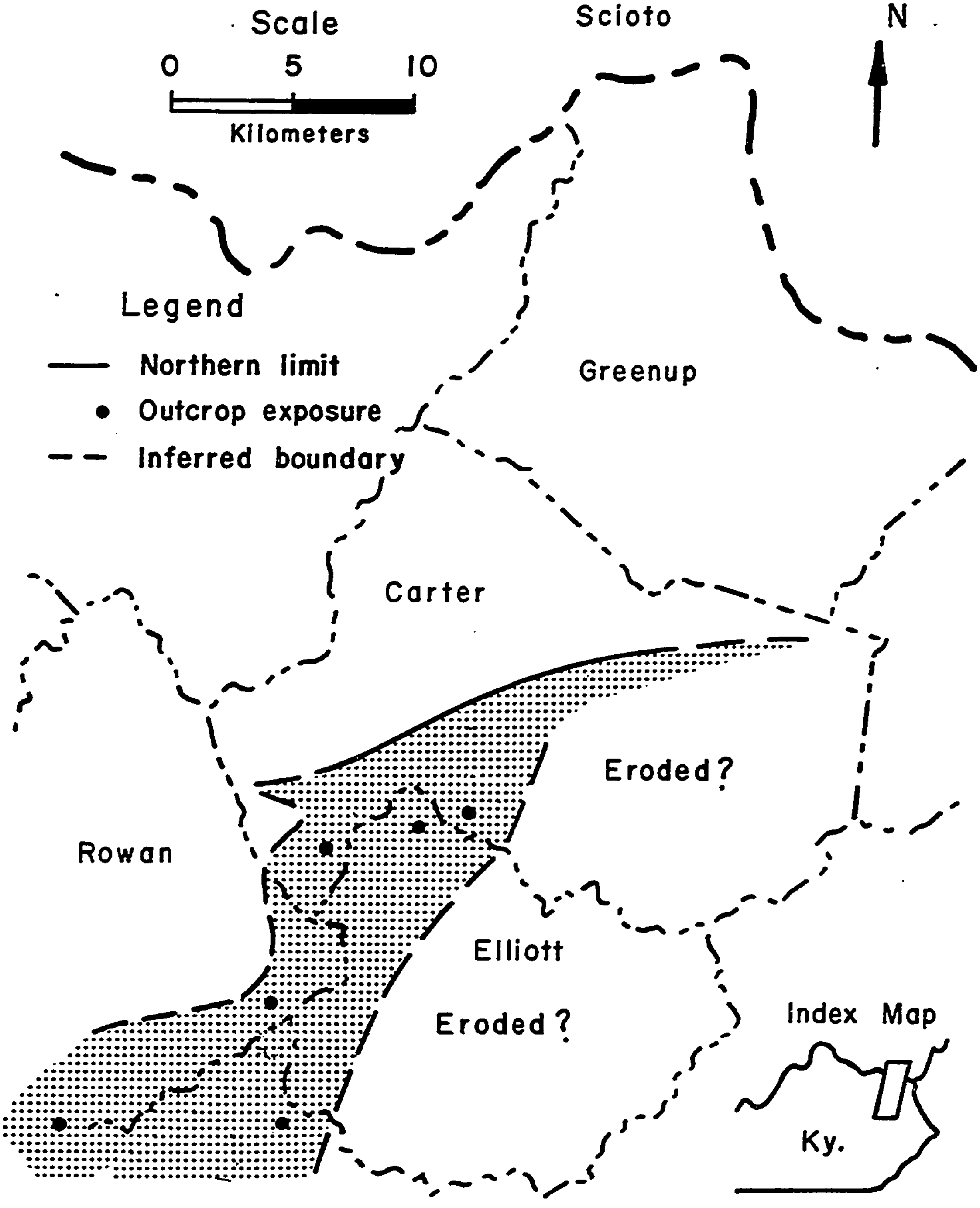


Fig. 14: Areal distribution of facies G sandstones. Unit appears to have been removed by erosion on eastern margin by facies A-south processes.

mines are covered after the clay is removed. Patterson and Hosterman (1960, 1962, 1963) have reported extensively on the clay bed and the following description is taken from their work:

> "The Olive Hill bed is an underclay that occurs near the base of the Lee Formation, enclosed by an exceedingly variable sequence of beds. The coal that overlies the clay ranges from 0 to about 10 inches in thickness, but in most outcrops is only 3-6 inches thick. The coal extends over more than three-quarters of the area of the clay, and in most places where it is absent, its stratigraphic position is marked by nearly black discoloration in the uppermost part of the clay or a thin zone of carbon-rich black shale above the clay....
>
> ...The Olive Hill clay consists of irregular lenses that rest on an undulatory surface. Neither the lenses nor the area in which the clay is missing show any regional alignment or preferred orientation. The maximum thickness of most lenses is 10 feet (3 meters), but in one old mine, now inaccessable, the bed is reported to be 25 feet (7.5 meters) thick...
>
> ...The Olive Hill clay bed is itself composed of three types of clay in irregular, nonbedded lenses of variable thickness and shapes. About one-third of the bed is flint clay and the other two-thirds is chiefly semiflint clay with subordinate amounts of plastic clay, but all variations in hardness from flint to semiflint and from semiflint to plasticclay are present in different parts of the bed...
>
> ...The plant-root fossil Stigmaria is commonly preserved in all three types of clay in the form of carbonaceous films..."

The clay appears to be present only on the northern, or uplifted side of the Kentucky River Fault System and has not been mined any further north than the extreme southern portion of Ohio along the Ohio River. Morningstar (1922, p. 10) describes the Sciotville clay (correlative to the Olive Hill clay of Kentucky) as "more extensively developed in southern Ohio but to the northward become(s) thin and finally disappear(s)". The best development of the clay is in eastern Rowan County and western Carter County, Kentucky, and is coincident with the distribution of facies B sandstones and the proposed position of the Waverly Arch.

Petrography

To facilitate the interpretation of the stratigraphy, environment of deposition, and ultimate source for the sediments under consideration, 125 samples were prepared for thin-section analyses of the composition and textural parameters. The samples were taken from measured sections, and efforts were made to insure that several specimens of each species, excluding the shales, were examined.

Fifty-two of the prepared thin sections were point counted for major constituents using 200 counts per slide and a spot interval method of counting. Prior to examination, each of the slides containing quartz and feldspar was stained using Bailey and Steven's method (Allman and Lawrence, 1972, p. 108). Thos thin sections containing carbonates were stained using Dickson's method (Allman and Lawrence, 1972).

Shale samples were analyzed using x-ray diffraction to determine the major minerals present. Initial attempts to use cation exchange analyses to help interpret marine from nonmarine environments of deposition (Spears, 1973) proved confusing and is not included here.

The results of the petrographic analyses are shown in Table I. Quartz is identified only as monocrystalline or polycrystalline varieties and feldspars as plagioclase or potash based on the stain applied and visible twinning. Some difficulty was encountered in determining clay matrix from weak shale and siltstone rock fragments which have been compacted and contorted to form a pseudomatrix material and this should be kept in mind when a rock name is applied to the samples.

Petrographically, the eight facies described in the previous section can be further subdivided into seven divisions based on the dominant minerals present, the monocrystalline-polycrystalline quartz ratios, the amount of rock fragments and feldspars present, the nature of the cement, the presence or absence of fossils, and the composition of the clay minerals. Notice that facies A is subdivided into facies A-north and facies A-south. This division of facies A has proven to be important in determining the petrology of these rocks and will be referred to later.

Facies A-South

Samples representative of facies A-south are from Station 16, Elliott County, Kentucky (Fig. 5). The sandstones and conglomerates from this facies, on the average, contain more matrix material, feldspar, and rock fragments than any samples from the other facies. Total quartz content ranges from 80.5 to 93.0 per cent of the total rock with moncrystalline-polycrystalline ratios ranging from 2.5 to 6.8. Most of the monocrystalline quartz exhibits straight to slightly undulose extinction, as does the polycrystalline variety. Abnormally high percentages of polycrystalline quartz are in samples taken from conglomerate zones because the majority of the quartz pebbles consist of these composite grains.

The feldspar and rock fragment content of these sandstones is generally low, the most abundant feldspar observed being only 3 per cent and the largest rock fragment concentration being only 10 per cent. The majority of the feldspar is potassium-rich and most of the rock fragments consist of shale particles, chert, and siltstone grains. Much of the shale and siltstone has been compressed and forms a pseudo-matrix similar to that described by Meckel (1967) in Pottsville sediments of Pennsylvania.

TABLE I
Petrographic Analyses of Thin Sections

Sample	Facies	Quartz		Feldspar		Matrix		Cement		Mica	Rock Frags.			Heavies
		Mono.	Poly.	Plag.	Pot.	Clay	Fe	Si	Fe		Chrt.	Slt.	Shl.	
16-1	X	71.5	10.5	0.5	---	2.5	7.5	1.5	---	1.5	---	0.5	---	---
16-2	X	77.5	11.0	---	0.5	3.0	3.0	1.5	---	Tr.	---	3.0	---	---
16-3	X	54.0	35.0	1.0	0.5	5.0	---	---	---	1.0	1.0	1.0	1.0	---
16-4	X	63.5	27.0	0.5	Tr.	4.5	0.5	---	---	1.0	2.0	Tr.	---	---
16-6	X	62.0	24.0	0.5	1.0	Tr.	0.5	---	---	1.5	2.5	1.0	6.5	---
16-7	A-S	71.0	16.0	Tr.	1.5	Tr.	4.0	---	---	1.0	0.5	Tr.	5.5	Tr.
16-8	A-S	67.5	23.0	0.5	Tr.	3.5	---	---	---	1.5	1.0	1.0	0.5	Tr.
16-9	A-S	74.5	17.0	0.5	0.5	3.5	1.5	---	---	0.5	1.0	0.5	Tr.	Tr.
16-10	A-S	65.0	26.0	Tr.	2.0	4.0	0.5	---	---	1.0	0.5	0.5	0.5	---
16-13	A-S	68.5	18.5	Tr.	3.0	4.5	---	1.5	---	Tr.	0.5	1.0	2.0	0.5
16-14	A-S	62.5	21.5	Tr.	1.0	6.5	Tr.	---	0.5	1.0	0.5	0.5	5.5	Tr.
16-15	A-S	57.5	23.0	Tr.	1.5	9.5	2.0	0.5	---	1.5	1.5	0.5	1.0	0.5
16-16	A-S	67.0	25.5	Tr.	2.0	3.0	Tr.	---	---	0.5	1.0	0.5	Tr.	0.5
16-17	A-S	76.0	17.0	Tr.	1.0	2.5	---	---	---	1.0	0.5	Tr.	1.5	Tr.
16-18	A-S	71.5	19.5	1.0	1.5	2.0	---	1.0	---	0.5	1.0	0.5	2.0	Tr.
16-19	A-S	68.5	22.5	Tr.	2.5	2.0	Tr.	---	---	0.5	0.5	0.5	3.0	---
16-20	A-S	62.5	23.0	0.5	2.5	5.0	---	2.5	0.5	1.5	0.5	Tr.	1.5	Tr.
16-21	A-S	65.6	20.0	1.0	1.5	4.0	3.0	---	---	Tr.	1.0	Tr.	3.0	0.5
16-22	A-S	78.5	11.5	0.5	0.5	1.0	2.0	---	---	1.0	1.0	1.0	3.0	---
65-1	B	80.5	10.5	0.5	0.5	5.0	---	---	---	1.0	1.0	0.5	1.0	---
65-2	B	94.0	4.5	Tr.	Tr.	---	Tr.	---	---	1.0	---	---	---	Tr.
65-3	B	46.5	----	---	---	---	---	---	53.5	---	---	---	---	---
65-4	X	77.0	6.5	Tr.	0.5	7.5	0.5	---	1.5	1.0	1.0	Tr.	4.5	0.5
65-5	X	76.5	9.5	Tr.	0.5	7.0	Tr.	---	---	0.5	0.5	---	3.5	---
82-1	B	74.0	15.5	---	0.5	8.5	---	0.5	---	0.5	Tr.	Tr.	1.0	---
82-2	B	88.0	11.5	---	0.5	Tr.	Tr.	---	Tr.	---	---	---	Tr.	Tr.
82-3	B	74.5	16.0	Tr.	0.5	3.0	Tr.	---	---	2.0	0.5	---	1.0	1.0
82-4	B	74.5	17.0	Tr.	0.5	5.5	---	---	Tr.	1.0	0.5	Tr.	0.5	Tr.
82-5*	B	55.5	6.5	Tr.	0.5	30.0	---	---	1.0	1.0	0.5	Tr.	---	---

TABLE I (cont.)

Sample	Facies	Quartz Mono.	Quartz Poly.	Feldspar Plag.	Feldspar Pot.	Matrix Clay	Matrix Fe	Cement Si	Cement Fe	Mica	Rock Frags. Chrt.	Rock Frags. Slt.	Rock Frags. Shl.	Heavies
82-7	B	80.5	12.5	Tr.	Tr.	3.5	---	1.0	0.5	0.5	1.0	0.5	0.5	Tr.
88-9	B	69.0	10.5	0.5	1.5	8.5	---	---	1.0	1.5	2.0	0.5	3.5	0.5
107-1	D	87.5	6.0	---	---	2.0	1.5	1.5	---	Tr.	Tr.	0.5	---	Tr.
107-2	D	95.0	3.0	0.5	---	1.0	Tr.	---	---	Tr.	---	Tr.	---	0.5
107-3	D	83.0	15.0	---	---	0.5	0.5	0.5	---	Tr.	Tr.	0.5	---	Tr.
107-4	C	81.5	13.5	Tr.	---	1.0	2.0	1.0	---	0.5	Tr.	---	---	---
107-5	C	75.5	17.5	Tr.	---	3.0	1.0	0.5	---	Tr.	Tr.	Tr.	---	Tr.
107-6	C	77.0	14.0	---	---	---	7.5	---	---	Tr.	Tr.	Tr.	---	Tr.
124-1	A-N	44.0	43.5	---	---	2.0	8.5	---	---	---	---	0.5	---	---
124-2	A-N	88.0	7.5	---	---	---	3.0	0.5	---	0.5	---	0.5	---	---
124-3	A-N	94.0	3.5	---	---	---	1.0	0.5	---	---	---	---	---	0.5
124-4	A-N	86.5	10.0	---	---	1.5	---	0.5	---	---	1.5	---	---	---
124-5	A-N	84.5	10.0	---	---	1.0	1.5	2.0	---	Tr.	0.5	0.5	---	Tr.
133-1	D	74.5	5.0	---	---	2.0	2.5	---	---	Tr.	---	---	15.5	Tr.
133-2	D	91.0	7.5	---	Tr.	0.5	Tr.	0.5	---	---	---	---	---	Tr.
133-3	D	82.0	13.5	---	Tr.	1.5	3.0	---	---	Tr.	Tr.	Tr.	Tr.	Tr.
133-4	D	86.0	12.0	---	---	---	1.0	0.5	---	---	---	Tr.	---	Tr.
133-5	D	87.0	9.0	Tr.	---	Tr.	1.5	1.0	---	Tr.	---	0.5	Tr.	1.0
133-6	D	88.0	10.0	---	---	Tr.	Tr.	1.5	---	Tr.	Tr.	Tr.	---	0.5

Sample	Facies	Quartz Mono.	Quartz Poly.	Matrix Dolo.	Matrix Clay	Matrix Fe	Cement Si	Cement $CaCO_3$	Cement Fe	Mica	Rock Frags. Chrt.	Rock Frags. Carb.	Rock Frags. Slt.	Heavies
22-	G													
65-3A	F	19.0	Tr.	71.5	---	---	6.5	---	---	---	2.5	---	---	---
67-1	G	65.5	3.5	---	Tr.	5.5	---	24.5	---	---	0.5	---	0.5	Tr.
82-6	F	21.0	1.5	74.5	---	---	---	---	0.5	0.5	0.5	---	---	---
88-4	F	2.0	---	70.5	---	---	---	1.5	---	---	---	25.0	---	---

The clays are dominantly kaolinite with lesser amounts of illite and traces of chlorite. It was not determined how much of this material is authigenic; however, only very little definite authigenic clay minerals were observed.

Mica is a minor constituent, ranging from trace amounts to 1.5 per cent. Muscovite is the dominant mica present. Heavy minerals are present in trace amounts, the most abundant being zircon and tourmaline with traces of rutile. Iron oxides are also fairly abundant as rims on quartz grains or as discrete particles. Where samples were collected from a weathered zone, iron oxide may form 100 per cent of the cement.

The sandstones of this facies are termed sublitharenites according to the classifications of Pettijohn et al. (1973, p. 158) and McBride (1963).

Facies A-North, B, and D

Rocks of these facies are very similar petrographically and therefore will be treated as a unit in this discussion. Compositionally, these rocks are nearly identical to those just described under facies A-south, the principal difference being the relative abundance of the components present.

Table II outlines the average composition of these facies and that of facies A-south and facies C. As is shown, the total quartz content of facies A-north, B and D is relatively high compared to facies A-south. Likewise, the monocrystalline-polycrystalline quartz ratios are much higher, reflecting the predominance of monocrystalline quartz in these rocks. Exceptions to this trend are present in samples 124-1 and 133-1;

TABLE II
Average Composition of Facies
A, B, C, & D

Facies	Mono. Qtz.	Poly. Qtz.	M/P Ratio	Feldspar	Rock Fragments	Mica
A South	68.2	20.2	2.5-6.8	1.6	3.4	0.9
A North	88.2	7.7	8.4-26.8	Tr.	1.0	0.1
B	80.8	12.3	4.4-20.9	0.4	1.0-1.5	0.8
C	75.7	13.9	4.3-6.6	0.5	1.5	0.5
D	87.4	9.5	6.1-31.7	Tr.	0.2-1.9	Tr.

[1]Values are in per cent and represent averages.

however, these anomalies are because of the presence of quartz pebbles composed of composite grains. Concurrent with higher quartz values in these facies is a reduction in the amount of feldspar, rock fragments and mica. Again, as in facies A-south, the rock fragments are chert, siltstone and shale. The mica is dominantly muscovite.

Cementation is generally lacking, as reflected in the silica cement content which ranges from 0 to 1.5 per cent. Sample 65.3, from facies B, contains 53.5 per cent iron oxide as cement; however, this sample was taken from a weathered zone and iron oxides are seldom present otherwise.

The sandstones of these facies range from sublitharenites to quartzarenites in the classification of Pettijohn et al. (1973, p. 158) and McBride (1963).

Facies C

Facies C rocks are petrographically similar to other facies discussed, again the principal difference being the relative amounts of components present. Table II outlines the average composition of this unit.

The average quartz values and the monocrystalline-polycrystalline ratios are similar to those of facies A-south, but less than those of the other facies. Polycrystalline quartz values are slightly higher while feldspar, rock fragment and mica values are similar to those of facies A-north, B and D.

Clay minerals form the matrix material with kaolinite and illite again predominant. Iron oxides form 7.5 per cent of sample 107-6 as cement and rims on quartz grains; however, silica is the principal cementing agent.

Rocks of this facies are termed sublitharenites in the classifications of Pettijohn et al. (1973, p. 158) and McBride (1963).

Facies E

Facies E consists of shales with similar amounts of sandstone and siltstone. Patterson and Hosterman (1962, p. F28) have estimated the bulk composition of the shale facies of the Lee Formation as 70 per cent shale, 20 per cent sandstone, 5 per cent siltstone and 5 per cent underclay. The shale facies has been subdivided in this report on the basis of lithologic and biogenic characteristics, but because of similar mineralogic properties will be considered as a unit here.

X-ray diffraction analyses were performed on 14 samples from this facies and 5 samples from Stations 65 and 73 were dissolved in Stoddard solvent and examined for microfossil content. Kaolinite, illite, mixed-layer clays and quartz are the dominant minerals present with chlorite shown in trace amounts. Based on relative peak heights, the minerals appear to vary in abundance from sample to sample; however, kaolinite seems to be, overall, the most prevalent clay mineral with illite nearly as abundant. Most of the mixed-layer clays appear to be illite-montmorillonite (Patterson and Hosterman, 1962, p. F29). A typical x-ray diffractogram is shown in Figure 15.

Quartz peaks are especially well-developed in silty or sandy shales and quartz grains are abundant and easily observable upon disaggregation.

Small mica flakes are sometimes observable along bedding planes of hand specimens; however, this mineral is only a minor part of the bulk composition. Coaly and carbonaceous material is locally abundant.

No body fossils other than plant material were observable in any subfacies except E_4; however, a single occurrence of the genus Lingula has been reported from Open Fork Valley in the northern Haldeman quadrangle (Patterson and Hosterman, 1962, p. F30, F32).

Facies F

This facies consists of both detrital and chemically deposited sediments and therefore will be discussed under two subheadings, the first dealing with the clastic phase.

Clastic phase: The clastic phase of this facies is composed of gray and green shale with lesser amounts of red shale. As in facies E,

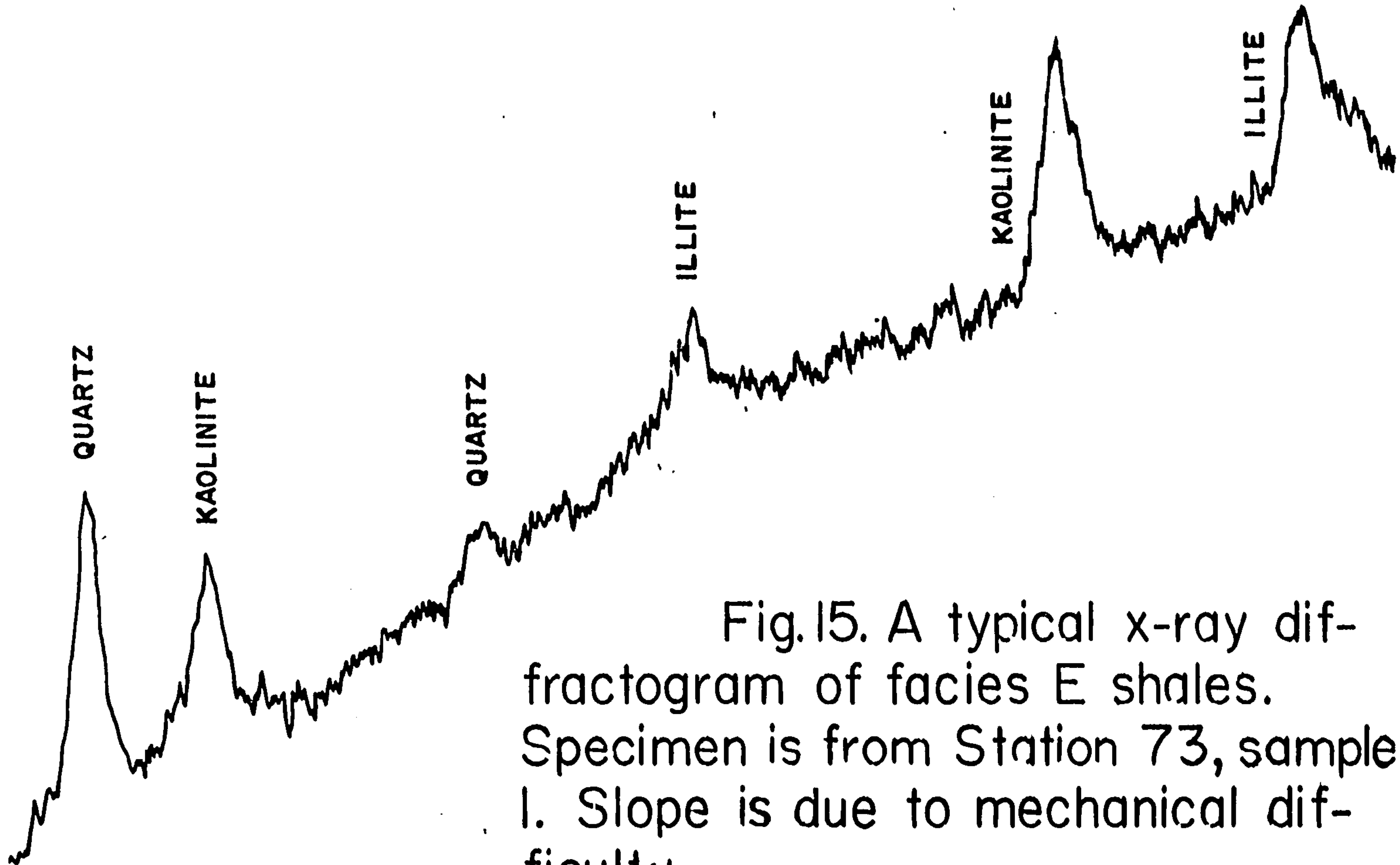


Fig. 15. A typical x-ray diffractogram of facies E shales. Specimen is from Station 73, sample 1. Slope is due to mechanical difficulty.

these shales consist of kaolinite and illite with lesser amounts of mixed-layer clays. Quartz is locally abundant. Patterson and Hosterman (1962, p. F30) have examined samples of the green and red shale from the Haldeman and Wrigley quadrangles and report mineralogies similar to that given above.

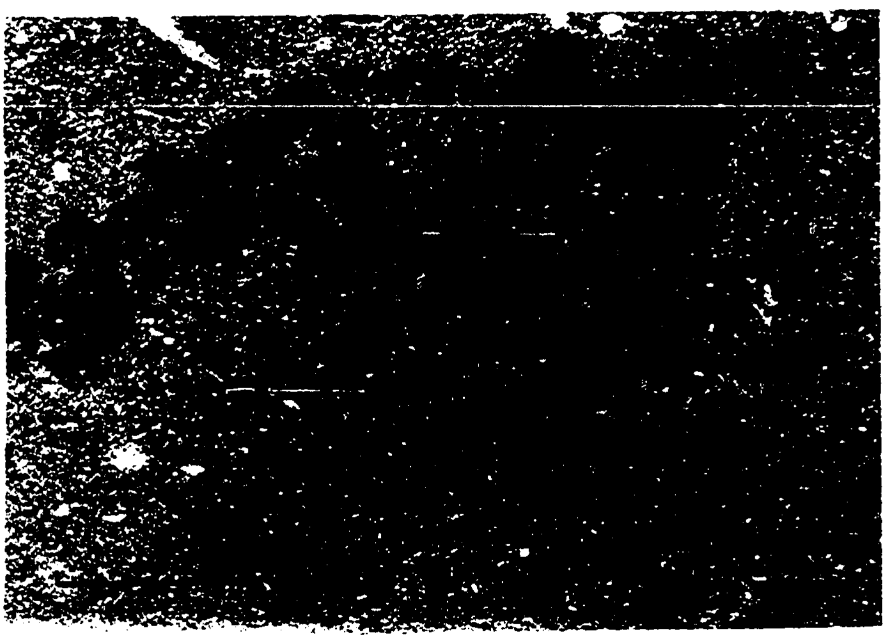
Carbonate phase: The carbonate phase of facies F consists of argillaceous limestones, sandy and cherty dolomite and limy dolomite. This phase, based on limited observations, appears to exhibit slightly different mineralogical properties in the two separate areas sampled. At Station 88, the carbonates are comprised of argillaceous, fossiliferous limestones and fossiliferous dolomites with little or trace amounts of quartz (Table I). Sample 88-4 contains 25 per cent fossil fragments consisting of gastropods, ostracods, pelecypods and bryozoa (Plate 21). Many of the fossil fragments have been replaced by dolomite. At Stations 65 and 82 where the facies is represented by only a single dolomite bed, the strata consists of dolomite and chert matrix encompassing local accumulations of quartz grains. No fossil fragments are present in these sediments; however, dense, spherical particles resembling pelletal remnants are locally abundat in the dolomite (Plate 22). The quartz content in these two samples ranges from 19 to 22.5 per cent and is almost entirely monocrystalline. At Station 82, the facies is represented by a single bed consisting of quartz grains and rounded fragments of carbonate and fossil fragments.

Samples 65-3A and 82-6 are from the area coincident with the axis of the Waverly Arch and sample 88-4 is from approximately 24 kilometers (15 miles) to the northeast in central Carter County. Sample 88-4 is best termed a dolomitized biomicrite to biomicrudite in Folk's (1968)

Plate 21. General view of fossiliferous, limy dolomite from the carbonate phase of facies F. Matrix material is finely crystalline dolomite. Many of the fossil fragments have been replaced by the dolomite material. Scale is in millimeters. Picture is of sample 88-4.

Plate 22. Pelletal remnants in recrystallized dolomites of sample 82-6. Scale is in millimeters.

ordinary light



ordinary light

classification and dolomitic wackestone or packstone in Dunham's (1962) classification. Samples 65-3A and 82-6 are best termed silty to sandy, finely crystalline dolomites in Folk's classification and dolomitic mudstones to quartzose dolomitic mudstones or wackestones in Dunham's classificaton.

Facies G

Facies G consists of carbonate cemented sandstone which contains varying amounts of fossil fragments and plant material depending on geographic and stratigraphic location. Sample 67-1, from southeast Carter County, is composed almost entirely of monocrystalline quartz which has been cemented by iron-poor sparry calcite (Table I). Minor amounts of polycrystalline quartz and traces of siltstone and chert rock fragments are present; however, no fossil fragments other than plant material are observable. Microscopic structures resembling burrows are present. The sample is best termed a carbonate cemented orthoquartzite according to the classifications of Pettijohn et al. (1973, p. 158) and McBride (1963).

At Station 22, this facies is again composed of carbonate cemented monocrystalline quartz; however, at this location the facies is characterized by sparse occurrences of echinoderm and ostracod shells (Table I). As previously discussed, the lower contact of this facies at this location is gradational into the Newman Limestone and the exact contact is difficult to pinpoint. Four samples, including 22-1, representing a vertical sequence across this contact were examined and described but not counted, to check for any gross vertical changes in composition. The most apparent trend is the increase in plant material and iron coatings from bottom to top, accompanied by a decrease in the amount of fossil shell material. Near the very top of the facies, dolomite in the form of finely crystalline rhombs is present in minor amounts. Quartz content appears constant throughout.

Facies H

As stated previously, no analytical operations were performed on the Olive Hill Clay Bed of Crider (1913) during this study, and the following minerological analyses are taken largely from Patterson and Hosterman's work with that unit.

Kaolonite is by far the dominant clay mineral present in the clay bed, in places forming 90 to 95 per cent of the clay minerals. Crystallinity ranges from poor to well depending on the type of clay examined (flint, semi-flint or plastic). The crystallinity of the kaolinite seems to be independent of the proportion of nonclay minerals present. Illite is reported as the second most abundant mineral in the bed, ranging from trace amounts to about 40 per cent in plastic and semi-flint clays. Complex mixed-layer minerals are closely associated with the illite and resemble montmorillonite structures. Chlorite is present in trace amounts.

Nonclay minerals present in the clay beds are reported to be quartz, zircon, tourmaline, ilmenite, and magnetite (Patterson and Hosterman, 1962, p. 65). Quartz can range from trace amounts to 50 per cent while the other minerals are present only in trace amounts. Siderite may be present as an authigenic mineral in amounts as great as 10 per cent and pyrite and iron oxide minerals are present in minor amounts. Siderite commonly occurs in oolites, spherulites, euhedral crystals, or nodular concretions which may contain irregular inclusions of kaolinite. The pyrite may assume a disseminated form or small concretions which are usually associated with carbonaceous films of Stigmaria. Anastase is present in very fine particles throughout large bodies of the clay.

Coaly organic matter appears abundant because of conspicuous carbonaceous films; however, the total organic matter content is low. Most of the organics appear to be Stigmaria rootlets and in some areas complete root systems are preserved (Patterson and Hosterman, 1962, p. 67).

Cluster Analysis of Mineralogical Properties

A cluster anlysis of cases program was performed on selected samples from this study to help ascertain which facies have mineralogical characteristics which are similar, and conversely which are dissimilar. If differences are found, the information is valuable for correlation purposes and resulting depositional environment interpretations.

The cluster program was performed on an IBM 360 computer at the University of Cincinnati using the Biomed program developed at the University of California, Los Angeles (Biomed, 1975). The program utilizes 37 cases, or thin-section analyses, with variables consisting of percentage amounts of monocrystalline quartz, polycrastalline quartz, rock fragments, feldspar, and matrix material. The samples used and their corresponding facies assignment are shown in Table III. Values for the variables are in Table I.

The results of the cluster analysis is shown as a vertical tree printout in Figure 16. The principal division indicated is that between facies A-south and facies A-north, B, C, and D. The samples which are shown to be most similar mineralogically are those from facies A-north and facies D, while those samples from facies B and C are grouped more or less together, although several samples from facies B are similar to those of facies A-north and facies D.

Textural Data

Textural analyses were performed on 50 samples using a Leitz photomicroscope and thin-sections. Grain size analyses were conducted on the thin-sections using an occular micrometer and an interval method of point counting utilizing 100 grains per thin-section. The longest apparent axis of each grain was measured because this method has been shown to be in best agreement with seive analyses (Krumbein, 1935; Rosenfeld et al., 1953; Friedman, 1958; Textoris, 1971). Data was recorded in 0.25 phi intervals. The shape of the grains was visually estimated by comparing them to images of known roundness (Powers, 1953, fig. 1), while the arrangement was merely described from the overall view of the thin-section.

Data presented in the charts and diagrams and references to grain size have been converted from thin section values to seive values utilizing a computer program developed by J. Harrel, University of Cincinnati geology department.

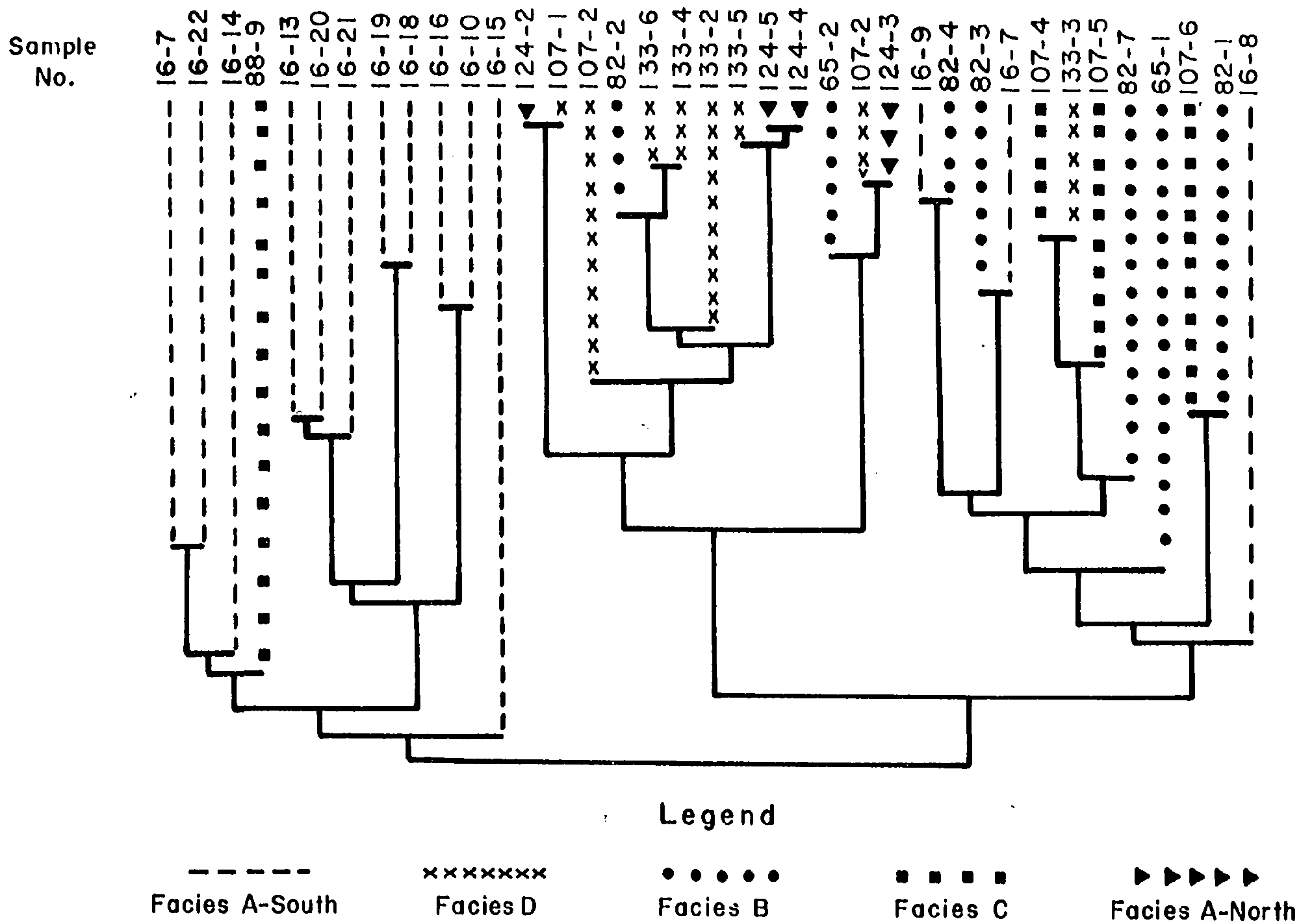


Fig. 16: Cluster analysis of cases showing mineralogical similarity of particular facies defined within the study area.

TABLE III
Samples Used in Cluster Program and
Corresponding Facies

Facies	Samples
A-South	16-7, 16-8, 16-9, 16-10, 16-13, 16-14, 16-15, 16-16, 16-17, 16-18, 16-19, 16-20, 16-21, 16-22
A-North	124-2, 124-3, 124-4, 124-5
B	65-1, 65-2, 82-1, 82-2, 82-3, 82-4, 82-7
C	88-9, 107-4, 107-5, 107-6
D	107-1, 107-2, 107-3, 133-2, 133-3, 133-4, 133-5, 133-6

Facies A

Facies A, as has been shown, consists of two separate lithologically similar units which are not identical mineralogically. Therefore, these two units will be discussed separately.

Facies A-south: These rocks consist of a grain supported framework with fine to coarse grains and abundant quartz pebbles ranging from several centimeters to fractions of a centimeter in diameter. Figure 17 shows the average grain size plotted against the distance from the base of the unit at Station 16. As can be seen, grain size decreases upward with three fining upward cycles dipicted. Samples 1 through 4 represent a lower facies (see Plate 45) and are not included in facies A-south. Quartz grains from this unit are generally angular to subround while sorting ranges from very poor to moderate, becoming better sorted near the top with concurrent decrease in grain size. Several grains show

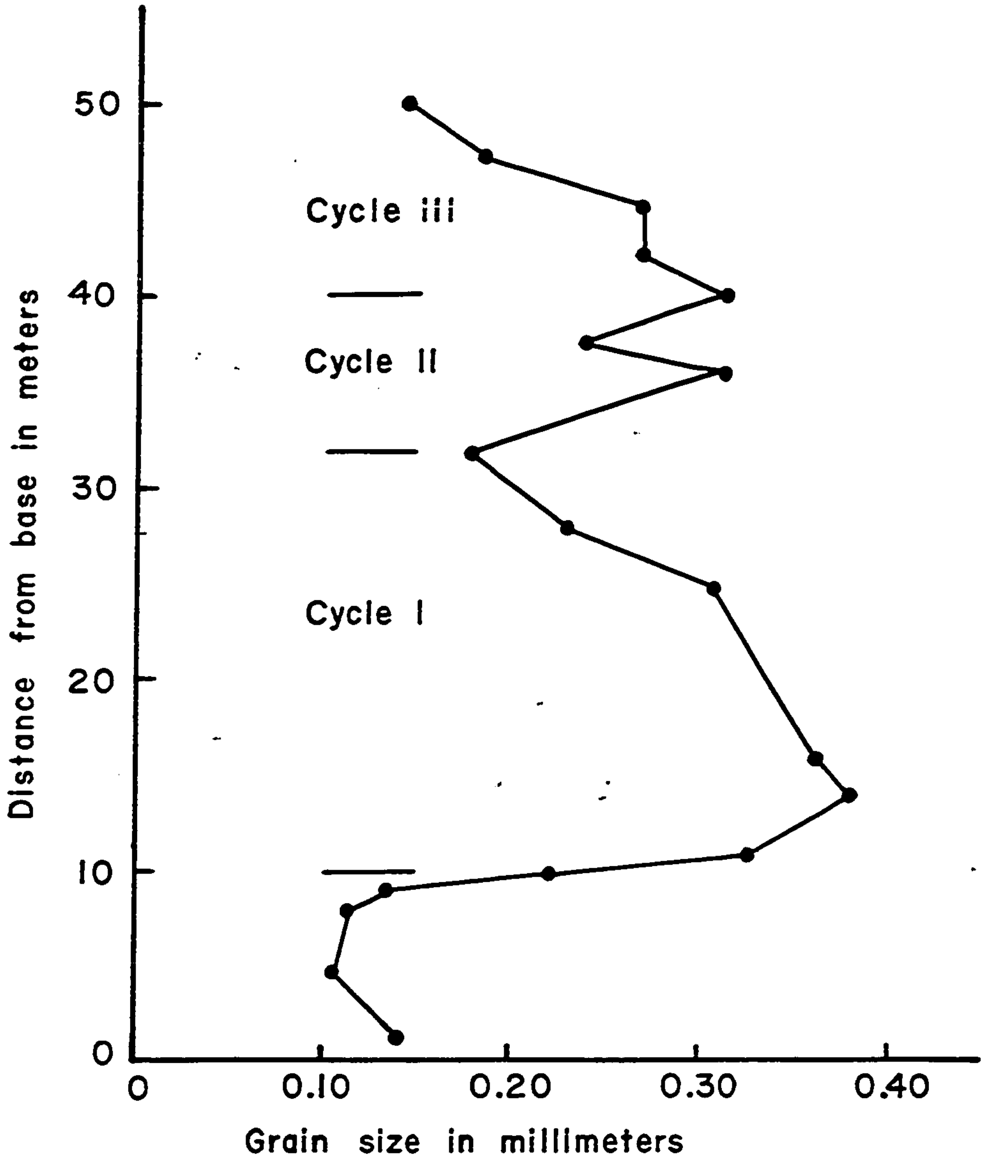


Fig. 17: Vertical variation in mean grain size within facies A-south at Station 16, Elliott County, Kentucky. The lower four samples are not from facies A. See plate 44 for an outcrop illustration.

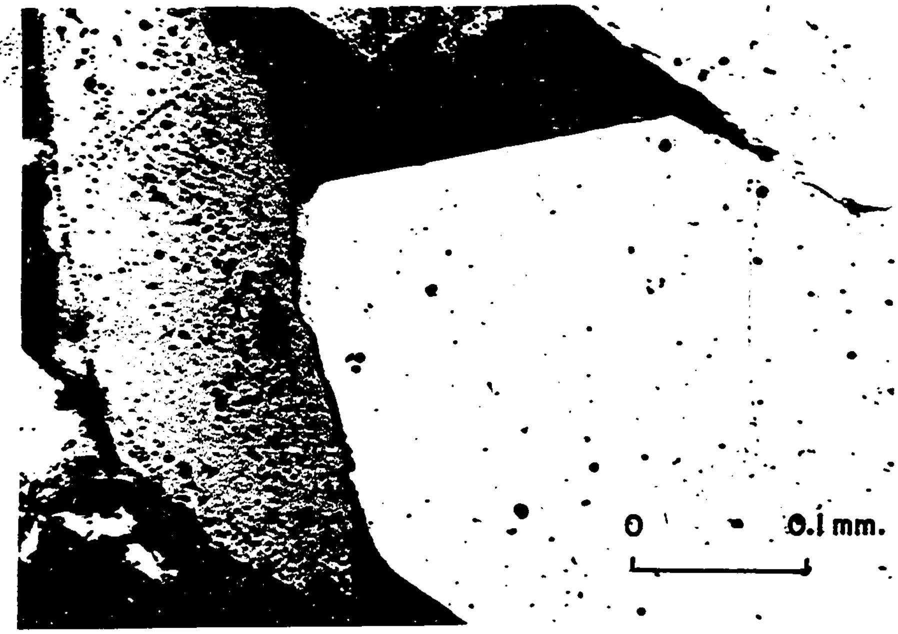
very good development of euhedral crystal faces (Plate 23); however, these are exceptional and are not characteristic of the facies as a whole. Feldspars, when present, may exhibit rounded edges and show good cleavage (Plate 24) or may be in a stage of sericitization and partly altered, displaying ragged edges. Chert grains and lithic clasts are normally subrounded to rounded, while zircons and tourmalines are well-rounded.

The matrix material is composed largely of shale fragments which have been squashed between major grains (Plate 25). There is some evidence of authigenic clays in the form of clay booklets in interstitial pores. Cementation is largely in the form of quartz overgrowths and interpenetration of grains, while iron oxides are of secondary importance. Cement rarely averages more than 5 per cent of the total rock. Texturally, the rocks are submature.

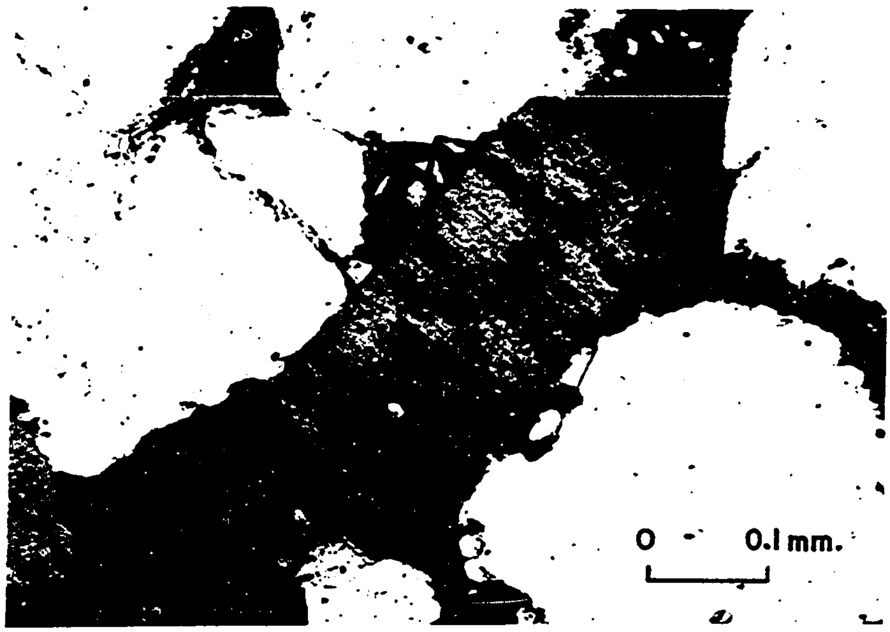
Facies A-north: Facies A-north is also a grain supported framework consisting of fine to coarse grains and pebbles. Figure 18 shows the upward decrease in grain size at Station 124 in eastern Scioto County, Ohio. The initial, large average diameter is the result of quartz pebbles which are present as a basal deposit in the area. Some of the polycrystalline pebbles appear to be breaking into much smaller silt- and fine sand-size particles (Plate 26), which may partially explain the extremely bimodal size distribution in the lower part of the outcrop. The rocks here are predominantly angular to round quartz particles with the roundest grains occurring in the largest size fractions. Small amounts of chert and mica are also present; the chert, as in facies A-south, is subround to round (Plate 27), while the mica is generally

Plate 23. Euhedral quartz grain from facies A-south. Grains such as this are not common in this facies but are sparsely present. Scale is in millimeters. Picture from sample 16-15.

Plate 24. Well preserved feldspar grain from sample 16-7. Most of the feldspar grains show some degree of alteration. Scale is in millimeters.



x-nicols



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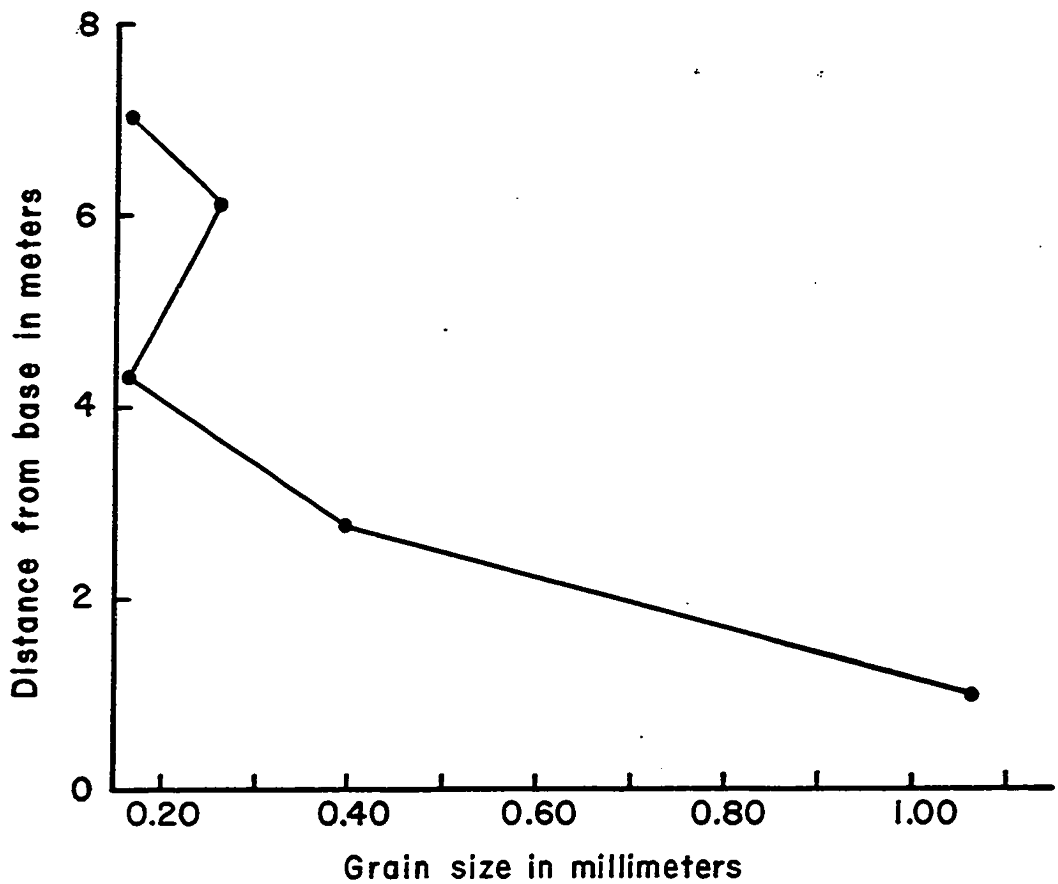
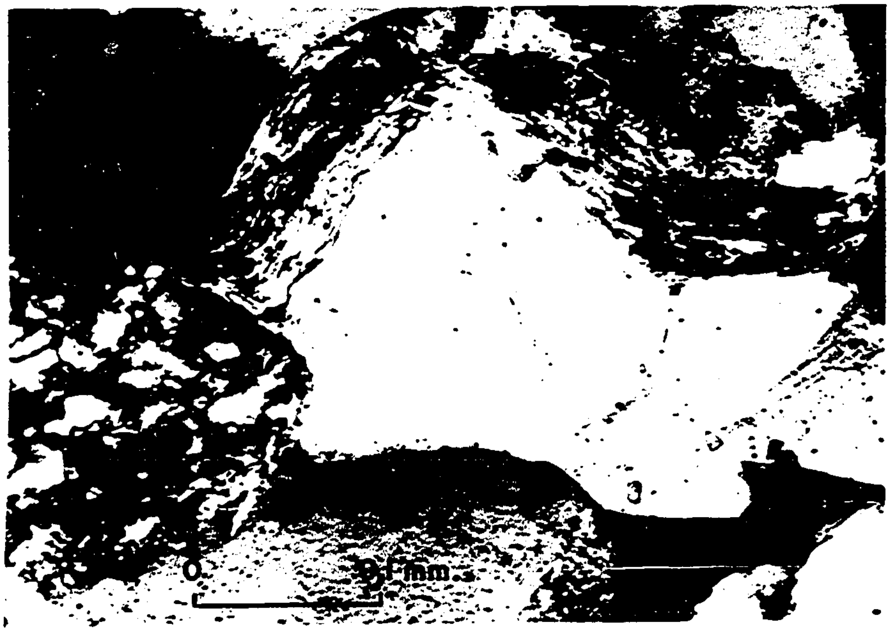


Fig. 18 : Vertical variation in the mean grain size within facies A-north at Station 124 in Scioto County, Ohio. Note the strong upward decrease in mean size.

Plate 25. Shale fragment which has been squashed around adjacent quartz grain. This type of "squashing" forms a pseudomatrix where many shale particles occur together. Picture from sample 16-10. Scale is in millimeters.

Plate 26. Breakup of composite quartz pebble into much smaller silt and fine-size grains. Picture from sample 124-1. Magnification X 30. Scale is in millimeters.



x-nicols

x-nicols

oriented along bedding planes. Tourmaline and zircon grains, although rare, are well rounded (Plate 28) when observed. The samples exhibit poor to moderate sorting.

Clay minerals form the matrix material, and in the basal part of the outcrop these minerals may completely support the pebbles (Plate 29). Iron oxide cement ranges from 0 to 8.5 per cent, being most abundant in the basal portion. Silica cement in the form of overgrowths and pore fillings can only be estimated as forming 0 to 2.0 per cent of the rock. Cement never formed more than 10.5 per cent. Texturally, the rocks are mature to supermature.

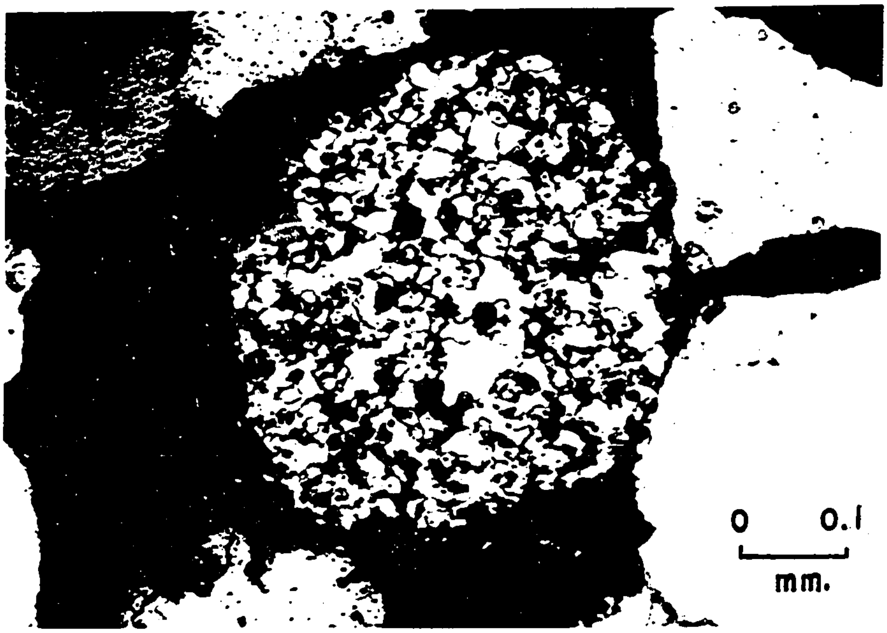
Facies B

Facies B ranges from a grain supported framework in basal portions of the unit to a matrix supported framework in the upper portions. This upward increase in matrix material is coincidental with an upward decrease in grain size (Fig. 19), and an increase of coaly and carbonaceous material. Clay matrix increases from 8.5 per cent in sample 82.1 to 30 percent in sample 82-5. Likewise, coaly particles increase from trace amounts to 4.0 per cent. Iron oxides form, at most, 0.5 per cent of the total cement, which is dominantly silica in the form of overgrowths and pore fillings. Total cement does not exceed 2.0 per cent.

Quartz grains are angular to subrounded and occasionally are arranged in circular networks resulting from reworking of the sedment by burrowing organisms (Plate 30). Micas are oriented along bedding planes. Sorting ranges from poor to moderate, generally being best in the lower parts of the unit. Texturally, these rocks are mature to supermature in the

Plate 27 A well-rounded chert grain from facies A-north, sample 124-2. Scale is in millimeters.

Plate 28. A well-rounded tourmaline grain from facies A-north, sample 124-3. Grains similar to this were also observed in facies D. Scale is in millimeters.



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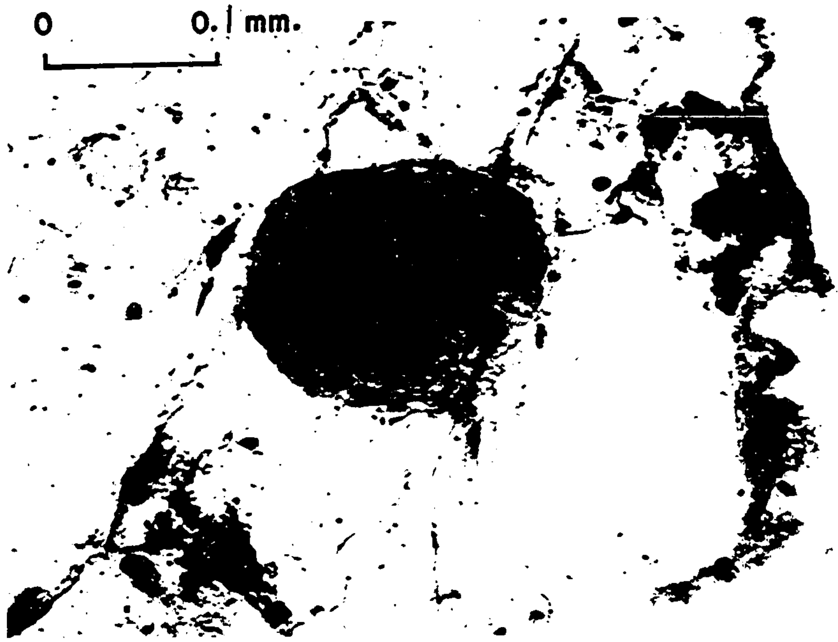

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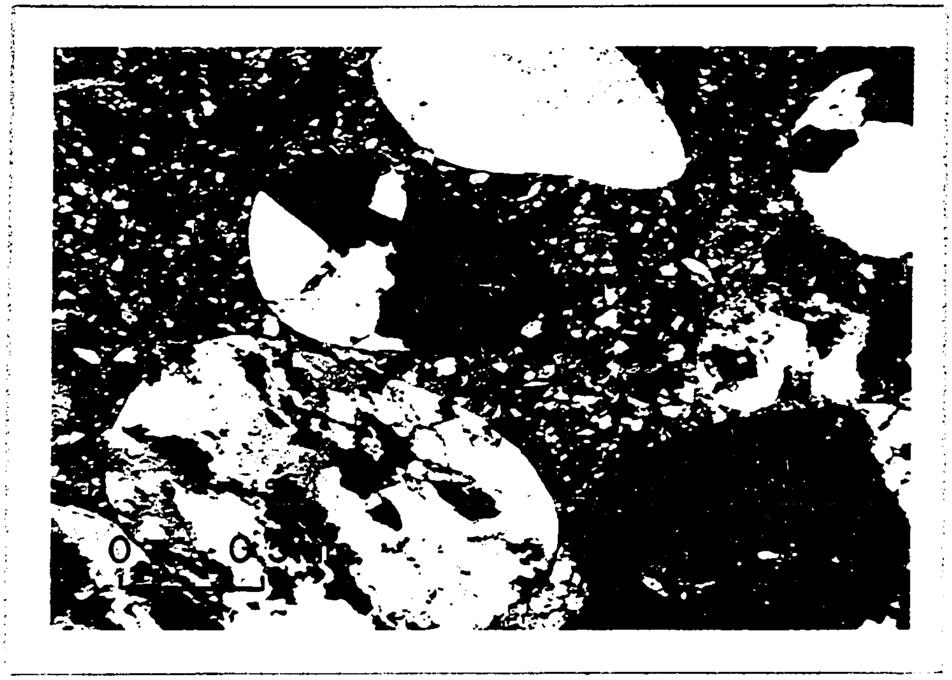
Plate 29. Matrix supported framework in the basal portion of facies A-north. Matrix is dominantly clay minerals and some silt-size quartz. Picture of sample 124-1. Scale is in millimeters.

Plate 30. Circular arrangement of quartz grains in facies B. It is believed that this arrangement is characteristic of reworking of the sediment by burrowing organisms, probably worms. Picture is of sample 82-3. Scale is in millimeters.



x-nichols

x-nichols

lower portions of the facies and submature to mature in the upper portions.

Facies C

Facies C is represented by only three samples from Station 107, and therefore the data should be considered only as an approximation of the true nature of the facies. Coarse silt- and fine sand-sized quartz particles form 91 to 95 per cent of these rocks. The quartz is angular to subrounded and poorly to moderately sorted. No trend in sorting was observed. Zircons and tourmalines, which form a minor amount of the rocks, are generally well-rounded. Matrix material is sparse, forming only 3 per cent of the total components. Likewise, cement is not abundant; iron oxides form the bulk of the cement, 7.5 per cent in the upper sample, and silica is present as secondary cement, forming only 1 per cent in the lower sample.

Many of the quartz grains are arranged in a circular network similar to that described in facies B, and these are most likely burrow structures. Individual beds within the facies exhibit fining upwards trends; however, on an outcrop scale the facies may show a slight coarsening upwards trend (Fig. 19), or a fining upwards trend depending on the overlying lithology. At Stations 27 and 88, the unit grades into overlying shales and exhibits decreasing grain size upwards. Texturally, these sediments are termed mature.

Facies D

Facies D is represented by two sets of samples, one from Station 133 and the other from the basal portion of Station 107 (see Fig. 5 for

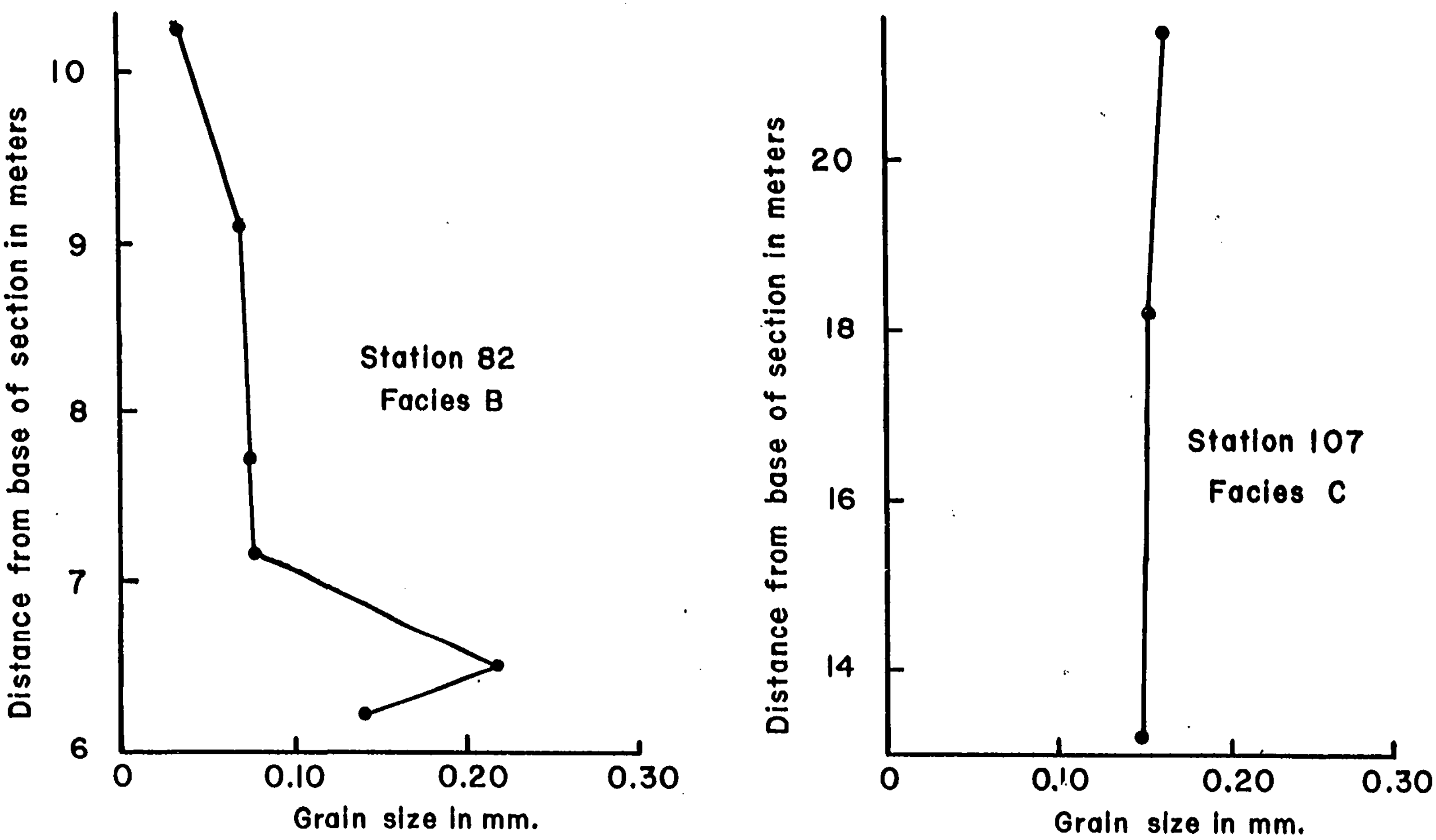


Fig. 19 : Vertical variation in mean grain size within facies B and C. Facies B (left) exhibits a fining upwards trend, while facies C (right) shows only a very slight coarsening upwards trend. See figure for the locations of the stations.

locations). In all instances, except sample 133-1, fine- to medium-grained, angular to well-rounded quartz forms 93.5 to 98.5 per cent of the total rock content. Trace amounts of zircon and tourmaline are present and these grains are all very well rounded. Clay matrix is poorly developed and where it is present appears to consist of grains which have been squashed between larger framework grains. Cementation is dominantly in the form of quartz overgrowths and minor amounts of pore filling, possibly because of sutured grain contacts which are sparsely present. Iron oxide is also a cementing agent and is locally more important than silica, especially as a case hardening agent on the surfaces of weathered outcrops.

Sorting is generally very poor in the basal parts of the facies. In many instances, as sample 133-1, this is because of the bimodal grain size distribution. The sorting does improve upwards and the rock is moderately sorted in the upper portions. Grain size shows a slight fining upwards trend in both sets of samples (Fig. 20). This is in contrast to the trend reported by Martin (1975) for the Carter Caves sandstone. Texturally, the rocks are mature to supermature.

Facies E

Textural analyses of shale samples were not performed; however, grain size trends in particular outcrops were observed and are noted here. Because the shales of this facies are subdivided according to facies description, the same format will be used here.

Subfacies E_1: In all instances where this unit is present as a channel fill, as at Stations 27 and 114, the shale exhibits a fining

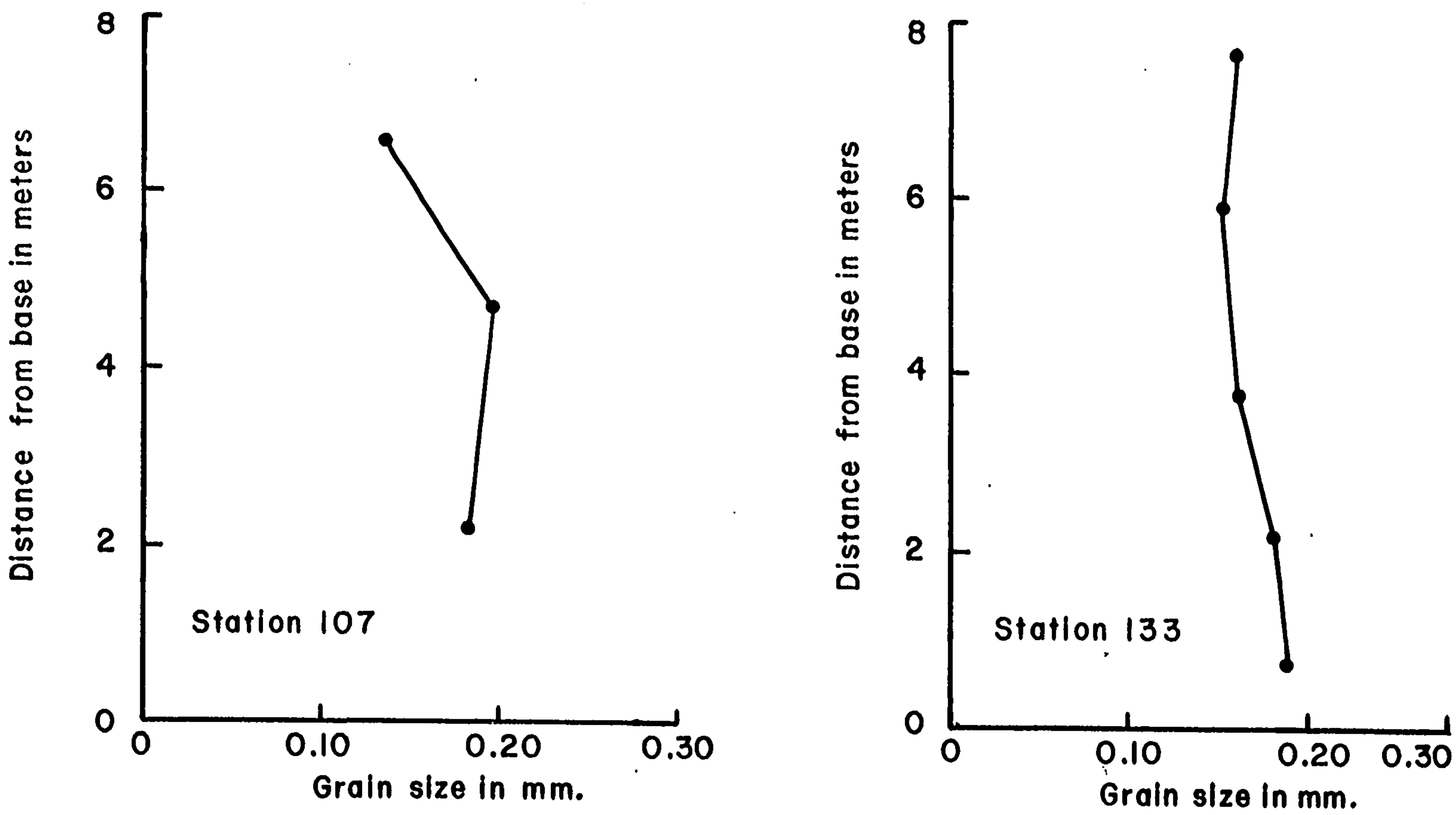


Fig. 20 : Vertical variation in mean grain size within facies D. Station 107 is in western Greenup County and Station 133 is in eastern Greenup County. Both show slight fining upward trends.

upwards trend, grading from sandy or silty shale at its base to clayey or only slightly silty shale at the top. Thin coal beds commonly form basal channel deposits or terminate the fining upwards trend. At occurrences other than channel fill sequences, no evidence of grain size trends were observed.

Subfacies E_2: This subunit is generally part of a coarsening upwards sequence and, accordingly, grades from a clayey or slightly silty shale at its lowest exposures to a sand shale in its uppermost exposures. The unit is gradational into overlying sandstones. Station 119 is the best exposure of this subunit (Fig. 35).

Subfacies E_3: By definition, this unit is clayey to only very slightly silty. Small, fine-grained sandstone pods are locally present; however, the shale does not appear to exhibit any textural trends in the vicinity of these bodies. Neither does there appear to be any lateral or vertical trend within the subfacies itself.

Subfacies E_4: No apparent grain size trends were observed in this unit. The shale is characteristically clayey to only slightly silty and may contain calcilutite lenses.

On very general terms, the shales exhibit an overall fining trend from north to south, with shales of subfacies E_1 and E_2 most abundant in the north and shales of subfacies E_3 and E_4 most prevalent in southern exposures.

Facies F

Shales of facies F range from clayey to silty or slightly sandy, but based on limited observations, do not exhibit any lateral or vertical textural trends.

Thin-section analyses of the carbonate phase show sediments ranging from a matrix supported framework of fragmented and whole shells of brachiopods, ectoprocts, echinoderms, gastropods and ostracods at Station 88 (Plate 21) to rhombohedral dolomite crystals intermixed with varying amounts of quartz grains at Stations 65 and 82. At Station 88, the fossil material has been partly replaced by dolomite. Dolomite crystal size is essentially bimodal in these rocks with the shell-replacing dolomite being somewhat larger than that dolomite occurring as matrix material. All of this material is very fine to fine crystal size, and the crystals are, in all instances, well developed rhomboids. In areas where matrix material dominates, dark, dense pelletal remnants are present (Plate 22). Silt-size quartz grains are also present in minor amounts throughout the rock.

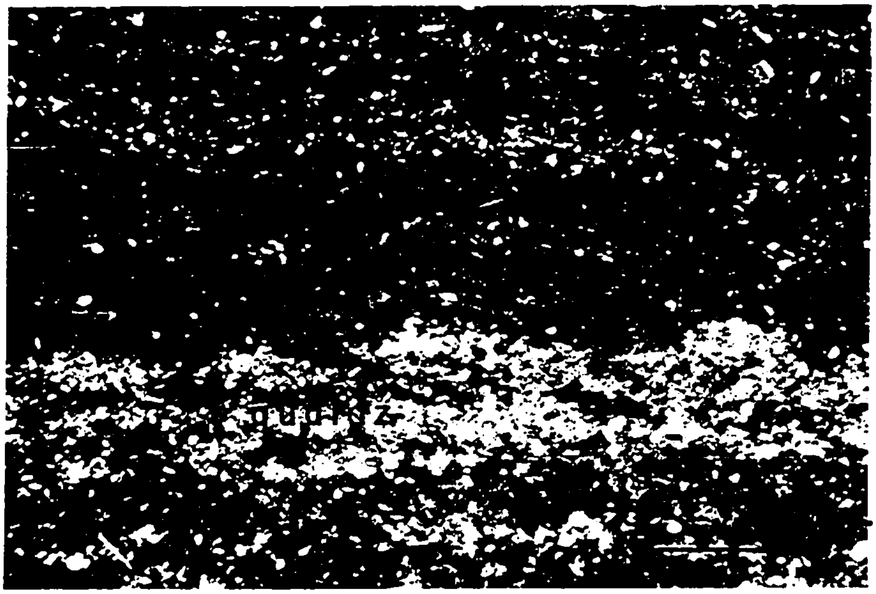
At Station 82, well developed dolomite crystals form the bulk of the facies. Silt-size angular to subrounded quartz grains are locally segregated into individual laminae which are interbedded with dolomite laminae (Plate 31). Pelletal remnants are again locally abundant. At Station 65, fine silt- to sand-size, angular to subrounded quartz grains are distributed throughout a matrix of dolomite and chert. Where the dolomite dominates, only the fine sand-size quartz and pelletal grains are preserved in the matrix.

Facies G

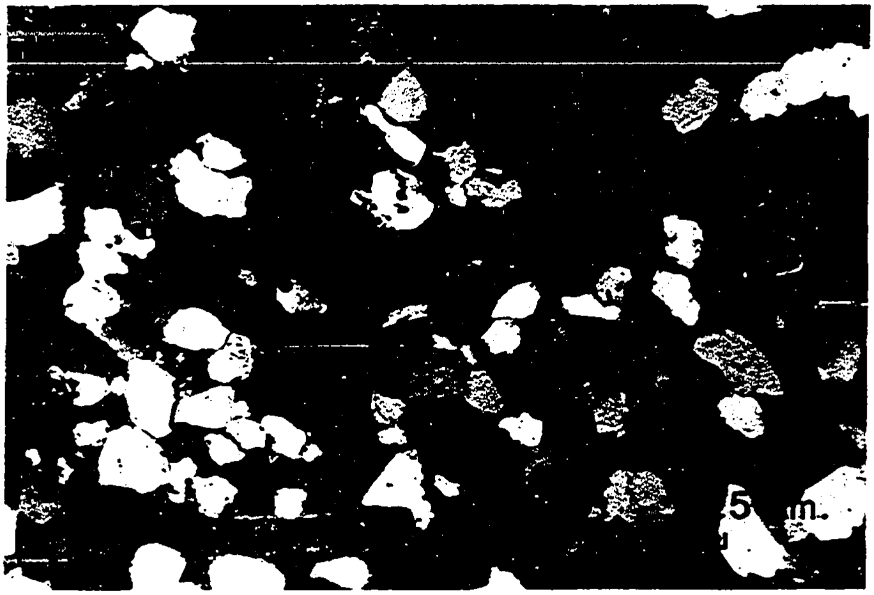
Facies G is a framework supported, carbonate cemented, locally fossiliferous sandstone (Plate 32). The fine, sand-size quartz grains are angular to subrounded and moderately well sorted, although sorting

Plate 31. Interbedded laminae of silt-size quartz grains and dolomite grains in sample 82-6, facies F. Scale is in millimeters.

Plate 32. General view of framework supported, carbonate cemented, fossiliferous sandstone of facies G. Picture is of sample 22-1. Scale is in millimeters.



x-nichols



x-nichols

becomes poorer from the base upwards. Rounding appears to be best developed in the larger grains. Samples from the base of the unit show broken fragments of brachiopods and echinoderms aligned along individual laminae. Fragments of plant material are scattered throughout the facies, but are more abundant in the upper portion. The upper part of the unit also contains finely-crystalline dolomite grains in the calcite cement. The dolomite occurs as well developed rhomboids and is generally most abundant in the vicinity of the plant fragments. Calcite cement forms up to 25 per cent of the rock.

Facies H

No textural data was recorded for the Olive Hill clay bed; however, Patterson and Hosterman (1960, p. 191) have noted textural properties and these are presented here:

> "Kaolinite grains in the flint clay lack preferred orientation; some of the kaolinite grains in semiflint clays are aligned parallel to slickenside surfaces, and much of the illite and mixed-layer clays in semiflint and plastic clay is partially oriented .... Lack of orientation is also shown in the electron micrograh of the flint clay .... Also no evidence of kaolinite orientation is present in the electron micrograph of the semiflint clay. However, basal reflections from kaolinite are more intense in traces from slickensided surfaces from semiflint clay than from slices cut at angles to the slickenside. Apparently some of the kaolinite grains are oriented parallel to slickensides.
>
> Some of the illite and mixed-layer clay in thin-sections of semiflint clays appear to be partly oriented into wavy distorted bands. Some of these partly oriented illite and mixed-layer bands extend along slickensides, and others are enclosed in clay showing no evidence of parting or movement."

Paleocurrent Data

It is well known that cross-bedding and ripple orientation data are useful in reconstructing the geometry and flow patterns of ancient detrital systems (Potter and Pettijohn, 1963). To aid in the understanding and interpretation of the sedimentary systems being studied, 598 paleocurrent directions were measured from crossbeds and ripples within facies A, D and G. Directional vectors were measured using a Brunton compass which was laid, where possible, on the axes of the trough crossbeds and on the foresets of the planar crossbeds. Two measurements were never taken from the same bed set and attempts were made to take at least five measurements from each outcrop.

The angles of dip on the dominantly trough cross-stratified sediments of facies D and G were generally lower than the angles from the facies A crossbeds. Cross-stratification dips from the former ranged from 8 to 27 degrees, while those from the latter ranged from 8 to 40 degrees.

Figure 21 shows the resultant directional vectors from the measurements taken. Each arrow represents the resultant of all the measurements from that station in a particular facies. The vector mean, magnitude and variance were calculated for each station using a vector program for directional data designed for the Texas Instrument SR-51 calculator. The program determines the vector mean by using the trigonometric arctangent function given below:

$$x_v = \text{Arctan} = \left(\frac{\sum_{i=1}^{N} t_i \sin x_i}{\sum_{i=1}^{N} t_i \cos x_i} \right)$$

The arctangent function yields a unique solution and displays the vector mean in degrees azimuth.

Vector strength (L), a measure of the concentration of the observations, was also calculated using the following function:

$$L = (R/N) \text{ X } 100$$

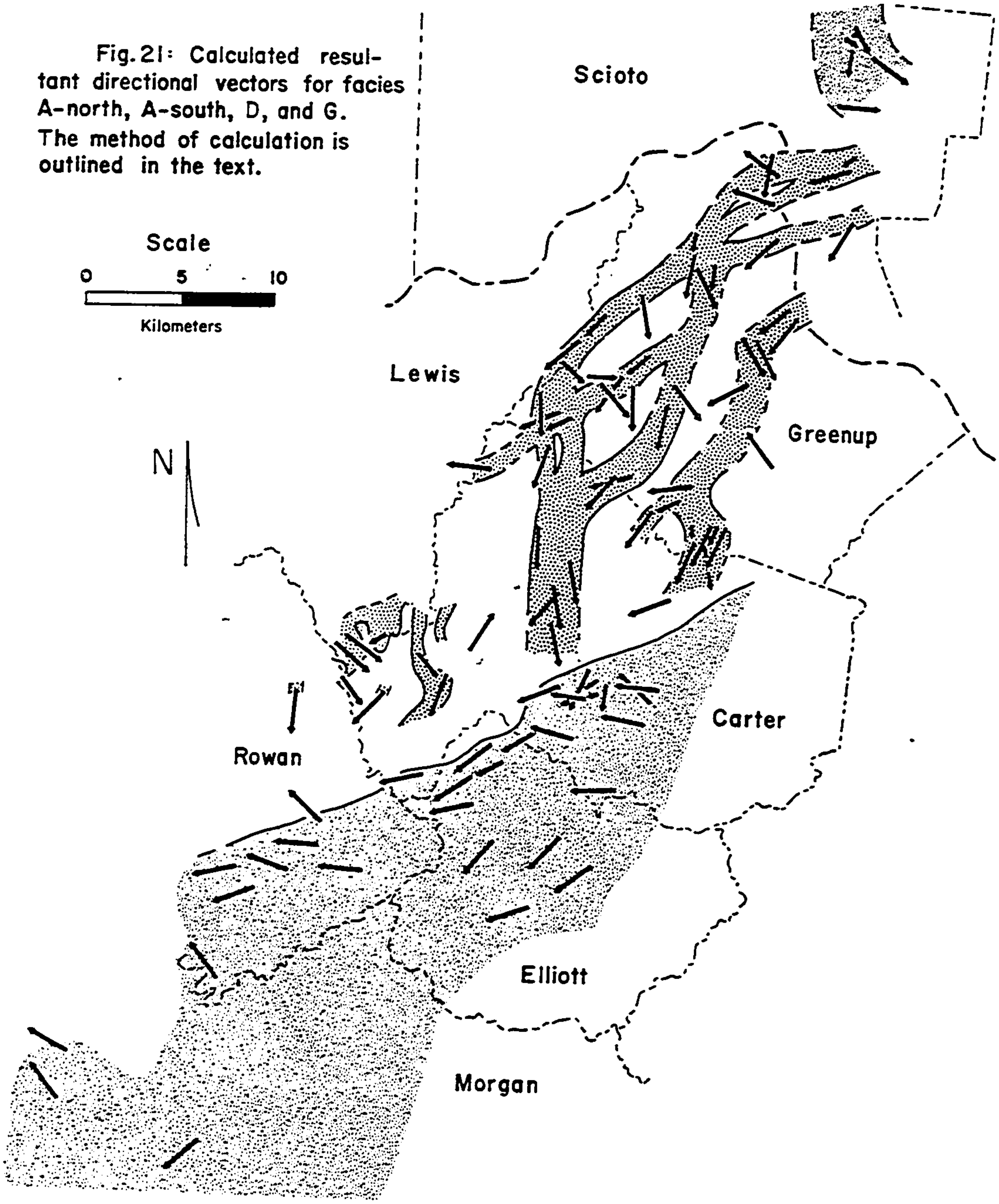


Fig. 21: Calculated resultant directional vectors for facies A-north, A-south, D, and G. The method of calculation is outlined in the text.

where R is the vector length of magnitude and N is the number of observations. L can range from 0 to 100 with larger values (L greater than 60), indicating a concentration of observations in the relative direction of $\underline{x}$v. Calculated values are given in Appendix C.

As can be seen in the figure, cross-bedding vectors in facies D show a marked southerly trend in the southern extremities, while in the northern parts the trend is more to the west-southwest. In all cases, the directional vectors are in good agreement with the mapped channel geometries and show the strong unidirectional nature of the transporting medium. These measurements are in good agreement with those of Martin (1975) from the Carter Caves sandstone, which is the major channel in north-central Carter County (Fig. 21). Martin's work included 183 measurements and yielded a grand mean of 181 degrees, or nearly due south.

Only five measurements were taken from facies G, these in southern Carter County at Station 74 (Fig. 6). These measurements indicate a west-southwest transport direction, nearly perpendicular to that observed in facies D.

Directional values taken from facies A-north show a trend similar to that of facies D, roughly to the south-southeast. This data conforms nicely to a description of the depositional axis of the Sharon Conglomerate in the area as described by Stout (1916, p. 40-41). Stout describes the conglomerate phase of the formation as ..."tongue shaped with the point south....and...."if the stratum continues from Porter Township, Scioto County, the trend is eastward, for the conglomerate is not represented, at least in any considerable thickness, along the Ohio River". Figure 22 is a reconstruction of Stout's description of the geometry of that unit. The paleocurrent data obtained during this study agree well with Stout's description, and in fact, near the southern limit of the exposures, the cross-bedding data do indicate a shift in the current pattern to the east-southeast.

Facies A-south shows a trend which is nearly perpendicular to that of facies D, but parallel to that of facies G. The dominant direction of transport in this unit appears to have been to the west-southwest. The direction is coincident with the trace of the Kentucky River Fault System and nearly parallel to the axis of those taken by BeMent (1976) for the Lee Formation in southeastern Kentucky and with that of Schlee (1963) from the same sequence in Tennessee, Georgia, and Alabama. These measurements indicate a transport direction nearly parallel to the axis of the Appalachian Basin.

Fossil Content

Fossil remains are generally very sparse and preservation poor in the sediments of interest in the study area; however, body fossils have been identified from facies F, isolated outcrops of facies G, and from particular outcrops of facies E_4 shale. Although body fossils are generally lacking, trace fossils, especially in the sandstones of facies B and C and occasionally in the shales of facies E_2. The identification of these faunal and floral remains provides an important tool for stratigraphic interpretations, predictions of relative rates of sedimentation and the reconstruction of depositional environments.

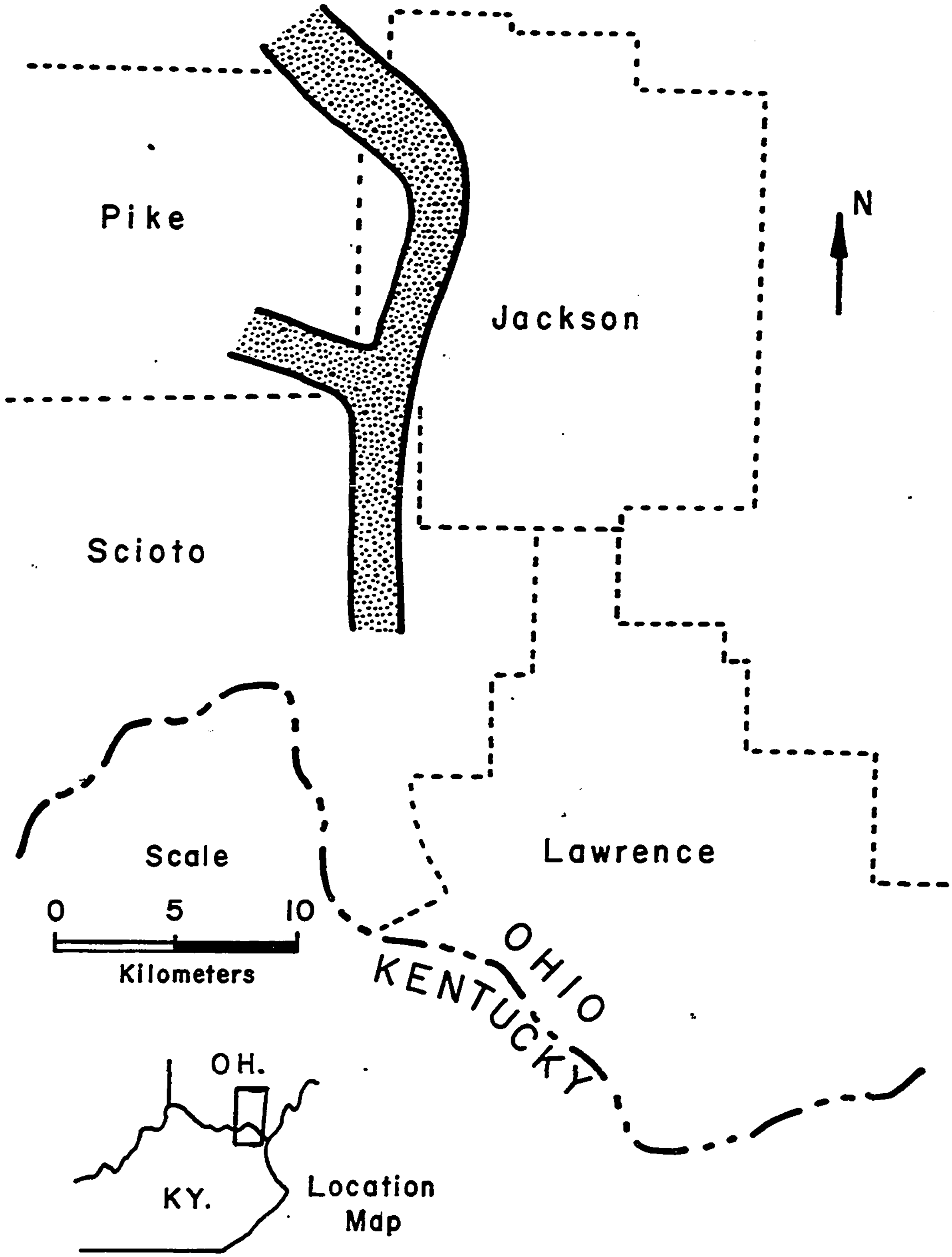


Fig. 22: Depositional axis of the conglomerate phase of the Sharon Conglomerate in southeastern Ohio. Reconstructed from Stout (1916, pp. 40-41).

Body Fossils

Body fossils were found at Stations 22, 25, 32, and 88. At Stations 22 and 25, scattered remains of echinoderms and ectoprocts are present along the bedding planes of fine-grained, rippled sandstones overlying the Newman Limestone; however, specific identifications were not performed on these specimens. At Stations 32 and 88, good specimens of brachiopods, echinoderms, ectoprocts, ostracods, and pelecypods are present in thin-bedded, argillaceous limestones and dolomites of facies F. Species from this horizon have previously been identified by J. T. Dutro, Jr. (Sheppard and Dobrovolny, 1963; Englund and Windolph, 1971), and these positive identifications are listed in Appendix A. Many of these specimens are complete and show little signs of abrasion.

Several specimens of fenestrate ectoprocts were found in outcrops of black shale of facies E_4 overlying the Newman Limestone along State Highway 1274 in the Bangor quadrangle. Ettensohn (1975) has reported additional occurrences of marine fossils from this locality and also the presence of the plant fragments charophyte oogonia, spores, and the fresh water alga Botryococcus in these sediments. It seems likely that these nonmarine species were transported into this environment.

Patterson and Hosterman (1962, p. F30) have reported finding specimens of the brachiopod Lingula in dark gray shales about 0.5 meters (1.5 feet) above the Olive Hill clay bed in the vicinity of Open Fork Valley in the Haldeman quadrangle. Specimens of the plant fossil Dictyoxylon have also been found by the same authors and identified by Mamay (Patterson and Hosterman, 1962, p. F32). These fossils were found in shales above the Olive Hill clay bed at the Licking River limestone quarry about 2 miles southwest of the Wrigley quadrangle.

Conodont studies have been performed on shales of facies E and F by several workers (Horowitz and Rexroad, 1972; Merrill, 1973; Bliefnick, 1975) as a means to aid in interpretations of depositional environments, and in determining the precise location of the Mississippian-Pennsylvanian boundary. These authors found conodonts especially abundant in the thin limestones and shales of facies F, but generally lacking in the shales and siltstones of facies E.

Trace Fossils

Tracks, trails and burrows known as trace fossils are abundant in several of the facies described in this study. The greatest diversity of these fossils is found in facies B; however, several types of trails and burrows were also found in facies C and E. In no instance were body fossils found in association with the trace fossils.

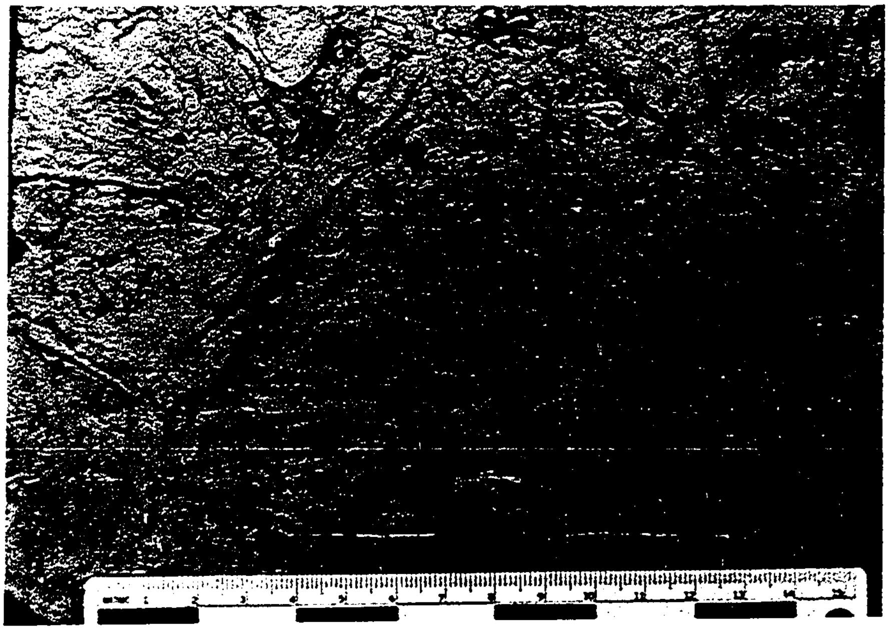
Facies B: This facies contains a variety of trace fossils ranging from Cubichnia, or resting traces, to Fodinichnia, or feeding burrows (Seilacher, 1964). Many of the traces found in this unit resemble a group described by Bandel (1967) from Upper Pennsylvanian sandstones and shales in Kansas. In many instances, the traces are so abundant that all other lithologic structures are destroyed and this makes identification of the trace fossil itself very difficult.

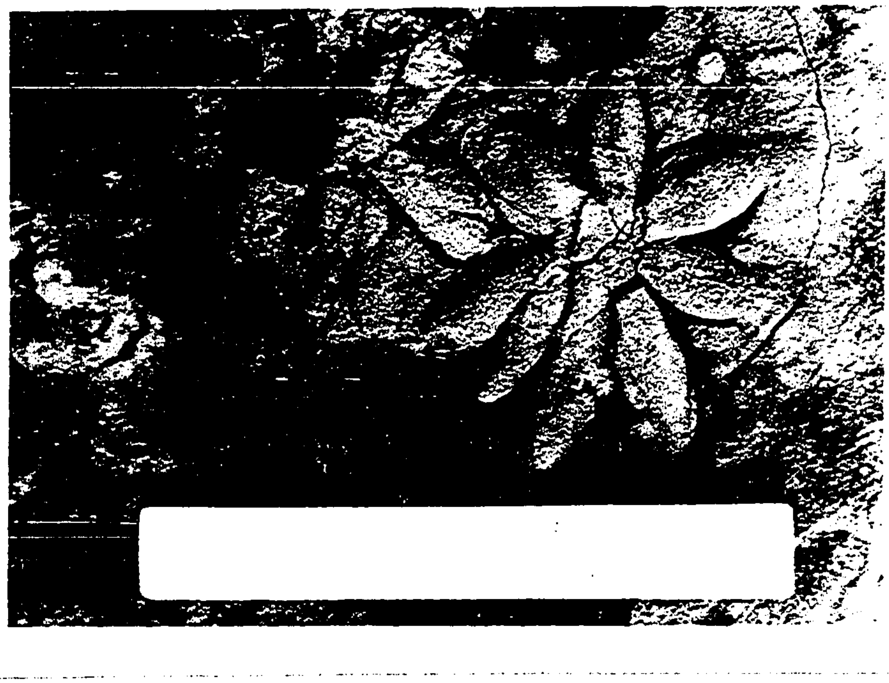
Plate 33 illustrates a type of trace fossil which is characteristic of this facies, that of overlapping burrow casts which probably represent feeding probes. The burrows are fairly consistent in size, averaging 5-10 mm. (0.2-0.4 inches) in diameter with unknown lengths. The burrows are often flattened because of compaction of the sediments and generally are best exposed on the bottoms of fine-grained sandstone beds which are commonly rippled. This trace fossil cannot be placed with any known trace fossil taxon; however, similar traces have been described by Warme and Olsen (1971) in Upper Pennsylvanian Winchell Limestone of Texas which is interpreted as having been deposited in marine to marginal marine environments (Warme and Olsen, 1971, p. 36-37).

Star-shaped traces which consist of rays 5-15 mm. (0.2-0.6 inches) in diameter, 25-35 mm. (1.0-1.4 inches) long, and preserved as concave epireliefs are also common in this facies (Plate 34). The structures vary in the number of rays present, ranging from seven to perhaps thirty in some instances. The fossils occur along bedding planes and are most common on those which have an abundance of clayey or carbonaceous material. Bandel (1967) has described similar structures from the Rock Lake Shale Member of the Stanton Limestone (Upper Pennsylvanian) in Douglas County, Kansas, naming them Asterichnus lawrencensis. The Rock Lake Shale is interpreted as shallow marine or littoral in that area. According to Bandel, the trace is interpreted as feeding traces made by an infaunal organism which extended itself down a burrow and along a bedding plane, taking in the sediment of the area and extracting food particles before filling part of the feeding burrow with waste sediment. Many animals which are capable of producing star-shaped traces on the surface of the sediment have been recognized and described; however, relatively few, if any, recent forms which burrow down and follow bedding planes have been described. These traces are similar to surface tracks of Scrobicularia plana, a pelecypod, of the North Sea tidal flats (Schafer, 1962; Bandel, 1967).

Plate 33. Overlapping burrow casts from facies B sandstones at Station 82. This trace fossil cannot be placed in any known trace fossil taxon. Scale is in centimeters.

Plate 34. The trace fossil Asterichnus lawrencensis from facies B sandstones at Station 82. Specimens of this trace fossil were also found at Station 80 and from facies C at Station 27. The scale is 15 centimeters long.





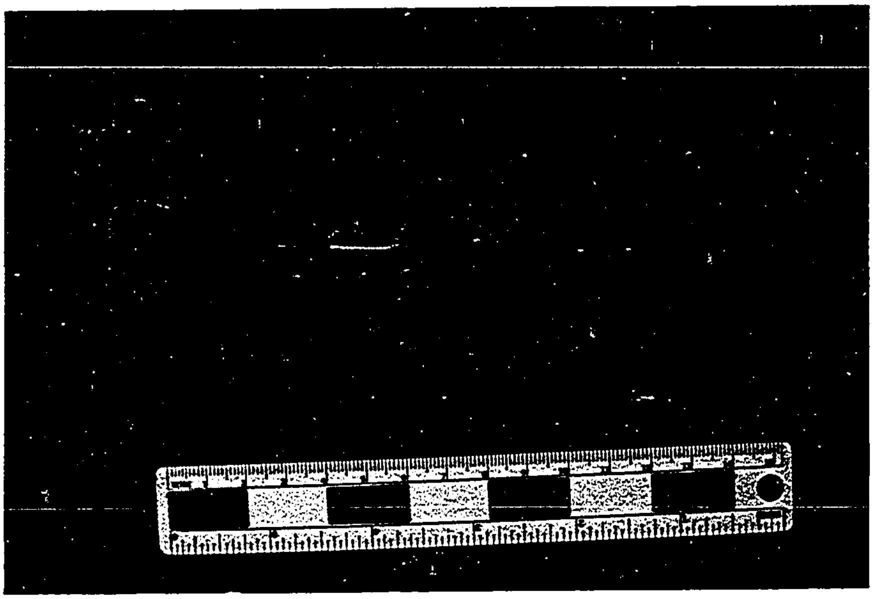
A single specimen of what appears to be Crossopodia dichotoma (Bandel, 1967) was found in a fine-grained, rippled sandstone at Station 98 in the southern Brushart quadrangle. This trail, which appears as a concave epirelief, is approximately 29 centimeters (11.5 inches) long and 2-3 centimeters (0.8-1.2 inches) wide (Plate 35). Bandel (1967, p. 5-6) suggests that trails of this type should be considered dwelling burrows (Domichnia) of animals with chelicerate appendages, possibly crustaceans or annelids. Single trails fitting this description have been observed along rippled bedding planes of facies B at Station 82. Bandel suggests that trails like Crossopodia were used several times, either by the same animal or a group of animals.

Ball-like features 10-15 mm. (0.5-0.6 inches) in diameter which seemingly have no preferred orientation are common on the ripple-bedded surfaces of facies B (Plate 36). The balls are slightly flattened because of compaction, but were probably nearly spherical at the time of their formation. Often the balls sit directly on the sediment surface, usually with a thin lamina of clay material separating them from the sediment interface. In most instances, the balls show no subsurface connection; however, in several instances the balls were found sitting directly atop a vertical burrow, suggesting that they are the result of sediment being moved out of the burrow.

Bandel (1967) has described ball-like structures from the Rock Shale in Douglas County, Kansas, which are very similar to those described above. That author assigned the traces to the genus Cylindrichnus and applied a new specific name, reptilis. Bandel attributes the traces to large, worm-like animals which burrowed below the sediment surface and

Plate 35. The trace fossil *Crossopodia dichotoma* from facies B sandstones at Station 98 in the southern Brushart quadrangle. This was the only specimen of this species found during the study. Scale is in centimeters.

Plate 36. The trace fossil *Cylindrichnus reptilis* from facies B sandstones at Station 28 in the central Soldier quadrangle. The balls are probably waste excreted from burrowing worms. Scale is in centimeters.



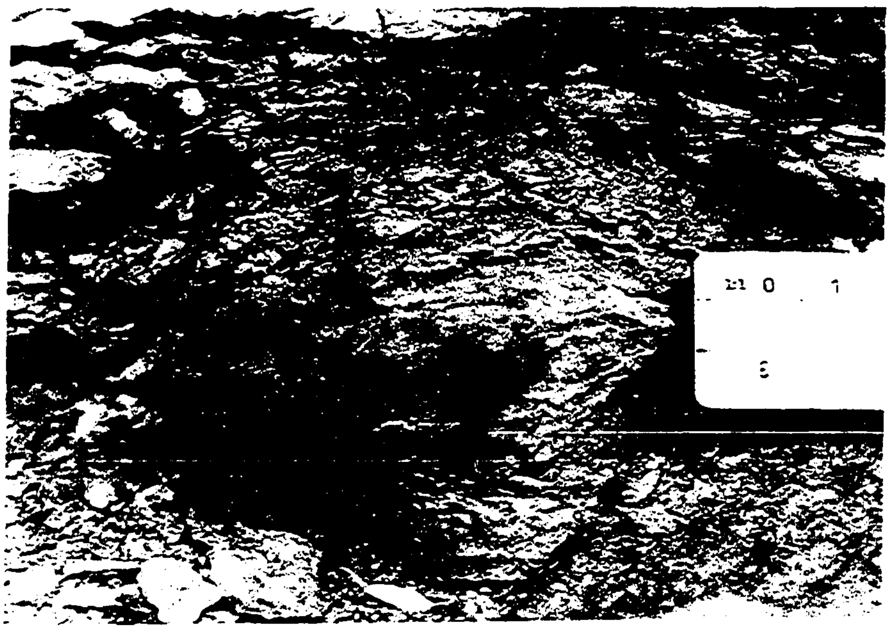
compacted or packed the sediment into balls. As the worms moved along the sediment plane, they ingested the sediment, extracted food particles and deposited the waste in balls. Vertical burrows connecting balls to other bedding planes probably represent the movement of the animal from one stratum to another when food supplies were not favorable. The animal seems to have preferred clay- or organic-rich laminae present between the sandstone beds.

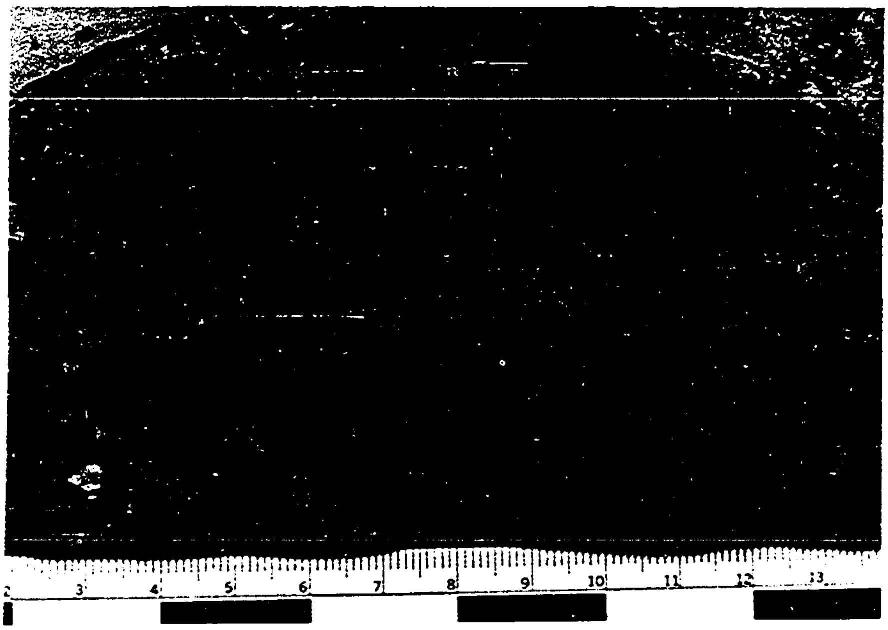
Concentric marks on the surfaces of bedding planes are common at many outcrops, but are best developed at Stations 28 and 82. The traces vary in size, but are commonly 2-3 cm. (0.8-1.2 inches) in diameter (Plate 7). The cores of the fossils resemble vertical tubes or burrows and probably represent the pathways used by the organisms. Henbest (1960 has described traces of this variety from the Morrow and Atoka Series of Washington County, Arkansas, and assigned them to the genus Laevicycles. The concentric marks are thought to have been produced by the waving tentacles of a polychaete worm, but may also represent dia-genetic halos resulting from the burrowing activity. Henbest notes that these burrows are particularly characteristic of sediments composed of thin, alternating, ripple-marked beds of sandstone and clay. This description fits the sediments of facies B very well. The sediments containing the traces in Arkansas are interpreted as shallow marine or possibly estuarine deposits (Henbest, 1960).

Several samples of funnel-shaped trace fossils were also found in facies B sediments at Stations 65, 82, and 114. These traces are roughly 7-8 cm. (2.7-3.1 inches) in diameter at the top and taper to 2-2.5 cm. (0.8-1.0 inches) at the base (Plate 37). Laminae within the trace are

Plate 37. The trace fossil <u>Conostichnus</u> Lesquereux, 1876 from facies B sediments at Station 65 in the southern Morehead quadrangle. Other specimens of this species were found at Stations 82 and 114. Scale is in centimeters.

Plate 38. The trace fossil <u>Chondrites</u> (?) found in float material at Station 79 in the wouthwestern Haldeman quadrangle. This is the only specimen of this species found during this study. Scale is in centimeters.





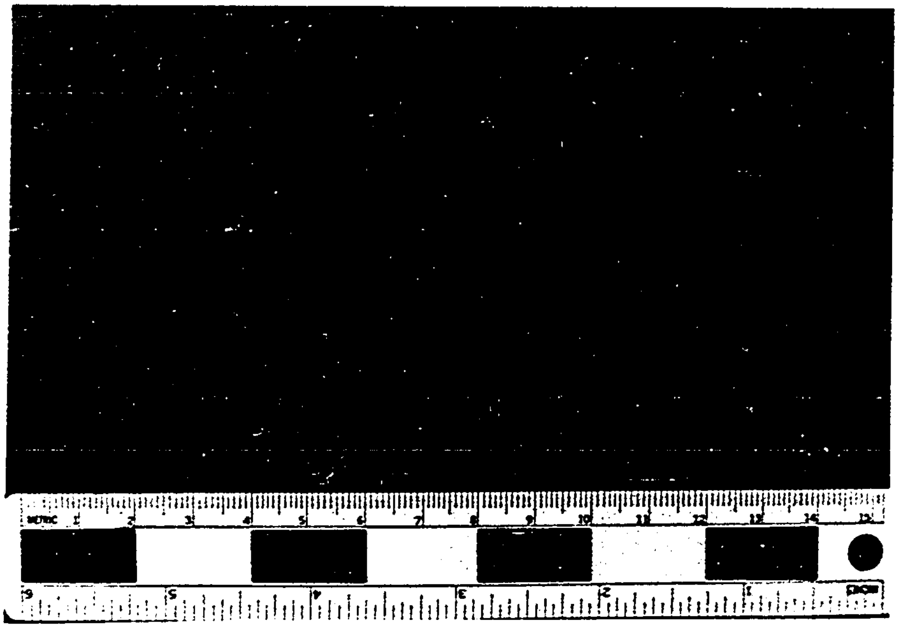
oblique to bedding and appear to be the result of infilling of a broad, vertical burrow. No sign of a preserved connecting burrow was found below the trace fossil. Henbest (1960, fig. 177.1-C) has described similar trace fossils from the Cane Hill Member of the Hale Formation in Arkansas, and attributes them to sedentary burrowing animals with subsequent filling of the burrow. Pryor (1975, pers. comm.) has suggested that these may represent anemone sitzplatz, or resting traces. Tentative assignment is to Conostichnus Lesquereux, 1876.

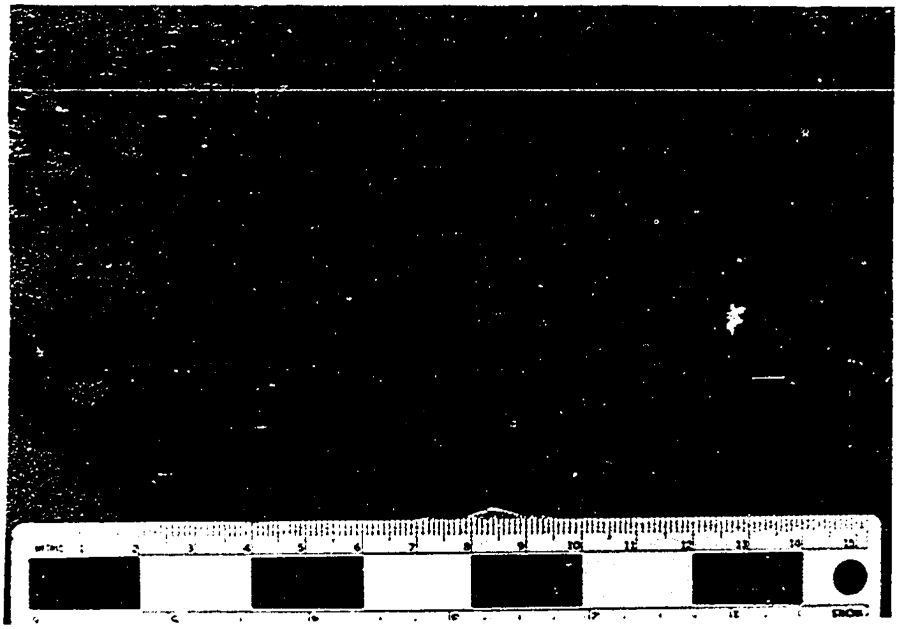
A single specimen tentatively identified as Chodrites (Plate 38) was found in float material at Station 79 in the Haldeman quadrangle. The trace consists of a branched network of burrows which resemble the limbs of a tree and all the burrows are of generally the same width, approximately 1-2 mm. (0.04-0.08 in.). The trace occurs as a convex epirelief. The fossil is believed to represent dwelling (Domichnia) or feeding (Fodinichnia) burrows of marine worms (Hantzchel, 1966, p. W187-W188).

Zoophycos traces are also present, although not in great number, in the sediments of this facies. Two such trace fossils were observed at Station 82; however, both were in float material and one was broken into several pieces. The preserved specimen (Plate 39) is approximately 8 cm. (3.1 in.) long and 6 cm. (2.4 in.) wide at its widest point. The broken specimen was 2-3 times larger. The trace is probably only a segment of the feeding traces (Fodinichnia) of the organism which made it. Contrary to earlier ideas which restricted Zoophycos to deep water and flysch deposits (Seilacher, 1964), Henbest (1960) has reported these trace fossils in the marine phases of Pennsylvania cyclothems in Illinois.

Plate 39. The trace fossil Zoophycos from facies B sediments at Station 82, central Haldeman quadrangle. Scale is in centimeters.

Plate 40. The trace fossil Pelecypodichnus from facies B sediments at Station 48 in the eastern Portsmouth quadrangle. Note the spicate nature of the locomotion traces outlined in black ink. Scale is in centimeters.



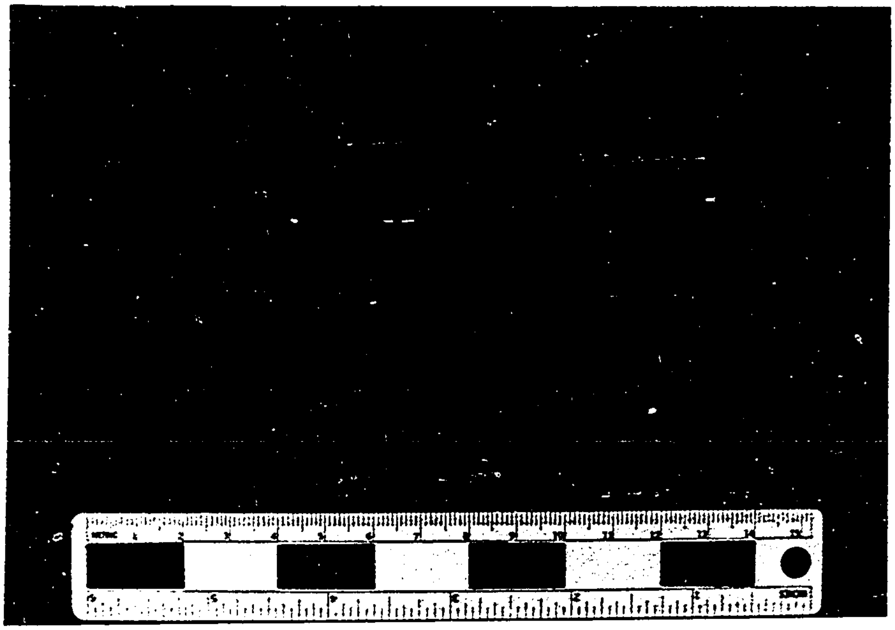


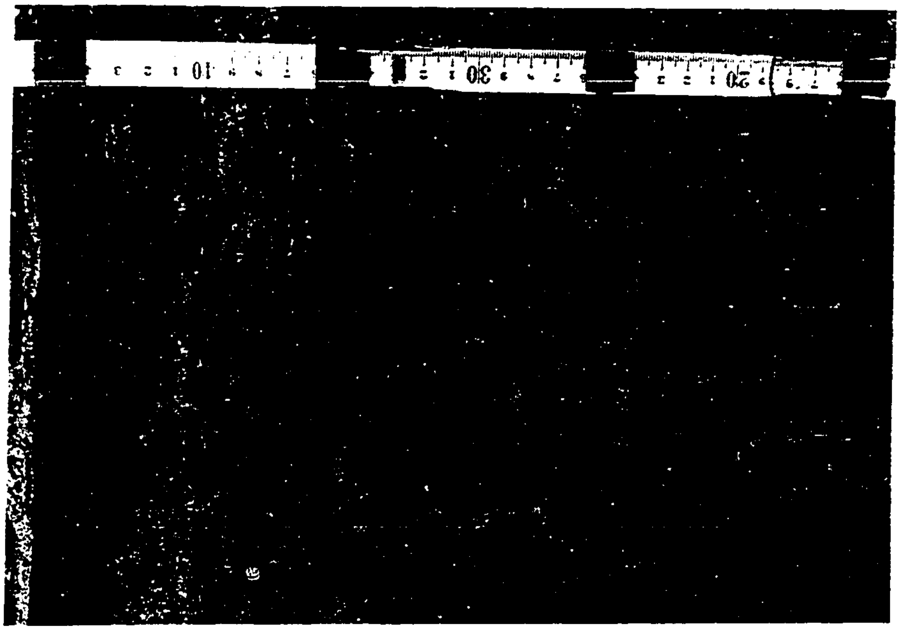
Isolated patches of facies B sedments are found in the northern part of the study area in interchannel (between facies D sandstones) areas (Fig. 10). The degree of bioturbation in these sediments is much less pronounced than in those just described, and the nature of many of the trace fossils is also different. One interesting trace fossil characteristic of these sediments is found at Station 48. This fossil is an almond-shaped, pod-like, convex hyporelief roughly 1 cm. (0.4 in.) long and 3-5 mm. (0.1-0.2 in.) wide (Plate 40). These apparent resting traces (Cubichnia) are associated with probable locomotion trails (Repichnia) which leads to or from the pod-like depressions. In several instances, these trails were observed to be spicate with ridges branching from a median ridge on both sides opposite one another. These traces have been observed in Early Pennsylvanian sediments in eastern Kentucky (Gardner, pers. comm., 1976). Seilacher (1953) first termed these trace fossils Pelecypodichnus, and Bandel (1967) has since termed similar fossils from the Vinland Shale Member of the Stanton Limestone in Douglas County, Kansas, as Pelecypodichnus ornatus. Bandel suggests that the organism making the trace lived completely buried below the sediment interface.

Several other types of trace fossils occur within this facies, the majority of which are burrows or tracks of undeterminable origin. One such track from Station 27 (Plate 41) resembles the genus Gordia; however, complete specimens were too poorly preserved and too few for positive identification. Evidence of burrowing activity is also abundant on a microscopic scale. Circular arrangements of quartz grains (Plate 30) and horizontal concentrations of fine-grained sediments within coarser-grained material are probably the result of burrowing by organisms.

Plate 41 Trace fossil resembling Gordia from facies B sediments at Station 27 in the central Soldier quadrangle. These traces are thought to be grazing traces of animals (Pascichnia) in search of food. Scale is in centimeters.

Plate 42. Bioturbated outcrop exposure of facies C sediments at Station 94 in the northeastern Tygart's Valley quadrangle. Scale is in centimeters.





Facies C: Trace fossils in this facies consist principally of tracks and burrows; however, because of the susceptibility of the rock type to weathering and erosion, exposures for observation or individual specimens are difficult to obtain. Plate 42 shows a typical bioturbated outcrop within this facies. In these areas, the rock consists of a series of intertwined burrow structures 5-10 mm. (0.2-0.4 in.) in diameter and of undeterminable length. Much of the fine-grained sandstone which forms the burrows has been cemented by iron oxide; however, even these reinforced structures are very fragile.

Most of the burrows are horizontal and are concentrated along the organic-rich bedding planes. The organisms, probably worms, burrowed along these nutrient-rich beds, feeding as they went. Zones of moe intense bioturbation may indicate slower sedimentation rates or possibly a more favorable environment for these organisms. These structures do not correspond to any described trace fossil taxon.

Facies E: Trace fossils found in this facies, subfacies E_4, are restricted largely to burrows, some of which may attain diameters of 2 cm. (0.8 in.), but are usually somewhat smaller, on the order of 1 cm. (0.4 in.) in diameter. The burrow morphologies which have been observed are principally of three types, those consisting of single burrow structures, those which have burrows stacked one upon another, and those which occur in pairs.

Single burrow structures are the most common and usually occur along the bedding planes of silty, carbonaceous shales (Plate 43, a). It appears that the burrows are the result of worm-like organisms moving through the sediment while feeding (Fodinichnia). These structures have not been found to correspond to any known trace fossil taxon.

A variation of the single burrow results when the trace fossil is formed by vertical, usually upward, displacement of the horizontal burrow (Plate 43, b). A thin lamina of clayey or carbonaceous material usually separates the individual burrows, each of which is slightly flattened because of compaction. Seilacher (1955) has described this type of trace fossil in Late Cambrian sediments of Pakitan and has assigned them to the genus Teichichnus. The burrows are probably feeding traces (Pascichnia). Trace fossils of this variety were found at Stations 27, 48, and 83.

A single specimen of a third type structure was found at Station 119. This trace occurs as a pair of horizontal burrows which lie stacked one atop the other along the bedding plane; however, individual traces do not exactly follow the same path as the burrow adjacent to it as does the Teichichnus variety (Plate 43, c). It is possible that this configuration is merely a chance occurrence and that the burrows are actually separate entities made by different organisms at different times. This structure has not been found to correspond to any known fossil taxon.

Scalarituba traces were found in black, silty shales of this facies at Station 57 in the southeast Brushart quadrangle. The traces occur as arc-or hook-shaped, carbon-rich impressions along bedding planes and are approximately 1 mm. (0.04 in.) in diameter and generally less than 1 cm. (0.4 in.) long.

The trace fossils identified within the various facies, with the exception of Zoophycos, belong to the Cruziana facies of Seilacher (1964) which he interpreted as indicative of littoral and shallow marine environments. Bandel (1967) made a similar interpretation for the

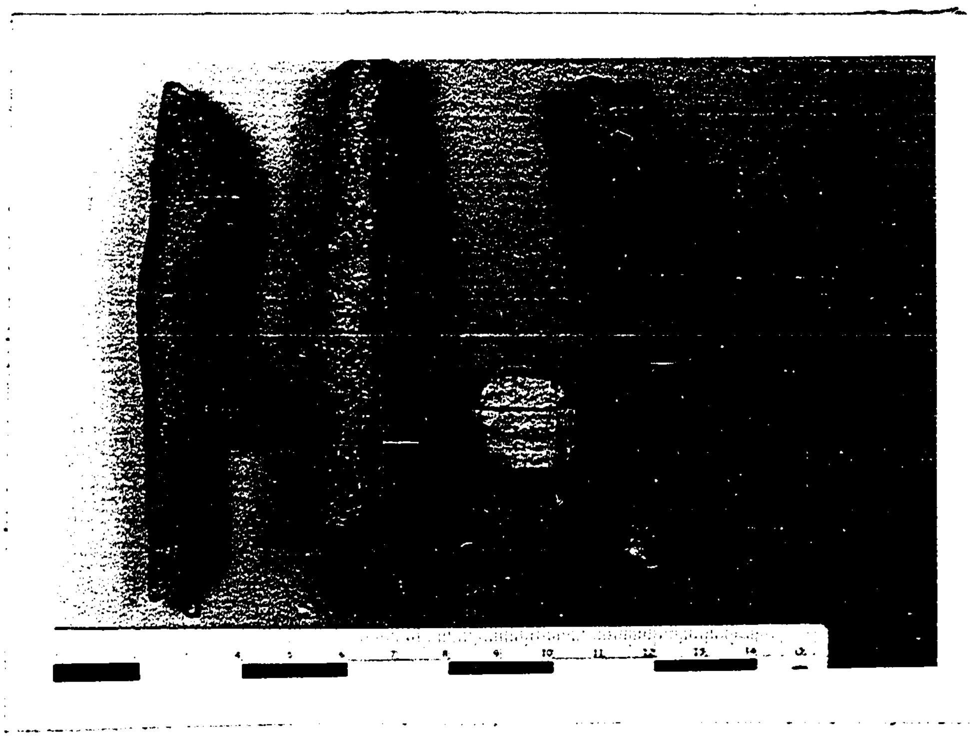


Plate 43. Various types of burrow structures found in subfacies E_4. Type "b" is assigned to the genus Teichichnus; however, the other types have not been found to correspond to any known trace fossil taxon. Scale is in centimeters.

environment of deposition of the Vinland Shale Member of the Stranger Formation and the Rock Lake Shale Member of the Stanton Limestone in Kansas, both of which contain many of the trace fossil species found in northeastern Kentucky. Wagner (1964) and Heckel (1975) have interpreted the Rock Lake as part of a nearshore, argillaceous marine stage and the Vinland Shale as partof a coastal plain or tidal flat receiving fine silt and clay from nearby streams. Wilson (1957) points out that certain sandstones of the Rock Lake resemble deltaic or channel sandstones.

The majority of the traces in northeastern Kentucky have been interpreted as formed by infaunal burrowers, which may be an indication of a high stress environment (Rhoads, 1975). Rhoads has also interpreted the presence of tube dwellers, such as Crossopodia dichotoma, as indicative of rapidly shifting environments. These data, when combined with lithologic and stratigraphic information, are very useful in depositional environment reconstructions.

Dating of the Sediments

Historically, the sediments involved in this study, except for a few outcrops of Pennington in the Tygart's Valley quadrangle, have been considered Early Pennsylvanian in age. The location of the Mississippian-Pennsylvanian boundary has been considered to be at the base of the conglomerates of facies A; however, the absence of these sediments on the northern side of the Kentucky River Fault System makes this distinction impossible based on that property. Compounding the problem is the patchy nature of the Pennington and Newman formations in that same area. Mappers for the U. S. Geological Survey show patches of the Pennington only in the Tygart's Valley quadrangle (Sheppard, 1964) with portions of the Carter Caves sandstone mapped in the Ault, Olive Hill, Soldier, and Grahn quadrangles (Delaney and Englund, 1973; Englund and Windolph, 1975; Philley et al., 1975; Englund, 1975). The paucity of body fossils only complicates the question of the exact position of this boudary.

White (1900) was the first to introduce a means for correlating and dating sediments of the Pennsylvanian System with his study of the Pottsville flora in Pennsylvania. Later works by Read (1947) and Read and Mamey (1960) support White's work and establish nine floral zones for regional correlations and stratigraphic equivalence. According to these works, the floral assemblages from the Sharon Conglomerate in northeastern Ohio indicate a late Early Pennsylvanian age. These are probably the same sediments which outcrop in southeastern Ohio (Morningstar, 1922).

Sheppard and Dobrovolny (1963), contrary to previous age assignments of clastics above the Newman Limestone in northeastern Kentucky, established a Late Mississippian age for the Carter Cave sandstones (facies D) based on age determinations of body fossils preserved in overlying limestones and shales (facies F, Appendix A). One sample of Diaphragmus cf. D. cestriensis from Box Canyon (Station 32) indicates a late Chester age. According to these determinations, the Carter Caves sandstone, its lateral equivalents, and the limestones and shales of facies F overlying them, are Late Mississippian and possibly later Chester in age.

Macrofossils are scarse within the study interval, however, and workers have recently turned to other methods of dating these sediments. Merrill (1973) and Bliefnick (1975) have sampled and studied conodonts from sediments along U. S. Highway 64 and State Route 60 in Carter and Rowan Counties. Both authors found Mississippian species in the same limestones discussed above, and Merrill found Mississippian specimens from a stratigraphically similar limestone at Station 88 of this study. Merrill also collected samples from a section at Station 87 (see Fig. 6) which indicate a Mississippian age for the limestones and a Pennsylvanian age for the overlying black shales (Fig. 23).

Horowitz and Rexroad (1972) have collected conodont samples from shales and thin limestones overlying the Newman Limestone at Armstrong Hill, which is just north of Station 30 of this study, which suggest a very late Chester age for the shales outcropping at this locality.

Patterson and Hosterman (1962) have reported the occurrence of the plant fossil Dictyoxylon from a coal occurring just above the base of the Olive Hill clay bed in the northeastern corner of the Ezel quadrangle. According to these authors, this fossil is indicative of Lower Pennsylvanian rocks and has not been known to occur in any Mississippian strata.

As can be seen from the foregoing discussion, most correlations and age determinations in northeastern Kentucky have relied largely on lithology, stratigraphic sequences, and the megafauna. Recently, however, the use of spore assemblages, where possible, have proven to be a valuable tool. Wier (1974) has reported spore dates from coal beds exposed in the lower tongue of the Breathitt Formation (see Fig. 3) in the Slade quadrangle south of the study area. Relative age determinations of these samples indicate an Early Pennsylvanian age.

BeMent (1976) has also assigned relative dates to several limestones and coals within the Pennington and Lee Formations in southeastern

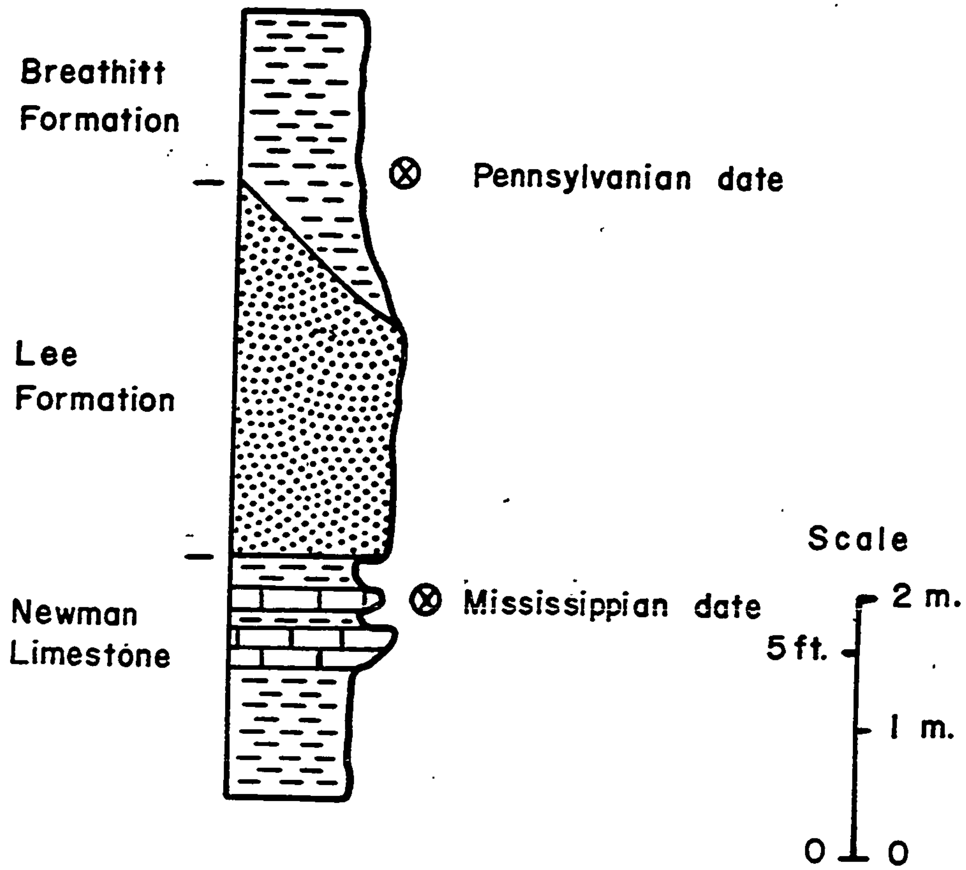


Fig. 23: Columnar section showing locations of conodont samples used for age determinations of Merrill (1973). Location is Rt. 60 of Merrill, Station 87 of this study. Formation identifications are from Merrill.

Kentucky. According to his determinations, the Mississippian-Pennsylvanian boundary occurs within the Pennington Formation as it is mapped by the U. S. Geological Survey. BeMent further suggests, based on this information, that Lee sediments in northeastern Kentucky are Pennsylvanian and that the systemic boundary, like in southern Kentucky, is within the Pennington Formation. It should be pointed out that all of the Mississippian dates are from limestones bodies and based on conodont studies, while the Pennsylvanian dates are from coals and based on spore data.

More recently, Peppers (Ettensohn, pers. comm., 1976) has dated coal samples from within the study area and preliminary results show that thin coals do exist in the Pennington Formation in this area and that many of these are Mississippian. Two samples taken from thin coals and carbonaceous shales of facies E near the southern margin of the study area (Appendix B, sample 2128) indicate a Late Chester age, while five other samples taken from carbonaceous shales of facies E and the middle of facies G indicate an Early Pennsylvanian age.

Several samples were also collected from shales near the contact with the overlying Corbin Sandstone Member of the Lee Formation (facies A-south, see Fig. 3). Two of these, collected on State Route 1274 in Menifee County (Appendix B, samples 2123 and 2131), indicate a Pennsylvanian age. Another, collected from a thin coal 4.6-6.0 meters (15-20 feet) above the Newman Limestone at the Licking River limestone quarry in Morgan County (Appendix B, sample 2125) also indicates a Pennsylvanian age; however, a sample taken from an overlying coal at this location indicates a Mississippian age.

It should be pointed out here that the Lee Formation (facies A-south) is a time transgressive unit which originated along the axis of the Appalachian Basin and moved laterally to the northwest with time (Englund and Delaney, 1966 a, b). In northwestern Virginia and extreme southeastern Kentucky, the Lee Formation intertongues with the Pennington Formation and the lower part has been suggested as possibly Late Mississippian in age (Englund, 1964, 1966; Wanless, 1975, plate 13).

Climate

Sediments of the Pennsylvanian Period in the Appalachian Basin contain flora which record plant growth in a warm, humid climate. The first evidence that the climate was tropical or subtropical was presented by White (1913, 1932). Based on these and later works Schopf, 1972; Meyen, 1969, 1970), it is generally accepted that the areas within the Appalachian Basin and northern European coal fields represent the warmest and most humid climates recorded (Schopf, 1975). Koppen and Wegner (1924) were the first to postulate that the location of these coal fields might mark the location of the Carboniferous equator, and this still appears to be a vaid concept (Schopf, 1975). The approximate location of the Carboniferous equator is shown in Figure 24.

Pennsylvanian flora developed largely from that which had evolved in the Mississippian Period, which White (1913, p. 74) described as "impoverish, restricted, and seemingly stunted". Schopf (1975, p. 29) describes the rapid expansion of new plants during the Pottsville as evidence of climatic evolution and believes that this was perhaps the time of greatest and most evenly distributed rainfall. These two fac-

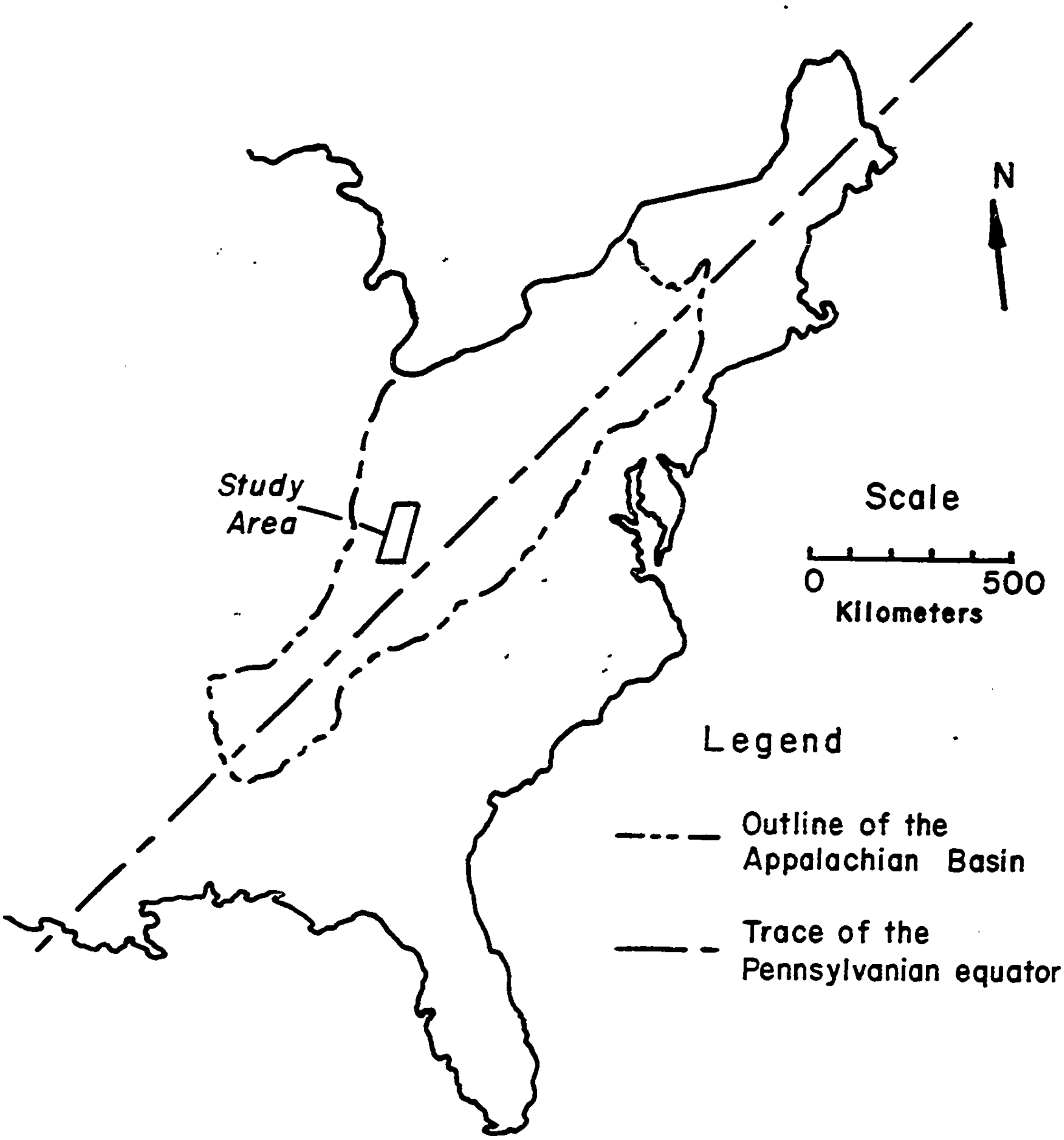


Fig. 24: Approximate position of the equator in relation to the Appalachian Basin and the study area during the Pennsylvanian. Adapted from Schopf (1975, p. 26).

tors, climate and plant growth, coupled with the extensive epicontinental seas and coastal elevations of little more than several feet (Schopf, 1975) led to the accumulation of the major coal deposits in the basin.

The possible presence of Mississippian coals in northeastern Kentucky implies that environments capable of supporting coal-forming conditions existed prior to the Pennsylvanian Period. Evidently, the climate was suitable for coal formation and the plant growth was sufficient to produce the organics necessary. This opens to speculation the nature of the environment of deposition. Wanless et al. (1969) pointed out that the predominant opinion is that most Carboniferous coals accumulated in situ, and they list eight examples of environment of accumulation for these sediments. Four of the environments encompass deltaic, estuarine, or fluvial settings, while the remaining four include narrow coastal strips similar to the modern Atlantic coast, lagoons behind offshore barriers, a plain exposed after an abrupt marine regression, or a level depositional plain formed by burial of pre-Pennsylvanian topographic irregularities.

LATERAL AND VERTICAL RELATIONSHIPS

Introduction

To arrive at a viable model describing the depositional environments of the sediments being studied, it is necessary to construct a three-dimensional picture which outlines the lateral and vertical relationships of the facies which have been described. The areal distributions of these facies have previously been described and illustrated; however, to illustrate the vertical and lateral relations, cross-sections have been constructed using measured sections, outcrop descriptions, well cutting descriptions and U.S.G.S geological quadrangle maps.

Nine separate cross-sections have been constructed. Because of the patchy nature of the Newman Limestone in the northern part of the study area, it has been necessary to use both the Newman and Borden formations as datums for the construction of the cross-sections. It is doubtful that this datum actually represents a level line, but because of considerations which will come to light, it is believed that this is the best possible choice.

Cross-section #1

Cross-section #1 (Fig. 25), located in northeastern Greenup County, Kentucky (Fig. 26), is oriented north-south and utilizes recent road exposures along U. S. Highway 23.

The most obvious characteristic shown in this section is the channel-like geometry of the sandstones of facies D. Three channels are present; all exhibit sharp basal contacts and the two larger ones have undulatory

LEGEND

FOR FIGURES CONTAINED IN TEXT

Lithology

- Facies A sandstone
- Facies B sandstone
- Facies C sandstone
- Facies D sandstone
- Facies G sandstone
- Facies H flint clay
- Borden siltstone
- Coal

Facies E

- Clay shale
- Silty shale

Facies F

- Green shale
- Limestone
- Dolomite

Symbols

- Plant fossils
- Invertebrate fossils
- Bioturbation
- Ripple drapes
- Siderite
- Carbonate cement
- Observable contact
- Inferred contact
- ? Unknown extent
- Facies change
- Covered interval

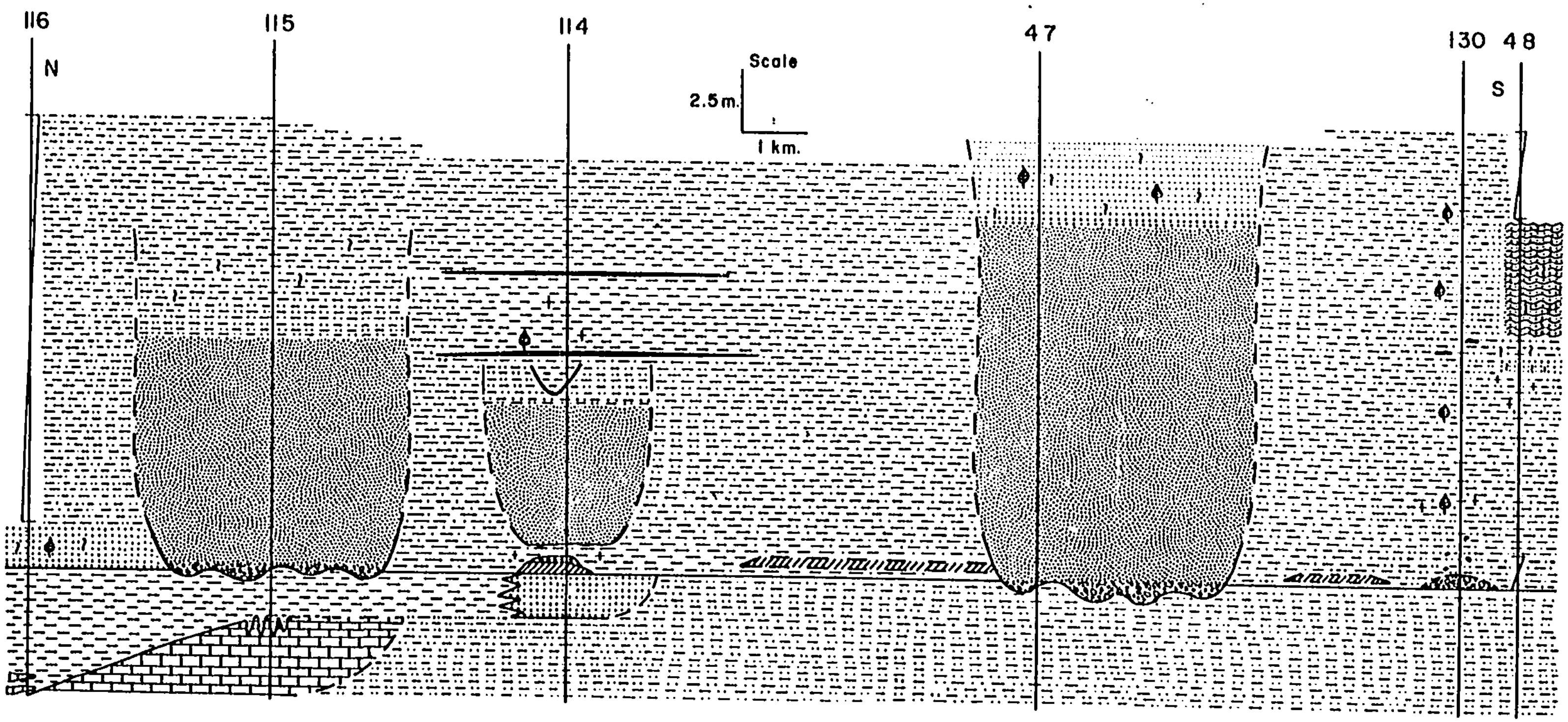


Fig. 25: Cross-section I oriented north-south and showing the channel-like geometry of facies D. Datum is the top of the Borden and Newman formations.

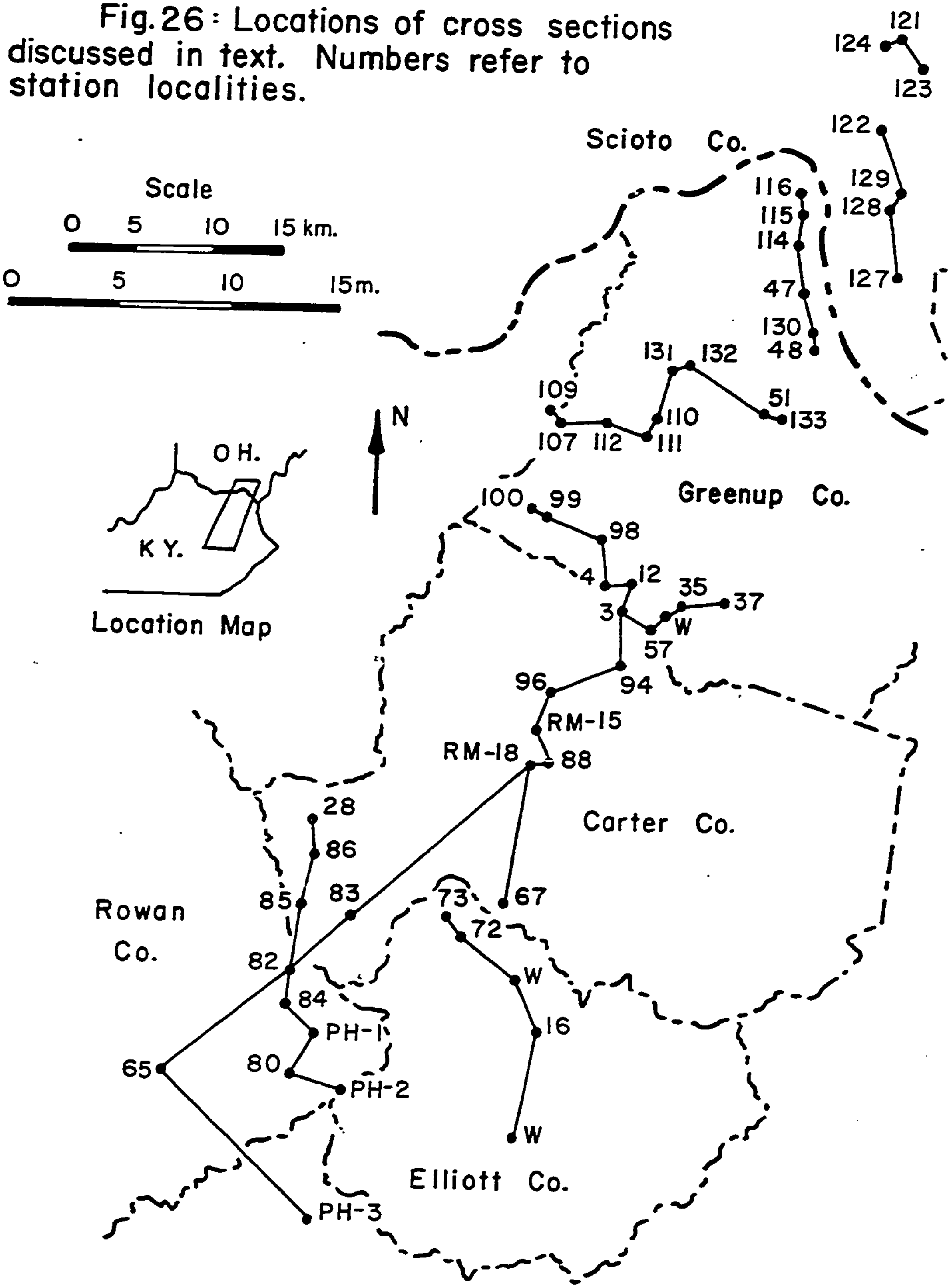


Fig. 26: Locations of cross sections discussed in text. Numbers refer to station localities.

bases with relief up to 1.5 meters (5 feet, Plate 18). The sandstones at the north end of the outcrop belt rest on green shales which have been mapped as the Newman Limestone (Sheppard, 1964). The limestone itself can be found underlying the shales, and at Station 115 these carbonates show an extensive development of solution cavities up to 2.0 meters (6.5 feet) deep which have been infilled by the green shale (Plate 18). The limestone is not developed extensively and appears to pinch out to the south, because it is not present at Station 114. At this location and all others to the south within this cross-section, sandstones and shales are found lying directly on the Borden Formation. At Station 130, a rubble zone consisting of angular chert and limestone pebbles and cobbles up to 8-9 cm. (3.0-3.5 inches) in diameter with many coal stringers and an abundance of carbonaceous material, marks this contact. The rubble zone is 0.5 meters (1.6 feet) thick. At Station 114, the top of the Borden is locally covered by a several centimeter thick iron oxide covering which contains angular chert and limestone pebbles.

The channels consist of fine- to medium-grained sandstone with lag deposits consisting largely of angular to subangular chert pebbles and a lesser amount of well-rounded quartz pebbles. Vertically, the sandstones grade into siltstones and eventually black shales of facies E_1 (Plate 18). Facies D channel sandstones at Station 114 grade into carbonaceous black shales of facies E_1 which contain three thin coal beds. The lowest of these coals appears to be a channel fill deposit, while the upper coals, judging from their geometry, are the result of deposition in more areally extensive environments.

Laterally, the sandstone bodies grade into siltstones and shales of facies E_1 and E_2,; however, discrete channel boundaries are generally not visible because of poor exposures. A lateral gradation is observable between Stations 47 and 130 where the lithology changes from sandstones of facies D to siltstones and shales of facies E_1. The sandstones themselves pinch laterally into the adjacent lithologies; however, this geometry is not shown on the cross-sections because of the vertical exageration.

Locally occurring and marginal to some channels (Station 48) are sandstone bodies characteristic of facies B sediments. Bioturbation consisting of worm burrows and traces of Pelecypodichnus are common on the ripple and flaser bedded sandstone. This unit was probably deposited concurrent or just prior to channel formation in this area.

Locally, the Olive Hill clay bed can be found underlying or marginal to the channel sandstones. At Station 114, the clay bed underlies the sandstone, probably because the channel did not erode into these underlying sediments; however, in other instances the clay bed is only marginal to the sandstones, indicating removal of erosion or nondeposition.

Cross-section #2

Cross-section #2 (Fig. 27) is oriented roughly east-west in western and central Greenup County (Fig. 26). The cross-section depicts the channel-like geometry of the facies D sandstones and the nature of the enclosing sediments.

The sandstone bodies are enclosed in a matrix of black, silty shales which are dominantly characteristic of facies E_1; however, there

LEGEND
FOR FIGURES CONTAINED IN TEXT

Lithology

Facies A sandstone	Facies E
Facies B sandstone	Clay shale
Facies C sandstone	Silty shale
Facies D sandstone	Facies F
Facies G sandstone	Green shale
Facies H flint clay	Limestone
Borden siltstone	Dolomite
Coal	

Symbols

Plant fossils	Observable contact
Invertebrate fossils	Inferred contact
Bioturbation	? Unknown extent
Ripple drapes	Facies change
+ + + Siderite	Covered interval
Carbonate cement	

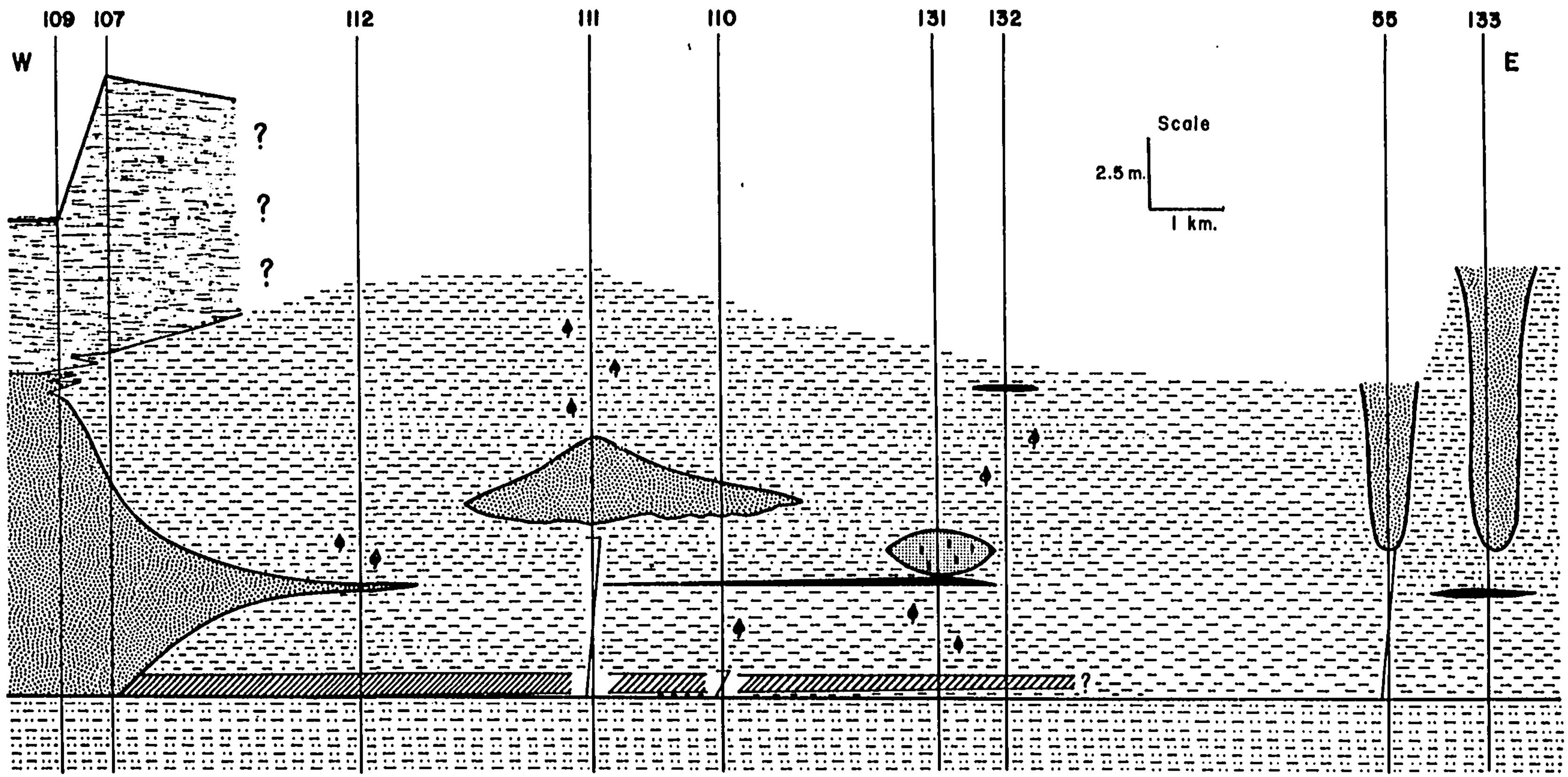


Fig. 27: Cross-section 2 oriented east-west in northern Greenup County, Kentucky. Note presence of flint clay and channel-shaped sand bodies. Datum is the top of the Borden Formation.

are local occurrences of bioturbated sandstones of facies B. At Station 131, a fine-grained, rippled, bioturbated sandstone containing many large (10-20 cm., 4-8 inches in diameter) woody fragments overlies a 10-cm. (4-inch) coal. This coal is possibly the same which occurs at Station 110; however, at this location the coal is overlain by silty shales of facies E_1.

The Olive Hill clay bed appears to be extensively developed in this area, being absent only on the west end of the section where it seemingly has been removed by erosion of the channel sandstone and possibly on the eastern edge, although exposures are too poor to be certain in this area.

At Stations 107 and 109, a large channel sandstone wich contains a basal lag deposit of woody fragments and small quartz pebbles with a maximum diameter of 5 mm. (0.2 in.) is present. The sandstone is characteristic of facies D and locally contains convolute or contorted bedding with an erosive base into the underlying Borden Formation. The lateral extent of the unit is not well-defined, and a 0.25-meter (10-inch) fine-grained sandstone containing abundant woody fragments, quartz pebbles and clay clasts may be its equivalent at Station 112.

Generally, black shales of facies E_1 form the top of this section; however, at the western end, overlying the facies D sandstones, is a local occurrence of facies C sediments. At Station 109, this unit appears to be interbedded with sandstones of facies D; however, to the east at Station 107 these two units are separated by a 5.2-meter (17 feet) covered section which appears to consist of shales of facies E_1. The facies C body is lost under cover to the east and its lateral extent is not determinable.

Cross-section #3

This cross-section (Fig. 28), oriented slightly northwest-southeast in southwestern Greenup County (Fig. 26), shows the relationships between the sediments of facies B, C, D, E and H. Again, the channel geometry of facies D sandstones is apparent; however, at this location the sandstones do not rest on the Newman and/or Borden formations, but on black shales of facies E_1 and E_2, which in turn lie on the datum line sediments. The Newman in this area is very patchy and is often represented by interbedded limestone and shale in the upper parts.

Four channels are shown in this section; however, the sandstone at Station 57 may actually be a continuation of the body shown at Station W and 35. These sandstones contain most of the characterstics of facies D sediments, lacking only the lag deposits described in the previous section; however, plant material such as Annularia pieces often from a basal lag concentration (Station 96).

Marginal to, and sometimes underlying facies D sediments, are sandstone body characteristics of facies B. Locally underlying these sandstone bodies is a 7-20 cm. (3-8 inch) coal bed (Stations 98, 99). At Station 98, the coal lies immediately below the facies B sandstone; however, at Station 99 the coal is separated from the sandstone by 0.5 meters (1.6 feet) of black, carbonaceous shale which contains abundant plant material (facies E_1). Laterally to the east and west, the coal and sandstone disappear and are replaced by sandstones of facies D. A small sandstone is present below the channel sandstone at Station 12; however, because of poor exposures it cannot be ascertained if this is a continuation of the bioturbated sandstone at Stations 98 and 99. The

LEGEND
FOR FIGURES CONTAINED IN TEXT

Lithology

- Facies A sandstone
- Facies B sandstone
- Facies C sandstone
- Facies D sandstone
- Facies G sandstone
- Facies H flint clay
- Borden siltstone
- Coal

Facies E

- Clay shale
- Silty shale

Facies F

- Green shale
- Limestone
- Dolomite

Symbols

- Plant fossils
- Invertebrate fossils
- Bioturbation
- Ripple drapes
- Siderite
- Carbonate cement
- Observable contact
- Inferred contact
- Unknown extent
- Facies change
- Covered interval

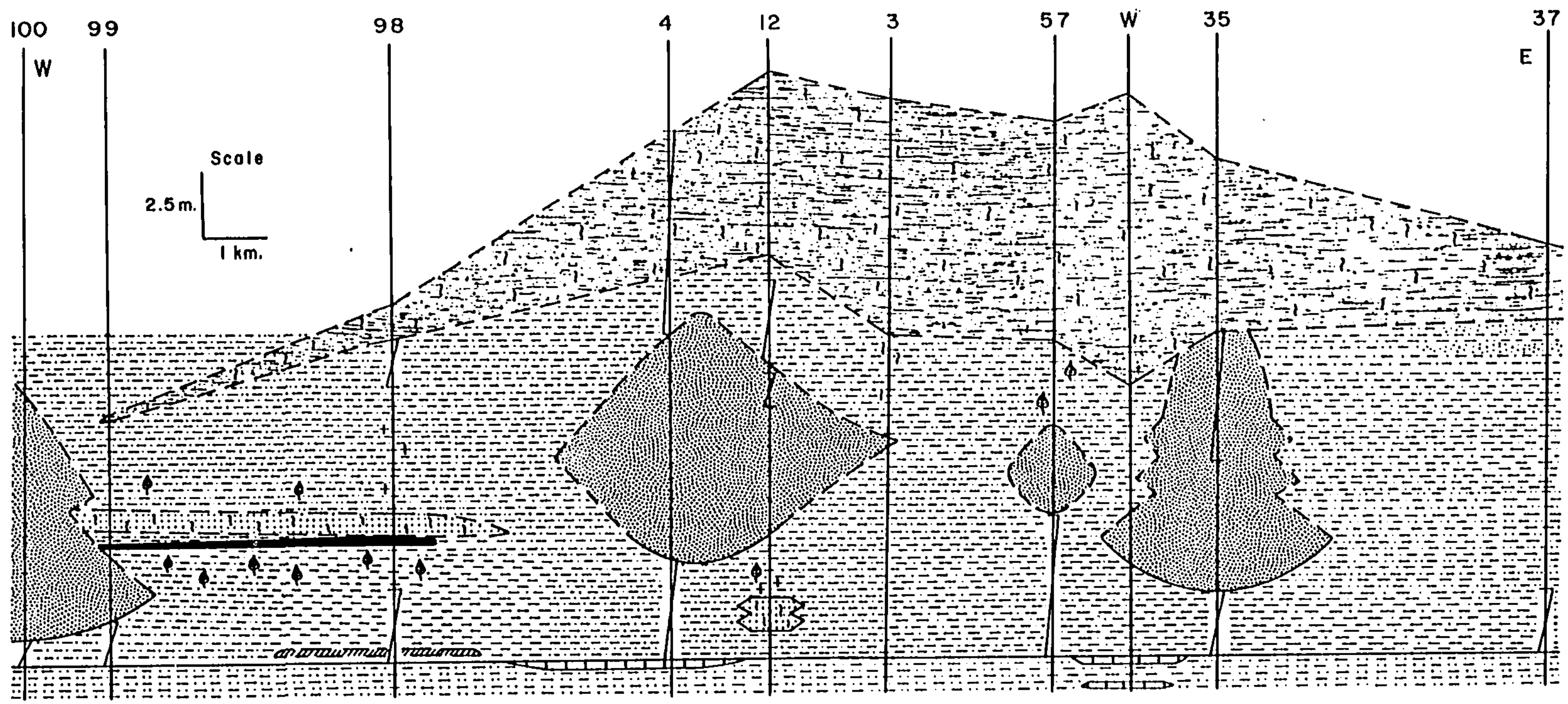


Fig. 28: Cross-section 3 oriented east-west in southern Greenup County, Kentucky showing the relationships between the sediments of facies B, C, D, E, and H. Datum is the top of the Newman and Borden formations.

bioturbated sandstone probably represents a minor transgression over a coal-forming environment by shallow, probably marine waters.

Facies C sandstones comprise the uppermost exposures throughout most of this cross-section. The unit overlies sandstones of facies B and D and thins both to the east and west, eventually pinching into shales of facies E_1. At Station 57, shales of facies E_2 lie between sandstones of facies D and C and contain traces of Scalarituba burrows in the upper part. The boundary between the shales and facies C is gradational and probably represent a transition from facies D sedimentation to that of facies C.

The Olive Hill clay bed is present on the west end of the cross-section; however, it was never seen in outcrop. Stations 98, 99 and 100 are clay strip pits, and pieces of the clay can be seen in float material.

Cross-section #4

Cross-section #4 (Fig. 29), oriented roughly north-south through central and northwestern Elliott County (Fig. 26), shows the pinching of facies A-south sandstones to the north. These sandstones, where fully developed, reach thicknesses up to 60-70 meters (200-230 feet), but thin rapidly to the north-northwest (Fig. 8). At Station 73, 5 meters (16 feet) of coarse-grained, planar cross-bedded, pebbly sandstone is visible, while about 1.9 km. (1.2 miles) to the southeast this same sandstone is 25.5 meters (84 feet) thick.

The sandstone normally rests on black shales and siltstones of facies E_1. Load structures are present at the contact at Station 72 and show a common alignment of 335 degrees. At Station 16, the underlying

LEGEND
FOR FIGURES CONTAINED IN TEXT

Lithology

Facies A sandstone	Facies E
Facies B sandstone	Clay shale
Facies C sandstone	Silty shale
Facies D sandstone	Facies F
Facies G sandstone	Green shale
Facies H flint clay	Limestone
Borden siltstone	Dolomite
Coal	

Symbols

Plant fossils	Observable contact
Invertebrate fossils	Inferred contact
Bioturbation	Unknown extent
Ripple drapes	Facies change
Siderite	Covered interval
Carbonate cement	

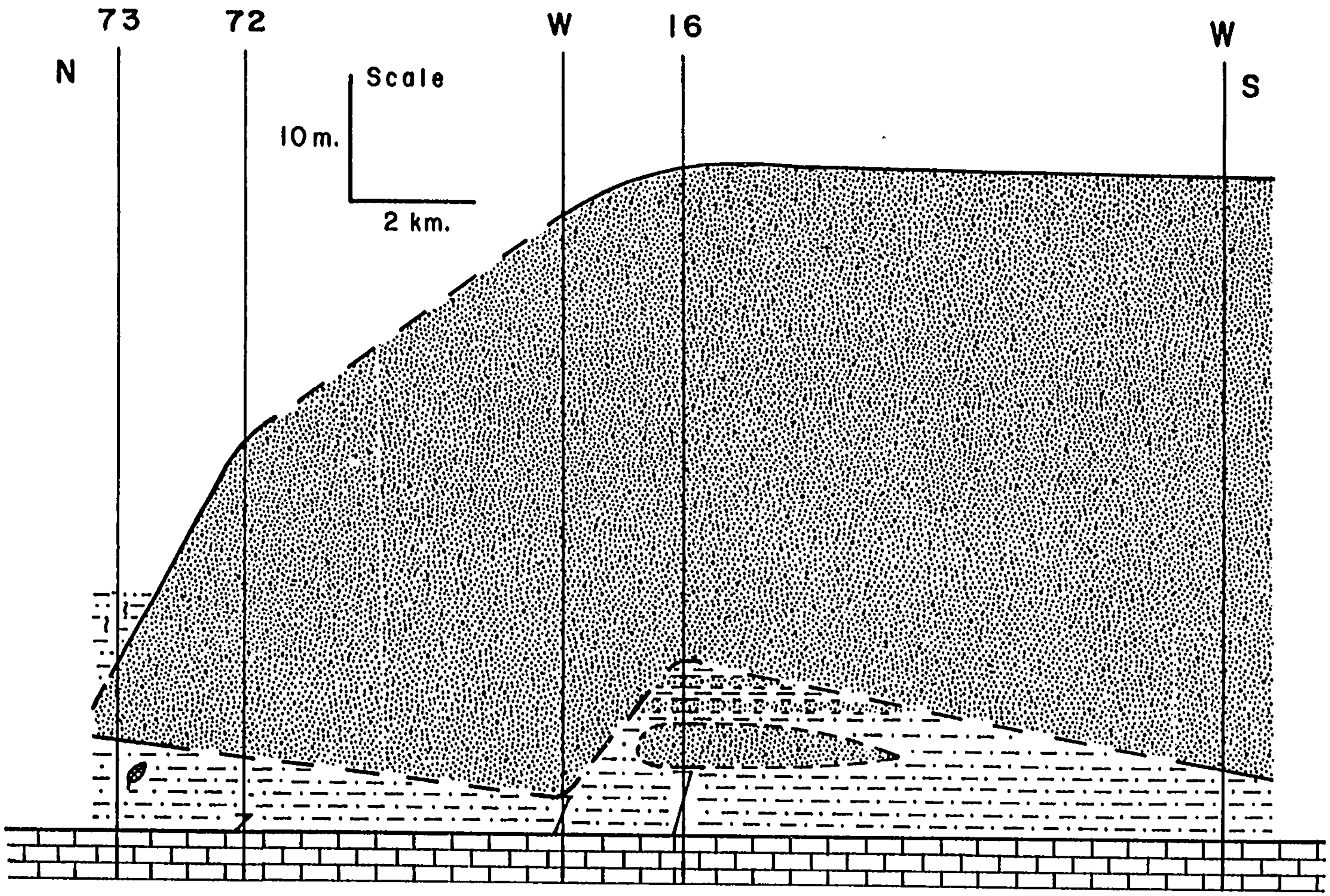


Fig. 29: Cross-section 4 oriented north-south in central Elliott County, Kentucky. Section shows the thinning and eventual pinch-out of facies A to the north. The Kentucky River Fault System occurs just south of Station 16. Datum is the top of the Newman Limestone.

shales are interbedded with planar bedded, silty sandstones (Plate 44) which contain abundant microcross-laminations. Slumps of shale into the underlying convolute bedded sandstone are also present here.

At Station 73, thin to laminar bedded shales and siltstones which have unidentifiable bioturbation structures consisting of tracks and trails on bedding planes, overlie the facies A-south sandstones. Pods and lenses of fine-grained sandstone also occur in this interval. At this and all other localities, the sandstone of facies A-south grade vertically into black shales which are part of the Breathitt Formation (Delaney and Englund, 1973, Plate 6).

The Newman Limestone is more fully developed in these southern exposures of the study area and forms the datum at all localities. The more extensive development of the limestone here has been attributed to activity on the Kentucky River Fault System which isolated areas on the northern, or uplifted, block during deposition (Dever, 1973; Ettensohn, 1975, 1976). This fault system also appears to have influenced the deposition of facies A-south sediments, because the unit begins to thin in the area where the fault system has been mapped (Figs. 2, 7, 8, and 29). Evidently, the northern block was still elevated enough to halt the northwestward transgression of facies A-south depositional processes.

Cross-section #5

Cross-section #5 (Fig. 30), oriented north-south in eastern Rowan and southwest Carter Counties (Fig. 26), shows the thinning of facies A-south as it crosses the Kentucky River Fault System and the vertical relation between that facies and facies B. The thickness distribution of facies B is also apparent.

Plate 44. Facies A-south sandstones overlying interbedded shales and planar bedded, microcross-laminated, silty sandstones at Station 16 in central Elliott County, Kentucky. Measured section is shown in Appendix D.

LEGEND
FOR FIGURES CONTAINED IN TEXT

Lithology

- Facies A sandstone
- Facies B sandstone
- Facies C sandstone
- Facies D sandstone
- Facies G sandstone
- Facies H flint clay
- Borden siltstone
- Coal

Facies E

- Clay shale
- Silty shale

Facies F

- Green shale
- Limestone
- Dolomite

Symbols

- Plant fossils
- Invertebrate fossils
- Bioturbation
- Ripple drapes
- Siderite
- Carbonate cement
- Observable contact
- Inferred contact
- Unknown extent
- Facies change
- Covered interval

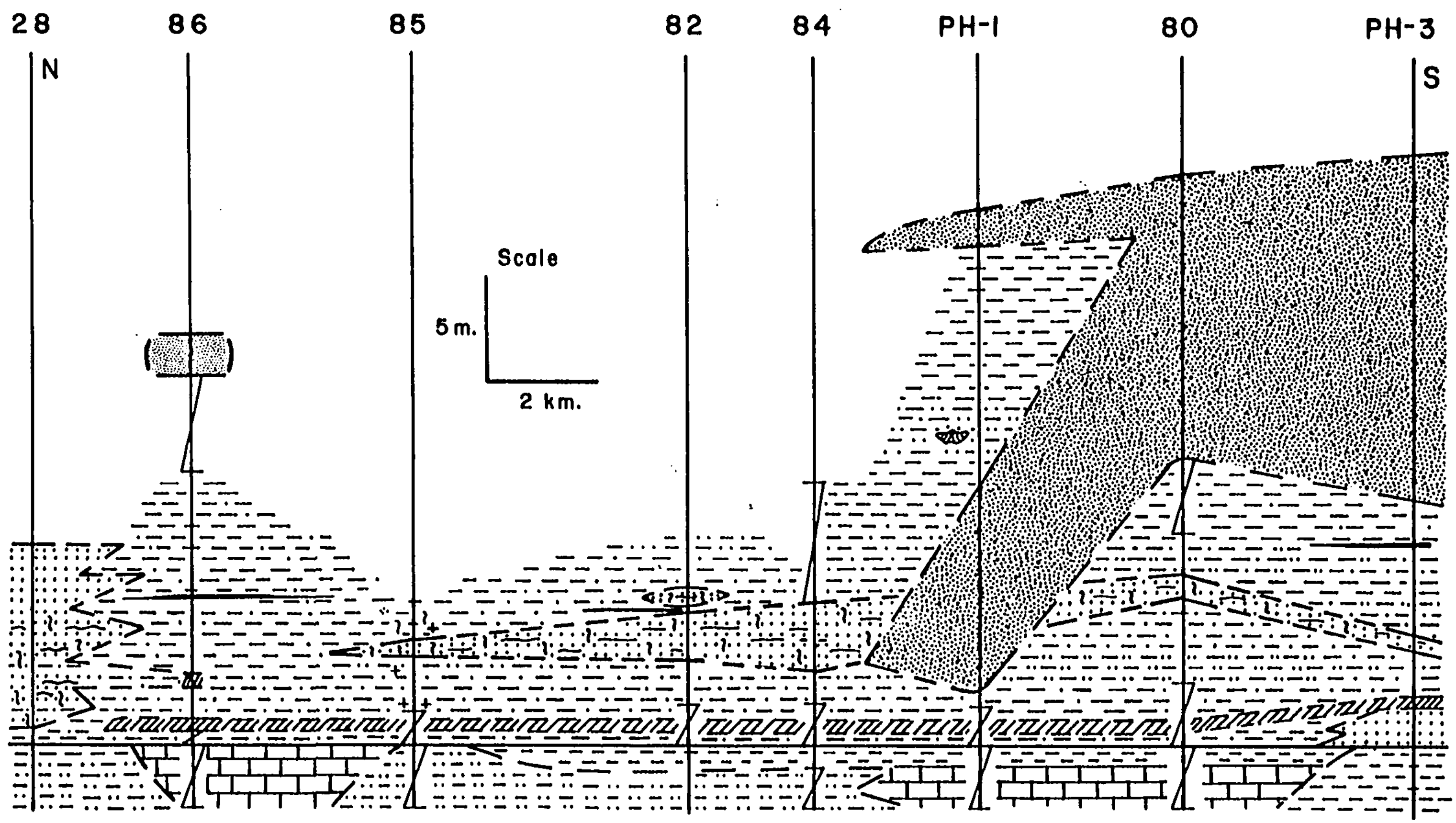


Fig. 30: Cross-section 5 oriented north-south in eastern Carter Co., Kentucky. Note the northward pinch-out of facies A-south and the vertical and lateral relationships of facies A-south, B, D, E, F, and H. Datum is the top of Newman and Borden formations. The Kentucky River Fault System occurs on the southern edge of the section.

Each of the stations from which the cross-section is constructed, except PH-1 and PH-2, is taken from now closed clay strip pits. This indicates a very widespread development of the Olive Hill clay bed in this area. Only at Station 86, however, was the clay actually observed in outcrop, there attaining a thickness of 1.2 meters (3.9 feet). The clay rests very near the Borden and Newman formations, both of which form the datum for this section. The Newman is not extensively developed here, probably because of activity on the Waverly Arch during its deposition (Ettensohn, 1975, 1976). Likewise, the extensive development of the Olive Hill clay bed and facies B sandstones in this area is probably due to favorable conditions which existed atop this positive feature during their formation.

Facies B is not continuous throughout the cross-section, being absent in the northern part at Station 86 where the section consists of black shale of facies E_1 and sandstones of facies D. The Newman is present at this location, however, and may represent a local depositional low which accumulated fine-grained sediments. The thin coals present in the shales infer a more marginal marine or fresh water type environment in contrast to the more marine environment suggested by the facies B sandstones. This area may mark the approximate position of the shoreline during that time of deposition.

A small dolomite bed is present at Station 82 in the upper part of facies B just above the coal pictured. This dolomite, which appears to be part of facies F, probably represents a slight deepening of the waters before subsequent deposition of overlying facies E_1 shales. The coal may be correlative to the coal at Station 86; however, exposures are too poor to trace the bed laterally.

Facies B sandstones underlie the sandstones of facies A-south in all instances except at Station PH-1. This section is taken from Patterson and Hosterman's (1962) work and has not been documented by this author. However, according to the former author's description, the lower sand body belongs to the Corbin Sandstone Member of the Lee Formation, or facies A-south, rather than facies B. If this is true, facies A-south sandstones at that locality appear to be the result of erosion into underlying sediments of facies B and E. The erosion may have been caused by onlap of this depositional system onto the uplifted block of the Kentucky River Fault System, thereby causing erosion and the resultant depositional pattern.

Cross-section #6

Cross-section #6 (Fig. 31), oriented north-south in central Carter County (Fig. 26), shows the relationships between sediments of facies A-south, C, D, E, G, and H.

The lower sandstone body shown in the cross-section is assigned to facies D of this study and has been mapped by the U. S. Geological Survey as the Carter Caves sandstone. This body is interpreted here as an extension of the channel sandstone depicted in cross-sections #1, #2, and #3. Earlier workers (Sheppard and Dobrovolny, 1963; Englund and Windolph, 1972, Martin, 1975) have defined the northern limit of the body as occurring in the southern Brushart quadrangle; however, this study shows that the unit actually extends northward to near the Ohio River and, in fact, consists of a series of channels rather than the single channel previously defined (Fig. 12).

LEGEND
FOR FIGURES CONTAINED IN TEXT

Lithology

- Facies A sandstone
- Facies B sandstone
- Facies C sandstone
- Facies D sandstone
- Facies G sandstone
- Facies H flint clay
- Borden siltstone
- Coal

Facies E
- Clay shale
- Silty shale

Facies F
- Green shale
- Limestone
- Dolomite

Symbols

- Plant fossils
- Invertebrate fossils
- Bioturbation
- Ripple drapes
- Siderite
- Carbonate cement
- Observable contact
- Inferred contact
- Unknown extent
- Facies change
- Covered interval

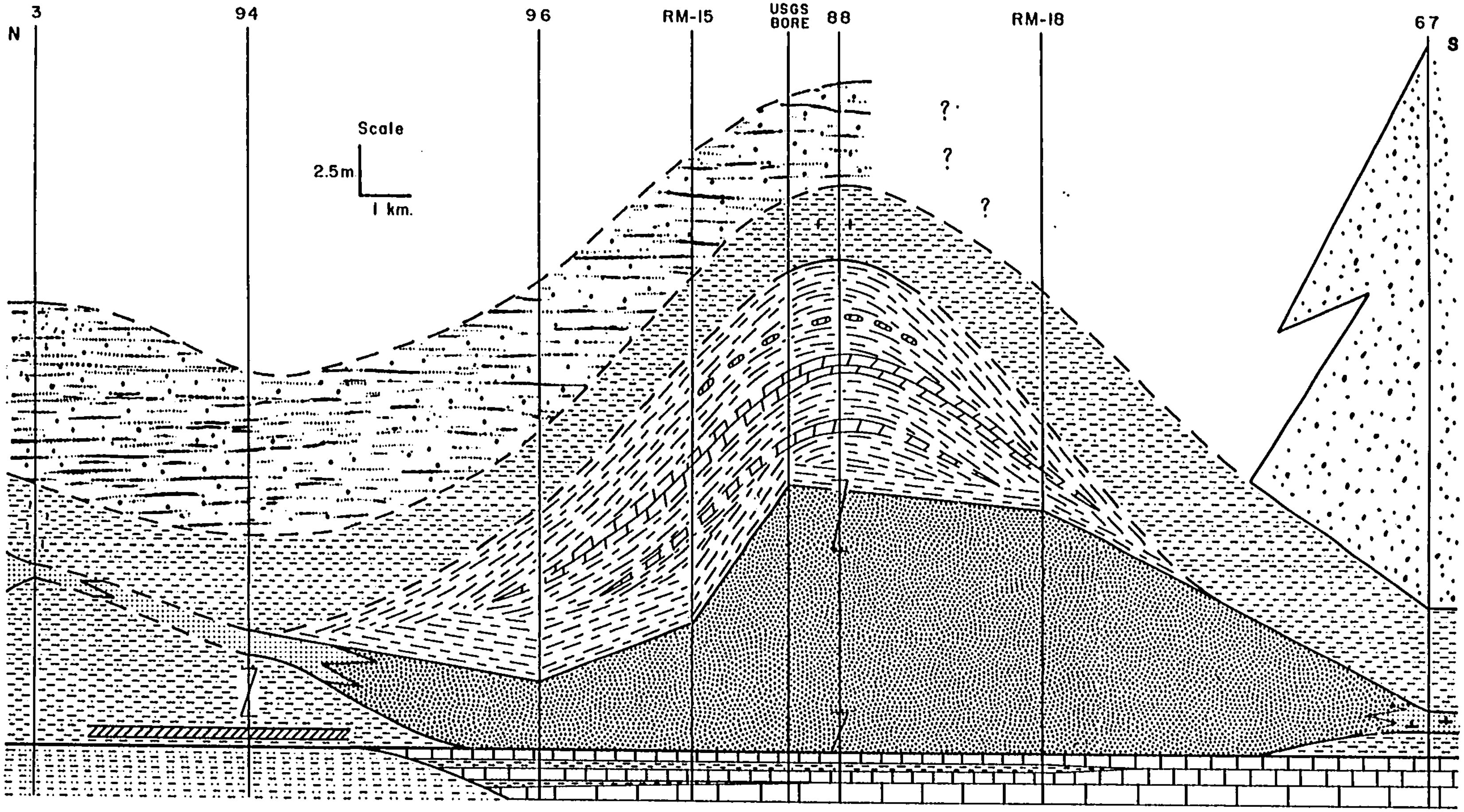


Fig.31: Cross-section 6 oriented north-south through central Carter County and showing the relationships of facies A-south, C, D, E, F, G and H. The datum is the top of the Borden and Newman formations.

At the southern limit of the section, at Station 67, the sandstone stratigraphically equivalent to the facies D sandstone is lithologically characteristic of facies G and apparently represents a change in the depositional conditions from the channel environment to one more influenced by marine conditions.

Locally overlying facies D sandstones at Stations 88, 96, RM-15, RM-18, and U.S.G.S. Bore Hole are limestones and shales of facies F. These are the same limestones which yielded fossil dates indicating a Late Chester age for these sediments (see Dating of the Sediments). This section shows the limited north-south extent of this unit and its probable pinch out into shales of facies E_1. However, to the south this facies is again developed extensively, and the southern pinch out is probably only a local occurrence.

At the southern limit of the cross-section, conglomeratic sandstones of facies A-south can be seen overlying sediments of facies G and F. This shows that deposition of facies A-south (Corbin sandstone) was after the deposition of the sands and carbonates of facies G and F, respectively. Once again, the sandstones of facies A-south thin rapidly to the north.

In apparent facies relation with the sandstones of facies A-south are sediments of facies C. At Station 88, these sandstones exhibit a channel-like geometry; however, to the north the unit is more sheet-like. The contact between facies C sandstones and the underlying facies E_1 shales is everywhere gradational; however, the contact between facies E_1 and the overlying facies F is very sharp, indicating a sudden change in environmental conditions.

The datum for this cross-section is comprised of both the Newman and Borden formations. At the most southern exposures, the Newman is completely developed; however, to the north in the vicinity of Stations RM-15 and 96, the upper part of the Newman is interbedded with green shale, while at Stations 3 and 94 the Newman is completely absent.

Flint clays are conspicuously absent throughout this cross-section except at Station 94 where 70 cm. (27 inches) of the clay is exposed. The absence is attributed largely to erosion from the facies D depositional processes.

Cross-section #7

Cross-section #7 (Fig. 32) extends from western Morgan County into southeastern Rowan County and thence northwestward into central Carter County (Fig. 26). The section is based on only six control points but is important because it shows the probable southern and western extension of the shales, limestones and dolomites of facies F. This provides a valuable tool for correlation and a means of dating these more southern exposures.

The relationship between facies F and facies D sediments has previously been depicted in cross-section #6. Sampling of sediments at Stations 65, 82 and 88 plus information from Patterson and Hosterman (1962, p. F25) and well cuttings (Station W) indicates the presence of a dolomite zone overlying the sandstones of facies D, B and G at these locations. These carbonate zones are shown in Figure 32 and correlated on the basis of lithologic similarity. This correlation encompasses sediments at Station 83, and although the dolomite has not been posi-

LEGEND

FOR FIGURES CONTAINED IN TEXT

Lithology

Facies A sandstone

Facies B sandstone

Facies C sandstone

Facies D sandstone

Facies G sandstone

Facies H flint clay

Borden siltstone

Coal

Facies E

Clay shale

Silty shale

Facies F

Green shale

Limestone

Dolomite

Symbols

Plant fossils

Invertebrate fossils

Bioturbation

Ripple drapes

Siderite

Carbonate cement

Observable contact

Inferred contact

Unknown extent

Facies change

Covered interval

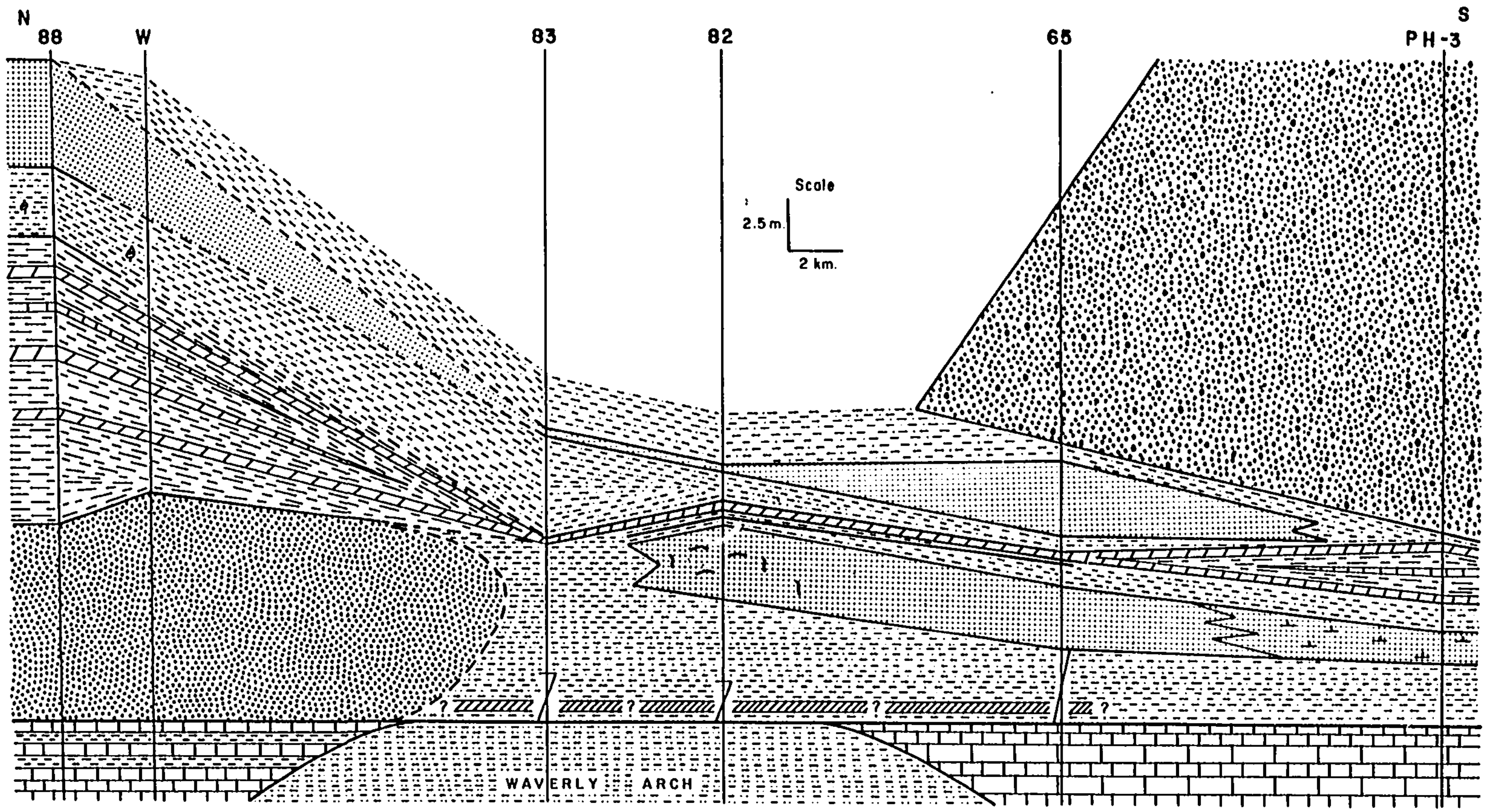


Fig. 32: Cross-section 7 oriented north-south in Carter, Rowan and Morgan counties showing the lateral and vertical relationships of facies A-south, B, D, E, F, G, and H. The datum is the top of the Borden and Newman formations. Note the position of the Waverly Arch.

tively identified at this location, a nodular zone is present there which is highly suspect of representing this interval. The carbonate zone has been found to the northwest of this locality at Station 86. Credence is added to this correlation by the presence of two 15-cm. (6 inches) coals below the dolomites at Stations 65 and 82. The position of these coals in the sequence of sediments makes their correlation likely.

As can be seen from the cross-section, the discovery and probable correlation of these dolomites and coals provides a usuable datum for further correlation purposes. At Station 88, facies F sediments overlie sandstones of facies D, in this case the Carter Caves sandstone. This sandstone can be traced south through Station RM-18, but is lost before reaching Station 83. Two kilometers (1.2 miles) south of Station 83, at Station 74, cross-bedded sandstones of facies G are again present in this stratigraphic position. At Stations 65 and 82, sandstones of facies B appear in this same stratigraphic position, indicating a probable facies relationship between these units. Further to the south at Station PH-3, cross-bedded sandstones which contain 25-40 per cent carbonate cement and sparse marine fossils are in this position. Throughout the cross-section, these sandstones of facies B, D and G are overlain by carbonates and sometimes shales of facies F.

Overlying the facies F sediments are black, silty shales of facies E_1. These shales are locally overlain by fine-grained, horizontally bedded, sometimes bioturbated sandstones. These sandstones are not present at Station PH-3, but appear at Station 65 and persist northward to Station 83. A similar, but much thicker, sandstone which is assigned to facies C is present at Station 88 and it is likely that these bodies are correlatable.

Forming the top of the cross-section in the south is the conglomeratic sandstones of facies A-south. At Station PH-3, the unit is 42 meters (140 feet) thick, but thins rapidly to 12 meters (39 feet) at Station 65 and is absent altogether at Station 82. This zone of thinning, as before, is coincident with the position of the Kentucky River Fault System.

The datum for the section is again the Newman and Borden formations. The Newman is well-developed in the south at Stations PH-3 and 65, but is absent at Stations 82 and 83 where the Borden Formation forms the base of the section. The Newman is well-developed once again, however, at Stations W and 88. The area where the Newman is absent is coincident with the axis of the north-south trending Waverly Arch (Fig. 2). Ettensohn (1975, 1976) has attributed the thinning and sometimes disappearance of the Newman in this area to activity on the arch during the Late Mississippian. The change in the nature of the lower sandstone units (facies B, D and G) is also probably related to topographic and depositional controls exerted by this feature and the Kentucky River Fault System during the deposition of these units. Additionally, the thinning of facies F sediments, the presence of thin coals at Stations 65 and 82, and the better development of the Olive Hill clay bed are all probably because of the positive nature of the arch.

Cross-sections #8 and #9

Cross-sections #8 and #9 (Figs. 33 and 34) are located in southwestern and eastern Scioto County, Ohio, respectively (Fig. 26), and because of their relatively simplistic natures will be discussed together. Both cross-sections show conglomeratic sandstones of facies A-north as the dominant lithology present in the area; however, unlike exposures of facies A-south, these sandstones do not overlie other sandstone facies of this report. Rather, as in cross-section #9, the conglomerates lie directly on, or near, the Borden Formation. The more southern exposures of the conglomeratic sandstone body at cross-section #8 lie on black shales of facies E_2.

In cross-section #9, the sandstone contains a basal conglomerate zone consisting of quartz pebbles with diameters up to 3 cm. (1.2 inches), limestone pebbles up to 10 cm. (4.0 inches) long, and chert pebbles with a longest axis of 10 cm. (4.0 inches). The lower contact is erosional and may exhibit relief up to 1.5 meters (4.9 feet). At Station 121, the sandstone can be seen cutting into the underlying Borden Formation.

To the south, at cross-section #8, the conglomeratic sandstones no longer rest on Borden sediments, but on black, silty shales of facies E_2. At Station 127, the shale contains sparse worm burrows, siderite nodules and thin coals in the upper part above the sandstone. This appears to be a gradation from shales characteristic of facies E_2 to shales of facies E_1. To the north, at Station 128, only shales of facies E_1 are present.

The significance of these cross-sections lies in their stratigraphic position relative to the Newman and Borden formations and their lateral

LEGEND
FOR FIGURES CONTAINED IN TEXT

Lithology

Facies A sandstone

Facies B sandstone

Facies C sandstone

Facies D sandstone

Facies G sandstone

Facies H flint clay

Borden siltstone

Coal

Facies E

Clay shale

Silty shale

Facies F

Green shale

Limestone

Dolomite

Symbols

Plant fossils

Invertebrate fossils

Bioturbation

Ripple drapes

Siderite

Carbonate cement

Observable contact

Inferred contact

Unknown extent

Facies change

Covered interval

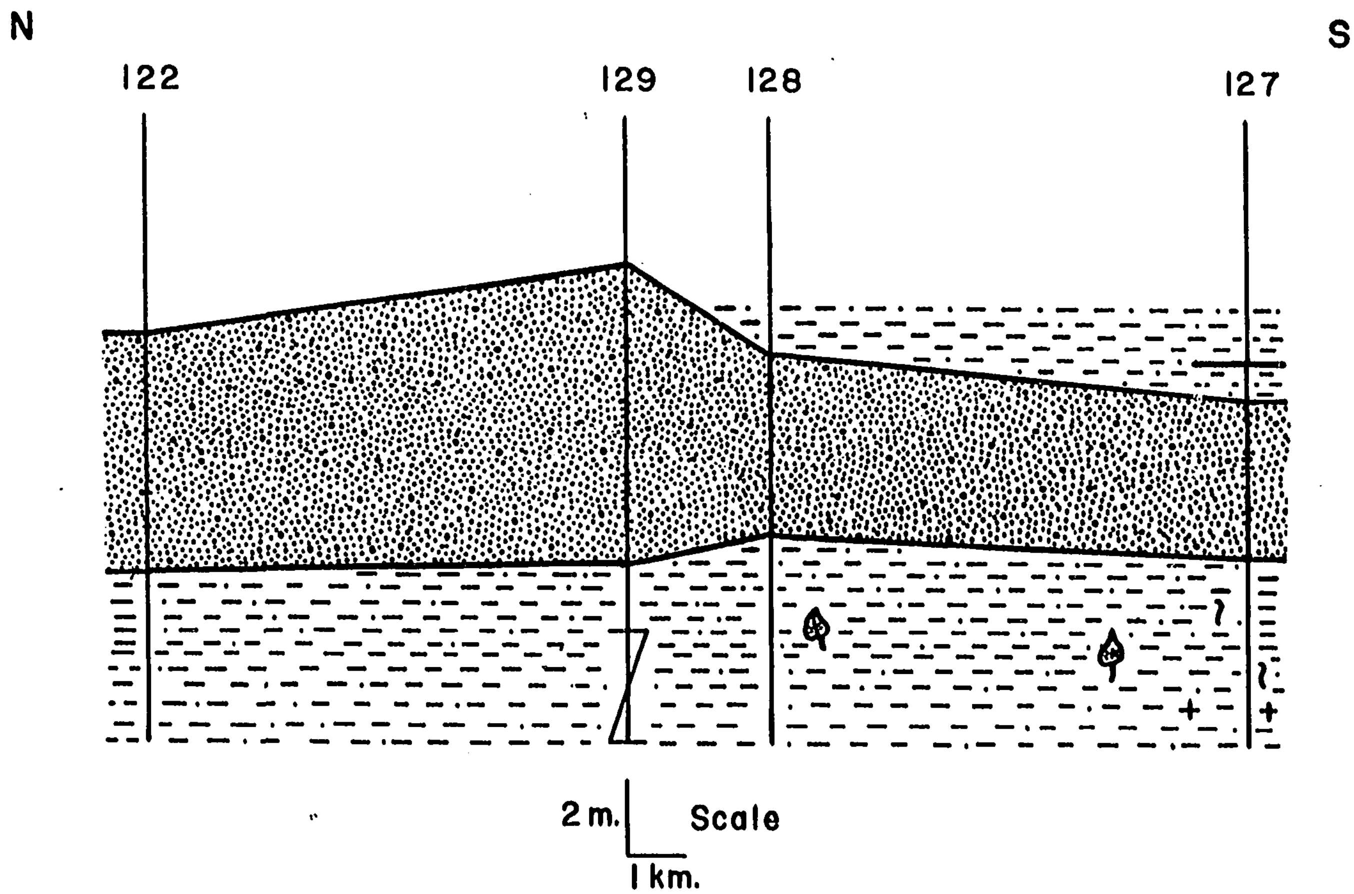


Fig. 33: Cross-section 8 oriented north-south in eastern Scioto County, Ohio. The sandstone is the Sharon Conglomerate. Upper shale is assigned to facies E-1, lower shale to E-1 and E-2. Shales rest on the Logan Formation which is equivalent to the Borden Formation of Kentucky.

LEGEND
FOR FIGURES CONTAINED IN TEXT

Lithology

Facies A sandstone	Facies E
Facies B sandstone	Clay shale
Facies C sandstone	Silty shale
Facies D sandstone	Facies F
Facies G sandstone	Green shale
Facies H flint clay	Limestone
Borden siltstone	Dolomite
Coal	

Symbols

Plant fossils	Observable contact
Invertebrate fossils	Inferred contact
Bioturbation	Unknown extent
Ripple drapes	Facies change
Siderite	Covered interval
Carbonate cement	

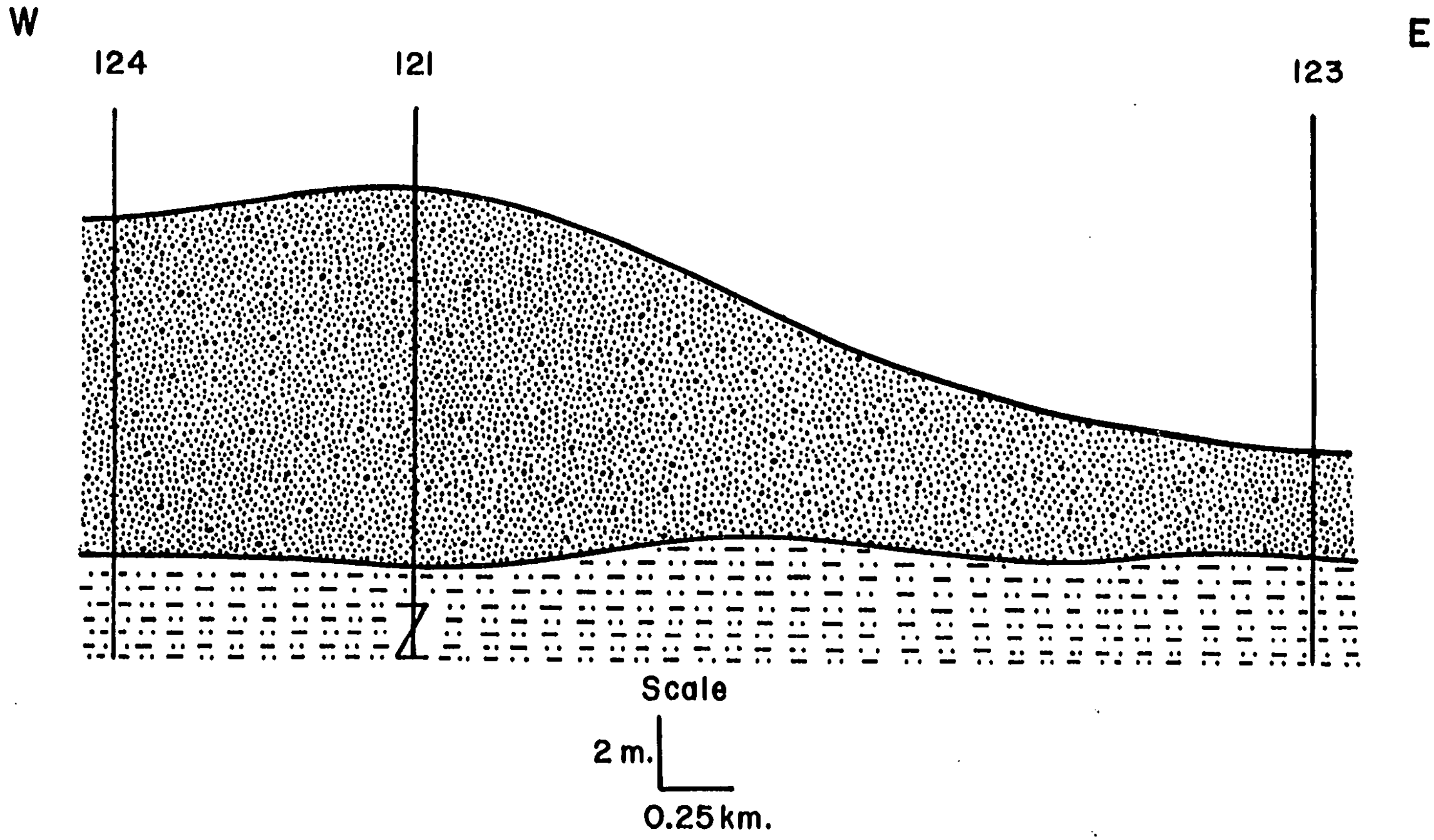


Fig. 34 : Cross-section 9 oriented east-west in eastern Scioto County, Ohio. The Sharon Conglomerate sharply overlies the Logan Formation, which is equivalent to the Borden Formation of Kentucky.

position relative to the channel sandstones of facies D. Seven kilometers (4.3 miles) to the west of cross-section #8, this same stratigraphic interval is occupied by the channel sandstones of facies D, sandstones of facies B, shales of facies E_1 and E_2, and the Olive Hill clay bed. Based on stratigraphic position, mineralogy and general lithologic composition, it is suggested that the facies A-north sandstones and the sediments present in cross-section #1 were all deposited concurrently. This line of reasoning will be pursued in the next chapter.

Station 119

This section is included here only because it represents a complete coarsening upwards sequence which is not observable elsewhere in the study area. Station 119 is an abandoned clay strip pit and although the clay itself is not exposed, abundant float material testifies to its presence. The lower 10 meters (32.8 feet) of the section consists of black, silty shales of facies E_2. It is from this zone that many of the Teichichnus trace fossils were collected. The shale becomes progressively siltier upsection (Fig. 35), becoming interbedded with thin, rippled and bioturbated beds of fine-graned sandstone similar to facies B sediments. At the top of this interval, a massive, horizontally bedded, bioturbated, fine-grained sandstone predominates.

The progressively coarsening upwards, bioturbated sequence is overlain by 5.4 meters (17.7 feet) of covered interval which, in turn, is overlain by 6.8 meters (22.3 feet) of facies D sandstone that contains common rounded quarts pebbles in the lower 4 meters (13 feet). Paleocurrent directions in the sandstone range from 124° to 234°, indicating

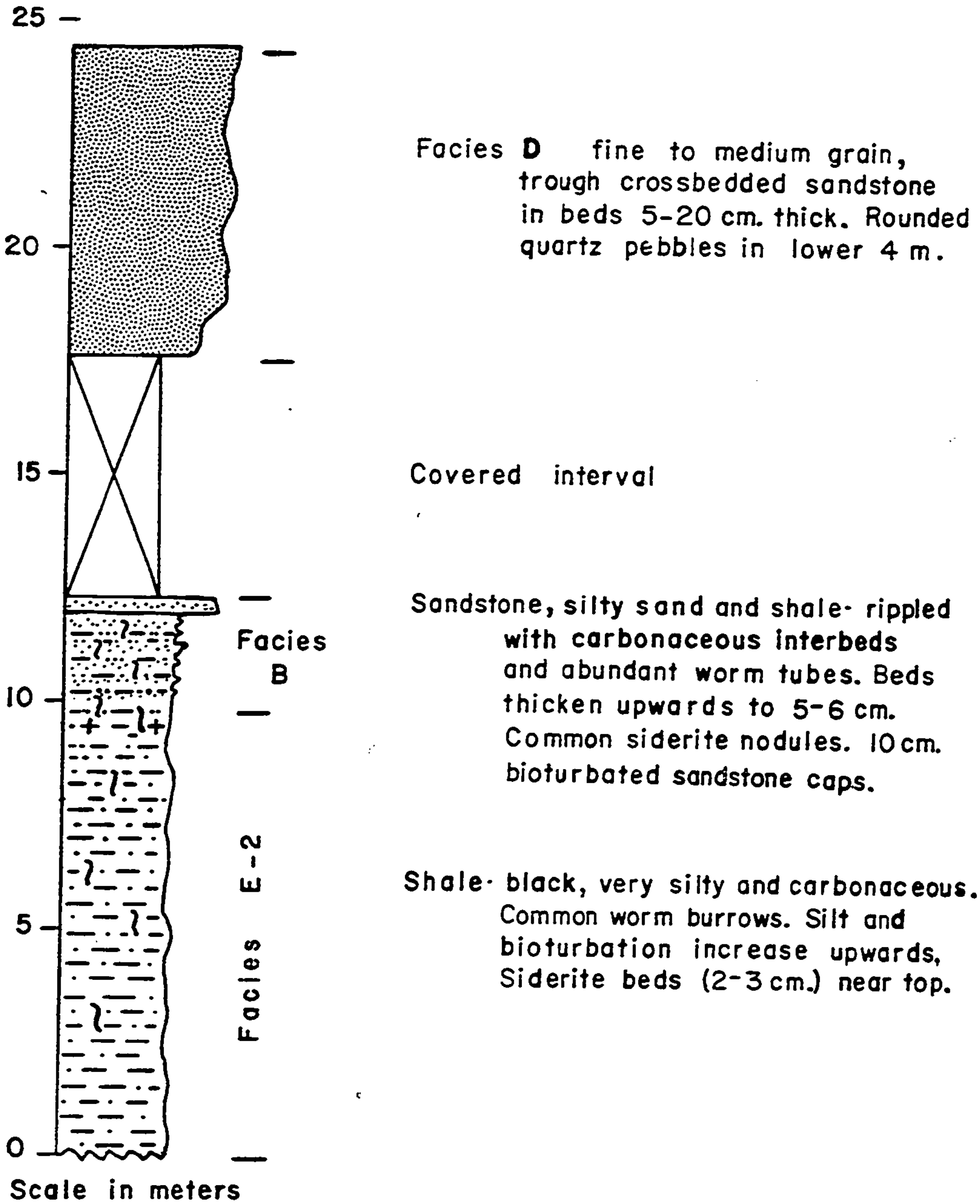


Fig. 35: Vertical section at Station 119 in northern Greenup County, Kentucky. Note the coarsening upward nature of the sediments and the bioturbation in the shale. Section located on an abandoned flint clay strip mine, however the clay bed is covered.

a generally southern transport direction, parallel to that previously reported for other facies D sandstones.

Similar vertical sequences have been described by Brown et al. (1973) in deltaic sediments of the Pennsylvanian Canyon Group of north-central Texas.

DATA ANALYSIS AND DETERMINATION OF DEPOSITIONAL ENVIRONMENTS

Introduction

Analysis of the data collected during this study and data collected by previous workers, in conjunction with the local interpretations just discussed in each of the cross-sections, has led to the following interpretations involving the sediments contained in the Pennington and Lee Formations in northeastern and east-central Kentucky and the Sharon Conglomerate of Ohio.

Provenance

Paleocurrent data from facies A-north (Sharon Conglomerate) suggests a southerly transport direction for these sediments, which is in good agreement with data taken by Fuller (1955), Meckel (1967) and Mrakovitch and Coogan (1975) for the same interval in northeastern Ohio. Furthermore, paleocurrent data from facies A-north conglomerates and facies D channel sandstones show good agreement between cross-sections #1 and #8, indicating a probable lateral equivalency between these two units. This lateral relation is further supported by the presence of large, angular chert and limestone pebbles and smaller rounded quartz pebbles in the basal lag deposits of both facies. In addition, mineralogical properties which have been compared by cluster analysis show that facies A-north and facies D are mineralogically the most similar of all the facies studied. Both are very mature sandstones which exhibit low angularity of grains, especially the tourmaline grains, relatively good sorting, a deficiency of rock fragments and feldspars, and low polycrystalline quartz content. These same factors were used by Potter and Pryor (1961, p. 1211) to establish the maturity of pre-Mississippian sandstones in the upper Mississippian valley. These factors suggest a lateral continuance between facies A-north and facies D and explains the very clean, or mature, nature of the facies D sandstones.

The orthoquartzitic nature of these sandstones in the vicinity of U. S. Highway 64 prompted Horne et al. (1971) to interpret the sandstone bodies as beach barriers. Likewise, the mineralogy contributed to Ettensohn's (1975, 1976) and Martin's (1975) interpretation of the Carter Caves sandstone as tidal flat and tidal channel, respectively. However, because lateral continuity exists between facies A-north and facies D, as the cross-sections, paleocurrent data and mineralogy indicate, no marine reworking is needed to explain the mature nature of the sandstones. In this case, the mineralogy is most likely because of the source area rather than depositional processes. Petrographic examination of the northern equivalents of these units by previous workers (Bownocker, 1921, 1926; Fuller, 1955; Meckel, 1967; Heimlich et al., 1975) shows that the Sharon Conglomerate of northeastern Ohio is a very mature sandstone (Table IV). Fuller (1955) and meckel (1967, 1970) propose a northern, or Canadian, sedimentary source for the origin of these sediments with a secondary tectonic source to the east to explain the mature mineralogy. Heimlich et al. (1975) propose a sedimentary orgin to explain the variability of the zircons contained in these sediments.

Based on these similarities and on the fact that the Sharon can be traced in outcrop northward to the outcrops studied in northeastern Ohio

TABLE IV
Mineralogical Properties of the Sharon Conglomerate in Northeastern Ohio

Author	SiO_2	Al_2O_3	Fe_2O_3	Other
Fuller (1955)	98.38%	0.71%	0.32%	0.59%
Bownocker (1921)	98.17%	0.43%	0.39%	1.01%
Meckel (1967)[1]	Mineralogically: supermature			

[1]Meckel did not give numerical values but rather termed the mineralogy supermature and the texture mature.

(Morningstar, 1922), it is proposed here that the sediments of facies A-north and its lateral equivalents were transported from this northern source before ultimately being deposited in southeastern Ohio and northeastern Kentucky.

Paleocurrent data for facies A-south sediments indicate transport from the northeast along the axis of the Appalachian Basin. The mineralogy of these sediments is less mature, indicating a source which was also less mature than that which supplied the facies A-north sediments. BeMent (1975) suggests that Pennington and Lee sediments of southeastern Kentucky were derived from low-rank metamorphic and sedimentary rocks which were northeast and east of that area and transported along the axis of the basin. Meckel (1967) has suggested a tectonic source for Pottsville sediments in Pennsylvania with the source area lying in eastern New York and eastern Pennsylvania. Based on mineralogical and paleocurrent data obtained during this study, it seems likely that the source area for the facies A-south sediments lay somewhere to the north and east of the study area. The exact nature of the source is uncertain.

Sedimentation Patterns

Looking at a two dimensional picture with the Newman and/or Borden formations as a datum, the sediments within the study interval exhibit a lateral decrease in grain size from north to south with shales becoming volumetrically more prominent in that direction. Additionally, as shown in cross-sections #6 and #7 (Figs. 31 and 32), the nature of the lower sandstone unit, mapped in places as the Carter Caves sandstone, changes to the south. In northern exposures, the unit occurs in channels which are enclosed in black carbonaceous shales which commonly contain thin coals in overlying sediments and trace fossils in the underlying lithologies. Just south of U. S. Highway 64, the channel geometry changes to a sheet geometry and the sandstones have cross-bedded values indicating transport perpendicular to that of the channels. Near the southern terminus of the study area, along State Highway 1274, the lateral equivalents of these sandstones contain abundant carbonate cement and remains of invertebrate marine organisms. The shales underlying the sandstones also become more fossiliferous in this area.

Facies B sandstones are also lateral equivalents of the sandstones of facies A-north, D and G (Fig. 32), but owe their existence to a particular environmental setting directly influenced by structural activity. The areal distribution of this facies corresponds to the proposed axis of the Waverly Arch. That portion of the arch on the northern, uplifted side of the Kentucky River Fault System was a positive area which did not receive much sediment relative to adjacent areas (Fig. 32), as evidenced by the thinning of particular facies across the structure. Additional evidence of low sedimentation rates is indicated by the extensive bioturbation present in the facies B unit. Because of the low sedimentation rates, organisms have time to extensively burrow and forage these sediments, ultimately destroying bedding and primary structures. The flaser bedding which is preserved indicates periods of sediment transport intermixed with periods of quiescence. The majority of the traces preserved in this unit are infaunal species, suggesting that the environment they inhabited was too harsh to support surface dwellers. Pennsylvanian sediments containing similar trace fossils in Kansas and Illinois have been shown to have been nearshore marine and tidal flat environments (Wagner, 1964; Bandel, 1967; Wilson, 1957; Heckel, 1975).

Greater thicknesses and a decrease in the intensity of bioturbation in the northern area of the sand's principal development (Fig. 30) and the presence of more interbedded shale in the thinner accumulations of the southern exposures indicates that the major source of sediment was from the north. Western trending paleocurrent data from facies G sandstones to the east of facies B also suggests that minor amounts were contributed from this direction.

Occurring between the channel sandstones are a variety of types of black shale assigned to facies E. Many of the interchannel shales are bioturbated (E_2), indicating marine influence, while others contain abundant carbonaceous plant imprints and thin coals, implying deposition in a more nonmarine setting (E_1). Fossiliferous shales further south indicate deposition in a more open marine environment.

The Olive Hill clay bed is best developed atop the Waverly Arch and in the interchannel areas. The clay is always associated with shale sequences of facies E_1 or E_2 except where channels have eroded these sediments away.

Locally overlying the clastics of facies B, D, E and G are the carbonates and shales of facies F. Areal distribution maps and cross-sections (Figs. 13, 31, 32) indicate that this unit represents a local occurrence in northeastern Kentucky that did not extend much further north than northern Carter County. It is not known how far to the east and west this unit was deposited because of limited exposures, but thick sequences of this facies to the south suggest a northerly transgression.

A sharp contact between facies F and overlying sediments indicates a rapid change of environmental conditions. These overlying sediments consist of facies A-south and its associated sediments of facies C and E (Fig. 32). Facis A-south depositional processes were apparently erosive in nature, especially on the uplifted block of the Kentucky River Fault System, because many times underlying units have been removed where this facies is present (Fig. 30). The presence of well-developed facies C sediments on the northern block and the absence of facies A-south sediments, plus the rapid thinning of facies A-south in the vicinity of the fault system, suggests that this southwesterly flowing system was contained from the northern block by the positive nature of that area (Figs. 8, 9, 11, 29, 30, 31), and that facies C environments were formed marginal to the main depositional trend.

Environments of Deposition

Facies involved in the initial phase of sedimentation overlying the Borden and Newman formations are the result of a southerly trending fluvial system (facies A-north) feeding into a marginal marine-deltaic environment which was very near sea level. Distributary channels (facies D) received the detrital material from the fluvial system and fed this to associated deltaic and shallow marine environments (facies B, E and G). Interdistributary bays (facies E_2) prodelta areas (facies E_3 and E_4) and marshes and swamps (facies E_1) collected clays and silts with the latter environments eventually building far enough above sea level to support the vegetation necessary to form thin peats and coals. Activity on the Waverly Arch and the Kentucky River Fault System during the deposition of the underlying Newman Limestone created positive areas which supported tidal flats (facies B) marginal to the delta, while other, smaller tidal flats formed at the heads of bays in interdistributary areas. Those tidal flats which formed on the "apical island" were probably the result of a buildup from a shallow marine environment. This is evidenced by the gradual change from massive, bioturbated sandstones to thin, flaser bedded, bioturbated sandstones. Eventually this area built far enough above sea level to support a marsh environment and form a thin coal (Stations 65 and 82). The marsh environment was subsequently transgressed by facies F deposition.

Interdistributary areas supported coal-forming swamps and marshes which gradually filled with clays and silts and built southward as the delta prograded in that direction. Distal areas of the embayments were more influenced by marine conditions and contain sparse bioturbation in the shales (facies E_2). Following coal deposition in these areas, environments became increasingly more marine, as evidence by thin, bioturbated sandstones containing carbonaceous clasts which directly overlie the coals and shales of facies E_1 (Fig. 28). This minor transgression may be correlatable to deposition of facies F sediments further south; however, precise lateral relationships are not determinable because of poor exposures.

The Olive Hill clay bed formed on the uplifted, northern fault block in association with swamp and marsh environments which, at one time or another, occupied areas between distributary channels and the positive area of the Waverly Arch. Multicycled, kaolinite-rich, clay-sized clastics transported into the area and residues from the underlying weathered limestones which had previously been exposed (Ferm et al., 1971; Philley, 1974; Swinchatt, 1974; Ettensohn, 1975, 1976) supplied the necessary sediments for the clay's formation. The clay was probably not formed in all areas until swamps and marshes provided the environmental conditions necessary (Keller, 1975, p. 69-71).

At Station 119 (Fig. 35), a nearly complete vertical sequence for the progradation of a small lobe of the delta into the shallow water of a marine embayment is observable. Siderite and macerated plant material are abundant in the lower portions of the lowest shale unit. Bioturbation in the form of worm burrows becomes more abundant upwards through the section as does the total sand content. This represents a transition from the marine-influenced, quiet water environment of the embayment to the more agitated delta front environment. Rippled, bioturbated, fine-grained sandstone beds interbedded with thin laminae of carbonaceous black shale represents this delta front environment, which was probably lateral to the main axis of delta-lobe progradation.

Overlying the delta front sandstones and shales is a covered interval which appears to consist of silty shales. The environment of deposition here can only be speculated, but probably was the site of interdistributary bay deposition. Overlying these shales is the distributary channel fill sediments of facies D. A similar delta-front sequence has been described by Brown et al. (1973, pp. 87-90) in Pennsylvanian deltaic systems of north-central Texas.

Tables V through XI compare characteristics of each of the facies described to the particular interpreted environment of deposition. The interpreted fluvial nature of facies A-north is not confined to evidence obtained for this report, but has also been discussed for northeastern Ohio exposures by Meckel (1967, p. 223), who postulated the Sharon to have been deposited by "two contemporaneous fluvial systems: one located in north-central Pennsylvania...and one in northeastern Ohio, which dispersed material to the south". Mrakovitch and Coogan (1975, p. 1186) interpreted these same sediments as "an alluvial plain formed by braided streams", and Fuller (1955, p. 159) suggested a "deltaic type of depositional environment".

Because of the stable, uplifted nature of the northern block of the Kentucky River Fault Sytem and the shallow water environment which existed there, preservation of progradational deltaic environments underlying distributary channels are rare. Because subsidence was negligible, the distributaries, as they prograded south, eroded into these lower sediments and reworked them into concurrently forming environments seaward. This stable platform also explains the thin accumulations of each of the facies and the dominantly lateral growth of the system. Similar stable platform, deltaic environments have been described by Donaldson et al. (1970), Morgan (1970) and Brown et al. (1973).

TABLE V

Comparison of Characteristics of Facies A With Ideal Fluvial Sequence[1]

Property	Facies A	Ideal Fluvial Sequence
Composition	Quartz rock fragments, feldspar, chert, some heavy mineral Mica.	Variable, dependent upon source area.
Texture	Clay to cobbles. Fines upward. Graded pebbles on cross-bed forsets. Poor to moderate sorting. Basal conglomerate.	Clay to boulders. Upward decrease in median grains size. Poor to moderate sorting. Basal conglomerate zone common. Tendency to poor rounding.
Sedimentary Structures	Trough and tangential cross-stratification. Ripples near top. Overturned cross-stratification. Convolute bedding. Scour and fill.	Large and small scale cross-stratification, scale dimenishes upwards. Asymmetrical ripples. Graded laminae. Parting lineation. Deformational structures. Sparse bioturbation.
Contacts	Top: Gradational Base: Sharp, erosional Lateral: Gradational	Top: Gradational Base: Sharp Lateral: Variable
Thickness	0-60 meters (0-200 feet)	Variable
Biota	Plant material (logs, woody fragments).	Wood and plant fragments, possible rework fossils.

[1] Data from Potter (1967); Williams and Rust (1968); Swanson (1975).

TABLE VI

Comparison of Characteristics of Facies B
With Tidal Flat Sediments[1]

Property	Facies B	Tidal Flat
Composition	Quartz, coaly and carbonaceous material, clays. Minor feldspar and rock fragments.	Quartz, clay, skeletal debris, bituminous films, dolomite, pyrite, glauconite.
Texture	Fine sand to clay. Grain size decreases upward and matrix increases. Grains angular to subround. Poor to moderate sorting.	Clay, silt, minor sand interlaminated. Supermature. Rounded quartz grains. Pelletal dolomite.
Sedimentary Structures	Wavy, flaser, and ripple bedding. Abundant bioturbation. Interlaminated sand and mud or carbonaceous material.	Fine, horizontal laminae to wavy, flaser beds. Ripples. Interlamination of mud, silt or sand. Burrows. Scours. Mud cracks.
Contacts	Top: Gradational Base: Gradational Lateral: Gradational	Top: Gradational Base: Variable Lateral: Gradational
Thickness	0-5 meters (0-16 feet)	Variable
Biota	Plant, carbonaceous and coaly material; Bioturbation: dominantly infaunal occurrences; Cruziana facies of Seilacher (1964); Asterichnus, Crossopodia, Cylindrichnus, Zoophycous, Pelecypodichnus.	Marine to brackish, Fossils low diversity and abundant individuals; Bioturbation: dominantly infaunal occurrences, Cruziana facies of Seilacher (1964), Pelecypodichnus, Scrobicularia; Zoophycous described in marine phases of Pennsylvanian cyclothems.

[1] Data from Van Straaten (1954); Seilacher (1964); Evans (1965); Laporte (1968) ; Selley (1969); Reinick and Wunderlich (1969); Potter (1967); Reinick (1972); Barnes and Klein (1975); Rhoads (1975); and Swanson (1975).

TABLE VII

Comparison of Characteristics of Facies D With Distributary Channels[1]

Property	Facies D	Distributary Channel
Composition	Quartz, minor feldspar, rock fragments, clay.	Quartz, mica, feldspar, rock fragments, authigenic pyrite and siderite. Fe_2O_3.
Texture	Fine- to medium-grain, angular to well-rounded quartz grains. Clay matrix. Poor to moderate sorting. Grain size shows slight decrease upwards. Local basal conglomerate.	Clay to sand. Fine to medium grain. Poor to moderate sorting. No significant vertical trend to slight fining upwards. Basal clay clast conglomerate.
Sedimentary Structures	Trough and planar cross-stratification. Horizontal beds. Asymmetrical ripples. Reactivation surfaces. Overturned crossbeds and convolute bedding in minor amounts. Minor bioturbation.	Large and small scale trough cross-stratification. Ripple-drift cross-laminations. Scour and fill. Horizontal laminae. Minor bioturbation. Contorted bedding common.
Contacts	Top: Gradational Base: Sharp, erosional Lateral: Gradational	Top: Variable Base: Sharp Lateral: Gradational
Thickness	0-20 meters (0-65 feet)	12-36 meters (40-120 feet): Common
Biota	Carbonaceous plant and woody fragments.	Plant and woody fragments.

[1] Data from Galloway and Brown (1972); Brown et al. (1973); McBride et al. (1975); Visher et al. (1975); Reinick and Singh (1973); Cotter (1975); Swanson (1975)

TABLE VIII

Comparison of Characteristics of Facies E_1 With Marsh-Swamp[1]

Property	Facies E_1	Swamp-Marsh
Composition	Clay, quartz, siderite, Fe_2O_3 Organics. Coal	Clay, quartz, siderite, pyrite $CaCO_3$ concretions. Organics.
Texture	Clay, silt, fine sand. May fine upwards in channel fill.	Clay, silt, minor sand. Homogeneous to inter-calculated. Peat and organic-rich silty clay. Minor grain size decreases upwards and finer to margins.
Sedimentary Structures	Fine to thin laminae. Some slickensides.	Fine laminae to massive. Root marks, slickensides. Slump structures, contorted bedding. Minor burrows.
Contacts	Top: Variable Base: Gradational Lateral: Gradational	Top: Variable Base: Variable Lateral: Gradational
Thickness	0-50 meters (0-160 feet)	Variable
Biota	Plant and woody organic remains. *Lingula* locally.	Abundant plant debris. Tree material. *Lingula*. Diatoms.

[1] Data from Galloway and Brown (1972); Brown et al. (1973); Swanson (1975); Visher et al. (1975); Coleman et al. (1964).

TABLE IX

Comparison of Characteristics of Facies E_2 With Interdistributary Bays[1]

Property	Facies E_2	Interdistributary Bay
Composition	Clay, quartz, siderite.	Clay, quartz, siderite, pyrite, anhydrite, gypsum.
Texture	Clay, silt, fine sand. May coarsen upwards to distributary sands or fine upwards to marsh or swamp.	Clay, silt, minor sand. Sequence may fine upwards or coarsen upwards; however, usually little change.
Sedimentary Structures	Fine laminae to massive beds. Common bioturbation.	Fine laminae to massive beds. Burrowed. Mini faults. Roots. Clay clasts. Lenticular laminations. Ripples.
Contacts	Top: Variable Base: Gradational Lateral: Gradational	Top: Variable Base: Gradational Lateral: Gradational
Thickness	Variable	Variable
Biota	Burrows. Common plant fragments.	Brackish to shallow marine. Some wood and plant fragments.

[1] Data from Selley (1970); Brown et al. (1973); Lankford and Sheppard (19); Swanson (1975); Coleman et al. (1964); Visher (1975); Reinick and Singh (1973).

TABLE X

Comparison of Characteristics of Facies E_3 With Prodelta[1]

Property	Facies E_3	Prodelta
Composition	Clay, minor quartz, minor macerated plant material.	Clay, minor quartz, skeletal debris, pyrite, siderite, glauconite, macerated plant material.
Texture	Clay, small, fine-grain sandstone pods.	Clay, minor silt. May coarsen upwards. Laminae or lenses of clean sand with sharp contacts.
Sedimentary Structures	Fine laminae to thin bedded.	Fine laminae to wavy, irregular laminae. Mini faults. May be bioturbated or barren. Slump blocks. If bioturbation present, decreases upwards. Ripples.
Contacts	Top: Apparantly gradational Base: Variable Lateral: Gradational	Top: Variable Base: Gradational Lateral: Gradational
Thickness	Unknown	Variable
Biota	Minor plant debris, otherwise barren.	Shallow marine fauna, little plant or wood debris. Possibly barren.

[1] Data from Brown et al. (1973); Visher et al. (1975); Swanson (1975); Cotter (1975); McBride et al. (1975); Murphy (1962).

TABLE XI

Comparison of Characteristics of Facies G With Offshore Marine Sediments[1]

Property	Facies G	Offshore Marine
Composition	Quartz, skeletal debris, plant fragments. Dolomite. $CaCO_3$ cement. Glauconite.	Skeletal bebris, quartz, clay, pyrite, glauconite. $CaCO_3$ cement.
Texture	Fine-grained sand with carbonate cement. Fossil and plant fragments.	Clay to sand. Moderate to poor sorting.
Sedimentary Structures	Tangential cross-bedding, ripples, thin to massive beds. Horizontal beds.	Fine horizontal laminae to massive beds. Burrow mottled. Rare crossbedding.
Contacts	Top: Variable Base: Gradational Lateral: Gradational	Top: Gradational Base: Variable Lateral: Gradational
Thickness		
Biota	Marine fossils: Echinoderms, ostracods. Plant fragments	Shallow marine fauna, little plant or wood debris.

[1] Data from McBride et al. (1975); Reineck and Singh (1973); Swanson (1975); Van Straaten (1960).

Sediments locally overlying this initial progradational sequence consist largely of dolomites, limestones and shales of facies F. Areas away from the axis of the Waverly Arch have much thicker accumulations of these sediments than do areas coincident with the structure (Fig. 32) and these areas commonly exhibit limestone and dolomite beds or lenses interbedded with beds or zones of green shale. The carbonates consist of calcium carbonate or dolomitized fossil fragments in a fine-crystalline dolomite matrix and are indicative of a shallow marine environment. The presence of minor amounts of quartz grains and abundant clay clasts testifies to the proximity of these carbonates to detrital input; however, energy conditions must have been low, for the preserved fossils are generally whole, or nearly so, and the bulk of the rock consists of carbonate mud which has been dolomitized. The silty green shales which enclose these carbonates are barren of megafossils and microfossils; however, they do contain abundant silt- and sand-sized quartz grains. These shale intervals are interpreted as representing times of increased sediment influx into the area, probably from deltaic systems which were shifted out of the area because of the transgression.

In the area of the Waverly Arch, facies F is represented only by a sandy dolomite bed. Alternating zones of quartz-rich and dolomite-rich laminae (Plate 31) are interpreted as representing periods of increased detrital input and may correspond to the shale zones which separate the carbonate beds to the east.

To the south, where shallow marine environments had persisted throughout delta progradation (facies G), only the initial stage of this transgression is detectable because the overlying conglomerates and sandstones of facies A-south have eroded away much of the sediments recording this onlap. Dolomite crystals have replaced carbonate cement in the upper portions of facies G and this zone is interpreted as the beginning of the transgressive phase. Fossil fragments record the marine influence and abundant woody fragments indicate the proximity to detrital input. The dolomite itself is not a primary occurrence but is the result of diagenetic processes which altered the fine-grained carbonate material at a later time. The fact that the dolomite crystals are not present in the lower parts of facies G, and the vertical relationship of facies B and D with facies F in adjacent exposures, prompts the correlation of the top of facies G to the base of facies F.

Similar carbonates have been described in destructional phases of ancient delta systems. Galloway and Brown (1972, p. 26) have described carbonate facies, less the dolomite, in Upper Pennsylvanian rocks of north-central Texas. Limestones there range from several centimeters to 0.6 meters (2 feet) in thickness and are biomicrudites, biomicrites or micrites in Folk's (1968) classification. Belt (1975) has also described transgressive or destructional phase carbonates and shales in Late Mississippian deltaic sediments of Scotland. Those limestones consist of biomicrites (Folk, 1968), commonly contain dolomite rhombs, and occur at the top of a transgressive phase represented by a fining upward, bioturbated, ripple laminated sandstone and shale sequence which is lithologically similar to the fining upward sequence of Stations 65 and 82 (Fig. 32, Appendix D). Similarly, Brown (1969, p. 45) has described lagoonal and bay destructional facies of Pennsylvanian delta systems of north Texas as containing "impure limestones and fossiliferous mudstones" and notes that they are hard to map because of their limited extent.

Table XII outlines the characteristics of facies F and compares these to published characteristics of destructional, or transgressive, phase sediments in other, ancient deltaic systems.

The final phase of deposition is indicative of a major progradation involving facies A-south (Corbin sandstone) and its associated environments. Lithologic properties of this facies are nearly identical to facies A-north and represent deposition in a similar, fluvial environment (Table V). Unimodal paleocurrent values suggest a southwest paleoslope which was nearly parallel with the axis of the Appalachian Basin; however, local structural influence from the Kentucky River Fault System and the Irvine-Paint Creek Fault System altered this paleoslope enough in the area between the structures to give a predominantly westward transport direction (Fig. 21). Relief on the Kentucky River system was great enough to halt the lateral, northwestward transgression of this system out of the basin. Thinning and eventual pinching of facies A-south to the north and south is interpreted as confinement of this depositional system between the two structures. This is reinforced by the strongly unimodal paleocurrent data and the graded texture of the quartz pebbles on the foresets of the crossbeds. Much of this coarse-grained sediment was carried by bed load streams.

Associated deltaic environments are rarely preserved within the area because of the erosive nature of the facies A-south depositional processes. In some instances, these sandstones are resting directly on the Newman Limestone (Station 68); however, in most cases, these sediments are found overlying abbreviated sequences of shale and fine-grained sandstone (Plate 45). Stations 17 and 65 (Fig. 6) display the most completely preserved sections of prodelta and delta front environments.

TABLE XII

Comparison of Characteristics o Facies F With Delta Destructional Phase Sediments[1]

Property	Facies F	Delta Destructional Phase
Composition	Dolomitized biomicrite to biomicrudite (Folk, 1968). Silt and clay.	Biomicrites to biomicrudites (Folk, 1968). Silty to sandy mudstone to argillaceous limestone. Recrystallized dolomite.
Texture	Clayey to silty shale. Dolomitized carbonate mud. Whole to partly whole fossils.	Clayey to silty shale. Carbonate mud with fossil fragments.
Sedimentary Structures	Nodules and beds of limestone. Laminar shales.	Nodular, concretionary, or massive bedding. Homogeneous to heavily bioturbated.
Contacts	Top: Sharp Base: Sharp to gradational Lateral: Gradational	Top: Sharp to gradational Base: Sharp to gradational Lateral: Gradational
Thickness	Carbonate beds several centimeters to 0.8 meters.	Generally thin. Several centimeters to 1 meter.
Biota	Marine fossils: Brachiopods, gastropods, ostracods, pelecypods, echinoderms.	Marine fossils: brachiopods, gastropods, ostracods, fish bones, algal debris.

[1] Data from Galloway and Brown (1969); Brown (1969); Belt (1975); Erxleben (1975).

The section at Station 17 and the interpreted depositional environments is shown in Figure 36. The gradual increase in te quantity of sandstone upsection typifies the progradational nature of the deltaic system. Abundant bioturbation in the upper part of the delta front sequence is attributable to the lateral position of this station to the main axis of delta progradation. Figure 9 shows that the greatest thickness of facies A-south accumulation, and therefore the main axis of progradation, is slightly north of Station 17, and that this location was lateral to the main influence of fluvial processes. This lateral position, perhaps that of an embayment, provided a hospitable environment for the burrowing infauna.

At Station 65, these same prodelta and delta front environments are preserved in an abbreviated section (Fig. 32, Appendix D). Prodelta shales overlie the thin dolomite of facies F and are overlain by delta front sandstones which are horizontally laminated and microcross-laminated. This station was also offset from the main axis of progradation (Fig. 6), but was more directly influenced by the fluvial processes as evidenced by the preserved primary structures. The fluvial processes supressed the activities of burrowing organisms and eliminated the effects of marine reworking.

At Station 22, which is between Stations 17 and 65 (Fig. 6), the complete sequence down to, and mostly through, facies F has been eroded away, reflecting the main influence of the fluvial environment in this area.

Concommitant with the deposition of facies A-south and associated deltaic environments on the downthrown side of the Kentucky River Fault

LEGEND
FOR FIGURES CONTAINED IN TEXT

Lithology

- Facies A sandstone
- Facies B sandstone
- Facies C sandstone
- Facies D sandstone
- Facies G sandstone
- Facies H flint clay
- Borden siltstone
- Coal

Facies E

- Clay shale
- Silty shale

Facies F

- Green shale
- Limestone
- Dolomite

Symbols

- Plant fossils
- Invertebrate fossils
- Bioturbation
- Ripple drapes
- Siderite
- Carbonate cement
- Observable contact
- Inferred contact
- ? Unknown extent
- Facies change
- Covered interval

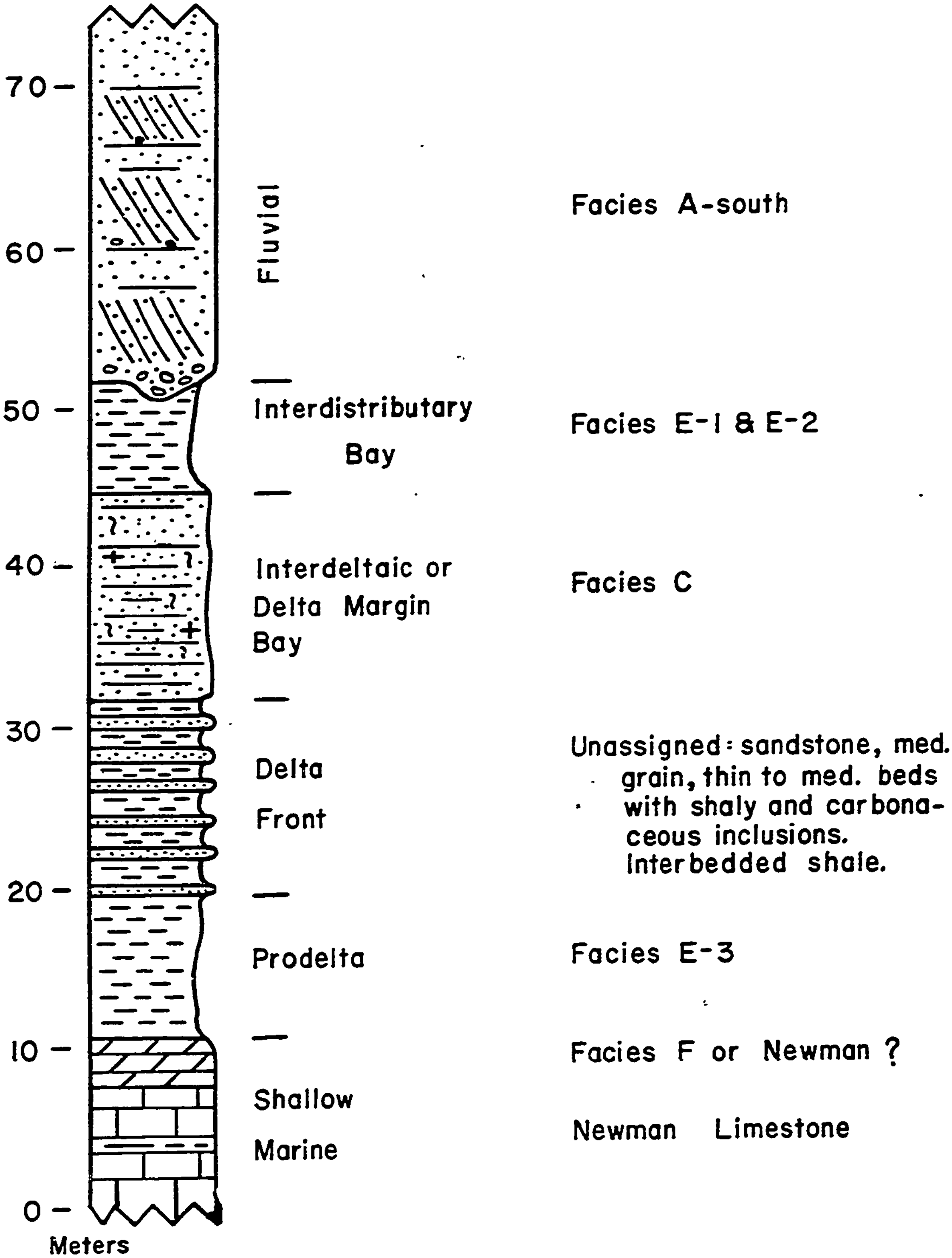


Fig. 36: Stratigraphic section at Station 17, Menifee County, Kentucky with interpreted depositional environments and facies assignments.

System was deposition of facies C sediments on the northern block. These sandstones are mineralogically similar to facies A-south sediments (Fig. 16) and lithologically similar to the bioturbated sandstones at Station 17. Facies C sediments are stratigraphically equivalent to the delta front sandstones at Stations 17 and 65 (Fig. 32) and were deposited concurrently.

Minor scour and fill structures and small trough cross-bedding indicates some current activity; however, this area appears to have generally been one of quiet water with periods of clastic influx alternating with periods of quiescence. Bedding is generally thicker and carbonaceous interbeds more numerous in the northern exposures, reflecting a probable source to the south from the main body of fluvial sediments. Abundant bioturbation attests to the proximity of this facies to marine influence and reflects the protected nature of the environment on the northern block. The gradational lower contact with underlying shales of facies E_2 and E_3 and sandstones of facies D shows the transitional nature of environmental change in that area. The variable nature of the underlying sediments reflects the north-south alignment of the previous deltaic system.

Facies C is interpreted as a bay fill sequence and Table XIII compares the characteristics of this facies to characteristics of bay fill sequences of known, ancient deltaic systems. Horne and Ferm (1975) have described similar bay fill sequences in Middle Pennsylvanian sediments of eastern Kentucky. There, fine-grained, graded bedded sandstones containing burrow structures and trails and iron carbonate concretions up to 1 meter (3.3 feet) in diameter grade laterally into distributary

TABLE XIII
Comparison of Characteristics of Facies C
With Bay Fill Sediments[1]

Property	Facies C	Bay Fill
Composition	Quartz, siderite, carbonaceous material, minor rock fragments.	Quartz, siderite, pyrite, gypsum, anhydrite.
Texture	Silt, clay, minor sand; Variable coarsening to fining upward sequences; Local graded beds within shales	Clay, silt, minor sand; Coarsen upward and laterally toward source.
Sedimentary Structures	Massive to finely laminated with carbonaceous interbeds. Lenticular laminae common. Small scale cross-stratification. Abundant burrows, some with siderite fillings.	Massive to finely laminated. Abundant lenticular laminae and common cross-laminae (0°-5°). Abundant burrows, local siderite fillings.
Contacts	Gradational bottom Gradational laterally Gradational top	Gradational bottom Gradational laterally Variable top
Thickness	0-20 meters (0-65 feet)	Variable (55 meters reported by Horne and Ferm, 1976).
Biota	Carbonaceous material (plant) Horizontal and vertical burrows.	Few brackish to shallow marine fauna. Wood and plant fragments. Burrows.

[1] Data from Brown et al (1973); Swanson (1975); Cotter (1975); Horne and Ferm (1976); and Visher et al. (1975).

mouth bars and underlie distributary sediments. Cotter (1975, p. 477) has also described delta front deposits in the Cretaceous Ferron Last Chance delta system which are very similar to those described here, as have Brown et al. (1973) in Pennsylvanian deltaic systems in north-central Texas. Swanson (1975, p. 22) has illustrated vertical stream-mouth-bar sequences which are also very similar to those sequences described at Stations 17 and 65.

This progradation marked the end of active deltaic deposition in northeastern Kentucky for a period of time, because overlying sediments consist largely of black, silty, micaceous shales, thin to thick coals and siderite beds. Active deposition was centered more to the south and east where subsidence was able to keep pace with sedimentation, for this is where the major sandstone bodies of the Breathitt Formation are located. Northeastern Kentucky became an area of quiescence, receiving only the finer detritus from these southern systems. The contact between facies A-south and overlying silts and shales is everywhere conformable, as is the shale-to-shale contact on the northern block, indicating that the shift of the locus of deposition was gradual. Deposition of the units described in this study had leveled previous paleotopography to the point where the area was able to support the vast swamps and marshes adjacent to the active deltas.

Idealized Stratigraphic Column

Figure 37 is an idealized stratigraphic column for the Late Mississippian and Early Pennsylvanian of northeastern Kentucy showing associated facies designations and stratigraphic nomenclature.

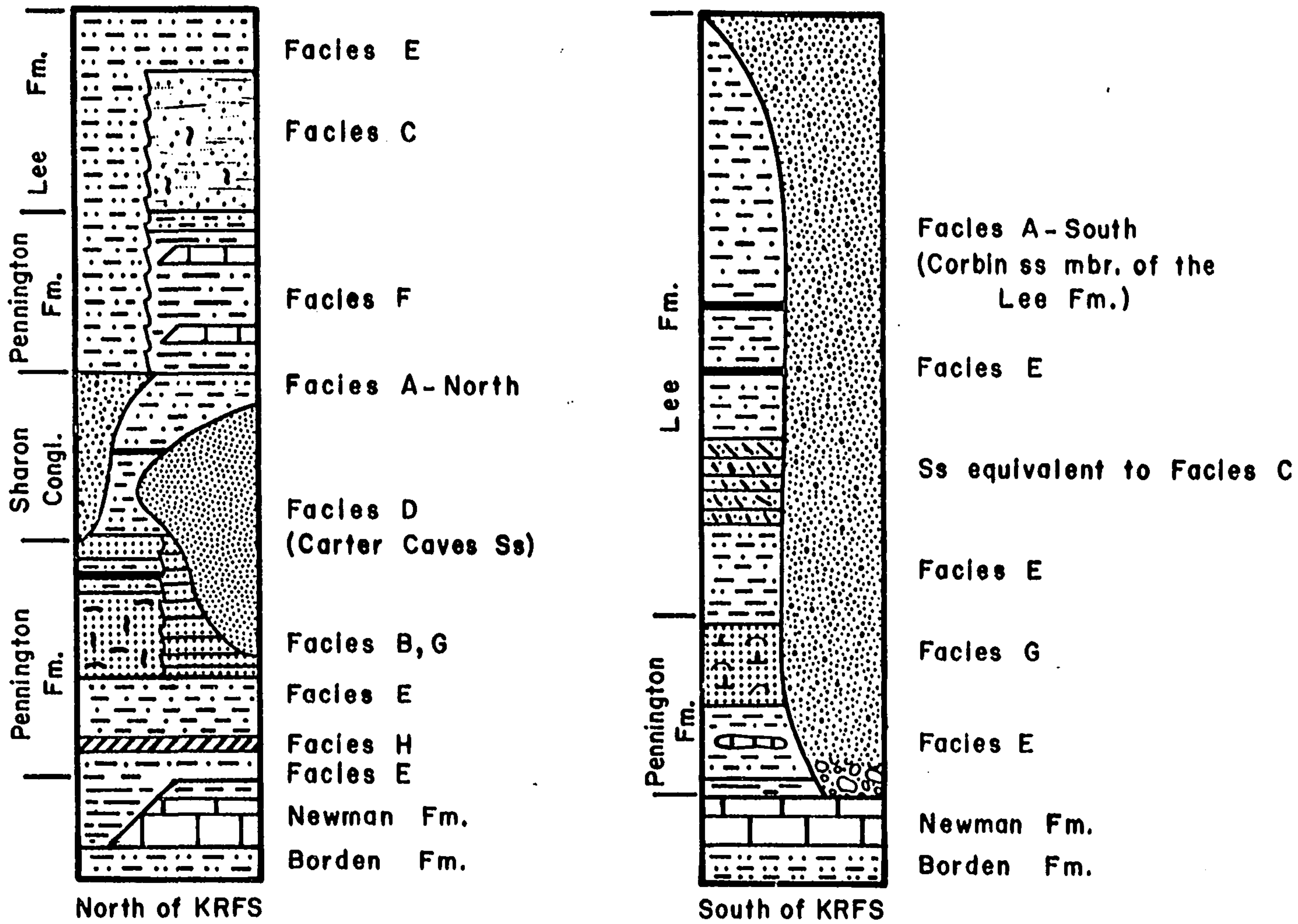


Fig. 37: Idealized stratigraphic sections for areas north and south of the Kentucky River Fault System.

DEPOSITIONAL MODEL AND THE LOCAL SYSTEMIC BOUNDARY

Local Depositional Model

The depositional model suggested here is the result of an intensive examination of the aforepresented data and, in the author's opinion, represents the most logical interpretation.

Phase I

Following uplift on the Kentucky River Fault System and Waverly Arch and exposure of the Newman and Borden sediments on the northern block, a southerly prograding deltaic system occupied the area of northeastern Kentucky and southeastern Ohio. Conglomerate sandstones of the Sharon Conglomerate were part of a southerly flowing fluvial system which originated in Canada and the northeastern United States. These southerly flowing streams eventually reached the coast, located in northeastern Kentucky. Figure 38 shows the areal distribution of the environments within the area at that time. The northern, uplifted block of the Kentucky River Fault System provided the stable, shallow water environment into which these clastics were deposited, while the north-south trending Waverly Arch dictated the southerly alignment of the distributary channels and provided an elevated area on which extensive refactory clay deposits and later tidal flat and shallow marine sediments were formed. The location of the Kentucky River Fault System also marked the area where more open marine conditions became dominant and was most likely represented as a break in slope rather than a pronounced fault.

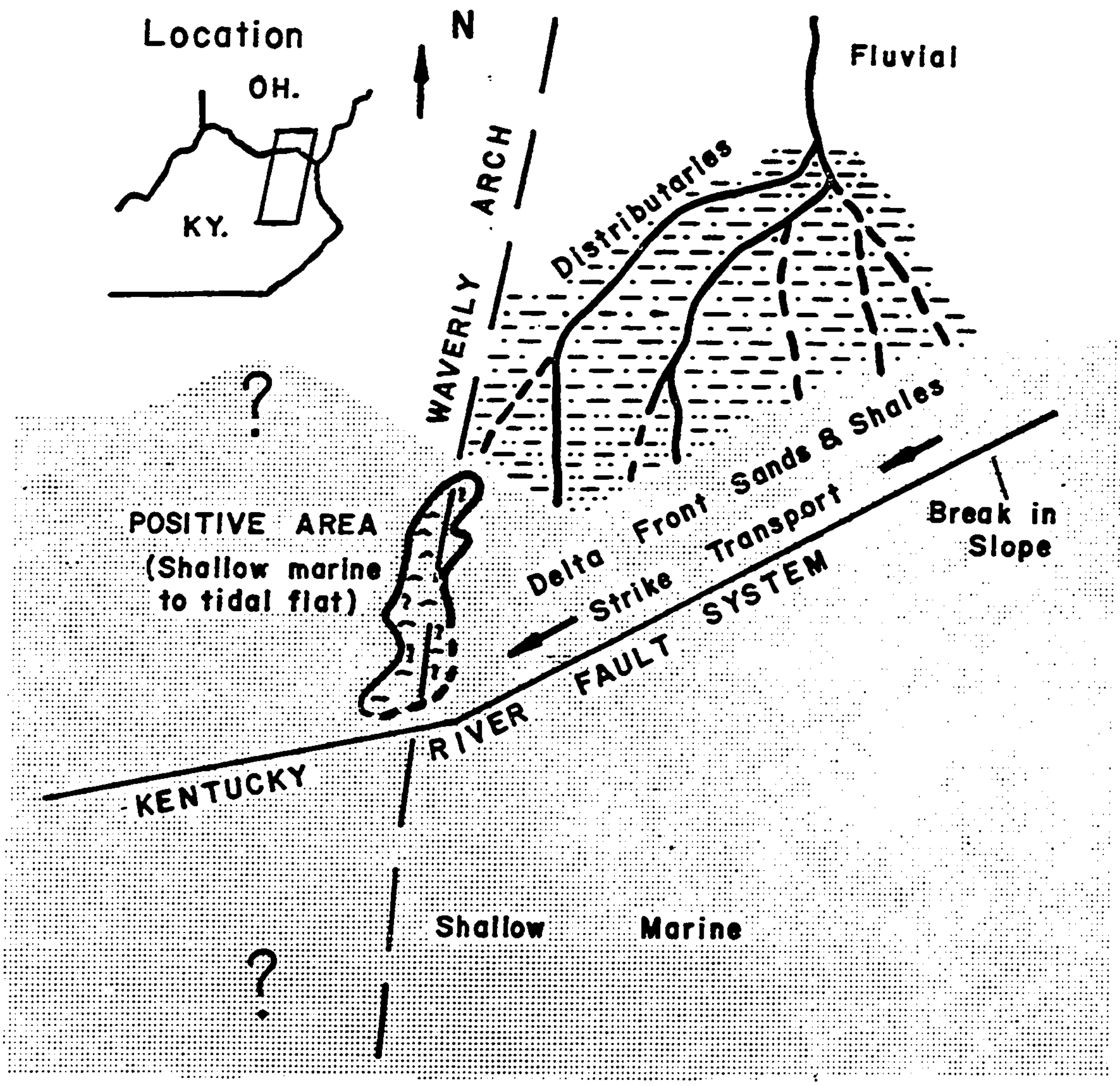


Fig.38: Phase I deposition. Southward progradation of Sharon fluvial system and Pennington deltaic and shallow marine sediments. Note the position of the Kentucky River Fault System and the Waverly Arch. The positive area was the site of major flint clay and facies B deposition.

Interdistributary bays collected mostly clays, silts and fine sands with occasional influxes of coarser clastics from splays and storm deposits. One such splay is observable on U. S. Highway 64 (Plate 19) and can be traced laterally into shales and siltstones of the bay deposits.

Refactory clay deposits were not confined to the positive area around the Waverly Arch, but also formed in interdistributary swamp areas in conjunction with thin coals.

Phase I persisted until Late Mississippian (Late Chester) when a minor transgression occurred which inundated the distal parts of the delta and deposited the clays and carbonates of Phase II.

Phase II

Deltaic deposition was interrupted in Late Chester time by a minor transgression which covered the distal parts of the previously formed delta and caused clastic sedimentation to shift northward toward land or eastward to more favorable sites of deposition. The exact cause of the transgression is not known, but appears to be due to only a slight fluctuation of the land or sea, because the positive area on the Waverly Arch received small amounts of the sediment as compared to adjacent areas. Figure 39 is a reconstruction of the environment at this time. As can be seen, the marine waters did not extend, in this area, much farther north than the previous delta fringes. This was caused by the small rise in sea level relative to the land mass and the local paleo-slope which was oriented to the south and opposite the direction of transgression.

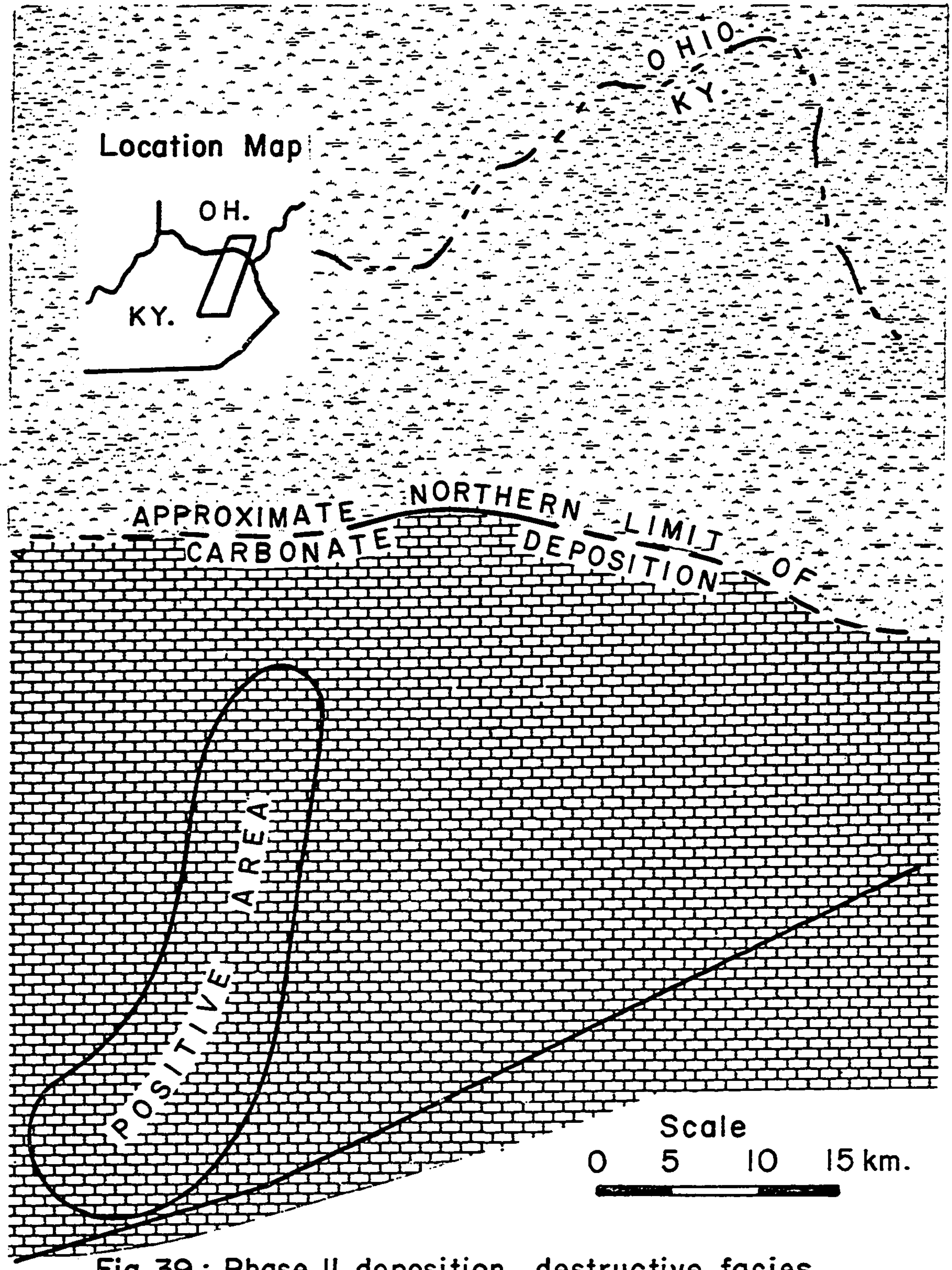


Fig. 39 : Phase II deposition, destructive facies.

Marine organisms preserved in the carbonates indicate a shallow marine environment; however, the abundance of quartz grains and clay chips suggest that these limestones were not far removed from clastic input. Silty shales collected nearer to shore in bays and protected marine settings.

On the basis of fossil evidence obtained from the carbonates, Phase II continued through Late Mississippian time. The transgressive, or destructional, phase of deposition was terminated by a major progradation which occurred parallel to the axis of the Appalachian Basin and represented by the clastic sediments of Phase III.

Phase III

Deltaic sedimentation which had originated along the axis of the Appalachian Basin shifted laterally into northeastern Kentucky ending carbonate sedimentation there. Minor relief on the Kentucky River Fault System and the Irvine-Paint Creek Fault System acted to confine the coarsest clastic material to between the two structuress, while the northeasternmost of the fault systems halted the northwest movement of the depositional system. Fine-grained bay fill sediments collected on the northern, uplifted block adjacent to the delta system. Deltaic subenvironments were, for the most part, subsequently eroded as the delta continued to prograde south and west. Coarse-grained sediments which are preserved represent the fluvial environment which had supplied sediment to the delta.

Figure 40 is a reconstruction of the area at a point in time when deltaic sedimentation was active in the area. Coals which were formed

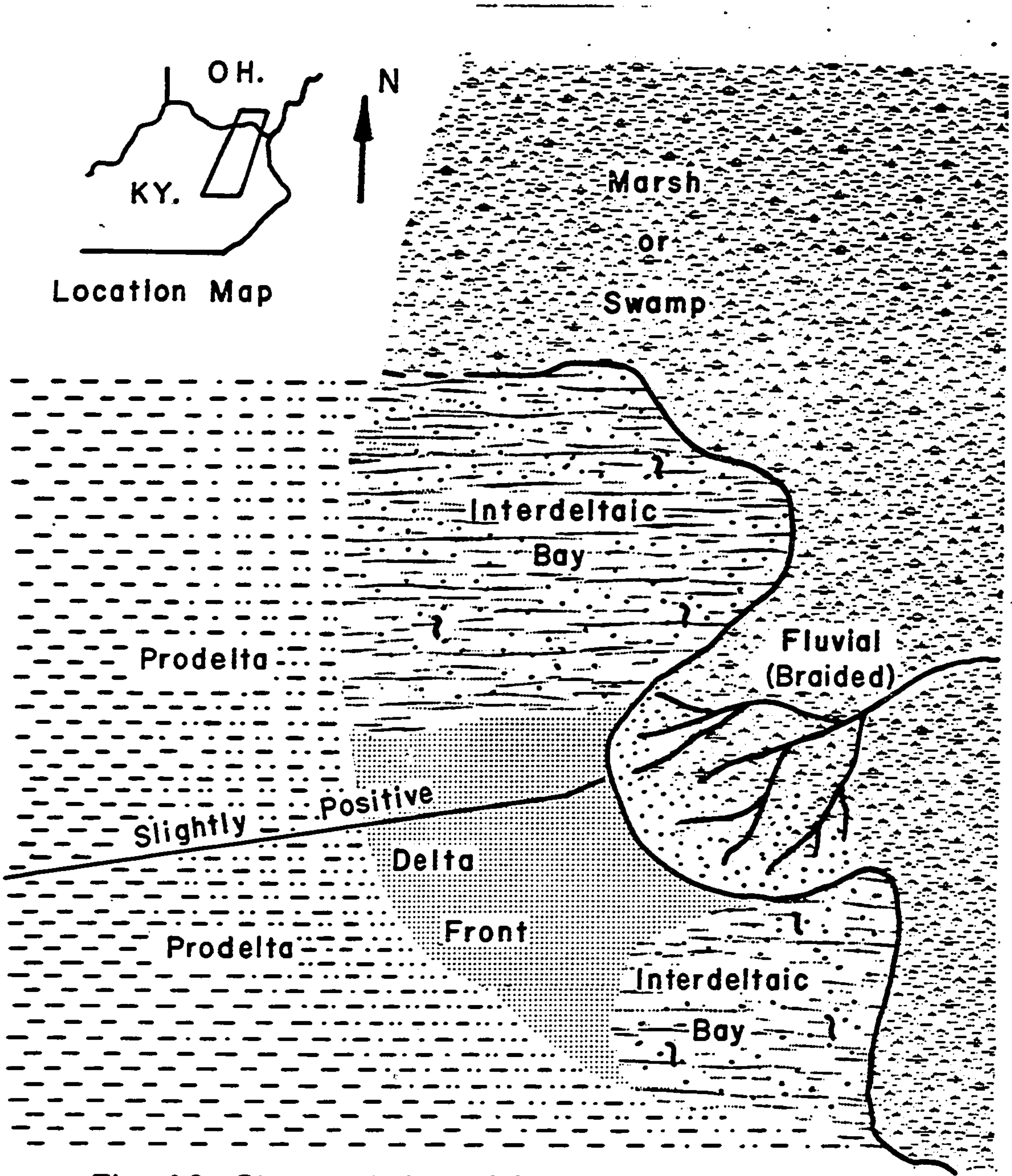


Fig. 40: Phase III deposition. Progradation of the Corbin deltaic system from the northeast. The slight elevation on the northern block of the Kentucky River Fault System contained most deposition to the southern block while the northern portion supported a vast bay and marshes or swamps. Progradation continued to the south and west with time.

concurrent with this progradation yield Pennsylvanian dates based on fossil spore assemblages. This southwesterly trending depositional system represents the initial stage of Pennsylvanian sedimentation in northeastern Kentucky.

Local Systemic Boundary

Locally, within the study area, there does not appear to be a major unconformity marking the Mississippian-Pennsylvanian boundary. Sedimentation was continous through Pennington and Lee time; however, erosion was commonplace during the progradation of distributary and fluvial systems.

The northern, upthrown side of the Kentucky River Fault System was affected only by distributary erosion during the initial progradational event, and many of the distributary sandstone bodies are found resting directly on, or very near to, Newman and Borden sediments. The general absence of Newman sediments, and the abundant subaerial exposure features present in those limestones present, attest to the lack of deposition in the area during that time; however, this occurrence during the Late Mississippian should not be confused with the Mississippian-Pennsylvanian boundary.

South of the fault system sedimentation was continuous through Pennington and Lee time. The lack of subaerial exposure phenomenon and the thick accumulation of Newman sediments also suggests that sedimentation was continous from late Newman time. A local erosional disconformity is present, however, at the base of the Corbin sandstone. The magnitude of this unconformable boundary is quite variable, however, in very short distances because of the variable erosive nature of the fluvial system.

Where the system was confined between the two fault systems there is generally a large erosive break; however, this break is less pronounced in areas marginal to this "trough".

The location of the Mississippian-Pennsyvanian boundary throughout northeastern Kentucky is most probably at the top of facies F dolomites and shales; however, this unit is not everywhere preserved, and in those areas not occupied by facies F, the boundary occurs within a black shale sequence, making the marking of the boundary very difficult.

Regional Picture

The interpretation of local depositional environments represented by the Pennington and Lee Formations in northeastern Kentucky and the Sharon Conglomerate of southeastern Ohio also fit nicely into a regional picture of the sedimentation patterns active in the Appalachian Basin during that time. Figure 41 shows the dispersal systems for the Late Mississippian and Early Pennsylvanian in the basin. Meckel (1967), based on evidence obtained from the Pottsville of central and east-central Pennsylvania, divided the basin into a platform area and a trough or deep basin area. The line of division is a proposed flexure zone which correlates well with the position of the basement fault as mapped by Woodward and which he proposes to extend into that area (Woodward, 1961). It appears that this fault system, or flexure, was one of the major controls on sedimentation patterns within the basin during that time. In addition to the flexure zone, Meckel mapped southerly trending dispersal systems in northeastern Ohio and, based on floral zones, assigned them to the Early Pottsville. These southerly trending

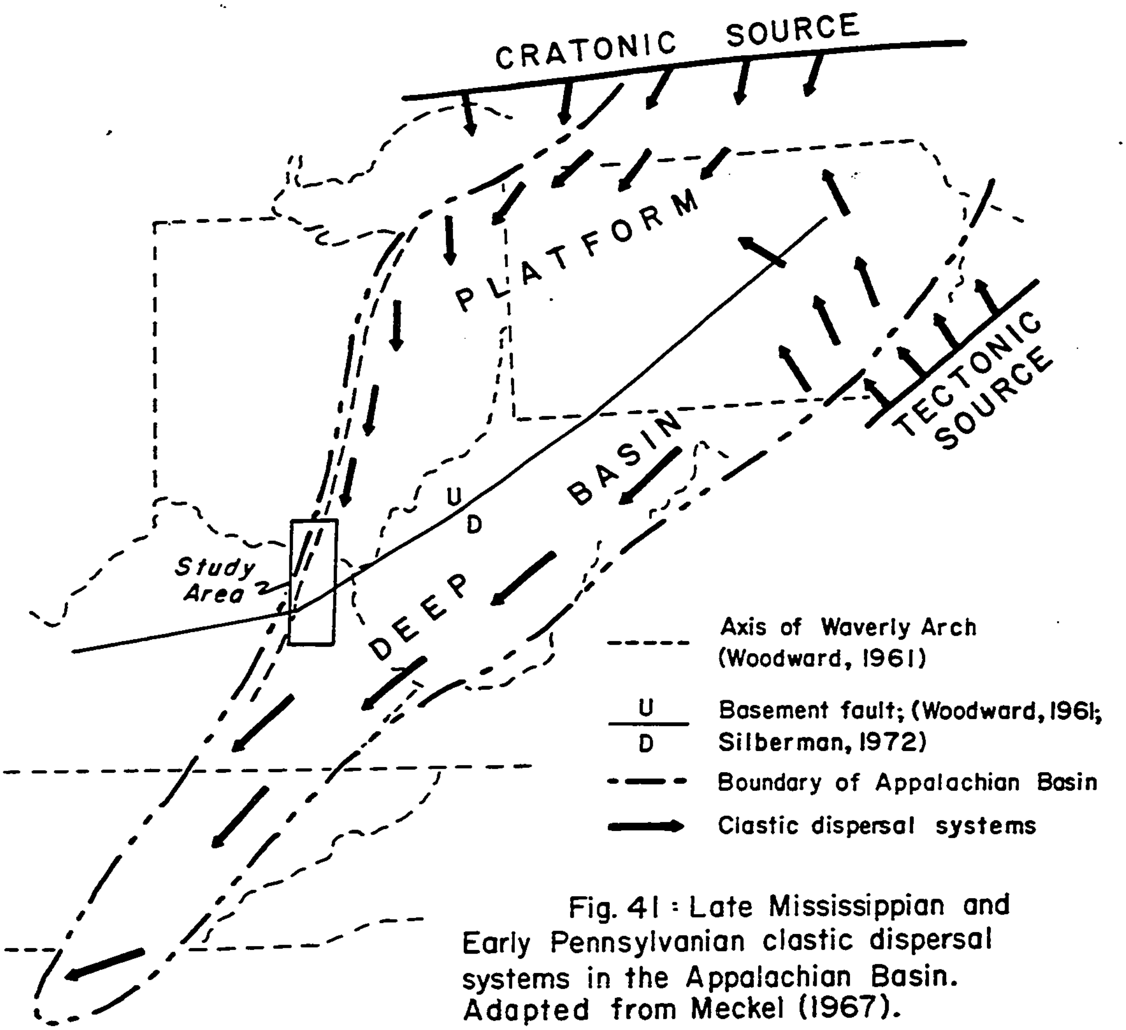


Fig. 41 : Late Mississippian and Early Pennsylvanian clastic dispersal systems in the Appalachian Basin. Adapted from Meckel (1967).

systems have been confirmed by Fuller (1955) and Mrakovitch and Coogan (1975). The sediments are thought to have originated from two source areas, one a tectonic source in the northern Appalachians, and the other a cratonic source on the Canadian Shield. The majority of the Ohio conglomerates and sandstones were derived from the cratonic, probably sedimentary, source (Rittenhouse, 1946; Heimlich et al., 1975) with minor input from the eastern tectonic source. This tectonic source contributed major amounts of material to depositional systems active along the basin axis, with additional dispersal systems active to the northwest across Pennsylvania (Meckel, 1967, 1970; Schlee, 1963). Contacts with underlying Mauch Chunk sediments are largely gradational south of the flexure zone, but appear to be erosive north of this feature (Colton, 1970; Dennison and Wheeler, 1975). Intertonguing relations between the basal Lee and upper Pennington in southeast Kentucky and southwest Virginia (Englund, 1966; Wanless, 1975) attest to the probable Late Mississippian age of these sediments in that area.

The nature of deposition north of the flexure zone on the platform was largely by fluvial processes (Meckel, 1967, 1970; Fuller, 1955; Mrakovitch and Coogan, 1975; Dennison and Wheeler, 1975). The positive Waverly Arch influenced sedimentation patterns in eastern Ohio by altering the southwestern paleoslope and creating a more southerly dipping depositional surface. The arch may have also been responsible for a paleo-high which existed in east-central Ohio (Stout, 1916; Wanless, 1975) and limited deposition of the Sharon to low-lying areas (Morningstar, 1922). In the area of the flexure (Kentucky River Fault System, Woodward's basement fault), shallow marine conditions prevailed (Donaldson, 1969, 1970; Wanless, 1975) as the fluvial systems began to deposit clastic material in thin, possibly coalescing deltas. Meckel (1967, p. 248) points out that the strata of Sharon age in West Virginia contain a "dominantly marine fauna, indicating that a marine environment lay approximately 100-150 miles to the south (of northeastern Ohio) at this time". These deltas were susceptible to slight changes in sea level and minor transgressions and shifts of loci of deposition were not uncommon.

Sedimentation to the south and east was largely confined to the axis of the basin during this early period; however, due to a disequilibrium of subsidence and deposition, these depositional systems began to shift laterally away from this locus (Englund and Delaney, 1966). With time, these environments reached the study area and became the dominant source of sediment in that area; however, the northwest transgression was halted by the positive nature of the flexure and energy was directed to a southwest progradation.

It is not known exactly how far this progradation progressed; however, sediments in the Cumberland Plateau of Tennessee and Alabama appear to be dominantly marine (Hobday, 1969). This may indicate a nearshore marine-nonmarine environmental setting similar to that which had developed earlier in northeastern Kentucky.

With the growth of the Appalachian Mountains and the subsequent development of new deltaic systems originating from these young highlands, Lee deposition came to a gradual end and was replaced by extensive, low-lying deltas of the Breathitt Formation.

Addendum

It is likely that the deltaic systems which developed in eastern Ohio and northeastern Kentucky during the Late Mississippian were not the first to be influenced by the Waverly Arch. Pepper et al. (1954) in their interpretation of the Berea and Sunbury clastics depict a major deltaic environment which was aligned north-south and nearly atop this structural feature (Fig. 42). Data from northeastern Kentucky shows that Devonian black shales thin across this structure, and that the arch was probably a positive feature during the deposition of these sediments. It does appear likely, therefore, that this feature exerted control over depositional patterns exhibited by the Devonian black shales and Berea and Sunbury sediments.

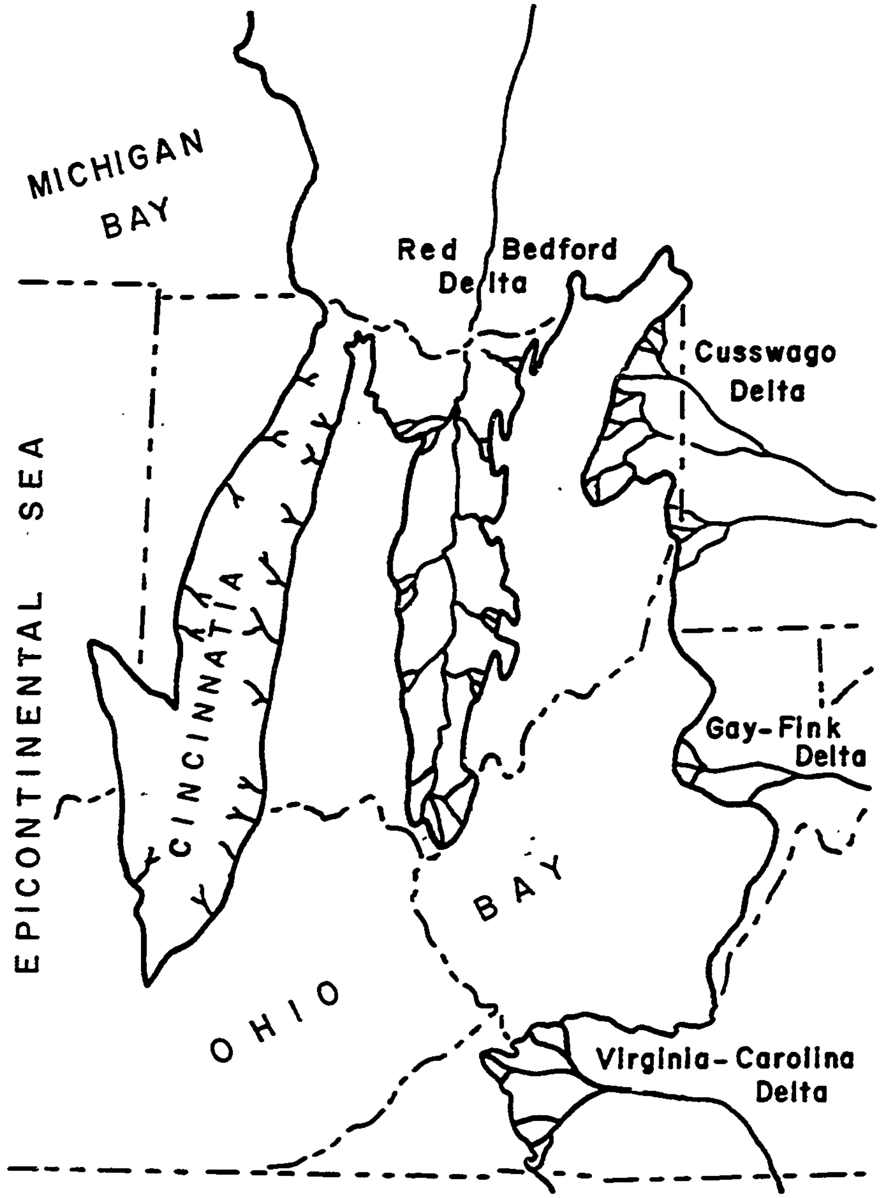


Fig. 42: Paleogeographic map of early Bedford time, adapted from Pepper et al. (1954). Note the position of the Red Bedford Delta which is coincident with the axis of the Waverly Arch (see figure 41 for the location of the structure in Ohio).

CONCLUSIONS

Stratigraphy

1. The Carter Caves sandstone of northeastern Kentucky is one of a series of channel sandstones contained within the Pennington Formation. These channels extend in outcrop from just south of the Ohio River to near U. S. Interstate 64.

2. The Carter Caves sandstone and its lateral equivalents in Kentucky are correlative to the Sharon Conglomerate of southeastern Ohio.

3. The Sharon Conglomerate of southeastern Ohio and the Lee Formation of east-central Kentucky are not continuous or correlative units and represent two distinct depositional systems.

4. The Corbin sandstone member of the Lee Formation of east-central Kentucky thins to the northwest and pinches out into shales, siltstones and fine sandstones in the vicinity of the Kentucky River Fault System.

5. Channel orientations and paleocurrent data in the Sharon Conglomerate of southeastern Ohio and the Pennington Formation of northeastern Kentucky suggest a southerly realignment by the Waverly Arch of the regional paleoslope on the western edge of the Appalachian Basin.

6. Regional stratigraphic correlations utilizing fossil dates from the Pennington Formation near Carter Caves State Park indicate a Late Mississippian age for the Olive Hill Clay Bed of Crider (1913).

7. The Mississippian-Pennsylvanian boundary on the northern block of the Kentucky River Fault System in northeastern Kentucky is generally conformable between the Pennington and Lee formations; however, local disconformities occur at the base of Pennington channel sandstones. A major unconformity is locally present at the Newman interval.

8. On the south side of the Kentucky River Fault System, a major erosional unconformity is locally present at the base of the Corbin sandstone.

Sedimentology

9. Fine-grained clastics of the Pennington Formation of northeastern Kentucky and coarse clastics of the Sharon Conglomerate of southeastern Ohio represent a depositional continuum of fluvial-deltaic deposition on a stable platform created by the Waverly Arch and Kentucky River Fault System.

10. Carbonates and green shales of the upper Pennington Formation in northeastern Kentucky represent a destructional phase in delta deposition following Pennington deltaic processes and prior to Lee fluvial-deltaic deposition.

11. The Lee Formation of east-central Kentucky represents fluvial-deltaic deposition which transgressed away from the axis of the Appalachian Basin with time and was finally halted by the positive, northern side of the Kentucky River Fault System.

12. The Corbin sandstone was deposited by fluvial processes, most likely braided streams.

13. Flint clay deposits within the study area were formed near a Newman-Borden erosional surface in marsh or swamp conditions which existed within delta complexes and atop the positive Waverly Arch on the northern side of the Kentucky River Fault System.

14. Trace fossil associations indicate deposition in shallow to marginal marine environments. Some occurrences were useful in determining relative rates of sedimentation between adjacent units.

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Appendix A

The following is a list of fossils collected by Sheppard and Dobrovolny (1962) from the thin, argillaceous limestones that overlie the Carter Caves sandstone at Box Canyon, Carter County, Kentucky (Locality C) and from near the junction of State Routes 182 and 2 in Carter County, Kentucky (Locality A). USGS numbers refer to United States Geological Survey sample collection numbers.

Locality A: Junction of State Routes 182 and 2, Carter County, Kentucky.

USGS 20204-PC: *Spirifer* cf. *S. leidyi* Hall

Composita subquadrata (Hall)

Eumetria cf. *E. vera* Hall

"Spirifer" spinosa (Norwood & Pratten)

USGS 20205-PC: Spirifer sp.

USGS 20206-PC: *Orthotetes* cf. *O. Kaskaskiensis* (McChesney)

Locality C: Box Canyon, Carter County, Kentucky; Station ___ of this study.

USGS 20207-PC: *Orthotetes* cf. *O. Kaskaskienses* (McChesney)

Allorisma sp.

USGS 20209-PC: *Orthotetes* cf. *O. Kaskaskienses* (McChesney)

Diaphragmus cf. *D. cestriensis* (Worthen)

Ovatia ovta (Hall)

Spirifer cf. *S. increbescens* Hall

Composita subquadrata (Hall)

Aviculopecten sp.

Bellerophon sp.

Straparollus (Euomphalus) sp.

Appendix B

The following is the locality register for samples collected by Ettensohn and Pepper for spore analysis. Locality numbers are University of Illinois Z-numbers. Localities are described below with their associated Carter Coordinates. Description taken from Ettensohn and Pepper (in prep.).

Z-530 Outcrop and drainage ditch on eastbound lane of Interstate 64, 1.3 km. (0.8 mi.) west of junction of Interstate 64 and U.S. 60; Carter County; U.S.G.S. 7.5' Olive Hill Quad.; 75' FEL x 1450' FNL, 4-V-77
Sample 2130: Dark gray shale 0.6 m. (2 ft.) above uppermost Glen Dean limestone;
Sample 2133: Flaser-bedded sandstone and shale approximately 1.5 m. (5 ft.) above uppermost Glen Dean limestone.

Z-566 Outcrop on Kentucky State Route 1274, 0.6 km. (0.4 mi.) south of Licking River bridge; Menifee County; U.S.G.S. Bangor Quad.; 925' FEL x 1450' FNL, 19-S-73
Sample 2128: Coal and carbonaceous shale approximately 5.8 m. (19 ft.) above the highest ridges on the eroded upper Glen Dean surface.

Z-567 Outcrop on Kentucky State Route 1274, 7.4 km. (4.6 mi.) southwest of Licking River bridge, locally known as Cold Cave; U.S.G.S. Enzel Quad. 950' FEL x 1500' FNL, 5-R-73.
Sample 2123: Thin coal just below base of Corbin Sandstone approximately 10.4 to 11.6 m. (34-38 ft.) above eroded top of Newman Limestone.
Sample 2131: Thin coal 0.5 to 1.8 m. (1.5-6 ft.) above eroded top of Newman Limestone.

Z-571 Abandoned Licking River Limestone Quarry on north side of the Licking River, northeast of Pretty Branch and Oakley Landing (partially flooded); Morgan County; U.S.G.S. Enzel Quad.; 125' FEL x 1050' FNL, 6-R-74.
Sample 2125: Thin coal 4.6-6.0 m. (15-20 ft.) above uppermost Glen Dean limestone.

APPENDIX C

The following is a complete list of cross-bedding measurements obtained for this study. Station locations are shown in figure 5 in the text. Facies designations are indicated. R refers to ripples.

Station	Cross-bedding values	Facies
2	63, 50, 49	D
4	241, 237, 216, 197, 195, 227, 175, 277	D
7	285, 135, 121, 234	A-S
8	290, 308, 208, 237	A-S
9	306, 268, 226, 290, 286, 331, 328, 332, 345, 351, 327, 335, 331, 336	A-S
10	252, 275, 293, 231, 212, 206, 201, 304, 276	A-S
11	311, 255, 270, 294, 258, 264, 316, 257, 340, 294	A-S
12	211, 214, 250, 217, 235, 223, 249, 288, 290	A-S
13	209, 234, 220, 231, 234, 243, 233, 218, 201, 233, 242, 277, 261	A-S
15	274, 271, 204, 229, 209, 197, 307, 315, 313, 222, 242, 274, 240, 280, 265, 236, 226	A-S
16	188, 186, 167, 132, 220, 202, 172, 306, 272, 308, 246, 288, 262, 237, 219, 217, 220, 226, 215, 236, 229, 202, 237, 254, 249, 260, 225, 206, 264, 238	A-S
17	320, 304, 327, 319, 351, 315, 307, 336	A-S
20	205, 211, 261, 215, 229	A-S
20-A	252, 239, 227	A-S
21	285, 311	A-S
22	339, 300, 321, 329, 300(R)	A-S
25	162, 173, 224, 218, 282, 271, 156(R), 120(R)	D

Station	Cross-bedding Values	Facies
27	142	D
29	135, 155, 132, 141, 170, 133	D G
30	3, 38, 43	D(?)
31	26, 54, 92	D(?)
34	194, 227, 209, 169, 237, 146	D
35	200, 194, 184, 279, 276, 304, 232, 238, 205(R), 350(R)	D
36	274, 264, 247, 195(R), 137(R)	D
38	324, 335, 295	D
40	293, 254, 193	A-S
43	330, 264, 308, 314, 310, 303, 324, 324, 326	A-S
44	271, 279, 293, 278, 257	A-S
45	283, 289, 303, 255, 277	A-S
47	227	D
49	225, 237	D
50	220, 218	D
51	133, 142, 162	D
52	191, 224, 234, 163, 208	D
53	185, 159, 165, 171, 153	D
54	200, 210, 159, 160	D
55	206, 210, 208, 220, 185	D
56	172, 165, 189	D
57	217 87, 131, 126, 115	D C

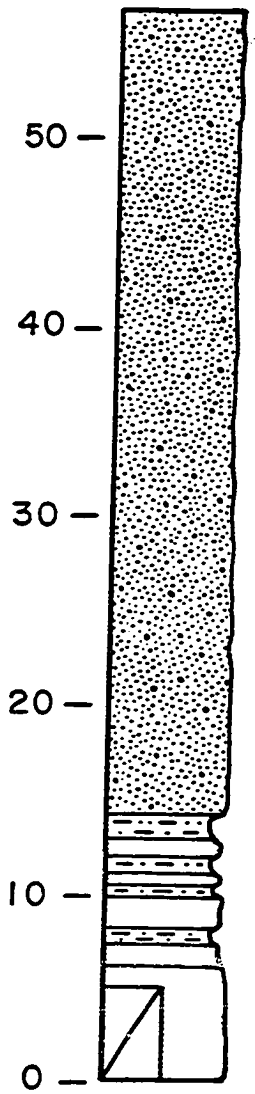
Station	Cross-bedding Values	Facies
59	94, 108, 101, 64	D(?)
61	75, 85, 76, 71 191, 185	D(?) C
62	339, 336, 246, 216, 257, 191	A-S
64	269, 285, 224, 230	A-S
65	307	A-S
66	329, 284, 244, 279, 283, 318	A-S
67	115, 137 213, 207, 216, 219, 230, 280 229, 354, 284	G A-S
68	231, 233, 191, 153, 204, 197, 200, 253 172, 235, 225, 264, 237, 261, 223, 251, 219, 238	A-S
69	224, 238, 274, 287, 257, 270	A-S
70	241, 245, 236, 184, 244, 228, 235, 283, 229, 235, 233, 268, 259, 267	A-S
71	192, 196, 263, 242	A-S
72	221, 238, 281, 214, 212	A-S
73	210, 253, 227, 190, 223, 242, 264, 206, 228, 258, 241	A-S
74	225, 267, 260, 273	G
76	123, 120, 141, 134, 129	D
77	120, 149, 105	D
78	210, 253, 244	D
79	257, 319, 225, 225, 284, 304, 292, 297, 326, 260, 234	A-S
80	251, 300, 170, 268, 284, 304, 304	A-S
81	312, 316	A-S

Station	Cross-bedding Values	Facies
96	224, 244, 174, 246	D
87	191, 237, 178, 221	D
90	301, 254	D
91	176, 205, 223	D
92	241, 233, 190, 245, 272, 278, 282, 292	D
93	242, 257, 264, 267, 278, 308, 259	A-S
95	176, 171, 187, 145, 147, 163, 110, 247, 194	D
96	169, 159, 171	D
99	274, 216, 264, 230	D
100	222, 256, 274	D
101	240, 165, 259, 156, 140, 129	D
102	216, 187, 173	D
103	145, 150, 103, 149, 144	D
104	224, 134	D
105	254, 211, 198, 204, 272, 183, 235	D
106	137, 134	D
107	226, 233, 249, 217, 250, 258	D
108	104, 127, 164, 138, 132,	D
111	241, 224	D
113	302, 133, 230, 218, 247	D
114	304, 273, 315, 264	D
115	304, 314, 307	D
116	199, 185, 192	D
117	264, 221, 289, 184, 152, 143, 118	D

Station	Cross-bedding Values	Facies
118	200, 167, 146, 99, 177, 234, 125, 207, 295, 190, 209, 231, 198, 212, 210	D
119	234, 124, 152, 148, 141	D
120	241	D
121	246, 141, 122, 243	A-N
122	332, 52, 71, 90, 84, 164, 192	A-N
123	144, 107, 122	A-N
124	70, 104, 242, 140, 116	A-N
125	143, 152, 156, 181, 152, 121	A-N
127	182, 198, 242, 229	A-N
128	112, 227, 267, 309	A-N
129	232, 217, 246, 201, 275, 248, 247, 229	A-N
133	137, 145, 151, 159, 150, 203, 144	D
134	137, 164, 199, 176	D
135	42, 59, 112, 68, 112, 68, 96, 55, 102, 79, 93	D

Station 16

Road exposures on State Highway 504 at the junction of Big Caney Creek, Beech Creek, and Powder Mill Branch in the western part of the U.S.G.S. Bruin Quadrangle, Carter Coordinates: I-T-77.



52-56 m.: Sandstone and shale. Sandstone is fine-to medium-grain in thin to medium beds and microcross-laminated. Shale partings, 5-10 cm. thick, appear.

14-52m.: Sandstone, white to brown, fine- to coarse-grain and massive to thin bedded. Sparse to common, well-rounded quartz pebbles present in lower portions. Wood fragments present throughout. Tangential and planar cross-bedded. Bed thickness diminishes upwards. Sparse, assymmetrical ripples on some bedding surfaces. Iron stained.

10-14m.: Sandstone and shale. Alternating beds of fine-grain, microcross-laminated sandstone and thin bedded to laminar bedded, black to dark gray shale. Sandstone is in thin to medium, discontinuous, horizontal beds.

5-10m.: Sandstone, fine-to medium-grains, tangential crossbeds and some convolute bedding. Load casts on soles of some beds. Siderite nodules. Slumps.

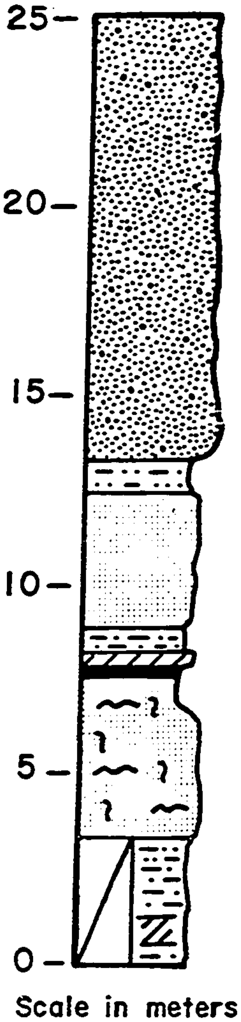
0-5 m.: Covered interval

Newman Limestone

Scale in meters

Station 65

Abandoned clay strip mine 3.5 kilometers south of Clearfield, Kentucky along State Route 519, U.S.G.S. Morehead Quadrangle. Carter Coordinates: 15-T-75.



13.4-25.0: Sandstone, medium to coarse grains and slightly conglomeratic. Planar & tangential cross-bedding in thick to massive beds. Woody fragments very abundant.

12.6-13.4 m.: Shale, black, silty and sandy in laminar to thin beds.

9.0-12.6 m.: Sandstone, fine to medium grains, pale red to yellow. Thin to medium, horizontal beds. Sparce cross-lamination and woody fragments.

8.1-9.0 m.: Shale, black, silty and barren. Laminar to thin discontinuous beds.

7.9-8.1 m.: Dolomite, finely crystalline in a single nodular bed. Nonfossiliferous.

7.8-7.9 m.: Coal

6.6-7.8 m.: Shale, fine-grain sandstone lenses in lower part, silty in upper. Siderite beds in lower portion, carbonaceous throughout. Thin beds.

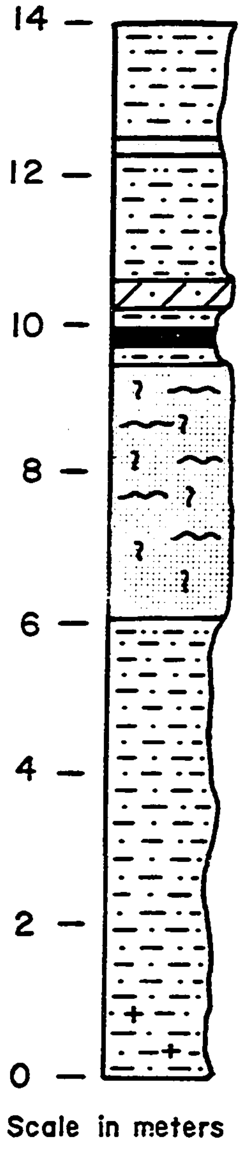
3.5-6.6 m.: Sandstone, silty and shaly. Very fine- to fine-grain. Rippled with carbonaceous drapes. Gray to black color. Abundant bioturbation throughout.

0-3.5 m.: Covered zone

Newman Limestone

Station 82

Abandoned clay strip pit on east side of Open Fork, 9 kilometers north of junction with Christy Creek, U.S.G.S. Haldeman Quadrangle. Carter Coordinates: 17-U-75.



10.5-14.0 m.: Shale, black and silty with lenses of fine-grained, bioturbated, carbonaceous sandstone.

10.2-10.5 m.: Dolomite, finely crystalline, silty and nonfossiliferous. Bioturbated.

9.6-10.2 m.: Shale, black and silty. Zone contains a 15 cm. coal.

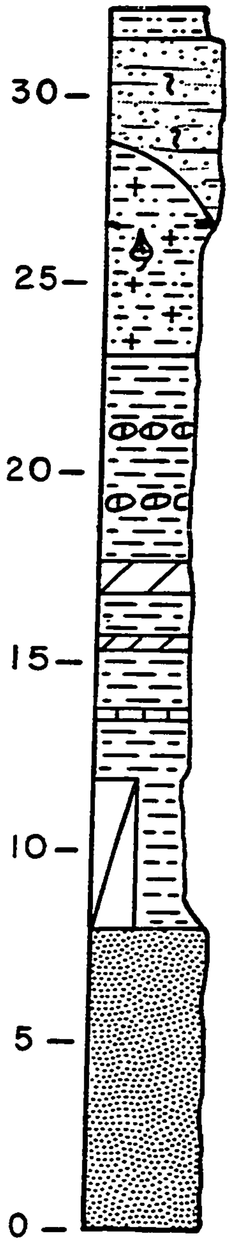
6.1-9.6 m.: Sandstone, white and fine to medium grains. Beds range from massive at base to thin at top. Abundant ripples with coaly and carbonaceous drapes. Minor amounts of coal lenses. Abundant bioturbation throughout.

0-6.1 m.: Shale, black to light gray with abundant carbonaceous material along bedding planes. Bedding is laminar at base and becomes blocky near top. Sparce siderite nodules in basal part disappear near top of unit. Unit becomes siltier from base to top.

Borden Formation lies 2.5 m. below base of section.

Station 88

Road exposure on north side of U.S. Interstate Highway 64 at it's junction with U.S. Highway 60, U.S.G.S. Grahn Quadrangle. Carter Coordinates: 21-W-77.



Scale in meters

31.7-32.5 m.: Shale and siltstone. Thin bedded, gray to black. Badly weathered.

26.6-31.7 m.: Sandstone, very fine - to fine-grain. Massive beds at base become thin at top. Abundant siderite concretions and carbonaceous partings. Abundant bioturbation.

23.2-26.6 m.: Shale, black, silty and contains sparse plant debris. Common siderite nodules. Thin bedded.

11.9-23.2 m.: Shale, limestone, and dolomite. Shale is green to light gray, clayey to slightly silty, laminar to thin bedded, and commonly fossiliferous.. Limestone is argillaceous and in nodules to thick beds. Contains abundant fossils and common shale inclusions. Dolomite is light to medium gray, fine crystalline, slightly fossiliferous and occurs in thin to thick beds and nodules.

8.0-11.9 m.: Covered zone

0-8.0 m.: Sandstone, fine-to medium-grain, trough cross-bedded. Upper and lower contacts concealed.

Newman Limestone