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ANNUAL AND FOURTH QUARTER REPORT FOR 1977–1978

By
Paul Edwin Potter
J. Barry Maynard
Wayne A. Pryor

October 1, 1978

Work Performed Under Contract No. EY-76-C-05-5201

University of Cincinnati
Cincinnati, Ohio

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ANNUAL AND FOURTH QUARTER REPORT
UNIVERSITY OF CINCINNATI FOR 1977-78
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ORD 5201-4

Prepared by

Paul Edwin Potter, Principal Investigator

and

J. Barry Maynard and Wayne A. Pryor,
Co-investigators

October 1, 1978

SUMMARY

Much was accomplished in the summer quarter of 1978 because all four graduate students worked full time, Professor Maynard worked two months and Professors Pryor and Potter each worked one month.

Positive accomplishments in the summer included:

(1) preparation of text for the basinwide paleocurrent map (this is an interim, "dry lab" basin analysis for a MERC report),

(2) advanced drafts of two papers on isotopic analysis of the Devonian Shale sequence for outside publication,

(3) two abstracts on the Brallier Formation plus many of its illustrations and tables,

(4) continued slow progress in the U.S.G.S. editorial mill of our Big Stone Gap study,

(5) completion of most of the field work for "Sedimentology and Stratigraphy of the Ohio Shale Along Lake Erie", an M.S. student research project,

(6) collection of the subsurface data on the thickness and elevation of the Devonian shale in the Middlesboro Basin (Pine Mountain overthrust sheet).

During the year we also helped Roy Kepferle prepare an inventory of all the cores that have been obtained from the Devonian Shale

sequence in the Appalachian basin. Throughout the year we also generated chemical data in our own laboratory: CHN, composition of organic matter in the shales, prepared samples on carbon and sulphur isotopic studies, and developed techniques in chromatographic analyses.

The poorest part of our contract performance so far is general shale petrology, which continues to lag. Most of what we accomplish in shale petrology is done by graduate students Broadhead, Lundegard, Samuels, and Stenbeck and will probably be based more on thin section and X-ray studies than on the SEM.

Administratively, our contract is properly funded and has functioned very well in its second year. A significant forward step was the hiring of Mrs. Kao, a full-time chemical technician, one who is exceptionally well qualified. Without her our geochemical effort would be severly handicapped.

We and the project have also greatly benefited from the presence of Roy Kepferle, who has been most helpful stratigraphically.

For the fall, winter, spring and summer of 1979 Professor Maynard has requested a sabbatical and will not be in Cincinnati, and Professor Potter plans to withdraw from the project in October 1979.

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PUBLICATIONS AND MANUSCRIPTS PREPARED

Kepferle, Lundegard, Potter, Pryor, Samuels, Schauf, Stenbeck and Wilson: Subsurface Correlation and Petrology of Big Stone Gap Member of Chattanooga Shale (Upper Devonian and Lower Mississippian), Wise County, Virginia. (Submitted to U.S.G.S., for MERC approval, and in final USGS editing for publication as a bulletin. This paper has 12 figures and 30 pages of text and is well described by its abstract below).

Abstract

Floods on the Powell River in April 1977 re-exposed a classic section of the Chattanooga Shale (Devonian and Mississippian) in Big Stone Gap, Virginia. Within a month of the flood the authors examined the section, collected samples, logged the radioactivity, measured joints, and described the lithology. The gamma-ray log of the section closely resembles the gamma-ray profile of the upper one-half of the Chattanooga Shale sequence in a nearby well, Columbia Gas Transmission Corp., Pennsylvania-Virginia Corp., farm well no. 20338, from which an oriented core has been taken by the U.S. Department of Energy's Morgantown Energy Research Center.

Mapped surface units were compared and correlated with units identified in greater detail on the gamma-ray log from the well. Units of the Big Stone Gap Member in this section are equivalent to the Sunbury Shale (Lower Mississippian), the Bedford Shale (Upper Devonian? and Lower Mississippian), and the Cleveland Member of the Ohio Shale (Upper Devonian). The middle gray siltstone member of the Chattanooga Shale of the surface mapping includes the equivalents of the Three Lick Bed of the Ohio Shale and of the upper and middle parts of the Huron Member of the Ohio Shale. The Foerstia zone was found in the outcrop samples after an intensive search of the interval indicated on the gamma-ray log as corresponding to the interval in which Foerstia were found in the core.

Composition, maximum grain size, and lamination were examined in 38 thin sections of the exposed rocks. Quartz and feldspar, clay, coarse micaceous minerals, organic matter, pyrite, chert, and rock fragments were recognized in decreasing abundance. Coarsest grains of quarts and feldspar range in size from fine sand to silt. Three classes of lamination recognized in thin section are: distinct silt laminae, distinct organic laminae, and massive, or non-laminated. Of these, distinct silt laminae are most abundant in the black shale in the lower part of the section.

Joint orientation from 76 measurements show perpendicular bimodality. One mode parallels the present structural strike. Slight variations are evident between differing rock types.

Maynard: Carbon Isotopes in The Devonian Shale Sequence: Utility as Provenance Indicators. For presentation at the Morgantown Octoberfest and later outside publication.

Abstract

The type of organic matter present in the shale-marine or terrestrial-may be important in gas generation because terrestrial carbon appears to yield more methane than marine-derived carbon. The ratio of C^{13} to C^{12} in the organic matter of recent sediments (expressed as δC^{13}) is a function of the provenance of the carbon: non-marine C is relatively negative, around -26, while marine C is about -21. The Devonian Shale sequence also shows a proximal-distal variation in C isotopes. Wood samples and non-marine black shales have δC^{13} values of -25 to -26, similar to the modern value. Marine shales, however, are more negative, ranging from -27 to -31, the values becoming more negative to the west and northwest within a given stratigraphic interval. Carbon isotopes also reflect distal-proximal changes in the organic matter at a given locality. Usually, gray shales have less negative (i.e. less marine) values than black shales. For instance, the Beford gray shale in Richland County, Ohio averages -27.6 whereas the immediately underlying Cleveland black shale averages -29.2.

As yet there is no explanation for the difference between the Devonian and the recent pattern, except to suggest that perhaps the marine organisms were different.

Our carbon isotope results suggest that Eastern Kentucky and Western West Virginia should be the most favorable areas for gas, and that Central Ohio and the Illinois Basin should be poor.

Table 1. Comparison between δC^{13} of Total Organic Matter and Extractable Hydrocarbons.

	Total Organic Matter	$ChCl_3$ Extract
Christian Co., Ky.		
2191.2 ft.	-30.4	-29.0
2230.2 ft.	-29.7	-29.3
2318.8 ft.	-30.2	-29.4
Letcher Co., Ky.		
214 ft.	-28.7	-28.3
234 ft.	-28.4	-29.0
244 ft.	-28.0	-29.6
Outcrop samples		
Wood fragment, Olentangy Shale, Ohio	-25.6	-27.1

Table 2. Basin-wide Vertical Variation in Carbon Isotopes

Stratigraphic Unit	Average δC^{13}	Number of Samples
1. Appalachian Basin		
a. Marine Samples		
1) Sunbury	-30.3	4
2) Bedford	-27.7	5
3) Cleveland	-28.8	25
4) Chagrin-Three Lick Bed	-27.3	12
5) U. Huron	-29.3	6
6) M. Huron	-28.9	12
7) L. Huron-(Dunkirk)	-29.7	31
8) Java		
Hanover (U.Olentangy)	-29.4	4
Pipe Creek	-29.1	1
9) West Falls		
Angola	-27.2	1
Rhinestreet	-29.7	7
b. Non-marine Samples		
1) Catskill Shale, Gilboa, N.Y.	-24.8	1
2) Wood fragment, Olentangy Sh, Ohio	-25.6	1
3) Wood fragment, Huron Sh, Kentucky	-26.8	1
2. Illinois Basin		
1) Grassy Creek	-29.8	10
2) Swetland Creek	-29.8	7
3) Blocher	-30.3	2

Maynard: Sulfur isotopes of iron sulphides in shales of the Appalachian Basin: influence of sedimentation rate (to be submitted to the American Journal of Science).

Abstract

Sulfur isotopes of sulfides in recent sediments are related to sedimentation rate, δS^{34} becoming more positive with increasing rate. A functional relationship for this behavior is derived which is then applied to ancient rocks. Pyrite in Devonian-Mississippian shales of the western Appalachian Basin shows the expected qualitative behavior: proximal gray shales have relatively positive δS^{34} values, distal black shales are relatively negative. Quantitatively, the sedimentation rates inferred by comparison with recent sediments are too high. Possibly the basin was restricted from contact with open seawater, and consequently contained dissolved sulfate with an unusually positive δS^{34}. Alternatively, the biochemistry of the sulfate reduction process may have changed since the Devonian.

Conclusions

Studies from recent sediments show that sulfur isotopes of sulfide minerals are controlled ultimately by the sedimentation rate, although initially by the rate of sulfate reduction which increases with increasing sedimentation rate. This primary effect is then modified by the degree of contact with open seawater. If contact is restricted, the resulting δS^{34} vlaues are more positive. Such restriction can result from a restricted basin, or from sulfide formation well below (>10 cm) the sediment-water interface in a relatively well-oxygenated basin. The two are easily distinguished by low sulfur contents (<0.3 percent) in the second case.

For ancient shales, sulfur isotope results from the Kupferschiefer suggest an initially open basin followed by increasingly restricted conditions, culminating in the Zechstein sequence. Devonian-Mississippian shales of the western part of the Appalachian Basin show more positive δS^{34} values of pyrite in the proximal gray shales, more negative in the distal black shales. Extremely negative values are found in the very thin black shales along the crest of the Cincinnati arch. Comparison with the sedimentation rate curve from recent sediments, however, gives rates much too high. It is suggested that unless there has been a change in bacterial biochemistry the basin was somewhat restricted with respect to seawater sulfate, shifting the δS^{34} sedimentation rate curve to more positive values. Thus it appears that sulfur isotopes can be used to determine relative sedimentation rates. For instance, it appears that the pyritic gray shales in this study differ from the black shales in having higher sedimentation rates rather than in any property of the organic matter. However, absolute rates cannot be determined with certainty, and little information can be gained from a few analyses. Studies of this kind must include a range of samples from throughout the basin of deposition.

Table 1

Stratigraphic Units of the Devonian-Mississippian Included in this Study.

Name	Predominant Color	Lithology Mineralogy
Mississippian:		
Bedford Fm. (=Price, Grainger)	Gray	Siltstone and shale. Turbidites abundant. Abundant siderite, marcasite near base in some areas.
Sunbury Shale	Black	Shale. Abundant pyrite.
Bedford Shale (+Berea SS).	Gray	Shale and siltstone w. occasional siltstone turbidites (Euclid Mbr), Berea Sand irregularly present, mostly in Ohio. Bedford has siderite in base in Ky., large pyrite spheres (>2cm) in top.

Table 1 - Continued

Devonian:		
Ohio Shale (=Chattanooga)		
Cleveland Mbr.	Black	Shale Pyritic
Chagrin Mbr.	Gray	Shale and siltstone, turbidites common to east. Siderite abundant, pyrite common.
U. Huron Mbr.	Black	Shale Pyritic
M. Huron Mbr.	Gray & Black	Shale, interbedded gray & black. Pyritic, occasionally some siderite.
L. Huron Mbr. (=Dunkirk of N.Y.)		Shale Pyritic
New Albany Shale (=total Ohio Sh + Sunbury Sh where Bedford absent)	Black	Shale Pyritic, phosphate nodules abundant at top.
Java Group		
Hanover Shale	Gray	Siltstone and Shale
Pipe Creek Shale	Black	Thin black shale interbeds in gray shale.
West Falls Group		
Angola Shale	Gray	Shale
Rhinestreet Shale	Predominantly black	Shale
Leicester Marcasite (becomes Tully LS to east)		Marcasite and pyrite replacing shell fragments.
Unconformity		
Hamilton group (undivided)		(not studied)
Marcellus Shale		
Unconformity		
Middle Devonian and older carbonates.		

Table 2

Sulfur isotopic composition of iron sulfides from Devonian-Mississippian rocks of the Appalachian Basin.

Stratigraphic unit	δS^{34}
1. Borden Formation	
Farmer's Siltstone	-11.1
(Rowan Co., Ky.)	-21.4
Kenwood Siltstone	-11.1
(Bullit Co., Ky.)	
2. Sunbury Shale	- 7.4
(Adams Co., Ohio)	
3. Bedford Shale	
(Rowan Co., Ky.)	+20.0
(Rowan Co., Ky.)	+16.6
(Cuyahoga Co., Ohio)	- 7.5
Euclid Siltstone, Mbr	
(Cuyahoga Co., Ohio)	
1m turbidite bed	+26.7
4. Ohio Shale	
Cleveland Member	
(Cuyahoga Co., Ohio)	- 9.2
(Lorain Co., Ohio)	- 5.2
(Rowan Co., Ky.)	- 3.6
(Powell Co., Ky.)	- 4.6
Chagrin Member	
(Lorain Co., Ohio)	+ 2.6
(Wise Co., Va. - core)	+ 3.3
Upper Huron Member	
(Powell Co., Ky.)	-10.1
Middle Huron Member	
(Adams Co., Ohio)	+23.5
(Powell Co., Ky.)	-10.8
(Wise Co., Va. - core)	+29.8
Lower Huron Member	
(Wise Co., Va. - core)	- 3.8
(Wise Co., Va. - core)	- 6.5
(Wise Co., Va. - core)	- 7.1
(Delaware Co., Ohio - core)	+ 6.3
(Delaware Co., Ohio - core)	- 0.9

Table 2 - Continued

Undifferentiated (=New Albany shale)	
(Overton Co., Tenn. - core)	-20.5
(Overton Co., Tenn. - core)	-29.9
Unconformity at base of Ohio Shale	
(Adams Co., Ohio)	
massive pyrite	- 4.2
sandy, phosphatic zone	-24.2
(Rowan Co., Ohio)	
sandy, phosphatic zone	-29.0
5. Leceister Marcasite - massive sulfide	
(Erie Co., N.Y.)	
top	- 1.4
base	- 0.2

Averages	
Unconformities	-11.8
Black shales	- 7.9
Gray shales	+11.6
Later mineralization (Borden)	-14.5

Table 3

Sedimentation rates inferred from sulfur isotopes.

Stratigraphic unit	Relative sedimentation rate [1] (cm/year)
Middle Huron	1.6
Bedford	1.1
Chagrin	0.6
Lower Huron	0.4
Cleveland	0.3
Sunbury	0.3
Upper Huron	0.2
New Albany	0.01

[1] Calculated by assigning a value of 0.01 cm/yr to the New Albany samples. This is equivalent to raising Δ by $10^{0}/oo$.

Potter, Pryor, Lundegard, Samuels, and Maynard: Devonian paleocurrents in the Appalachian Basin (ready to send to Morgantown for review).

Abstract and Outline

Paleocurrents in the Devonian clastics of the central and northern Appalachian basin were uniformly oriented to the west judging by the orientation of sole marks on interbedded siltstones and sandstones and by the available directional data from the interbedded black and gray shales themselves. The paleocurrent indicators are at right angles to isopachs of total Devonian thickness, which decreases westward from 12,000 ft. in eastern Pennsylvania to a few hundred feet in west-central Ohio. This clastic wedge is largely of Upper Devonian age and includes alluvial and delta plain environments (in the east) as well as shelf (east-central), turbidite slope, and basin plain environments (west central and west), the latter representing most of the black shales. Lithologies within the wedge are more continuous north-south, parallel to depositional strike, than east-west.

The methodology of paleocurrent studies in shaly basins using both outcrops and oriented cores is set forth as is the relationship between paleocurrents and gas potential.

Key Ideas: Paleocurrent systems in shaly basins and gas potential, methodology, Devonian of Appalachian basin, unresolved problems, and annotated bibliographies.

Table 1

BASIN SUMMARY OF DEVONIAN OF APPALACHIAN BASIN

Time Span

Fifty million years.

Geometry and Size

Large, incompletely preserved wedge covering about 260,000 km^2 north of Tennessee with greatest thickness of 12,000 ft. along its southeastern side in Pennsylvania.

Lithic Fill

Lithologies: Exceedingly varied including fluvial red pebbly sandstones and red shales, fluvial, deltaic, beach, and shelf sandstones plus slope and basin siltstones mostly of turbidite origin, widespread gray and black marine shales and shallow water carbonates chiefly in lower part (Holderberg Stage) but also in the Middle and Upper Devonian on the craton and its margins.

Arrangement: General progression from east to west of non-marine clastics through beach, shelf, and slope to deep basin westward with prominent clinoform deposition and westward overlap. Depositional strike is very uniformly oriented north-south throughout the basin except possibly near present western limit and thus even thin shale units have much better north-south than east-west lithologic continuity.

Composition

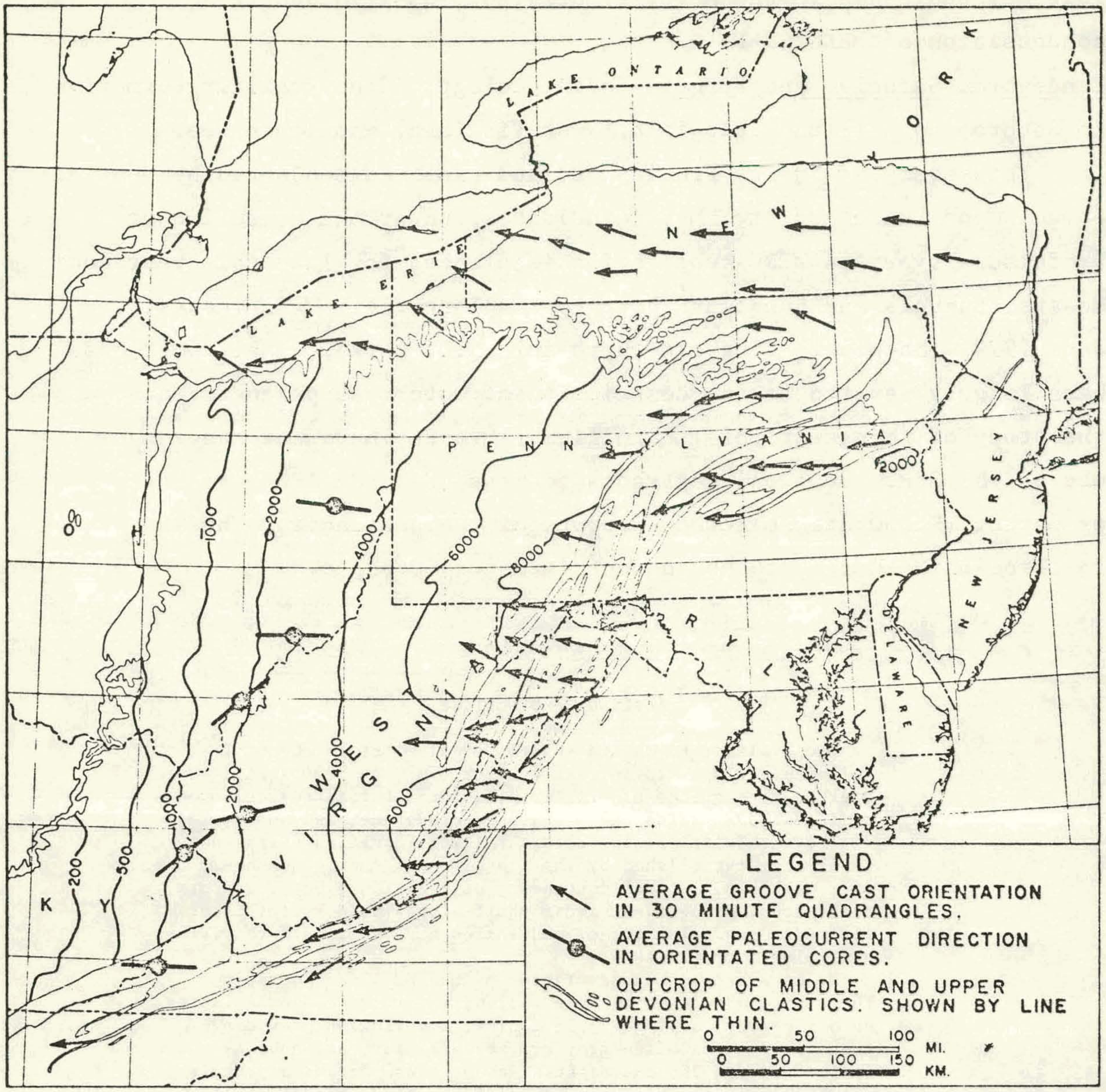
Sublithic to subfeldspathic arenites and wackes; illitic and chloritic, organic rich shales and gray mudstones.

Paleocurrent System

Interbedded siltstones and sandstones, and presumably most of the shale in the basin, have paleocurrents very uniformly oriented to the west and generally perpendicular to isopachs even though black shales, which dominate in western part of basin, imply deposition in a restricted basin.

Paleogeography and Tectonic Setting

Large delta complex in Upper Devonian, now beheaded by continental separation, overlaps cratonic margin. Terrigenous debris supplied by a large river draining a stable, continental land mass, in which volcanic rocks were largely absent. Retroarc basin?



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AVERAGE PALEOCURRENTS AND THICKNESS (FT.) OF DEVONIAN ROCKS

Provo, Kepferle, Potter: Division of Ohio Shale in Eastern Kentucky. This was published in the AAPG, v. 62/9, p.1703-1713 and is a condensation of MERC/CR-FF-2.

Lundegard, Samuels, and Pryor: Sedimentology of the Brallier Formation in Outcrop in Maryland, Virginia, West Virginia, and Tennessee.

This study is in its final phase and has been conducted by Messrs. Samuels and Lundegard, two M.S. candidates, under the direction of Professor Pryor. A MERC publication is planned for late this year and Messrs. Samuels and Lundegard hope to complete their M.S. Theses by June 1979, (both are going elsewhere for Ph.D. work). Their work has been largely devoted to the description of outcrops, paleocurrents, and the study of thin sections. Significantly, they have not made much use of the SEM. However, abstracts for the GSA and AAPG have been prepared. Below are selected excerpts of the abstracts. Their forthcoming MERC report should contain about 60 pages.

Abstract and Outline

The Brallier Formation (Upper Devonian) of the Central Valley and Ridge Province is a thick (2000 to 3000 feet) regressive sequence of proximal to distal turbidites composed of interbedded siltstone, mudstone, claystone, and shale.

The turbidite origin of the Brallier Formation siltstones is clearly established by the presence of Bouma sequences, sole markings, lateral continuity of individual beds, uniform directional properties, and a shelf-slope-basin facies tract. The mudstones, claystones, and shales have a mixed turbiditic-hemipelagic origin.

We have recognized six facies of the Brallier Formation. These are, a siltstone-shale facies, a siltstone bundle facies, an olive-gray mudstone-shale facies, a yellowish-gray claystone facies, an olive-gray claystone facies, and a black shale facies. The characteristics of these facies and their areal distribution are the basis of our depositional model.

We interpret the Brallier Formation as a slope deposit lithogenetically related to the underlying black shales and overlying shelf sediments. Low variant westerly paleocurrent trends and facies distributions indicate a depositional system in which the slope prograded uniformly basinward. There are no indications that strongly arcuate, long lived submarine fans were a part of this depositional sequence. Submarine fan terminology is only partially applicable to the Brallier Formation depositional system.

Small, low-density turbidity currents probably originated from suspended sediment plumes caused by storm agitation of the outer shelf or by high river discharges, rather than by localized mass movement.

Petrographic data indicate a source area of sedimentary and low-grade metasedimentary rocks somewhere to the east. Lower- and middle-slope turbidite siltstone bundles make attractive reservoir bodies where they are interbedded with black shales in distal facies.

Introduction
- Study area and sample localities
- Stratigraphic sequence-regional and local; schematic cross section (E-W)
- The problem: including previous work

Facies of the Brallier
- Sand/shale ratio
- Lithology and thickness
- Coarse-grained bed thickness
- Sedimentary structures
- Distribution
- Interpretation

Cross sections

Shale petrology
- Mudrock classification
- Outcrop and hand specimen features
- Mineralogy
- Texture
- Physical and biogemic structures
- Organic carbon

Depositional model
- Comparison with submarine fan model
- Clastic ramp model
- Paleocurrents and facies distribution

Provenance
- Petrography of shale and siltstone

Appendix
- Measured sections
  - Standard reference sections
  - Other sections

Facies Descriptions from the Brallier

Mudrocks: Mudrocks of the Brallier Formation consist predominantly of a very finely crystalling aggregate of clay, which exhibits first order yellowish-orange birefringence and pleochroism in shades of olive. In the shales there is strong unit extinction of the clay flakes indicating a preferential orientation. Unit extinction is much weaker in mudstones and claystones. Clay minerals of the mudrocks have undergone some recrystallization as indicated by areas of larger crystal size, gradational with the finer crystalline clay and by anomalously higher birefringence (second order blue).

Quartz grains are angular to subangular. In silt laminae, individual grains may be difficult to identify because of annealing and suturing of quartz grains and development of quartz overgrowths. This same mobilization of silica occurred in the siltstones as well. Trace amounts of relatively fresh plagioclase are present in the Brallier Formation mudrocks.

Organic matter occurs predominantly as structureless streaks and is disseminated throughout the clay, comprising usually less than 5 percent. Organic matter is nearly opaque and dark-brown in reflected light when fresh, and orange in reflected light, when weathered. Spores are generally very rare in Brallier Formation mudrocks, but are common in some samples from east Tennessee.

Micas comprise up to 14 percent of some samples. These are predominantly muscovite with lesser amounts of chlorite and rare weathered biotite flakes. Micas are strongly oriented parallel to bedding in shales but are weakly or randomly oriented in mudstones and claystones.

There are five major lithofacies in the Brallier. Of these, four are predominantly mudrock. The remaining facies consists of packets or bundles of siltstone turbidites up to nearly 100 feet thick. These packets generally occur in the lower half of the section and are found throughout the study area.

The mudrock subfacies, here informally called A, C, D, and E, differ in their basic mud character as well as in their associations with siltstone turbidites.

Subfacies E consists of black (N1) to dark gray (N3) shale, with structural lamination and rare silt laminae. The shale tends to weather fissile with 2 to 5 mm thick, smooth partings. Parting surfaces commonly have a grayish-red (5R4/2) iron stain. Minor, indistinct bioturbated zones a few millimeters thick and weathering yellowish gray (5Y8/1), are present in most of the shales of this facies. Siltstone beds in subfacies E comprise up to 20 percent, but typically less than 10 percent. They are predominantly cross-laminated, Tc beds with rippled upper surfaces.

Subfacies D, more common in the lower half of the section and to the southwest in Virginia and Tennessee consists of up to hundreds of feet of olive-gray shale with subordinate burrowed claystone. The structurally laminated shale also contains silt laminae up to 3mm thick. Indistinct horizontal burrows less than 3 mm across the bedding in the shale give it a mottled appearance. Biogenic color lamination 3 to 5 mm thick results from a concentration into layers of horizontal burrows. Siltstone beds are rare and less than 0.1 feet thick.

The lack of significant siltstone beds and the presence of intensive burrowing suggests slow to very slow hemipelagic sedimentation of clay. Silt laminae and thin beds probably resulted from rare, small, turbid flows.

Olive gray mudstone and shale comprises subfacies C. Found throughout the study area, this facies is more common in the lower half of the section. Like subfacies D, horizontal burrows 3-5 mm across are common (Pteridichnites biseriatus). Small brachiopods are rare. The mudstone parts with a hackly surface. Siltstone beds are more common and thicker than in facies D, ranging from 0.05 foot to 0.3 foot. Base truncated Bouma sequences (Tcde, Tde, Tce) are common. Tops of beds are commonly rippled.

The similarity of subfacies C and D speaks in favor of similar deposition: that is, slow hemipelagic sedimentation. Larger burrows suggest somewhat more oxygenated conditions. The presence of disseminated silt and thicker turbidites are indicative of increased proximality.

Subfacies A consists of siltstone and shale and/or mudstone interbedded in variable proportions. Typically the shale is light olive gray (5YS/2) to moderate olive brown (5Y4/4) in color and exhibits structural lamination only. Found throughout the vertical extent of the Brallier Formation, subfacies A exhibits an upward increase in sand/shale ratio and in siltstone bed thickness. Only in extreme southwestern Virginia and eastern Tennessee is this facies absent.

Coarse-grained bed thickness, typically between 0.05 feet and 1.0 feet, exhibits a modal thickness of about 0.2 feet. Base-truncated Bouma sequences are dominant with current and organically formed sole marks common. Vertical burrowing, although rare, does occur in the siltstones.

Abundant shale and mudstone with such siltstone interbeds argues again in favor of an area undergoing hemipelagic sedimentation. Here turbidite events are much more frequent and of a larger scale than in subfacies C.

Stratigraphic Sections: A total of 22,500 feet of Brallier have been measured, described, and scintillometered. Below is an example.

Huntingdon Section

Incomplete section of Brallier Formation exposed for 0.28 miles in roadcuts along north side of Penn Street at intersection with US Rt. 22, 0.9 miles east of Pennsylvania Rt. 26. Base of section is located 1300 feet east of Standing Stone Creek on Penn Street, Huntingdon, Huntingdon County, Pennsylvania, Huntingdon and Mount Union quadrangles. Section measured, described and sampled using Jacob's staff, Abney level, tape and compass by Neil D. Samuels, September 2, 1978.

	Thickness (feet)
Devonian (imcomplete):	
Brallier Formation (imcomplete):	
10. Interbedded siltstone (35 percent) and mudstone (65 percent). Siltstone is medium dark gray (N4) to medium gray (N5), weathers olive gray (5Y $^4/_1$) with dark yellowish orange (10 YR 6/6) limonitic stain, micaceous, planar and ripple lamination common in beds 0.1 to 1.0 feet thick with sharp, planar bases and gradational, rippled tops. Mudstone is medium dark gray (N4), weathers olive gray (5Y $^4/_1$) to small, thin chips, slightly to very silty, silt laminae absent. Irregular partings 3 to 5 mm. hackly weathering surface.	103
9. Covered	91

8. Interbedded siltstone and shale like Unit 1 . . . . . 16.2

7. Siltstone (40 percent), mudstone (50 percent) and shale (10 percent). Siltstone like unit 10 in beds 0.05 to 0.5 feet thick with mode of 0.2 foot; Tce Bouma sequence with ripple lamination very common, Tbc and Ta sequences less common, content graded, sharp planar bases and gradational, rippled tops; organic sole markings common.
Mudstone like unit 10.
Shale is olive gray (5Y 3/2), weathers olive gray (5Y 4/1) with moderate yellowish brown (10 YR 5/4) limonitic stain; silt free to slightly silty, hard fissile partings are 2mm. Structural lamination present, occurs generally in 0.3 to 0.4 feet, highly bioturbated and weathered zones 30.3

6. Interbedded siltstone (45 percent) and mudstone (55 percent). Siltstone - like unit 10. Tabce and Tbce sequences common in beds 0.1 to 1.8 feet thick with mode of 0.2 to 0.4 feet; carbonized wood fragments very abundant along some bedding planes; beds are generally even and continuous. However, beds less than 0.1 foot thick commonly pinch and swell; beds generally massive and blocky. Mudstone like unit 10 with bladed weathering common . . 60.8

5. Siltstone (30 percent), shale (10 percent) and interlaminated mudstone and siltstone (60 percent). Siltstone is medium dark gray (N4) to medium gray (N5), weathers olive gray (5Y 4/1); micaceous, ripple lamination common in beds 0.05 to 0.5 foot thick with mode of 0.1 foot. Tac Bouma sequences common; pinch and swell common as are regular, lateral thickness changes, soft sediment deformation (flow rolls) also present; many beds with sharp planar bases and gradation, rippled tops.
Shale is like unit 7.
Interlaminated mudstone and siltstone on scale of 1 cm. Mudstone like unit 10. Siltstone is medium gray (N5) to olive gray (5Y 4/1) in very indistinct beds; argillaceous; planar and ripple lamination common; 53.5

4. Siltstone (75 percent) and mudstone (20 percent) and shale (5 percent). Siltstone is medium gray (N5), weathers olive gray (5Y 4/1) with dark yellowish orange (10 YR 6/6) limonitic stain; micaceous, planar and ripple lamination common, climbing ripple lamination common on few beds, massive and structureless beds also common; bed thickness ranges from 0.05 foot to 2.8 feet with mean of 0.7 foot and mode of 0.2 to 0.4 foot; rare sole marks include flute casts at 348° and

Thickness
(feet)

340° with blunt end toward north plus organic sole markings. Carbonized wood fragments very abundant on some bedding planes (with general orientation of 259°) planes and are often concentrated in linear bodies separated by about .5 foot of very low concentration (suggesting ripple troughs); content grading common with partings of 2 to 3 mm in upper 1 cm. of many beds, amalgamation common; sharp planar bases and gradational, rippled tops.

Mudstone is medium dark gray (N4), weathers olive gray (5Y 4/1), slightly to very silty. Non-laminated, irregular partings 3-4 mm.. Hackly appearance on weathered surface.

Shale is moderate olive brown (5Y 4/4) to medium dark gray (N4), weathers olive gray (5Y 4/1), silt-free, structural lamination, fissile, hard, regular, parallel partings 2 mm. generally occurs as Te (f?) unit gradational with siltstone beds 112.2. Beds strike 225°, dip 15° SE.

3. Siltstone (60 percent), mudstone (35 percent) and shale (5 percent).

Siltstone is medium dark gray (N4) to medium gray (N5), weathers olive gray (5Y 4/1) with dark yellowish brown (10 YR 4/2) and moderate yellowish brown (10 YR 5/4) limonitic stain; micaceous; thickness ranges from 0.1 foot to 1.1 foot with mode of 0.4 to 0.5 foot; ripple lamination (Tc sequences) common in beds less than 0.2 foot, planar lamination and structureless beds (Tac and Tabc) common in thicker beds; sole markings common with groove casts oriented 275° and 280°. Organic sole markings also common.

Mudstone like unit 4.

Shale like unit 4 . . . . 40.9

		Thickness (feet)
2.	Siltstone (30 percent) interlaminated siltstone and mudstone in unequal amounts (65 percent) and shale (5 percent). Siltstone like unit 3 in beds generally less than 0.25 foot with few beds 0.6 to 0.7 foot and maximum of 1.3 feet thick. Interlaminated siltstone (70 percent) and mudstone (30 percent) in scale of 1 to 3 cm. Siltstone is less distinctly bedded than described above and often contains ripple or planar lamination. Mudstone weathers medium gray (N4) to olive gray (5Y 4/1) to small blades, irregular, hackly partings 2 to 5 mm. silt-free to slightly silty with rare silt laminae less than 1 mm thick. Shale is olive gray (5Y 4/1), silt-free with regular, parallel partings 1 to 2 mm. Two 0.4 foot thick highly burrowed zones more highly weathered . . .	35.7
1.	Siltstone (70 percent), mudstone (25 percent) and shale (5 percent). Siltstone is medium dark gray (N4) to olive gray (5Y 4/1), weathers olive gray (5Y 4/1) with dusky yellowish brown (10 YR 2/2) limonitic stain; micaceous; bed thickness ranges from 0.1 foot to 3.9 feet with mode of 0.1 to 0.3 foot and mean of 0.7 foot; Tabc, Tab and Ta Bouma sequences common. Tc sequences less common, sole markings include flute cast at 295° with blunt end toward east and numerous fine grooves with general trend of 295°; amalgamation common, sharp, planar bases and gradational, rippled tops, blocky. Mudstone is olive gray (5Y 4/1), weathers olive gray (5Y 4/1), silty to very silty; hackly, irregular partings 3 to 7 mm. Shale is moderate olive brown (5Y 4/4), weathers olive gray (5Y 4/1); silt-free, structural lamination, fissile, soft, regular parallel partings 1 to 2 mm. . .	51.0
	Beds strike 236°, dip 25° SE	
	Total Brallier Formation (incomplete)	594.6

MANUSCRIPTS IN PREPARATION

Broadhead: Stratigraphy and Sedimentology of one Ohio Shale along Lake Erie. This study is by Ronald A. Broadhead, an M.S. candidate, who hopes to finish in the summer or spring of 1979. To date, Ron has measured 13 sections along Lake Erie and helped to describe the Cleveland No. 1 hole of the International Sale Company on Whiskey Island, in Cleveland. Scintillometer surveys were made of most of the outcrops. Preliminary results indicate that the scintillometer will register most black shales thicker than 0.5 ft., although some black shale beds are unexplained exceptions. In addition, some sedimentological data has been started - shale petrology, trace fossils, and paleocurrent indicators. Potter spent three days in June with Ron in field and Ron has been to the field a total of 46 days in 1978. Kepferle, Broadhead, Potter, and members of the Ohio Survey will spend two or three days in one field in late October.

Below is an outline of a forthcoming MERC publication.

Introduction

Stratigraphy of Upper Devonian Shales along Lake Erie
- Rocks below Ohio Shale
  - Silurian-Devonian Big Lime
  - Shales
    - Marcellus shale
    - Hamilton group
    - Rhinestreet shale
    - Angola shale
    - Hanover shale
    - Olentangy shale
    - Plum Brook shale
- Ohio Shale
  - Huron Member
  - Chagrin Member
  - Cleveland Member
- Rocks above Ohio Shale
  - Bedford Shale
  - Berea Sandstone

Stratigraphic Contributions
- Outcrop studies
  - Bed by bed description of measured stratigraphic sections of the Ohio Shale and Olentangy Shale along Lake Erie. This information is not available in the literature. The main purpose here is the stratigraphic analysis of the shales and siltstones of the Ohio and Olentangy Shales.
  - Gamma ray scintillometer profiles of measured stratigraphic sections. This creates a gamma ray log similar to those commonly taken in drilled wells.

Subsurface studies
The object of the subsurface studies will be the detailed correlation of the outcrop with the subsurface geophysical logs. Once the correlation has been made, lithofacies identified in outcrop will be mapped in the subsurface.

Petrographic Studies
Thin section petrography are being used to characterize the Ohio Shale and its various formal and informal stratigraphic subdivisions.

Ohio Shale Sedimentology
Trace fossil studies to indicate paleobathymetry

Sedimentologic analysis of the siltstones in the Ohio Shale
Paleocurrent analysis

Geologic history of the Ohio and Olentangy Shales along Lake Erie

Conclusions

Section Descriptions

Below is a description of sections that is representative of the work done along Lake Erie.

Excellent section of Huron Member of Ohio Shale and of Olentangy Shale exposed along the West Branch of the Huron River about 2.5 miles northeast of Monroeville in Ridgefield Township, Huron County, Ohio (Ohio Coordinate System: North Zone, 1.952.000 feet, 587 200 feet). Base of section is located at the base of the cliff south of the intersection of the Huron River with Lamereaux Road. The top of the section is overgrown with grass and trees. This section is at the type locality of the Huron Member of the Ohio Shale as designated by Newberry in 1871. Described and measured with handlevel and tape by R.F. Broadhead on July 23, 1978.

	Thickness (feet) Units	Cumulative
Top of Section:		
Devonian (incomplete):		
Huron Member of Ohio Shale (incomplete):		
50. Shale, black (N1), weathers greyish-red (10R4/2) and light-brown (5YR5/6). Silt is present as sparse laminae a few grains thick and as disseminated grains. Petroliferous. Parts into brittle plates 1 to 10 mm thick. Lower contact is abrupt and planar. Top of unit is overgrown with grass and trees. Contains large, black, spheroidal to ovoid, carbonate concretions a few feet in diameter. Unit 50 is a prominent bed of shale which is more resistant to weathering than the interbedded units exposed below..........	24.0	24.0
Total thickness Ohio Shale.....	24.0	

Olentangy Shale (incomplete):

Units 1 through 49 consist of an intercalation of medium-grey (N4-N5) shale with very dark-grey (N2) and black (N1) shales. The medium-grey shales contain small amounts of disseminated silts and weather dark-reddish brown (10R3/4) and light-brown (5YR5/6). The shale typically parts in 1 to 6 mm thick plates below unit 30. Above unit 30, partings are 1 to 20 mm thick and produce blocky, tabular, and platy weathering expressions. White and yellow sulfur minerals are commonly found on weathered surfaces. Pyrite is seldom seen. The medium-grey shale beds have a lesser resistance to weathering than the darker shales and are plastic when wet and weathered. The dark shale beds weather greyish-red (10R4/2) and light-brown (5YR5/6). They part in 1 to 6 mm thick brittle plates. Silt is present as both disseminated grains and as thin white to light-grey laminae a few grains thick. Thin coatings of sulfate minerals are commonly found on weathering surfaces. Contacts between the beds of light and dark shale are abrupt. Individual beds are laterally continuous with uniform thickness except in the lower 10 feet of the section where they commonly pinch and swell and where an intertongueing of the light and dark shales occurs. Although bedding oontacts in the upper part of units 1 through 49 are planar or slightly undulatory (amplitudes of as much as two inches), they are more undulatory near the base of the section (amplitudes are commonly 6 or 8 inches and some are greater and wavelengths are from 6 to 20 feet). A few high-angle soft-sediment faults are present in lower 10 feet.

Described below are thicknesses of beds 1 through 49 and features of individual beds which are exceptions from the generalized descriptions given above.

49. Shale, medium-grey, with sparse globular pyrite and some fine-grained, medium-grey,

	carbonate concretions which have the form of flattened spheroids up to 2 ft in diameter and 1 foot thick	1.7	25.7
48.	Shale, black	0.2	25.9
47.	Shale, medium-grey	0.6	26.5
46.	Shale, black	0.1	26.6
45.	Shale, medium-grey	0.5	27.1
44.	Shale, black	0.2	27.3
43.	Shale, medium-grey	0.4	27.7
42.	Shale, black	0.2	27.9
41.	Shale, medium-grey	0.7	28.6
40.	Shale, black	0.1	28.7
39.	Shale, medium-grey	0.1	28.8
38.	Shale, black	0.2	29.0
37.	Shale, medium-grey	0.2	29.2
36.	Shale, black	0.1	29.3
35.	Shale, medium-grey	0.1	29.4
34.	Shale, black, sparse pyrite	0.8	30.2
33.	Shale, medium-grey	0.9	31.1
32.	Shale, black	0.2	31.3
31.	Shale, medium-grey	0.4	31.7
30.	Shale, black	1.9	33.6
29.	Shale, medium-grey, with 5 percent black shale laminae	5.3	38.9
28.	Shale, black	0.2	39.1
27.	Shale, medium-grey	0.2	39.3
26.	Shale, black	0.2	39.5
25.	Shale, medium-grey, with 5 percent black shale laminae which pinch and swell	2.2	41.7
24.	Shale, black	0.4	42.1
23.	Shale, medium-grey	0.2	42.3
22.	Shale, black	1.0	43.3
21.	Shale, medium-grey	0.1	43.4
20.	Shale, black	0.2	43.6
19.	Shale, medium-grey	0.2	43.8

18. Shale, black..............................	0.3	44.1
17. Shale, medium-grey, with 5 percent black shale laminae which are laterally undulose and uniform in thickness.........	1.3	45.4
16. Shale, black..............................	0.2	45.6
15. Shale, medium- grey.......................	0.7	46.3
14. Shale, black..............................	0.7	47.0
13. Shale, medium-grey........................	0.2	47.2
12. Shale, black..............................	0.8	48.0
11. Shale, medium-grey........................	0.2	48.2
10. Shale, black..............................	0.3	48.5
9. Shale, medium-grey.........................	1.3	49.8
8. Shale, black...............................	0.6	50.4
7. Shale, medium-grey.........................	0.8	51.2
6. Shale, very-dark-grey......................	0.5	51.7
5. Shale, medium-grey.........................	0.5	52.2
4. Shale, black...............................	0.3	52.5
3. Shale, medium-grey.........................	0.3	52.8
2. Shale, black...............................	0.3	53.1
1. Shale, medium-grey, with 5 percent thin to very thin black shale beds which are laterally undulose lenses 1 to 4 feet long and 0.1 to 0.3 ft thick.....	1.2	54.3
Total thickness Olentangy Shale...	30.3	

GENERAL SHALE PETROLOGY

This work is conducted by Thomas Stenbeck, an M.S. candidate, working under the direction of Professor Pryor. Neither had anything to report by September 18. The SEM is working well, but it is fair to say that we don't seem to be able to use it nor its energy dispersive unit effectively.

Nor has any significant progress been made on orientation of clay minerals and silt grains; i.e., clay fabrics - by either microscopic or X-ray methods.

ADMINISTRATIVE

This year, 1977-78, our contract functioned well in almost all administrative aspects.

Mrs. Kao, our chemical technician working for Professor Maynard, is an outstanding success and virtually insures Professor Maynard of continual, rather effortless productive efforts. Miss M. Jones, our former typist, was also excellent and most helpful. We are very satisfied with Mrs. D. Moorman, our new part-time secretary.

Travel funding has also been adequate but was fully used by the end of August. It should be noted that we have only used DOE travel monies for field work, stratigraphic meetings, and trips to Morgantown. None as yet has been used to go to national meetings.

We have greatly benefited over the year from the presence of Roy Kepferle of the USGS. He is most useful in stratigraphy and with students. We note however, that in having joint papers with Roy much extra lead time must be allowed to obtain USGS approval - something that we did not forsee, obvious as it should have been. Six to eight months should be allowed for this.

We had another year of successful shale seminar, but will not continue it in 1978-79, the last year of our initial three year contract. This summer Maynard spent two months on one contract, and Potter and Pryor each spent one month. Maynard worked a total of 8.4 weeks for two month's salary, Potter worked a total of 9.1 weeks for one month's salary and Pryor worked 9.3 weeks for one month's salary. Daily, weekly and/or monthly logs are available upon request.

EQUIPMENT

We are successfully using the CHN analyzer and liquid chromatographer purchased with our grant, but have failed so far to effectively use our small SEM or its elemental analyzer. We have, however, built the BET sorptometer and have made some progress toward the construction of an X-ray device for the study of fabric in shales.

FUTURE PLANS

In the forthcoming contract year of 1978-79 we have three MERC reports scheduled - the Brallier study, one on the sedimentology and stratigraphy of the Ohio Shale along Lake Erie, another on the Middlesboro (Pine Mountains) Syncline and perhaps one on general shale petrology plus some other outside papers on geochemistry and possibly one on whatever contributions we can make to basin analysis. However, our presently prepared Devonian Paleocurrents of the Appalachian Basin is an interim stop-gap effort toward a basin analysis, one that uses existing data. We are also close to completing a related effort entitled, Shales and How to Study Them.

Barry Maynard has applied for a sabbatical for the academic year, September 1, 1979 to September 1, 1980, and will be away from Cincinnati. Professor Pryor wishes to continue on the grant at a low level beyond its third year. Professor Maynard wants to continue the grant for another two years, primarily to continue geochemical studies. Professor Potter plans to leave the project at the end of Cincinnati's third year, October 1, 1979.