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BLACK SHALE STUDIES IN KENTUCKY

Quarterly Report, October—December 1977

Work Performed Under Contract No. EY-76-C-05-5202

University of Kentucky
Research Group
Lexington, Kentucky

U. S. DEPARTMENT OF ENERGY

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QUARTERLY REPORT

(OCTOBER-DECEMBER, 1977)

UNIVERSITY OF KENTUCKY

RESEARCH GROUP

DEPARTMENT OF GEOLOGY

KENTUCKY GEOLOGICAL SURVEY

Quarterly Report
Black-Shale Stratigraphy Group

1.0 Executive Summary--

During this quarter, most of our efforts were devoted to completing collection of field data from black-shale sections in order to meet a scheduled milestone at the end of December. Fourteen sections were described and measured (Figure 1), 12 from the outcrop belt on the eastern flank of the Cincinnati and two from the Pine Mountain outcrop belt. Five of Linda Provo's seven radioactive units were traced along the outcrop belts where possible. At the southern end of each outcrop belt, the units became increasingly difficult to differentiate, due to marked thinning on approaching the Cincinnati Arch. This thinning is evident from north to south in that successive basal units drop out southward. In northern parts of the outcrop belt, the basal unit in the black shale is unit 5, but in the southernmost section, unit 3 is the basal unit. Both units 5 and 4 have pinched out in the intervening distance.

Work is also continuing on the petrographic study of core material and on the well-log inventory. Initial examination and point counting is nearly complete. We are also at the point, where we are identifying microfacies in the core, but all interpretations are preliminary. The well-log inventory for two more counties, Powell and Wolfe were completed and the inventory for Magoffin has been started. An isopach map of unit 1 (Cleveland Shale Mbr.) from the northeastern part of the state, where the inventory is complete, has also been started.

A study of the clay-mineral stratigraphy from selected cores and outcrops has also been started in conjunction with the geochemical group.

We have also made an effort this quarter to disseminate some of our data and techniques. To this end, we have presented papers at the EGSP Symposium, the annual Geological Society of America Meeting, and the Kentucky Academy of Science. We will also present papers at the annual Eastern, Geological Society of America Sectional Meeting in April. Abstracts are enclosed in the Appendix.

2.0 Contract Objectives--

1.) Complete the description and measurement of all outcrop sections by December 30.

2.) Continued progress on petrographic studies and well-log inventory (toward isopach maps).

3.) Progress on east-west stratigraphic cross-section (Deadline date: Feb. 28, 1978).

4.) Progress on formulation of preliminary depositional model. (Deadline date: Mar. 30, 1978).

3.0 Technical Progress--

3.1 Outcrop Descriptions

3.1.1 All outcrops were measured and described by December 30, 1977. Preliminary copies of the outcrop descriptions and graphic representations of each outcrop are included in the Appendix.

3.1.2 The radioactivity profiles of outcrops in southern parts of the outcrop belt will probably be done over at closer intervals, so that more detail is available for deciphering individual units. We also hope to measure a section in northern Tennessee and southern Ohio so we can tie our line of section into adjacent states. Stratigraphic analysis and interpretation should be complete by June 30.

3.1.3 Interpretation of data and reprofiling southern sections if weather permits.

3.2 Progress on Petrographic Studies

3.2.1 Petrographic studies complete on Pine Mt., Perry County, and one half of Martin County Core. All microscope work should be completed by March 3.

3.2.2 Our major problem is that of obtaining thin sections. We must send all materials to be thin sectioned out-of-state; hence, there is often a considerable wait for sections.

3.2.3 Finish petrographic analysis of Martin County Core, and begin interpretation.

3.3 Well-Log Inventory

3.3.1 All counties in northeastern Kentucky completed; inventories in southeastern Kentucky begun. Isopach map of unit 1 begun.

3.3.2 At present, we average, about one county completed per month. In southeastern Kentucky, however, we are entering the Big Sandy Gas Field and there are many more wells to be examined. Hence, our progress may be slower than usual.

3.3.3 Continued inventory of Magoffin County and go on to Johnson and Martin Counties if time permits.

3.4 East-west cross-sections

3.4.1 Our parts of these sections are already in U.S.G.S. hands. At the recent January meeting in Reston, our suggestions for corrections, etc. were made known.

3.5 Formulation of Preliminary Depositional Model

3.5.1 Library research on this is in progress.

3.5.2 Unavailable, but necessary data from other contractors and parts of the project, may slow us down here.

3.5.3 Continued literature research and interpretation of data.

ABSTRACT

CORRELATION FROM THE SUBSURFACE TO THE SURFACE IN BLACK SHALE USING A SCINTILLOMETER AND GAMMA-RAY LOGS

ETTENSOHN, Frank R., Department of Geology, University of Kentucky, Lexington, Kentucky 40506; FULTON, Linda Provo, Department of Geology, University of Cincinnati, Cincinnati, Ohio 45221; KEPFERLE, Roy C., U.S.G.S., University of Cincinnati, Cincinnati, Ohio 45221

Stratigraphic studies of the Devonian-Mississippian Ohio/Chattanooga Shale (consisting primarily of black organic-rich shale) in the eastern portions of Ohio, Kentucky, and Tennessee indicate that radioactive units evident on subsurface gamma-ray logs from these formations can be distinguished in outcrops and in cores using a scintillometer. A vertical series of readings from a hand-held scintillometer taken at close intervals on the surface of a black-shale exposure or core are found to produce vertical radioactivity profiles which closely resemble gamma-ray curves from the same formation in the subsurface. Because the units of the scintillometer profiles and gamma-ray curves are not identical (counts/second vs. API units), the curves are not comparable on a one-to-one basis, although their patterns are qualitatively similar enough to allow good correlation.

Except for thin green-shale beds distributed throughout the black shale, exposures of the Ohio/Chattanooga Shale appear homogeneous. Use of this technique has shown, however, that these black-shale formations contain 7 major subunits, which can now be correlated with named surficial units elsewhere and drillers' units in the subsurface. With a scintillometer, the presence or absence and thickness of these subunits can be determined in otherwise homogeneous-appearing exposures of the black shale or in cores from drill holes lacking gamma-ray logs. Use of this scintillometer technique together with gamma-ray logs has proved useful in defining an internal basin-wide straitgraphy for the Devonian-Mississippian black shale.

Abstract of paper presented at the Geological Society of America Annual Meeting, Seattle, Washington, November 8, 1977.
Geol. Soc. Amer. Abs. with Programs, 9(7):970.

ABSTRACT

A PRELIMINARY MICROSCOPIC EXAMINATION OF DEVONIAN AND LOWER MISSISSIPPIAN BLACK SHALES IN EAST-CENTRAL KENTUCKY

MILLER, Michael L., Department of Geology, University of Kentucky, Lexington, Kentucky 40506; ETTENSOHN, Frank R., Department of Geology, University of Kentucky, Lexington, Kentucky 40506

As part of the E.R.D.A. eastern gas-shales project, the black, organic-rich Ohio, Sunbury, New Albany, and Chattanooga Shales of late Devonian and early Mississippian age are being examined with reflected light, transmitted light, and cathodoluminescent microscopy combined with x-ray diffraction. Five major microfacies are recognized based on the relative percentages of organic and mineral constituents, nature of lamination, and presence or absence of bioturbation. The five microfacies include in order of abundance: 1.) laminated, organic-rich shales, 2.) homogeneous, bioturbated, organic-rich shale, 3.) homogeneous, bioturbated, organic-deficient shale, 4.) organic-deficient bioturbated shales interlaminated with organic-rich shale, and 5.) organic-rich carobnates. Microfacies 1 and 2 above correspond to black-shale lithologies in the outcrop; microfacies 3 corresponds to a green-shale lithology whereas microfacies 4 corresponds to an interbedded black and green shale lithology. Microfacies 5 is represented by very thin, localized bands of dark dolomite.

Major organic constituents were named using coal petrology nonenclature and consist of macerals from the vitrinite and exinite groups. Detrital mineral constituents consist of very fine sand-size to clay-size grains of quartz, feldspar, micas, zircon, apatite, and clay minerals. Most of the clay minerals, however, are closely associated with very fine organic debris in clay mineral-organic complexes. Cathodoluminescence was used to distinguish silt- to clay-size grains of zircon, apatite, and quartz, as well as authigenic minerals such as chert, quartz overgrowths. calcite and dolomite.

Characterization of microfacies should provide a further basis for interpreting black shale depositional environments and identify zones of potential gas production.

ABSTRACT

THE STRATIGRAPHY OF DEVONIAN-MISSISSIPPIAN BLACK SHALES ALONG THE EAST-CENTRAL KENTUCKY OUTCROP BELT

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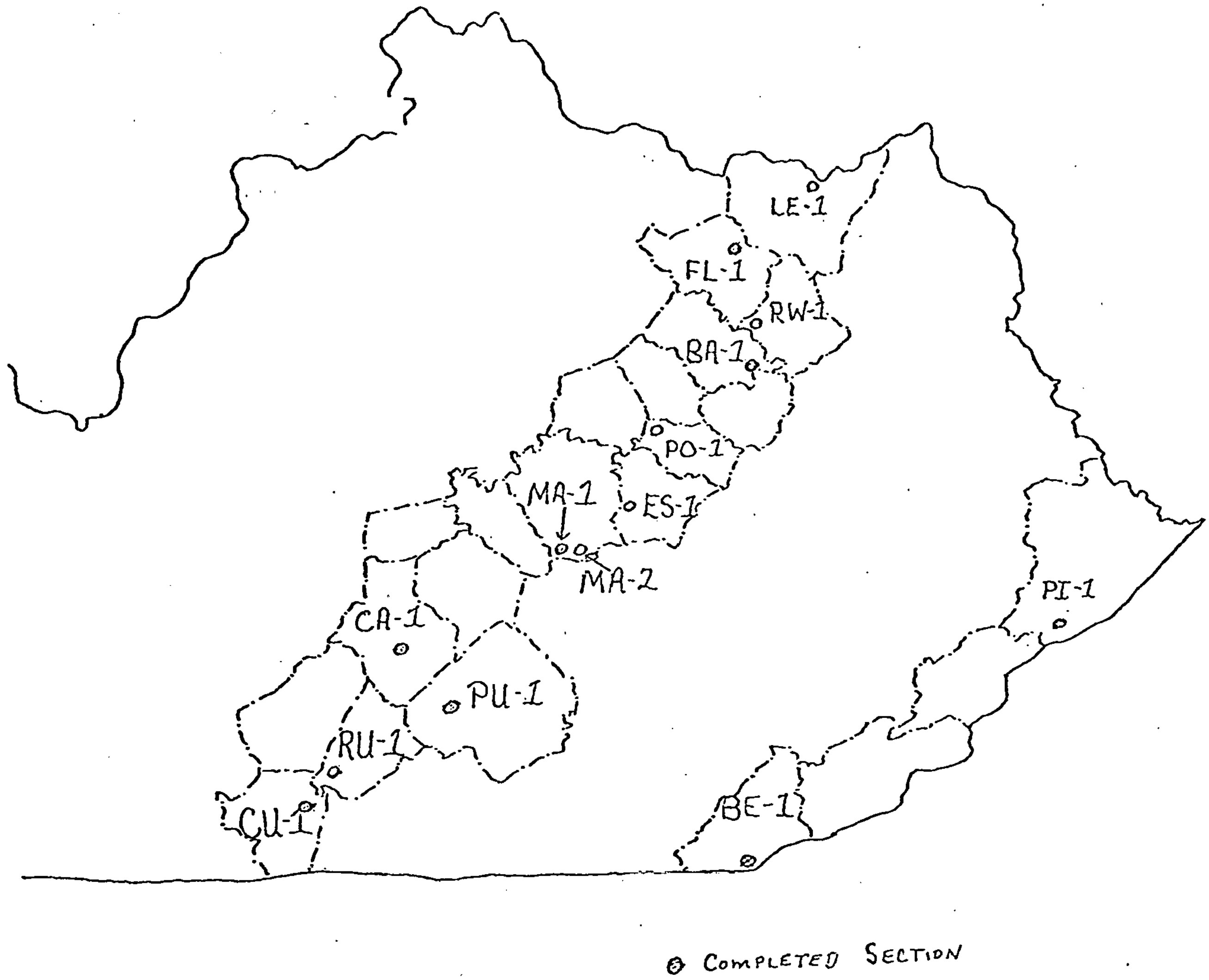
The Devonian-Mississippian black-shale sequence in the east-central Kentucky outcrop belt has a characteristic internal stratigraphy related to the radioactive properties of two dominant lithologic types: a brownish-black, organic-rich shale, and a greenish-gray, organic-poor shale. Seven radioactive units originally defined in the subsurface were based on gamma-ray logs by Provo (1977). In the present study, the five upper units have been identified from scintillometer-generated radioactivity profiles along the outcrop belt. Comparison of the radioactivity profiles of these sections reveals that three of the five radioactive units can be distinguished lithologically by the relative abundance of green and black shales. Whereas changes in the amount of radioactivity within continuous black-shale sequences are easily identified on radioactive profiles, they are lithologically indistinguishable in the outcrop.

At least two internal biostratigraphic zones can be tentatively defined within the Ohio Shale. A lower zone is marked by the presence of the pelagic alga *Foerstia*, and the upper zone is marked by concentrations of the brachiopod *Lingula*. Both of these zones occur in the same relative vertical positions throughout the outcrop belt.

The Ohio Shale and its equivalents in twelve measured sections range in thickness from 196 feet in northeastern parts of the outcrop belt to 28 feet in southwestern parts of the outcrop belt where the shale overlaps onto the Cincinnati Arch. Individual units within the shale also thin proportionally toward the arch.


LE-1
FL-1
RW-1
BA-1
PO-1
MA-1
ES-1
MA-2
CA-1
PU-1
RU-1
CU-1
BE-1
PI-1
COMPLETED SECTION

LE #1 Section

This section contains an incomplete section of the Ohio Shale in contact with the Bisher Limestone. The base of the section is located along Highway 10, 2.3 miles west of Vanceburg in Lewis County, Kentucky (Section 21-Z-74, 200' FNL x 400' FWL). The contact with the Bisher is in a creek valley just south of the highway. The upper part of the section is 0.3 miles northwest of Vanceburg along Highway 8. The entire section is located on the Vanceburg Quadrangle. Section measured using abney level, jacob's staff, tape and scintillometer. Section was measured and sampled by Dennis Swager, Frank Ettensohn, Mike Miller and Don Chesnut on August 26, 1977.

		Thickness (feet)
Silurian (incomplete):		
	Bisher Limestone (incomplete):	
(1)	The contact here is questionable, but there was a small amount of brassy-tan to tan colored, highly weathered, punky residuum which resembled the Bisher and there was a spring at the contact.	0.7
Devonian (incomplete):		
	Ohio Shale (incomplete):	
(2)	Above contact was a highly weathered light greenish gray (5GY 2/1) moldable claystone which included some brownish-black (5YR 3/1) clayey interbeds.	1.2
(3)	Covered interval which is within the Ohio Shale.	8.5
(4)	Shale, greenish-gray (5GY 6/1) with small interbeds of brownish-black (5YR 4/1) shale. Green shales are up to 2.3' thick with black shales up to 0.5' thick. Both lithologies are clayey. Unit forms a reentrant at base of outcrop. Black shales are jointed and blocky with rare Tasmanites.	6.8
(5)	Shale, brownish-black (5GY 2/1), very fissile with a blocky jointed outcrop that forms a ledge. Shale heavily iron-stained with Tasmanites common. Large concretions, semi-elliptical in shape up to 3' x 7' in dimension. They seem to be sideritic in nature with beds draped around them.	13.2
(6)	Shale, brownish-black (5YR 2/1) interbedded with greenish-gray (5GY 6/1) clayey shales 0.3' to 0.6' thick. Black shale is fissile, contains no silt and Tasmanites common. Occasional burrows in the green shales. Large nodules still present in the black-shale beds. Possibly sideritic. Nodules are from 3' x 4' to 5' x 6.2'.	5.7

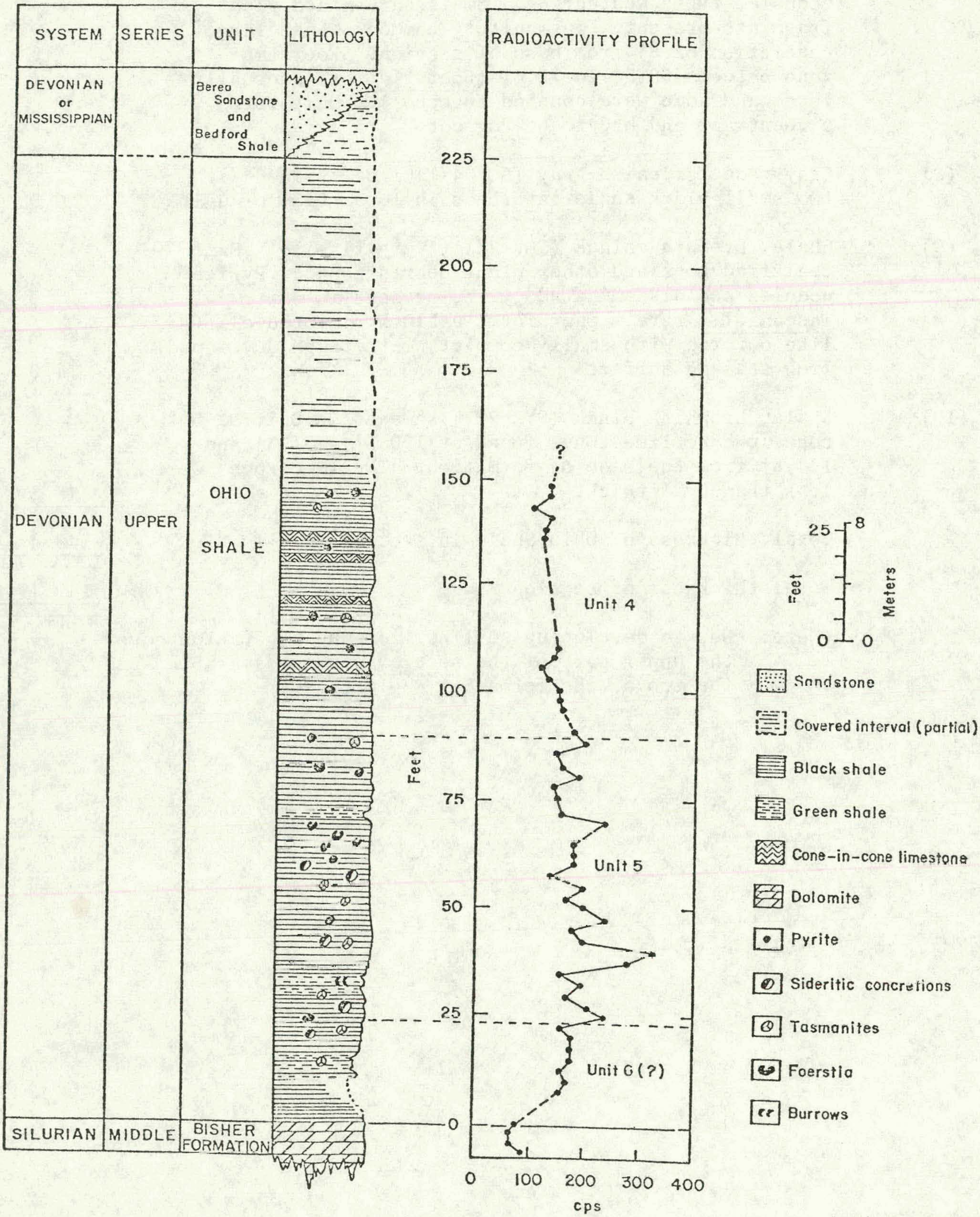
Devonian (continued): Thickness

Ohio Shale (continued):

		Thickness
(7)	Shale, brownish-black (5YR 2/1), very fissile, some "couplet-type" weathering. Small carbonized plant fragments present. Tasmanites common. Last large concretion 62.5' from base of section. Foerstia zone between 68.5' to 70.6' (Foerstia were unusually large and some were coupled together). Unit forms a reentrant and had to be dug out.	35.2
(8)	Claystone, greenish-gray (5GY 4/1) iron stained with two small black shale interbeds in lower 0.3' of unit.	0.5
(9)	Shale, brownish-black (5GY 2/1), very fissile. Some coalified logs and other plant debris found. Pyrite nodules and disseminated pyrite present in unit. Tasmanites rare. Unit forms a blocky jointed cliff-like outcrop with small "couplet weathering" developed. Iron stained surface.	34.0
(10)	Shale, brownish-black (5YR 2/1) same as in Unit 9, but cone-in-cone limestones found at 120.5', 131.3' and 134.8' from the base of formation. The limestones were less than 0.2' thick.	43.5
	Total thickness of Ohio Shale in section	148.4
	Total thickness of section	149.1

(Note: Due to developing soil horizon and vegitation cover, the upper part of the section was unmeasurable, and the top of the formation unpickable.)

LE #1 Section


SYSTEM
SERIES
UNIT
LITHOLOGY
RADIOACTIVITY PROFILE
DEVONIAN or MISSISSIPPIAN
Berea Sandstone and Bedford Shale
DEVONIAN
UPPER
OHIO SHALE
SILURIAN
MIDDLE
BISHER FORMATION
Feet
225
200
175
150
125
100
75
50
25
0
?
Unit 4
Unit 5
Unit 6 (?)
0 100 200 300 400
cps
25 8
Feet
Meters
0 0
Sandstone
Covered interval (partial)
Black shale
Green shale
Cone-in-cone limestone
Dolomite
Pyrite
Sideritic concretions
Tasmanites
Foerstia
Burrows

RW #1 Section

This section contains the complete Ohio Shale, Bedford Shale, and Sunbury Shale. Base of section is on south side of Interstate 75, 1.4 miles east of Bath-Rowan County line (1-T-71, 900' FNL x 1100' FWL). Upper section is on north side of Interstate 75, 3.1 miles from Bath-Rowan county line (25-U-72, 1100' FNL x 600' FEL). On the Farmers Quadrangle measured using hand level, jacob's staff, tape and scintillometer on October 17, 1976 by Dennis Swager, Frank R. Ettensohn, Paul E. Potter, Roy C. Kepferle, and John Goble.

		Thickness (feet)
Silurian (incomplete):		
	Crab Orchard Formation:	
(1)	Shale with interbedded dolomite stringers, shale is dark greenish-gray (5Y 5/1) and weathers to a brownish red crust (5YR 5/6) - highly oxydized. Dolomites are from 4 to 8 inches thick, discontinuous in the "chippy" shale with no visable bedding type.	8+
	unconformity	
Devonian:		
	Ohio Shale:	
(2)	Shale, brownish-black (5YR 2/1), thin-bedded and very fissile. Basal 6 cm is a basal conglomerate containing woody fragments, quartz pebbles. . .	2.4
(3)	Shale, brownish-black (5YR 2/1), thin bedded, but forms a cliff with massive weathering. Pyrite nodules present and some burrowing. . .	4.9
(4)	Shale, brownish-black (5YR 2/1) interbedded with greenish-gray (5 to 6/1) dolomitic shale forming a reentrant layer. Black shale beds are 5 to 7 centimeters thick as are the gray shales. Some <u>Foerstia</u> found in the black shales. Possible burrows found in the gray shales. . .	8.5
(5)	Shale, brownish-black (5YR 2/1) weathers to a brassy-red color (5YR 5/6), very thin bedded with massive weathering. Pyrite nodules and bedded pyrite near the base. Some rounded to irregular in shape. Coalified logs found near base. More silt than lower black shales.	21.6
(6)	Shale, dark greenish-gray (5GY 4/1) weathers to a greenish-buff with black shale interbeds. (5YR 2/1). Abundant <u>Foerstia</u> found in black shale bands. The gray shale forms small reentrants or a "couplet-type" weathering.	2.8

Devonian (continued):		Thickness (feet)
	Ohio Shale (continued):	
(7)	Shale, brownish-black (5YR 2/1). Very finely laminated with silty layers. Less silt than before; forming a less resistant outcrop. Coalified logs and dendritic type burrows occur throughout section. *Tasmanites* common.	57.7
(8)	Shale, brownish-black (5YR 2/1) same as lower unit with discontinuous cone-in-cone limestones in three horizons within an 11 foot interval. The limestone is medium dark gray (N4) to dark yellowish-orange (10YR 6/6).	39.3
	Three Lick Bed:	
(9)	Shale, grayish-green (5GY 4/1), clayey, thinly bedded, "crumbly" and not resistant.	2.2
	Shale, bronwish-black (5YR 2/1) very thinnly laminated, clayey but fissile containing some pyrite.	2.4
	Shale, greenish-gray (5GY 4/1) clayey, thinly bedded and not resistant.	1.1
	Shale, bronwish-black (5YR 2/1) very fissile with a crumbly appearance. Contains a discontinuous cone-in-cone limestone, pyrite and marcasite nodules.	4.1
	Shale, greenish-gray (5GY 4/1), thinnly bedded, clayey and not resistant. Contains some pyrite nodules. *Lingula* found.	1.1
	Total Three Lick Bed	10.9
(10)	Shale, brownish-black (5YR 2/1), fissile, forming "papery" plates when weathered. Pyrite nodules and woody fragments common. Phosphate nodules common. Abundence of *Lingula* increases near top. Shale has a conchoidal fracture.	48.5
	Total Ohio Shale	196.6
Mississippian (incomplete):		
	Bedford Shale:	
(11)	Shale, olive-gray (5Y 4/1-5Y 6/1), silty and slightly calcareous contains some siltstone and cone-in-cone layers. Heavily stained with limonite. Sharp contact with Ohio Shale.	

Mississippian (continued): | Thickness (feet)

Bedford Shale (continued):

Total Bedford Shale	21.5

Sunbury Shale:

(12) Shale, brownish-black (5YR 2/1) to (N1) weathers yellowish-orange (5Y 8/1) contains abundant large pyrite nodules. Forms a jutting outcrop. Lingula common.

Basal 2' lag zone found as a sharp contact with the Bedford Shale and contains conodonts, fish plates and woody fragments.

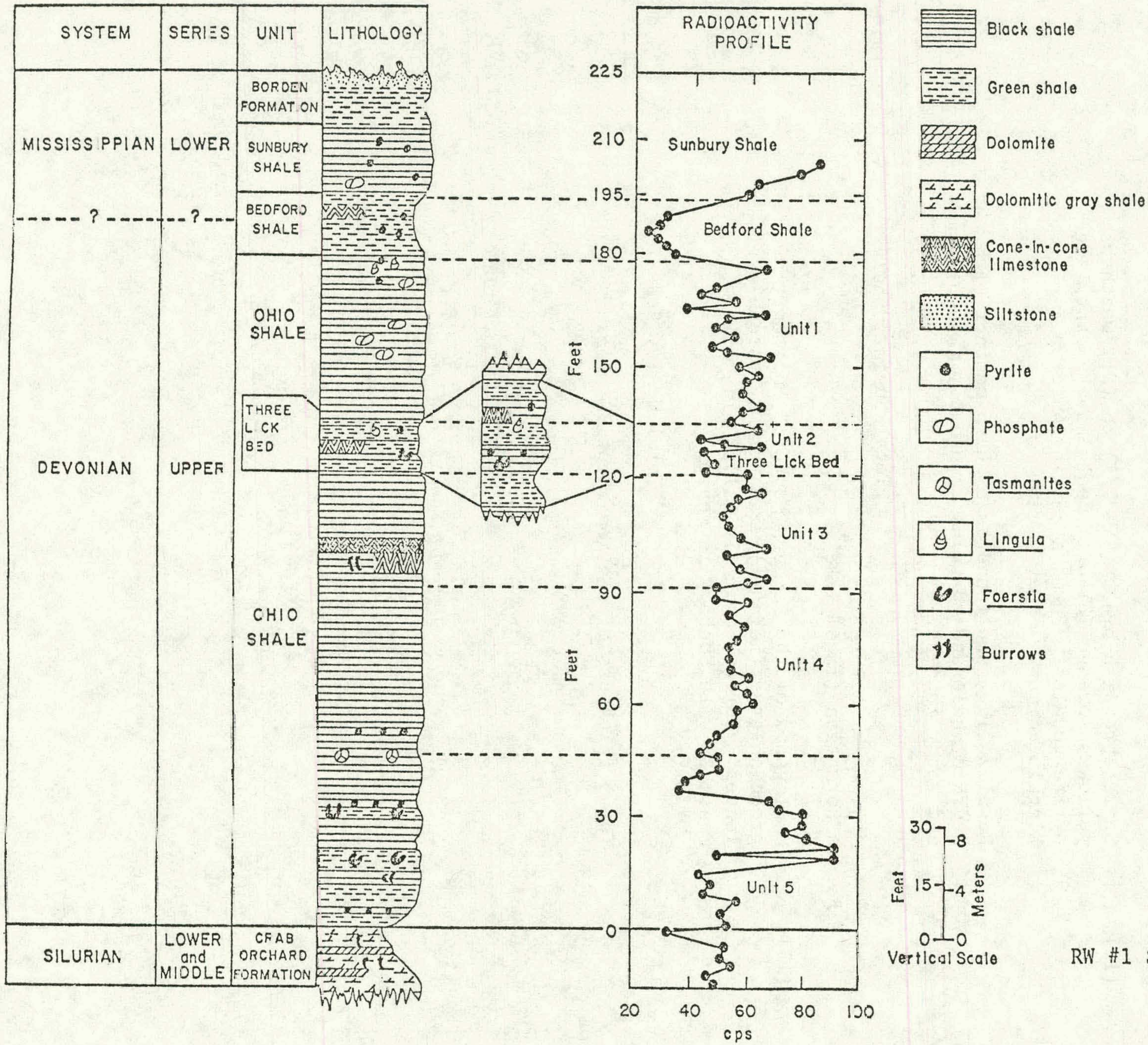
Total Sunbury Shale	19.4

Borden Formation (incomplete):

(13) Henley Bed of the Farmers Member: Mudstone, greenish-gray (5GY 6/1) with thin siltstone lenses. Burrows commonly filled glauconite. Contact with Sunbury is sharp.

Total Henley Bed	5.6

Total thickness of section about 251 feet.



SYSTEM
SERIES
UNIT
LITHOLOGY
MISSISSIPPIAN
LOWER
BORDEN FORMATION
SUNBURY SHALE
BEDFORD SHALE
?
DEVONIAN
UPPER
OHIO SHALE
THREE LICK BED
OHIO SHALE
SILURIAN
LOWER and MIDDLE
CRAB ORCHARD FORMATION
RADIOACTIVITY PROFILE
225
210
195
180
150
120
90
60
30
0
Feet
Sunbury Shale
Bedford Shale
Unit 1
Unit 2
Three Lick Bed
Unit 3
Unit 4
Unit 5
20
40
60
80
100
cps
Black shale
Green shale
Dolomite
Dolomitic gray shale
Cone-in-cone limestone
Siltstone
Pyrite
Phosphate
Tasmanites
Lingula
Foerstia
Burrows
30
15
0
8
4
Feet
Meters
Vertical Scale

RW #1 Section

FL #1 Section

This section contains the complete Bedford Shale and partial sections of the Ohio and Sunbury Shales. The section is exposed in a series of roadcuts on the east side of Kentucky Highway 559, 1.6 miles northeast of Wallingford in Fleming County, Knetucky. It is on the Burtonville Quadrangle (1-W-71, 3000' FNL x 1250' FEL). It was measured using hand level and tape, sampled and scintillometer readings gathered on July 26, 1977 by Dennis Swager and John Goble.

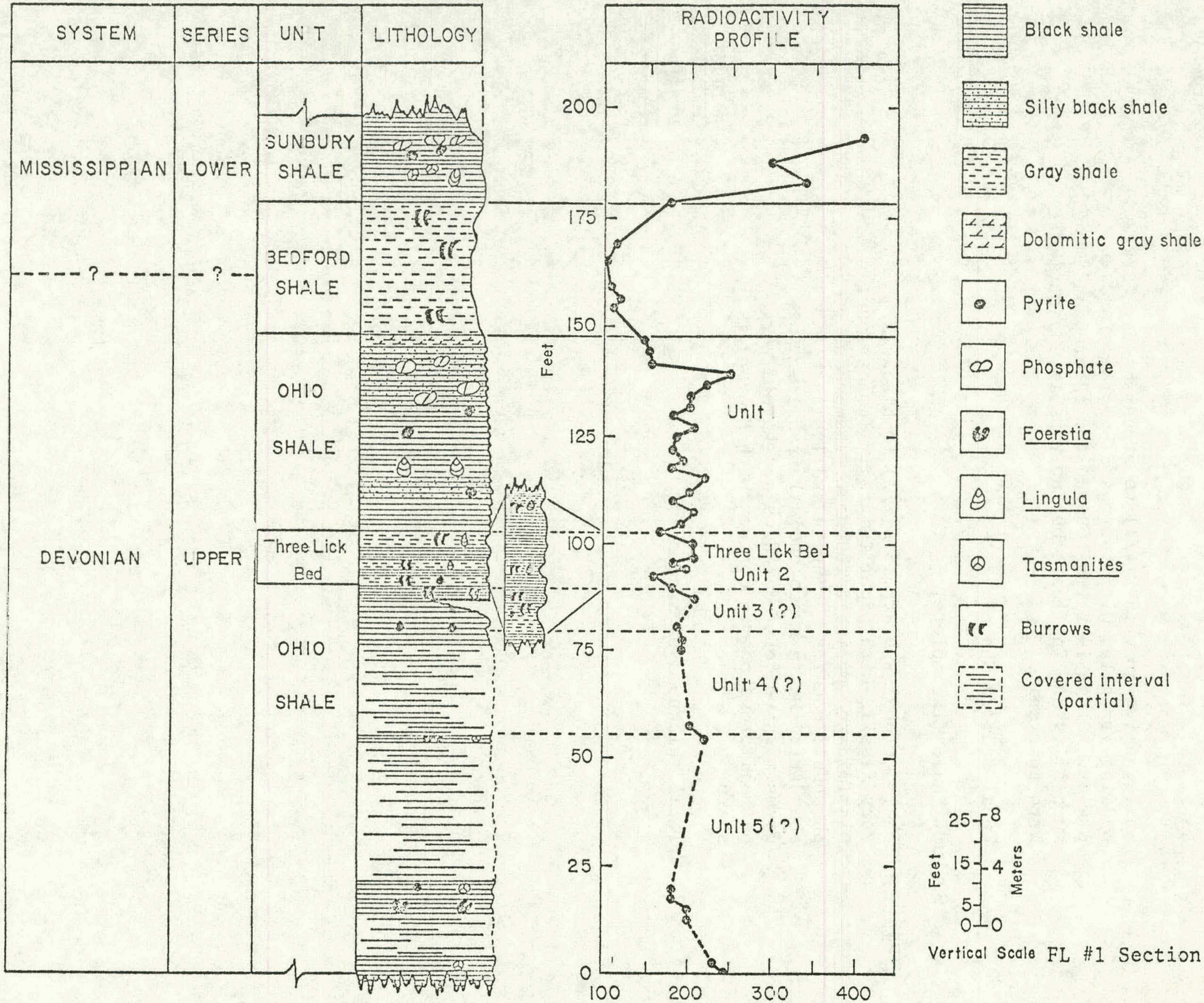
Devonian (incomplete):		Thickness (feet)
	Ohio Shale (incomplete):	
(1)	Shale, brownish-black (5YR 2/1) weathers to a dusky brown (5YR 5/6). Very finely laminated with silty layers causing a fissile outcrop. Tasmanites common. Unit forms a ledge with jointed, blocky appearance.	2.3
	(Note: This is a very small outcrop, but probably representative of the overlying covered interval.)	
(2)	Covered Interval, but definitely is a part of the Ohio Shale.	10.2
(3)	Shale, brownish-black (5YR 4/1), very fissile and heavily iron-stained as in unit 1. Highly weathered pyrite nodules found along with two (2) rhombohedral fish plates. Few Tasmanites present and less silt present than in unit 1. Zone of Foerstia found at 2.7' above base. Outcrop is jointed.	8.5
(4)	Covered Interval, but definitely is a part of the Ohio Shale.	32.9
(5)	Shale, brownish-black (5YR 2/1), very fissile with very little silt present. Mottled appearance may be "burrows" in the lower part of unit. Tasmanites common, syneresis cracks present. Very petroliferous odor evident. Outcrop is jointed and forms a ledge.	3.5
	(Note: Unit 5 outcrops in a small creek just east of the highway).	
(6)	Covered Interval, but definitely is a part of the Ohio Shale.	17.5
(7)	Shale, brownish-black (5YR 2/1), contains highly weathered pyrite nodules. There is no silt present. The unit is highly iron stianed and contains syneresis cracks. Outcrop had to be dug out with pick.	7.0
(8)	Covered Interval, but definitely is a part of the Ohio Shale.	4.5

Devonian (continued): Thickness (feet)

Ohio Shale (continued):

Unit	Description	Thickness (feet)
(9)	Shale, brownish-black (5YR 2/1) same as unit 7 without the pyrite and contains some burrows at the top.	3.8
	Three Lick Bed:	
(10)	Mudsotne, greenish-gray (5GY 4/1), traces of pyrite present. Unit is highly iron-stained; there is a burrowed sequence 4-7 centimeters thick at the base. Forms reentrant.	2.9
(11)	Shale, brownish-black (5YR 2/1), no silt present, highly weathered pyrite nodules. Tasmanites rare. Unit is highly iron-stained. Unit forms a ledge on the outcrop, but is covered with talus debris. Suggestion of burrows near the top. Upper and lower contacts sharp.	2.6
(12)	Mudstone, greenish-gray (5GY 4/1) same as unit 10, but one Lingula found.	1.2
(13)	Shale, brownish-black (5YR 2/1) same as unit 11, without the burrows. Contacts still sharp.	4.8
(14)	Mudstone, greenish-gray (5GY 4/1) same as unit 10. Upper contact sharp.	1.4
	Total Three Lick Bed	12.9
	(Note: The entire Three Lick Bed was badly covered with talus, and the whole sequence had to be trenched in order to expose its physical character.).	
(15)	Shale, brownish-black (5YR 2/1), very laminated with silt layers and very fissile weathering. Silt increases toward top of unit. Pyrite nodules and bedded pyrite present along with many phosphate nodules (whose abundance increases upward). Outcrops are highly jointed massive cliffs with distinct "couplet" weathering (each couplet ranges from .4 to .5 feet thick). Lingula common and more abundant near top. Petroliferous odor previlent.	41.8
(16)	Shale, medium gray (N3) to light greenish-gray (5YR 3/1), it is dolomitic. Possibly a highly weathered black shale, but forms a definite reentrant and is not silty in nature.	2.5
	Total Ohio Shale in section	147.5

Mississippian (incomplete):		Thickness (feet)
	Bedford Shale:	
(17)	Shale, olive-gray (5YR 4/1) to greenish-gray (5YR 2/1) bedding irregular with burrows along some bedding planes. Slope is talus covered and outcrop uncommon. Much siltstone in float, but no visable connection with this unit.	
	Total Bedford Shale	31.2
	Sunbury Shale (incomplete):	
(18)	Shale, brownish-black (5YR 2/1) to black (N2), very fissile with paper thin silt laminations. Dissiminated pyrite throughout. Numerous phosphate noudles. Lingula and Tasmanites abundant. Has a subconchoidal fracture. Unit forms massive jointed ledges and have a very petroliferous odor. Contact with Bedford is sharp.	14.3
	Total Thickness of section.	193.0


SYSTEM
SERIES
UNIT
LITHOLOGY
RADIOACTIVITY PROFILE
MISSISSIPPIAN
LOWER
SUNBURY SHALE
BEDFORD SHALE
OHIO SHALE
Three Lick Bed
DEVONIAN
UPPER
OHIO SHALE
Feet
200
175
150
125
100
75
50
25
0
100
200
300
400
CPS
Unit 1
Three Lick Bed
Unit 2
Unit 3 (?)
Unit 4 (?)
Unit 5 (?)
Black shale
Silty black shale
Gray shale
Dolomitic gray shale
Pyrite
Phosphate
Foerstia
Lingula
Tasmanites
Burrows
Covered interval (partial)
25
15
5
0
8
4
0
Feet
Meters
Vertical Scale

FL #1 Section

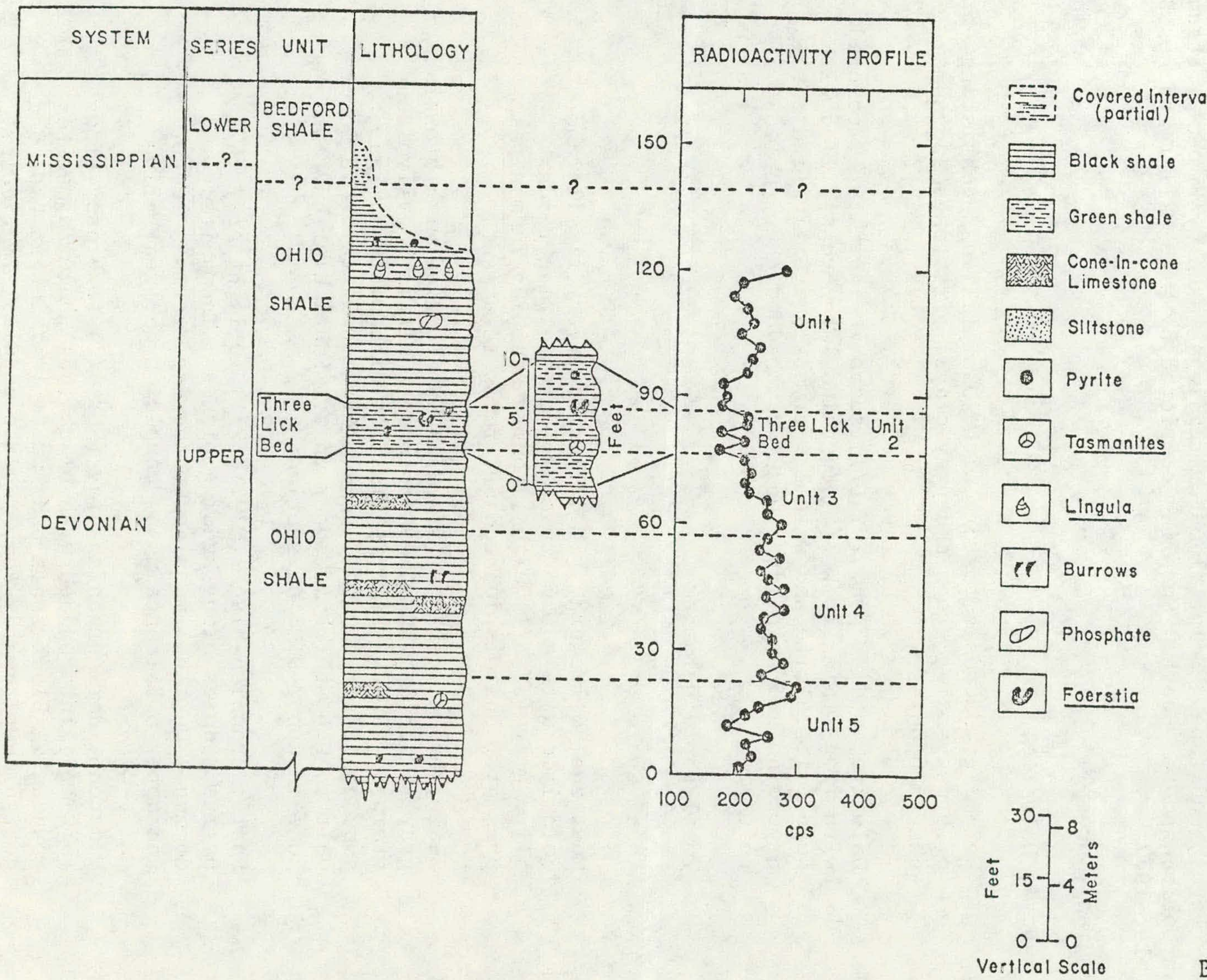
BA #1 Section

This is a partial section of the Ohio Shale exclusive of either bottom or top, but does expose the Three Lick Bed very well on the first ledge of the quarry. The quarry is located approximately 300 yards west of Kentucky Highway 211, 1.7 miles south of Salt Lick in Bath County, Kentucky. The quarry is represented on the Salt Lick Quadrangle section 23-T-71, 2000' FEL x 1300' FNL. The section was sampled, measured and described using hand level and tape on November 7, 1976 by Dennis Swager, John Goble and Mike Miller. The radioactive profile was measured by a scintillometer on May 12, 1977 by Dennis Swager and John Goble.

		Thickness (feet)
Devonian (incomplete):		
	Ohio Shale (incomplete):	
(1)	Shale, brownish-black (5YR 2/1), very finely laminated and fissile. Small amount of silt at base and silt increases toward the top of section. Pyrite nodules and Tasmanites abundant. Some bedded pyrite found. Cone-in-cone limestones, medium gray (N3) found to be discontinuous at several places in unit; they vary from 0.3 to 0.7 feet thick. Unit forms jointed blocky ledges with "couplet-type" weathering.	76.9
	Three Lick Bed:	
(2)	Mudstone, greenish-gray (5GY 6/1), clayey material with no silt present, heavily iron stained with a sharp basal contact. Pyrite nodules found and some burrows present. Unit forms a reentrant.	1.7
(3)	Shale, brownish-black (5YR 2/1), pyrite present, no silt present. Very fissile, highly weathered. Lower contact sharp.	2.3
(4)	Mudstone, greenish-gray (5GY 6/1) same as unit 2, with sharp basal contact.	1.0
(5)	Shale, brownish-black (5YR 2/1) same as unit 3, with sharp basal contact.	2.2
(6)	Mudstone, greenish-gray (5GY 6/1) same as unit 2, with spar contact.	2.0
	Total Three Lick Bed	9.2

(Note: The whole section of the Three Lick Bed was highly weathered and had to be trenched in areas. Description was difficult because of steep cliff.).

Devonian (continued):		Thickness (feet)
	Ohio Shale (continued):	
(7)	Shale, brownish-black (5YR 2/1), laminated and very fissile, but no silt apparent. Iron-stained, jointed outcrops form ledges. Pyrite nodules common. No fossils present. Basal contact sharp.	14.8
(8)	Shale, brownish-black (5YR 2/1) to black (N2), very finely laminated with silt. Subconchoidal fracture. *Lingula* abundant. Suggestion of "couplet-type" weathering near the top. Outcrops are resistant, jointed and partially covered. The exact top is indistinguishable due to the cover but last black shale found at 143.1 feet above base of quarry. Chips of Borden-type shale found along with siltstone talus. Unsure of exact top, but is close to the top of this unit.	42.2+
	Total thickness of Ohio Shale in section	143.1


SYSTEM
SERIES
UNIT
LITHOLOGY
RADIOACTIVITY PROFILE
MISSISSIPPIAN
DEVONIAN
LOWER
UPPER
BEDFORD SHALE
OHIO SHALE
Three Lick Bed
OHIO SHALE
Feet
Three Lick Bed
Unit 1
Unit 2
Unit 3
Unit 4
Unit 5
cps
Covered interval (partial)
Black shale
Green shale
Cone-in-cone Limestone
Siltstone
Pyrite
Tasmanites
Lingula
Burrows
Phosphate
Foerstia
Feet
Meters
Vertical Scale

BA #1 Section

PO #1 Section

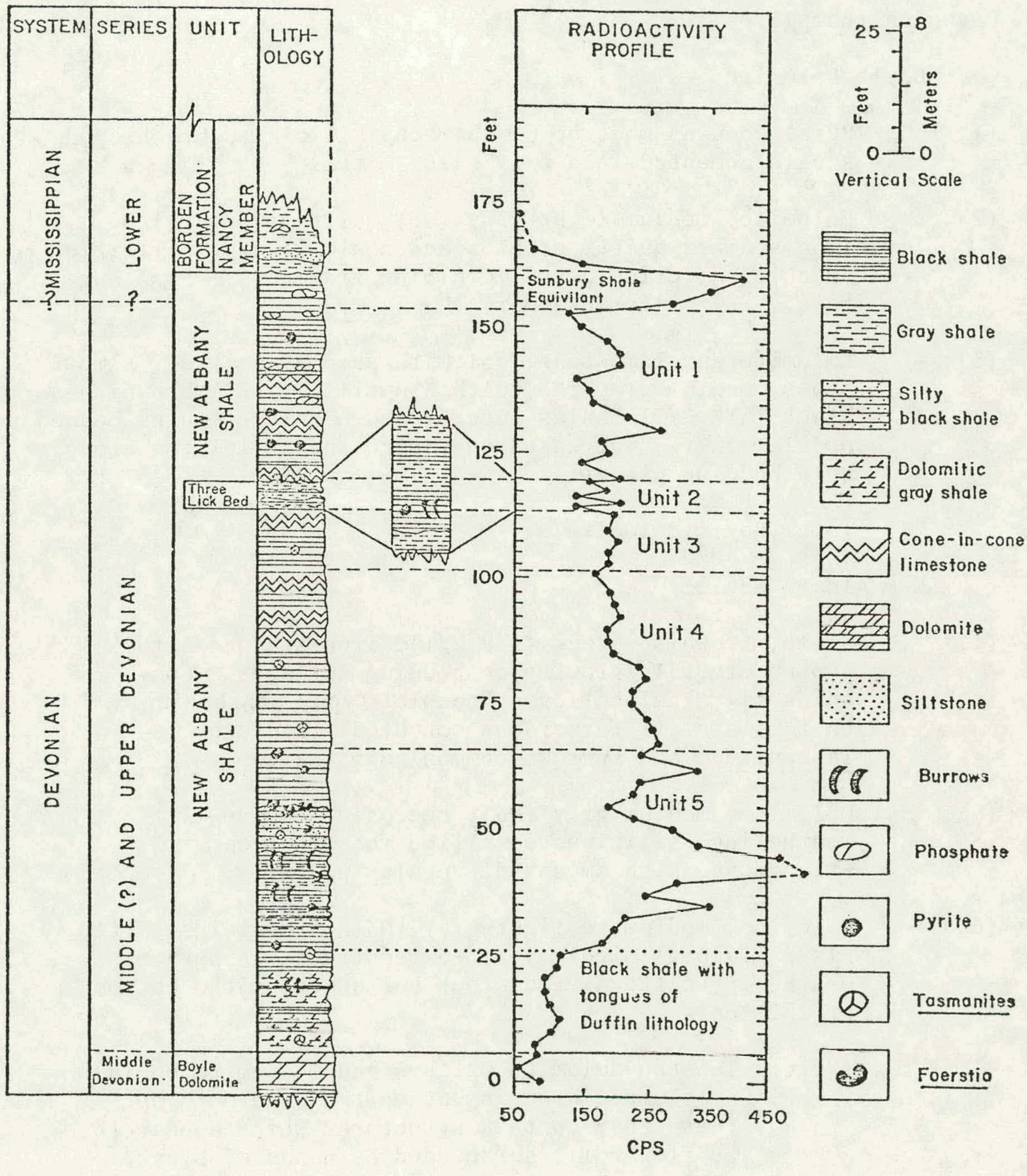
This section contains the complete New Albany Shale and partial sections of the Boyle Dolomite and New Providence Shale. The section is exposed and was measured on the north side of the Mountain Parkway, .25 miles west of the Clay City Interchange in Powell County, Kentucky on the Clay City Quadrangle (12-Q-67, 100' FSL x 1000' FWL). The upper section was measured and described in a quarry 0.3 miles north of Highway 11 along the east side of Highway 1057 in Powell County, Kentucky on the Levee Quadrangle (3-Q067, 0' FSL x 750' FWL). The section was measured and described by Dennis Swager and Roy C. Kepferle with jacob's staff, abney level, and tape. Scintillometer readings taken by Frank R. Ettensohn, John Goble, and Les Booth. Sampling completed by Mike Miller and Les Booth on May 19, 1977.

Devonian (incomplete):		Thickness (feet)
Boyle Dolomite:		
(1)	Dolomite, sucrosic texture with joint fillings consisting of brown shale, green and gray clays, siltstones and some quartz pebbles.	2.6
(2)	Dolomite, medium gray (5Y 6/1) sucrosic in texture, covered with iron stain (10YK 7/4) contains large vugs filled with dead oil, calcite and dolomite crystals. Silicified corals, bryozoans and crinoids. Nodular, bedded chert up to 0.7' thick.	4.2
	Total Boyle Dolomite	6.8
New Albany Shale:		
(3)	Mudstone, olive-gray (5Y 4/1) silty, very fissile and dolomitic with a 0.6' thick dolomite stringer, dark olive-gray (5Y 3/1) with limonite staining _Tasmanites_ present. Unit is jointed and forms reentrant.	5.8
(4)	Shale, brownish-black (5YR 2/1) interbedded with brownish-gray (5Y 6/1) dolomitic mudstone. Unit is heavily iron-stained. Black shale is fissile, with platy laminae, subconchoidal fracture. Beds are from 0.2' thick in lower unit to 0.6' thick in upper unit Lenticular, burrowed zone in upper 0.9' of section.	9.2
(5)	Shale, brownish-black (N2-5YR 2/1) to light gray (N7) pyrite nodules along bedding planes. _Tasmanites_ common. Unit has massive weathering, forms a ledge, and upper 6.8' contains a "couplet-type" weathering.	8.3
(6)	Mudstone, dark greenish-gray (5GY 4/1) to brassy-brown (5YR 3/2) interbedded with black (N3) shale _Tasmanites_ abundant. Black-shale beds up to 1' thick at base and get thinner towards top. Pyrite nodules, lenticular,	

	Devonian (continued):	Thickness (feet)
	New Albany Shale (continued):	
	Condrities and Tanaurous burrows present. "Couplet-type" weathering with the base of each couplet burrowed. Large continuous burrowed bed at 36.5'.	10.7
(7)	Shale, brownish-black (5YR 2/1), thinnly bedded with silt laminae. Many pyrite nodules, coalified plant fragments and Tasmanites present. Very fissile, outcrop has "couplet-type" weathering. Pyrite decreases near top. Foerstia zone 14 feet from base and about 26 feet thick. Foerstia do not exist at top of unit. Unit is talus covered in areas and had to be trenched.	46.0
(8)	Shale, brownish-black (5YR 2/1) as in unit 5. With cone-in-cone limestone, medium gray (N3) interbedded. The limestone is between 0.1 and 0.3 feet thick, they are continuous and occur in six horizons as follows: at base of unit, 5' from base, 6.2' from base, 12' from base, 14' from base and 17.3' from base.	28.8
	Three Lick Bed:	
(9)	Mudstone, light gray (N6) poorly laminated silty with iron stains on surface. Crumbly texture but cohesive, unit forms reentrant sharp basal contact.	1.4
(10)	Shale, brownish-black (5YR 2/1), very fissile laminated, no silt, few Tasmanites, pyrite nodules and burrows near base.	1.6
(11)	Mudstone, light gray (N6), same as unit 9.	0.5
(12)	Shale, brownish-black (5YR 2/1) same as unit 10.	1.6
(13)	Mudstone, light gray (N6), same as unit 9.	0.9
	Total Three Lick Bed	6.0
(14)	Shale, brownish-black (5YR 2/1), very fissile with papery thin laminae. Some silt laminae present. Pyrite nodules, burrows and Tasmanites common. Shale is jointed and has a "couplet-type" weathering. There are four distinct continuous cone-in-cone limestone, medium gray (N3) horizons from 0.3 from 0.5 feet thick as follows: 1.6' from base, 9.6' from base, 10.5' from base and 20.8' from base. Phosphate nodules also occur in this section at 22.1' from base and above to the top.	

		Thickness (feet)
	Devonian (continued):	
	New Albany Shale (continued):	
	Some orientation of phosphate nodules as follows: 280° and 320° in strike.	46.0
	Total New Albany Shale	160.8
	Mississippian (incomplete):	
	Borden Formation (incomplete):	
	New Providence Shale (incomplete):	
(15)	Mudstone, greenish-gray (5Y 6/1-5GY 6/1) weathers to a yellowish-gray (5Y 8/1) or greenish-gray (5GY 8/1) interbedded with small siltstone beds containing <u>Tanaurous</u> burrows. Mudstone weathers to chips forming a reentrant and contain clayey phosphatic nodules.	8.0
	Total thickness of section	175.4

PO #1 Section


SYSTEM
SERIES
UNIT
LITHOLOGY
RADIOACTIVITY PROFILE
Feet
Meters
Vertical Scale
MISSISSIPPIAN
LOWER
BORDEN FORMATION
NANCY MEMBER
NEW ALBANY SHALE
Three Lick Bed
DEVONIAN
MIDDLE (?) AND UPPER DEVONIAN
Middle Devonian
Boyle Dolomite
Sunbury Shale Equivilant
Unit 1
Unit 2
Unit 3
Unit 4
Unit 5
Black shale with tongues of Duffin lithology
CPS
Black shale
Gray shale
Silty black shale
Dolomitic gray shale
Cone-in-cone limestone
Dolomite
Siltstone
Burrows
Phosphate
Pyrite
Tasmanites
Foerstia

ES #1 Section

This section contains the complete New Albany Shale, partial Boyle Dolomite and a bit of the Nancy Shale. The section is located west of Irvine, Ky. in 1900' FSL x 100' FEL) on the Panola Quadrangle. Described and measured by Dennis Swager, John Goble, and Mike Miller on May 24, 1977 using hand level, tape, and jacob's staff. The section was sampled every five feet and a radioactive profile taken using a scintillometer.

Devonian (complete):		Thickness (feet)
Boyle Dolomite:		
(1)	Basal coquina made up of numcrous silicified brachiopod shells cemented in a clay sized matrix.	0.3
(2)	Dolomite, medium light gray (N6), silt sized grains. Iron stained quartz pebbles and shale clasts. Silicified brachiopod, crinoid and coralline fragments. Some burrows. Petroliferous odor.	1.1
(3)	Dolomite and limestone, dolomite same as unit 2. Limestone, medium gray (N3) with 3 small (.1-.3') brownish-black (5YR 2/1) shales interbedded. Unit contains bedded nodular chert, increased vug space and stylolites along some bedding planes.	13.6
	Total Boyle Dolomite	15.0
New Albany Shale:		
(4)	Shale, brownish-black (5YR 2/1), iron-stained with gypsum crystals growing on bedding surfaces. Contains silt laminae forms "couplet-type" weathering. Unit is a cliff former has concoidal fracture. <u>Tasmanites</u> and burrows common near the top.	7.3
(5)	Dolomite, medium gray (N3), sucrosic massive weathering, silicious coralline fossils iron stained and high amount of vugular porosity.	2.7
(6)	Dolomite, medium to light gray (N3-N6) contains silt sized grains. Highly jointed reentrant "chippy" weathering pattern. Numerous burrows near the bottom of this unit.	2.2

(Note: The two dolomite units 5 and 6 seem to be in a slumped area in one part of the outcrop. There they contain structures which appear to be flow rolls surrounded by bands of black shale.)

Devonian (continued):

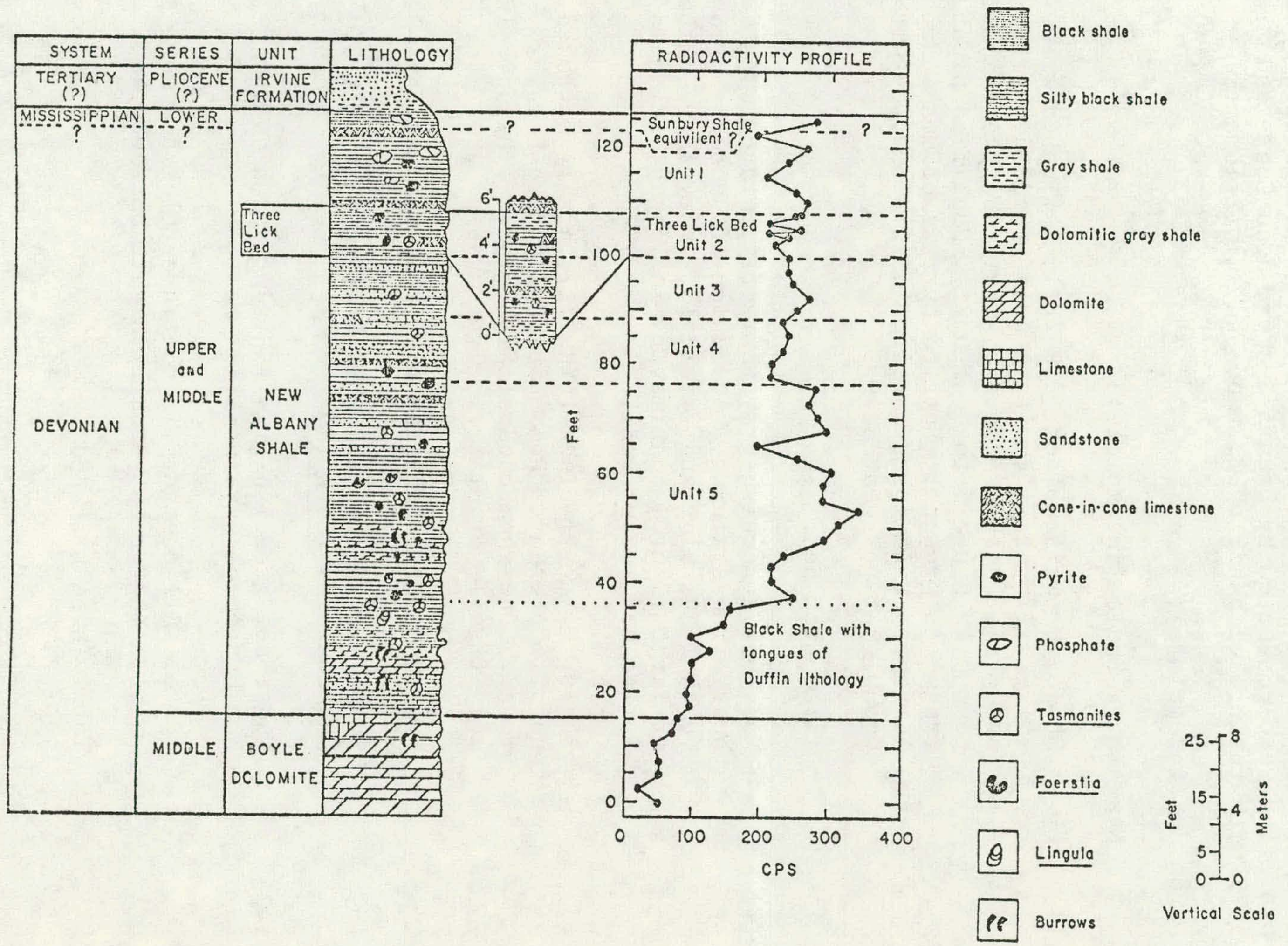
New Albany Shale (continued):

Unit	Description	Thickness (feet)
(7)	Shale, brownish-black (5YR 2/1) laminated and very fissile. Unit forms a small ledge and is continuous. Tasmanites abundant.	0.6
(8)	Shale, interbedded gray (N6) dolomitic shale and brownish-black (5YR 2/1) silty shale. There are five gray shales about 0.4 feet in thickness forming reentrants.	3.2
(9)	Shale, brownish-black (5YR 2/1) clay sized particles contains pyrite nodules, Lingula fragments and Tasmanites. Has subconchoidal fracture. Outcrop is jointed, massive and forms a ledge.	12.2
(10)	Shale, interbedded brownish-black (5YR 2/1) and gray (N8) dolomitic claystone. Black shale contains pyrite nodules, burrows, plant fragments and Tasmanites. Gray shale contains pyrite nodules in the beds form 0.7' to 1' thick. Unit forms reentrant. Foerstia found in float.	6.0
(11)	Shale, brownish-black (5YR 2/1) very fissile with some silty layers. Few pyrite nodules and some bedded pyrite. Few pyrite nodules and some bedded pyrite. Unit forms a large jointed massive ledge. Limonite stains on surface. Plant fragments and Tasmanites common.	7.7
(12)	Shale, brownish-black (5YR 2/1), clay sized particles. Very laminated and fissile with a "couplet-type" weathering. Small pyrite nodules, plant fragments and Tasmanites abundant. Bedded pyrite also found. Cone-in-Cone layers at 76', 83', and 85'. Foerstia zone found (very abundent) between 56.9' and 60.0'. Unit not as massive as unit 11.	45.4

Three Lick Bed:

Unit	Description	Thickness (feet)
(13)	Mudstone, greenish-gray (5GY 4/1) to light gray (N3) clayey shale. Forms a reentrant which had to be trenched. Heavily iron-stained. Possible burrows near the base.	0.6
(14)	Shale, brownish-black (5YR 2/1) very fissile, well laminated with pyrite nodules and a suggestion of burrows near the base. Unit forms a ledge on outcrop. Iron stained.	1.7
(15)	Mudstone, greenish-gray (5GY 4/1) same as unit 13.	0.4

Devonian (continued):	Thickness (feet)
New Albany Shale (continued):	
Three Lick Bed (continued):	
(16) Shale, brownish-black (5YR 2/1) same as unit 14, with a small discontinuous cone-in-cone limestone and _Tasmanites_ present.	2.3
(17) Mudstone, greenish-gray (5GY 4/1) same as unit 13.	0.4
Total Three Lick Bed	5.4
(18) Shale brownish-black (5YR 2/1), with more silt than unit 12. Contains pyrite nodules, phosphate nodules and _Tasmanites_. No _Lingula_ were found. Has a subconchoidal fracture. Unit forms a jointed semi-massive ledge with "couplet-type" weathering. (Not sure of top because soil horizon is beginning to develop and cover the upper section.)	22.9
Total New Albany Shale	115.6
Mississippian (incomplete):	
Borden Formation (incomplete):	
Nancy Member (incomplete):	
(19) On the top of the hill there were some chips of a light greenish gray argillaceous shale which might be the Nancy. It was hard to estimate any thickness.	?
(Note: According to the geologic quadrangle there should be Nancy on top of this outcrop. The few chips of shale are the only indication that it does exist there.)	


SYSTEM
SERIES
UNIT
LITHOLOGY
TERTIARY (?)
PLIOCENE (?)
IRVINE FORMATION
MISSISSIPPIAN
LOWER
?
DEVONIAN
UPPER and MIDDLE
NEW ALBANY SHALE
Three Lick Bed
MIDDLE
BOYLE DOLOMITE
6'
4'
2'
0'
RADIOACTIVITY PROFILE
Sunbury Shale equivilent
Unit 1
Three Lick Bed
Unit 2
Unit 3
Unit 4
Unit 5
Black Shale with tongues of Duffin lithology
Feet
0
20
40
60
80
100
120
0
100
200
300
400
CPS
Black shale
Silty black shale
Gray shale
Dolomitic gray shale
Dolomite
Limestone
Sandstone
Cone-in-cone limestone
Pyrite
Phosphate
Tasmanites
Foerstia
Lingula
Burrows
25
15
5
0
8
4
0
Feet
Meters
Vertical Scale

ES #1 Section

MA #1 Section

This section contains only the New Albany Shale sequence which is incomplete. The top of the section is approximately the top of the unit, but exact measurements are not positive. The entire Three Lick Bed is well exposed in the wall of this quarry. The quarry or borrow pit is located 100 yards southwest of Kentucky Highway 21, 1.5 miles west of its intersection with Interstate 75 at the Berea exchange. This section is located on the Berea Quadrangle section 6-M-63, 1600' FNL x 2150' FEL in Madison County, Kentucky. Measuring, describing, sampling, and radioactive profiling were conducted by Dennis Swager, John Goble and Mike Miller on April 16, 1977 with the use of hand level, tape and scintillometer.

		Thickness (feet)
Devonian (incomplete):		
New Albany Shale (incomplete):		
(1)	Shale, brownish-black (5YR 2/1), laminated with silty stringers. Pyrite nodules, bedded pyrite, and pyrite "cubes" common. Small phosphate nodules common in upper 5 feet of unit. Coalified plant fragments present. Mottled burrows common in upper 15 feet. Unit forms massive jointed outcrop with "couplet-type" weathering.	21.5
	Three Lick Bed:	
(2)	Mudstone, greenish-gray (5GY 4/1), clayey with heavy iron staining. Abundance of unusual burrows (both lenticular and vertical). Very large number of large (3 or 4 centimeters in length) <u>Lingula</u>. Pyrite nodules present.	0.3
(3)	Shale, brownish-black (5YR 2/1), highly burrowed no silt present. Phosphate and pyrite nodules found. One rhombohedral fish place. The unit is very fissile or platy.	1.0
(4)	Mudstone, greenish-gray (5GY 4/1) same as unit 2.	0.3
(5)	Shale, brownish-black (5YR 2/1) same as unit 3, but contains <u>Foerstia</u>.	1.0
(6)	Mudstone, greenish-gray (5GY 4/1) same as unit 2, but barren of any fossils.	0.8
	(Note: All contacts in the Three Lick Bed were sharp, but usually highly burrowed.)	
	Total Three Lick Bed	3.4

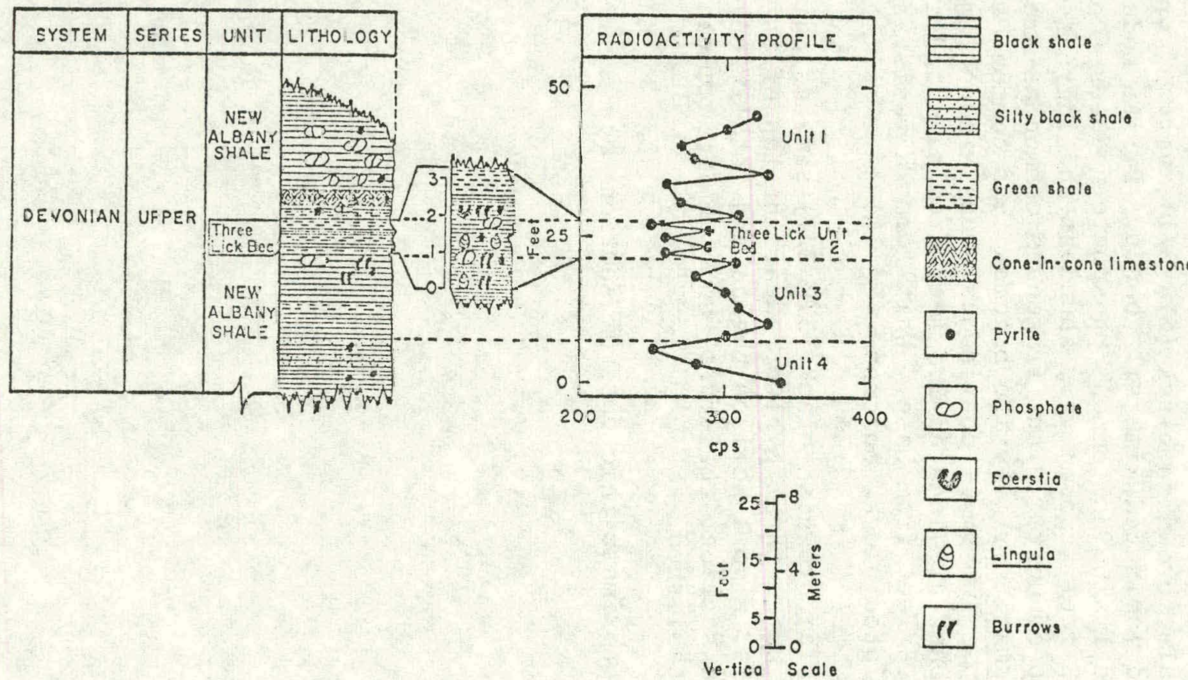
Devonian (continued):

Thickness (feet)

New Albany Shale (continued):

(7)	Shale, brownish-black (5YR 2/1), very fissile and laminated with silt bands. Pyrite nodules and framboids common, phosphate nodules (up to 1.2 feet across) very abundant and increase near top of unit. Plant fragments common as are Tasmanites. Pyrite becomes less common near top. Two small continuous cone-in-cone limestones are located 5.3 feet from base and at 13.8 feet from base. Unit forms a resistant jointed blocky outcrop.	15.8
(8)	Shale, brownish-black (5YR 2/1) same as unit 7, but without pyrite. Near the top of this unit, a soil horizon begins and totally covers the section; therefore, no definite top can be established.	5.2+
	Approximate thickness of section	45.9+

MA #1 Section



SYSTEM
SERIES
UNIT
LITHOLOGY
DEVONIAN
UPPER
NEW ALBANY SHALE
Three Lick Bed
NEW ALBANY SHALE
3
2
1
0
Feet
RADIOACTIVITY PROFILE
50
25
0
200
300
400
cps
Unit I
Three Lick Bed
Unit 2
Unit 3
Unit 4
25
15
5
0
8
4
0
Feet
Meters
Vertical Scale
Black shale
Silty black shale
Green shale
Cone-in-cone limestone
Pyrite
Phosphate
Foerstia
Lingula
Burrows

MA #2 Section

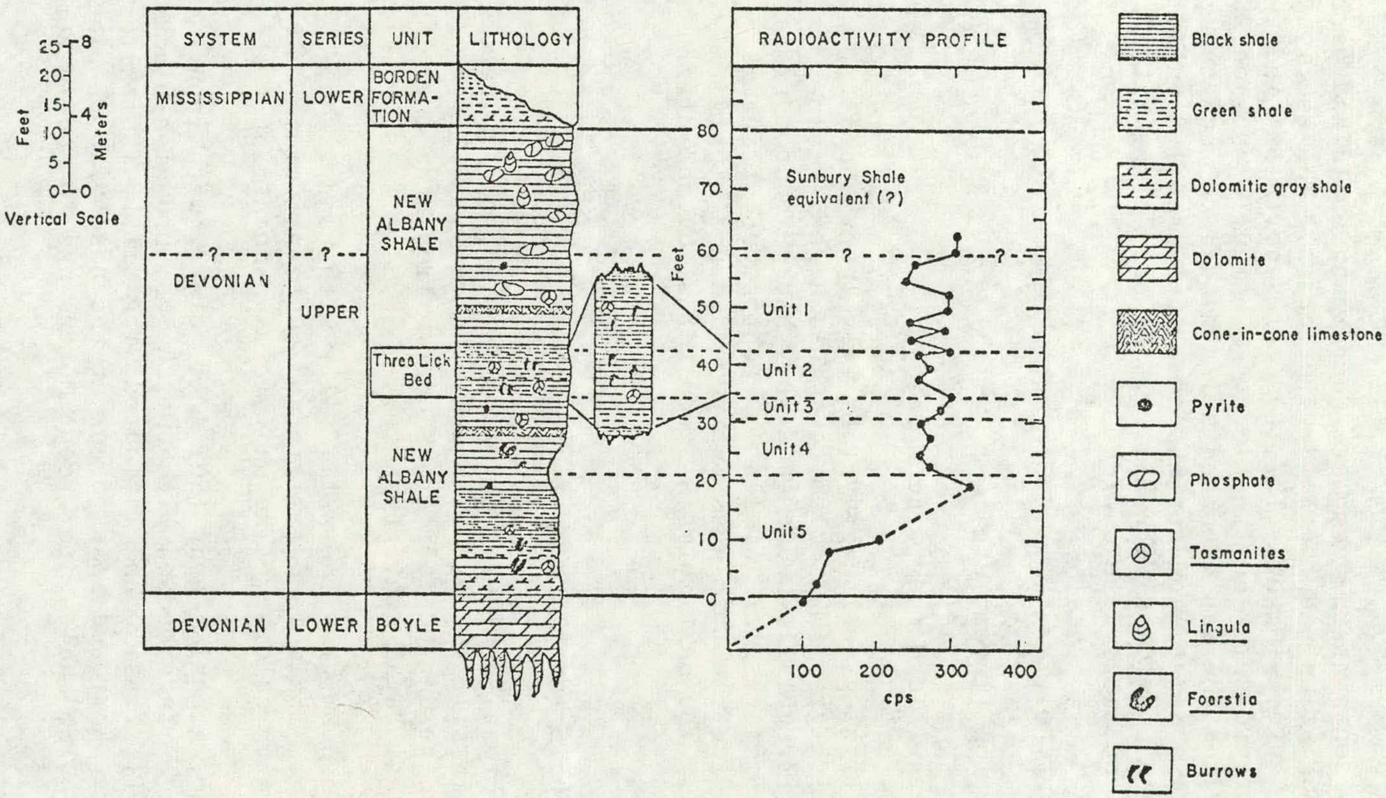
This section contains a nearly complete section of New Albany Shale exposed in road cuts along the north bound lanes of Interstate 75 near the Berea Exchange in Madison County, Kentucky. It is located on the Berea Quadrangle section 7-M-63; 575' FNL x 600' FWL. Nearly all the section had to be trenched with a pick due to the large amount of regolith covering it, and in areas was completely covered. The section was originally measured by Dennis Swager and John Goble on June 1, 1977 using hand level, tape and scintillometer. It was remeasured with a jacob's staff and abney level, on July 7, 1977 by Roy C. Kepferle, Dennis Swager, and John Goble.

		Thickness (feet)
Devonian:		
	Boyle Dolomite (incomplete):	
(1)	Dolomitic limestone, buff-tan to light gray (5YR 5/4-5Y 6/1) contains nodular, bedded chert, conglomeratic with shale clasts in a medium grained matrix. Vugs filled with quartz and dolomite crystals. Stylolites along some bedding planes. Containing silicified crinoid, bryozoan, and coralline fragments.	15+
Unconformity		
	New Albany Shale (incomplete):	
(2)	Mostly covered, some resistant outcrops reveal: shale, brownish-black (5YR 2/1) with small interbeds of gray dolomitic shale (5GY 2/1). Bedded and nodular pyrite found in the black shales along with plant fragments and <u>Lingula</u>. Outcrops are jointed and have subconchoidal fracture. Iron staining and small dolomitic beds (<1') near the base.	10.3
(3)	Convered Interval	9.9
(4)	Shale, brownish-black (5YR 2/1), paper thin laminations, very fissile, silty, iron-stained. Small weathered pyrite nodules. Small discontinuous cone-in-cone limestone 2.5 feet from top. Begins to lose the silt near the top. <u>Tasmanites</u> common.	26.1
	Three Lick Bed:	
(5)	Greenish-gray shale (5GY 4/1), clayey very fissile, iron stained, burrows (mottled in appearance) near base.	1.3
(6)	Brownish-black shale (5YR 2/1), clayey very fissile with iron stains. <u>Tasmanites</u> abundant, cone-in-cone bed near top is very thin and discontinuous.	1.1

Devonian (continued):		Thickness (feet)
	New Albany Shale (continued):	
	Three Lick Bed (continued):	
(7)	Greenish-gray shale (5GY 4/1), it is burrowed throughout, very fissile and iron-stained. It is a clayey shale.	.5
(8)	Brownish black shale (5YR 2/1), clayey, fissile iron-stained shale with _Tasmanites_ abundant; mottled burrows near top.	1.1
(9)	Greenish-gray shale (5GY 4/1), fissile burrowed, iron stained clayey shale. One _Lingula_ found near top.	.8
	Total Three Lick Bed	4.8
(10)	Brownish-black shale (5YR 2/1) very fissile, with a few silty laminations contains a few discontinuous irregular cone-in-cone limestone. Contains large egg-shaped phosphate nodules. Section is mostly covered, but some small outcrops seem to contain a "couplet-type" weathering. Some pyrite nodules and marcasite present. _Tasmanites_ common.	18.0
(11)	Brownish-black shale (5YR 2/1) same as below with more phosphate nodules. Has more silt, a concoidal fracture and petroliferous odor.	9.2
(12)	Above the last outcrop, section is very covered, seems to be a soil horizon developed containing chips of "Borden-like" shale. Top is not complete and exact elevation uncertain.	5+
	Total New Albany Shale	78.3+
	Total section about	100'

(Note: Some of the lower section was described from the walls of a quarry or borrow pit located about 50 yards east of the Interstate road cut. The Three Lick Bed and some of the lower units are well exposed there.)

MA #2 Section



Feet
Meters
Vertical Scale
SYSTEM
SERIES
UNIT
LITHOLOGY
MISSISSIPPIAN
LOWER
BORDEN FORMATION
NEW ALBANY SHALE
DEVONIAN
UPPER
Three Lick Bed
NEW ALBANY SHALE
DEVONIAN
LOWER
BOYLE
RADIOACTIVITY PROFILE
Feet
Sunbury Shale equivalent (?)
Unit 1
Unit 2
Unit 3
Unit 4
Unit 5
cps
Black shale
Green shale
Dolomitic gray shale
Dolomite
Cone-in-cone limestone
Pyrite
Phosphate
Tasmanites
Lingula
Foerstia
Burrows

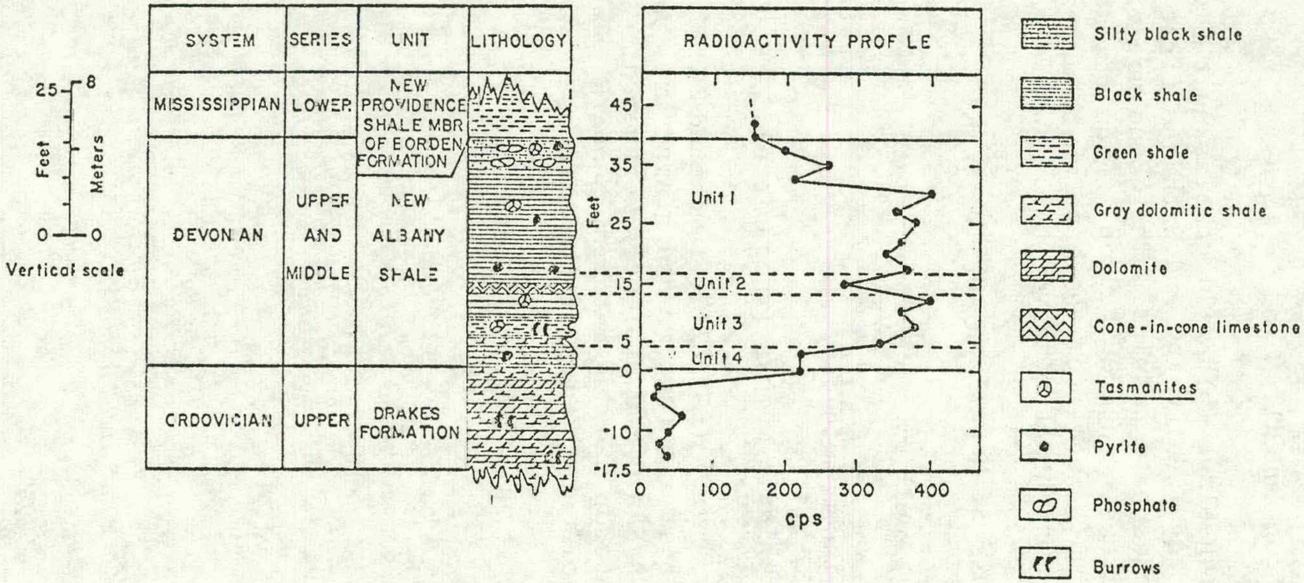
CA #1 Section

This section contains the complete New Albany Shale and partial sections of both the Drakes Formation and the Borden Formation. The section is exposed on the west side of Kentucky Highway 127, 0.2 miles north of Liberty in Casey County, Kentucky. It is represented on the Liberty Quadrangle, section 25-K-56, 500' FSL x 2250' FWL. The section was measured using hand level and tape; radioactive profile taken with a scintillometer and completely sampled on July 28, 1977 by Dennis Swager, John Goble and Mike Miller. By offsetting within the outcrop itself, all covered sections were avoided.

		Thickness (feet)
Ordovician (incomplete):		
Drakes Formation (incomplete):		
Preachersville Member (incomplete):		
(1)	Shale, light greenish gray (5GY 2/1) interbedded with olive-gray (N2) dolomite. The shale is dolomitic, irregularly bedded and very hacky in appearance. The dolomite is more or less in continuous stringers 0.5-0.8 feet in thickness, wavy-bedded and highly jointed. The unit forms a steep talus covered cliff.	18+
Devonian (complete):		
New Albany Shale (complete):		
(2)	Shale, brownish-black (5YR 2/1), fissile and laminated with thin silt layers. The shale has a conchoidal fracture and strong petroliferous odor. Iron staining dominant. Basal contact sharp.	1.1
(3)	Shale, medium gray (5G 6/1), silty with heavy iron staining. Shale is dolomitic and contains veins filled with calcite. The unit forms a reentrant.	0.6
(4)	Mudstone, greenish-gray (5GY 4/1), clayey with iron staining. Interbedded with two shales, brownish-black (5YR 2/1), fissile and laminated with silt. Tasmanites present. Burrowed zones occur at the base of both black shales. The shales are 7 centimeters and 20 centimeters thick.	1.4
	(Note: This unit 4 could possibly correlate with the Three Lick Bed.)	
(5)	Shale, brownish-black (5YR 2/1), very fissile with silt laminae. Bedded pyrite, pyrite nodules, Tasmanites common. One continuous cone-in-cone limestone, 4 centimeters thick, 3.4 feet above the base. Unit forms a jointed blocky ledge with "couplet-type" weathering dominant in the upper 27 feet.	29.6

Devonian (continued):	Thickness (feet)
New Albany Shale (continued):	
(6) Shale, brownish-black (5YR 2/1) same as unit 5 without the "couplet" weathering and with the first occurrence of phosphate nodules. The abundance of the phosphate increases toward the top. A quartz nodule was collected 0.3 feet from the base which appeared to be a pseudomorph after anhydrite.	5.8
Total thickness of New Albany Shale	38.5
Mississippian (incomplete):	
Borden Formation (incomplete):	
New Providence Shale Member (incomplete):	
(7) Shale, greenish-gray (5GY 8/1), laminated with glauconite. Silty in texture and grain size. Heavily iron-stained and extremely weathered. This small outcrop was dug out from beneath about 2.5 feet of soil at the top of the outcrop	5+
Approximate thickness of total section.	61.5+

CA #1 Section



SYSTEM
SERIES
UNIT
LITHOLOGY
RADIOACTIVITY PROFILE
MISSISSIPPIAN
LOWER
NEW PROVIDENCE SHALE MBR OF BORDEN FORMATION
DEVONIAN
UPPER AND MIDDLE
NEW ALBANY SHALE
ORDOVICIAN
UPPER
DRAKES FORMATION
Feet
Meters
Vertical scale
Unit 1
Unit 2
Unit 3
Unit 4
cps
Silty black shale
Black shale
Green shale
Gray dolomitic shale
Dolomite
Cone-in-cone limestone
Tasmanites
Pyrite
Phosphate
Burrows

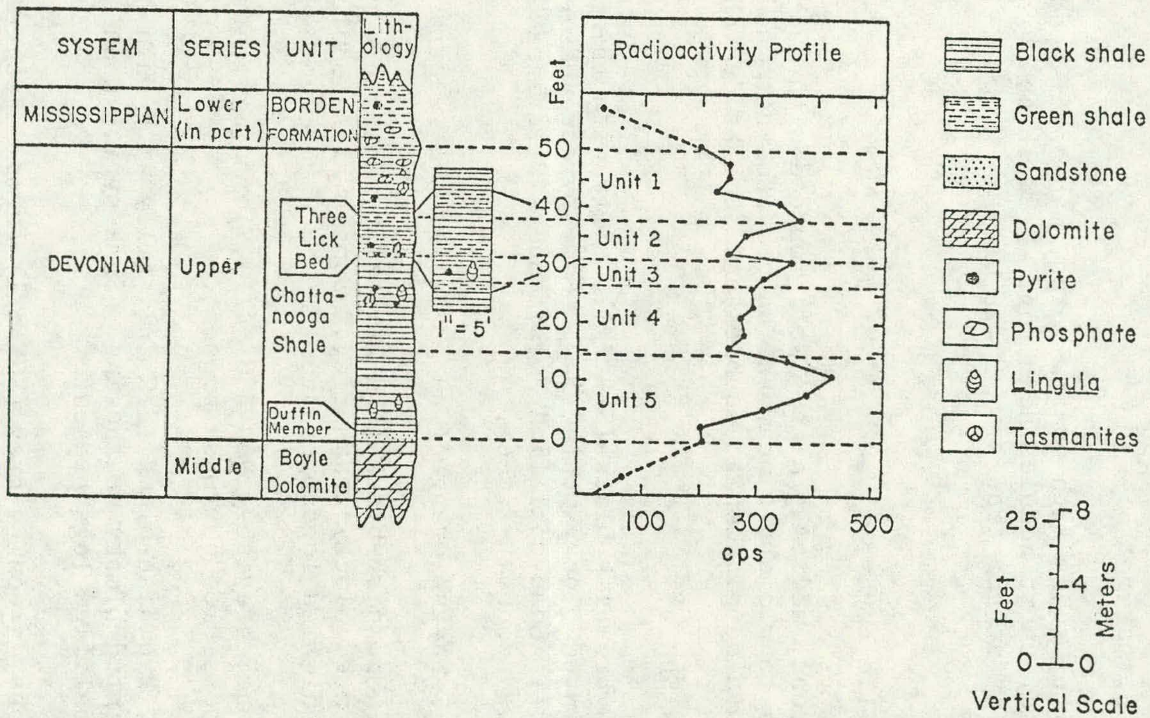
PU #1 Section

This section contains a complete thickness of the Chattanooga Shale and partial sections of the Boyle Dolomite and the Borden Formation. The section is located 4.2 miles west of West Sumerset along Ringgold Road in Pulaski County, Kentucky. The section is represented on the Delmer Quadrangle, section 19-H-58; its base at 2850' FSL x 2400' FEL and its top is 3000' FSL x 2450' FWL. Measured, described and sampled using jacob's staff, abney level and tape, and radioactivity measured with a scintillometer by Dennis Swager and John Goble on July 12, 1977.

		Thickness (feet)
Devonian:		
	Boyle Dolomite:	
(1)	Dolomite, olive-gray (5Y 4/1) containing nodular, bedded chert, pyrite and silicified brachiopods, bryozoans and crinoids. Has vugular porosity filled with dolomite and calcite crystals. Unit forms a massive sharp cliff. Stylolites along some bedding planes.	7.6
	Total Boyle in this section	7.6+
	Chattanooga Shale:	
(2)	Sandstone, "Duffin layer", olive-black (5Y 2/1), medium grained well rounded sandstone. Contains phosphatic pebbles, pyrite nodules and chert pebbles. A possible basal "lag zone" containing fish plates and plant debris. Unit forms reentrant.	1.0
(3)	Shale, brownish-black (5YR 2/1), laminated with silt layers at the base, but becomes clayey towards the top. Very fissile. <u>Tasmanites</u> abundant, <u>Lingula</u> fragments found. Pyrite nodules causing iron staining. Unit forms large cliff with "couplet-type" weathering.	31.7
	Three Lick Bed:	
(4)	Shale, brownish-black (5YR 4/1) interbedded with 3 small mudstones, greenish-gray (5GY 4/1). Mudstones vary from 0.1 to 0.25 feet thick, containing <u>Lingula</u> and pyrite. Black Shales contain <u>Tasmanites</u> and are burrowed at the top. All contacts are sharp. Unit forms slight reentrant, and had to be trenched.	2.7
	Total Three Lick Bed	2.7

Devonian (continued):	Thickness (feet)
Chattanooga Shale (continued):
(5) Shale, brownish-black (5YR 2/1), laminated and becomes silty towards the top of unit. Has subconchoidal fracture with phosphate nodules in the upper 8 feet. Pyrite nodules common and Tasmanites. The unit forms large jointed ledges with apparent "couplet-type" weathering dominant in upper section. The top of section is covered with soil, but the contact with the Borden had to be trenched.	13.7
Total Chattanooga Shale	49.1
Mississippian (incomplete):
Borden Formation (incomplete):
Nancy Shale Member (incomplete):
(6) Shale, light greenish-gray (5Y 4/1), silty in nature with reworked phosphate pebbles near base. Dissiminated pyrite throughout. Crinoidal debris. Glauconitic. contains geodes filled with quartz and hematite. Unit forms a cliff-like outcrop with talus covered slopes.	18+
Approximate thickness of section	74.7+

PU #1 Section



SYSTEM
SERIES
UNIT
Lith-ology
MISSISSIPPIAN
Lower (In part)
BORDEN FORMATION
DEVONIAN
Upper
Three Lick Bed
Chatta-nooga Shale
Duffin Member
Middle
Boyle Dolomite
1" = 5'
Feet
50
40
30
20
10
0
Radioactivity Profile
Unit 1
Unit 2
Unit 3
Unit 4
Unit 5
100
300
500
cps
Black shale
Green shale
Sandstone
Dolomite
Pyrite
Phosphate
Lingula
Tasmanites
25
8
4
0
0
Feet
Meters
Vertical Scale

RU #1 Section

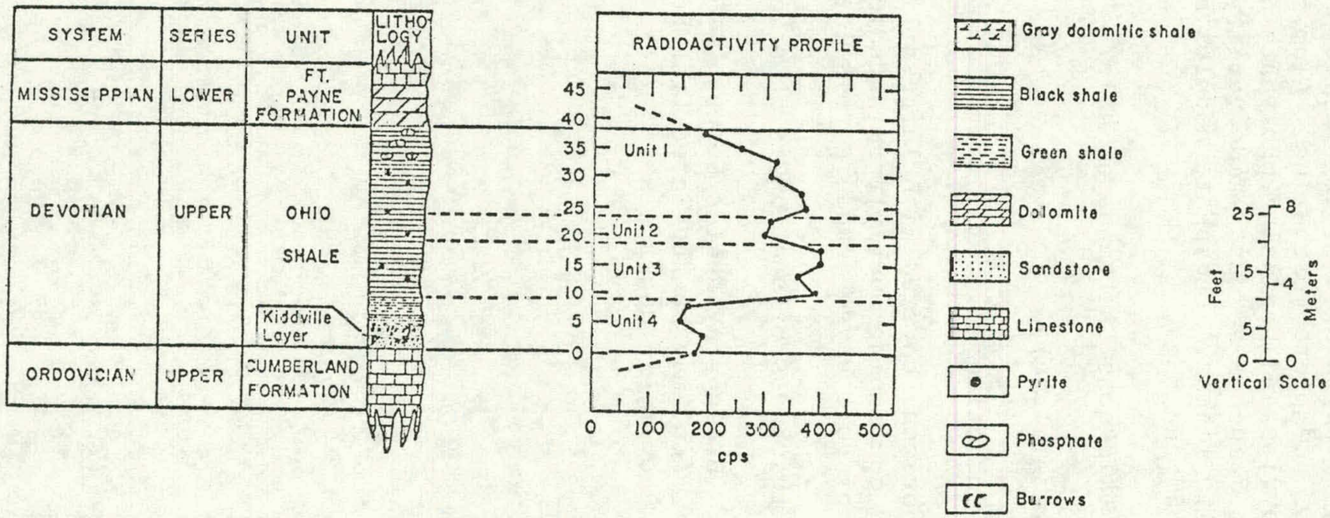
This section contains the complete Kiddville Layer and Chattanooga Shale. The section is on the south side of the road, 2.2 miles west of Creelsboro in Russell County, Kentucky, on Highway 379. The section is located on the Creelsboro Quadrangle, Section 15-E-52, 1900' FNL x 2225' FEL. Described and measured by Dennis Swager and John Goble using hand level, tape, and scintillometer on July 5, 1977.

		Thickness (feet)
Ordovician (incomplete):		
	Cumberland Formation:	
(1)	Dolomite, sandy with quartz veins, many semi-bedded globular chert nodules near top. Reddish and greenish clay at the top.	4
Devonian:		
	Kiddville Layer:	
(2)	Sandstone, medium grained, well rounded with quartz pebble conglomerate near the base. Phosphate nodules, iron stain, glauconite pebbles and semi-bedded chert.	.5
	Chattanooga Shale:	
(3)	Shale, brownish-black (5YR 2/1), silty with thin platy to jointed blocky weathering. Some pyrite nodules present. Some coalified logs found. Pyritized burrowed zone at 2 feet.	5
(4)	Shale, grayish-orange ( ), forms a reentrant.	.5
(5)	Shale, brownish-black (5YR 2/1) silty with thin platy to jointed blocky weathering. Some pyrite nodules and coalified logs present.	1.1
(6)	Mudstone, grayish-green (5GY 4/1), forms a reentrant with possible "burrows" present.	.3
(7)	Shale, brownish-black (5YR 2/1) silty with thin platy to jointed blocky weathering. Some pyrite nodules and coalified logs present.	.2
(8)	Mudstone, greenish-gray (5GY 4/1) forms a reentrant.	.4
(9)	Shale, brownish-black (5YR 2/1) silty, thin platy to jointed blocky weathering. Some pyrite nodules and coalified logs. Some burrows present.	1.3
(10)	Shale, brownish-black (5YR 2/1) with large joints and block outcrop. Some silty layers. Alum salts and pyrite layers present.	18.7

Devonian (continuted):		Thickness (feet)
	Chattanooga Shale (continued):	
(11)	Shale, brownish black (5YR 2/1) large joints and blocks. Complete weathering. Alum salts present. Less pyrite and beginning phosphate nodules from 0.5 to 7 inches across. Wide variety of forms from ovoid to linear. Phosphate nodules are very abund-and near the top.	12
	Total thickness Chattanooga Shale	38.5
Mississippian (incomplete);		
	Fort Payne Formation:	
(12)	Soil horizon, covered with large silica "geode-like forms" containing double terminated quartz crystals. Chips of Fort Payne found in this layer	5
	Total thickness of section is about	44.5

(Note: Green-gray shales between 5.5 feet and 7.5 feet may be the Three Lick Bed. This, however, is uncertain.)

RU #1 Section



SYSTEM
SERIES
UNIT
LITHOLOGY
MISSISSIPPIAN
LOWER
FT. PAYNE FORMATION
DEVONIAN
UPPER
OHIO SHALE
Kiddville Layer
ORDOVICIAN
UPPER
CUMBERLAND FORMATION
RADIOACTIVITY PROFILE
45
40
35
30
25
20
15
10
5
0
Unit 1
Unit 2
Unit 3
Unit 4
0 100 200 300 400 500
cps
Gray dolomitic shale
Black shale
Green shale
Dolomite
Sandstone
Limestone
Pyrite
Phosphate
Burrows
Feet
Meters
25
15
5
0
8
4
0
Vertical Scale

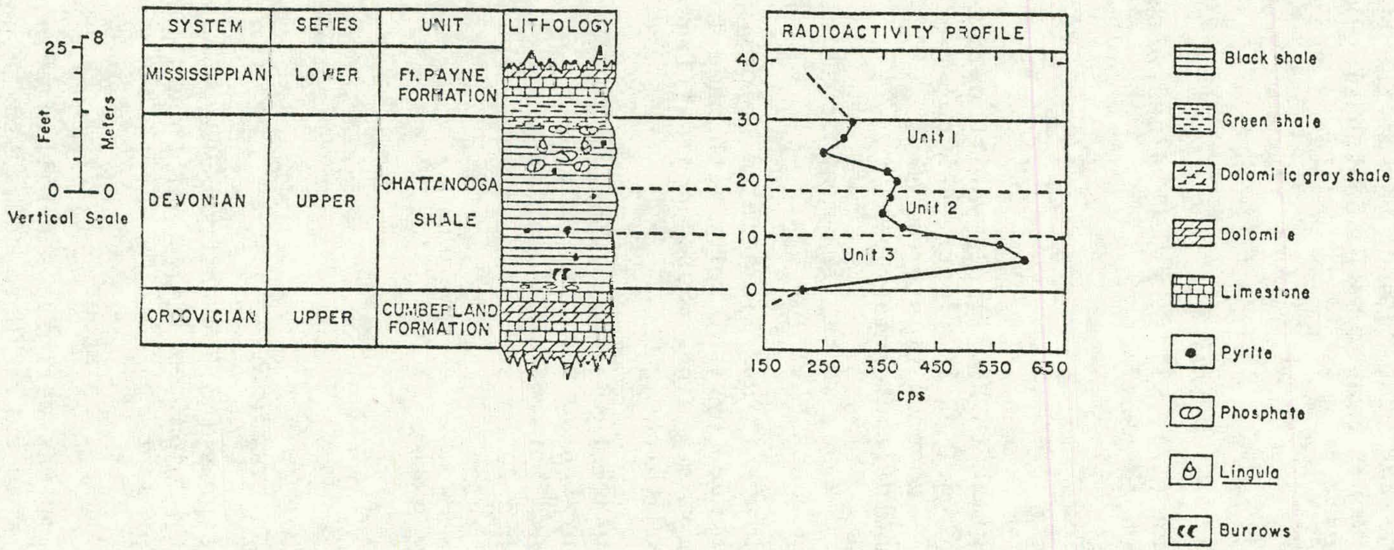
CU #1 Section

This section contains the complete Chattanooga Shale. The base is located 2.5 miles east of Burksville in Cumberland County, Kentucky on Highway 90. The section is on the north side of the road, on the third bench of the road cuts. Located in Section 21-D-50, 1250' FNL x 1400' FWL of the Burkesville Quadrangle. Described and measured by Dennis Swager, John Goble using hand level, tape, and scintillometer, July 5, 1977.

		Thickness (feet)
Ordovician (incomplete):		
	Cumberland Formation:	
(1)	Dolomite, buff-tan (N7), silty, fine grained with dendritic forms on the surface.	20±5
Devonian:		
	Chattanooga Shale:	
(2)	Shale, brownish-black (5YR 2/1) platy with pyrite, marcasite, coalified logs in float. 4-5 cm lag zone concentrat covered by a greenish-gray dolomitic mudstone at the contact.	1.9
(3)	Pyritized burrowed zone, woodly fragments coalified logs contained in black shale matrix.	.1
(4)	Shale, brownish-black (5YR 2/1), jointed, blocky weathering with bedded pyrite, silty with many logs, alum salts and iron staining. Subconchoidal fracture, pyrite beds 1-3 cm thick.	22.2
(5)	Shale, brownish-black (5YR 3/1), jointed, blocky weathering with pyrite nodules and phosphate nodules. No bedded pyrite. <u>Lingula</u> fragments found. Phosphate nodules are circular to amebo-form, 2-5 inches across.	4.3
	Total Chattanooga Shale	28.5
Mississippian (incomplete):		
	Fort Payne Formation:	
(6)	Mudstone, greenish-gray (5GY 4/1).	.2
(7)	Shale, dark olive-gray (N3) brachiopod and crinoid debris overlain by dolomites filled with quartz geodes. Pyrite present.	32.3±5.0
	Total thickness of section about	60

(Note: The section was well exposed within an almost vertical road cut. There seemed to be no trace of any unit which resembled the Three Lick Bed.)

CU #1 Section



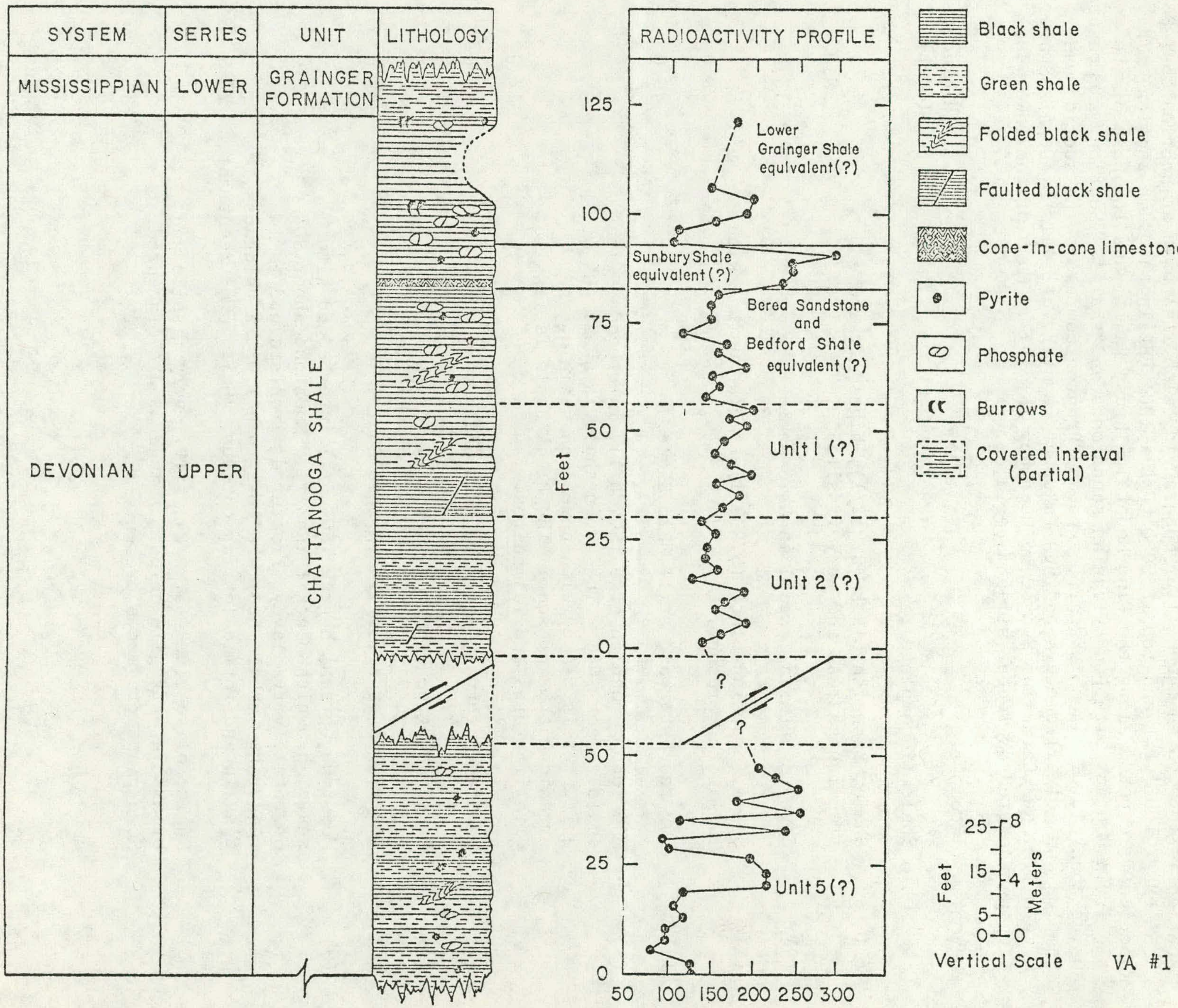
25
8
Feet
Meters
0
0
Vertical Scale
SYSTEM
SERIES
UNIT
LITHOLOGY
MISSISSIPPIAN
LOWER
Ft. PAYNE FORMATION
DEVONIAN
UPPER
CHATTANOOGA SHALE
ORDOVICIAN
UPPER
CUMBERLAND FORMATION
RADIOACTIVITY PROFILE
40
30
20
10
0
Unit 1
Unit 2
Unit 3
150
250
350
450
550
650
cps
Black shale
Green shale
Dolomitic gray shale
Dolomite
Limestone
Pyrite
Phosphate
Lingula
Burrows

VA #1 and VA #2 Sections

These sections contain exposures of the Chattanooga Shale and the Grainger Formation. The base of the roadcut is located on the east side of Highway 23E about 1 miles south of the Kentucky-Virginia line in Cumberland Gap, Lee County, Virginia. The section is located at 16-B071, 400' FSL x 1500' FWL on the Middlesboro Quadrangle. The section was meausred using abney level, jacob's staff, tape and brunton compass. Section was measured, sampled and scintillometer readings taken by Dennis Swager and Mike Miller on December 17, 1977. The single exposure is broken down into two separate sections because there is a fault of unknown displacement or relative motion located about 50 feet from the base of section VA #1.

		Thickness (feet)
Devonian (incomplete):		
Chattanooga Shale (incomplete):		
(1)	Shale, brownish-black (5YR 2/1) and mudstone, greenish-gray (5GY 6/1). 80% mudstone with small pyrite nodules present. Shale is silty with fractures and slickensides present. Iron staining present, outcrop forms a gradual talus covered slope which had to be trenched. Unit has apparent dip of 17^{o} from horizontal.	17.0
(2)	Shale, brownish-black (5YR 2/1), shale is silty, fissile and platy. Some crenulated beds with slickensides present. Bedding levels out to an apparent dip of 8^{o} from the horizontal.	3.5
(3)	Shale and mudstone interbedded as in unit 1. Mudstone about 80% of total. Bedding now has apparent dip of 5^{o}-6^{o} from horizontal.	8.5
(4)	Shale and mudstone interbedded as in unit 3, but mudstone makes up about 60% of total. Black shale beds vary from 0.9' to 3.5' thick. Dip of beds same as in unit 3.	16.0
(5)	Shale, brownish-black (5YR 2/1) same as in unit 2, but the shale is much more fissile and breaks into fragile plates. Only lower section of this unit is exposed. The remainder is covered and faulting suspected in this section of unknown displacement.	15.0+
	Approximate thickness of Chattanooga Shale in VA #1 Section.	60.0+
(6)	Claystone, greenish-gray (5GY 4/1), fractured and iron-stained with some pyrite present. Small fractures present in unit. Bedding has apparent dip of 10^{o} from horizontal. Unit forms small reentrant and had to be trenched.	2.2

	Devonian (continued):	Thickness (feet)
	Chattanooga Shale (continued):	
(7)	Shale, brownish-black (5YR 2/1), very fissile; unit is faulted and fractured, and contains slickensides. Small fault with 2.5' of offset recorded. Unit forms a blocky jointed outcrop.	3.4
(8)	Claystone, greenish-gray (5GY 4/1). Same as unit 6.	1.3
(9)	Shale, brownish-black (5YR 2/1) as in unit 7, interbedded with three mudstones, greenish-gray (5GY 4/1) as in units 6 and 8. The black shale beds are about 5 feet thick and the mudstones are about 1.5' thick. Unit forms cliff with small reentrants.	19.4
(10)	Shale, brownish-black (5YR 2/1) unit is partially covered, but forms a blocky jointed outcrop. Shale is very fissile, and breaks into fragile plates. Some small fractures and faults present.	24.3
(11)	Shale, brownish-black (5YR 2/1), very fissile and platy. Some small pyrite nodules present. Egg-shaped phosphate nodules present and increase in abundence towards top of unit. Some horizontal burrows present forming mottled appearance. Iron staining present. Folds, distorted bedding, fracutres, small faults and slickensides present. Slight petroliferous odor. Cone-in-cone limestone bed at 35 feet from base. Forms a blocky jointed cliff-type outcrop. Apparent dip of bedding is 11^{o}-16^{o} from horizontal.	54.4
(12)	Covered interval still in Chattanooga Shale	15.0
(13)	Shale, brownish-black (5YR 2/1), same as unit 11, but without the pyrite nodules.	2.4
	Total thickness of Chattanooga Shale in Section VA #2.	122.4
	Mississippian (incomplete):	
	Grainger Formation (incomplete):	
(14)	Shale, greenish-gray (5YR 2/1) and dark greenish-gray (5YR 4/2) with siderite nodules present.	
	Approximate thickness of Grainger Formation.	50+
	Approximate thickness of VA # 2 Section	172.4+
	Approximate thickness of Total Exposure	232.4+



VA #1 & #2 Sections

PK #1 Section

This section contains incomplete exposures of the Ohio Shale and Berea Sandstone along the access road to the Johnsohn Brother's Limestone Quarry, off Highway 197, 5.3 miles south of Elkhorn City, Pike County, Kentucky. The section is located on the Hellier Quadrangle, with its' base at section 25-T-86, 875' FNL x 1000' FEL and top at 2000' FNL x 100' FEL in the same section. The section is exposed along the Pine Mountain Thrust Fault, and the base of the sectio is in contact with Pennsylvanian sandstones and shales. Section was measured using abney level, jacob's staff, tape and Brunton compass. The section was sampled and scintillometer readings taken at regular intervals by Dennis Swager, Mike Miller and Catherine Swager on December 18, 1977. Much of the lower section was covered by recent slide material.

		Thickness (feet)
Devonian (incomplete):		
Ohio Shale (incomplete):		
(1)	Shale, brownish-black (5YR 2/1), highly fractured irch inorganics, and very fissile	5.0
(2)	Covered Interval, still in Ohio Shale.	15.0
(3)	Shale, brownish-black (5YR 2/1) same as unit 1 with *Tasmanites* present.	25.0
(4)	Covered Interval, still Ohio Shale.	45.0
(5)	Mudstone, greenish-gray (5GY 6/1), interbedded with shale, black (N1). The green shale is about 60% of unit. It is clayey with some iron staining and organic matter present. The Black Shale is fissile with fractures and *Tasmanites*.	12.0
(6)	Covered Interval, still in Ohio Shale.	35.0
(7)	Mudstone, greenish-gray (5GY 6/1), as in unit 5.	7.0
(8)	Covered Interval, still in Ohio Shale.	392.0
(9)	Mudstone, greenish-gray (5GY 5/1) interbedded with shale, brownish-black (5YR 3/1). Mudstone about 80% of total, very clayey, fractured, iron-stained, forms reentrant. Shale beds are less than 1.0' in thickness, fissile and form a jutting outcrop. Unit forms reentrant.	22.5
(10)	Shale, olive-black (5Y 2/2), silty, very fissile and breaks into fragile chips. Some beds are fractured. Some plant fragments present.	32

Devonian (continued): Thickness (feet)

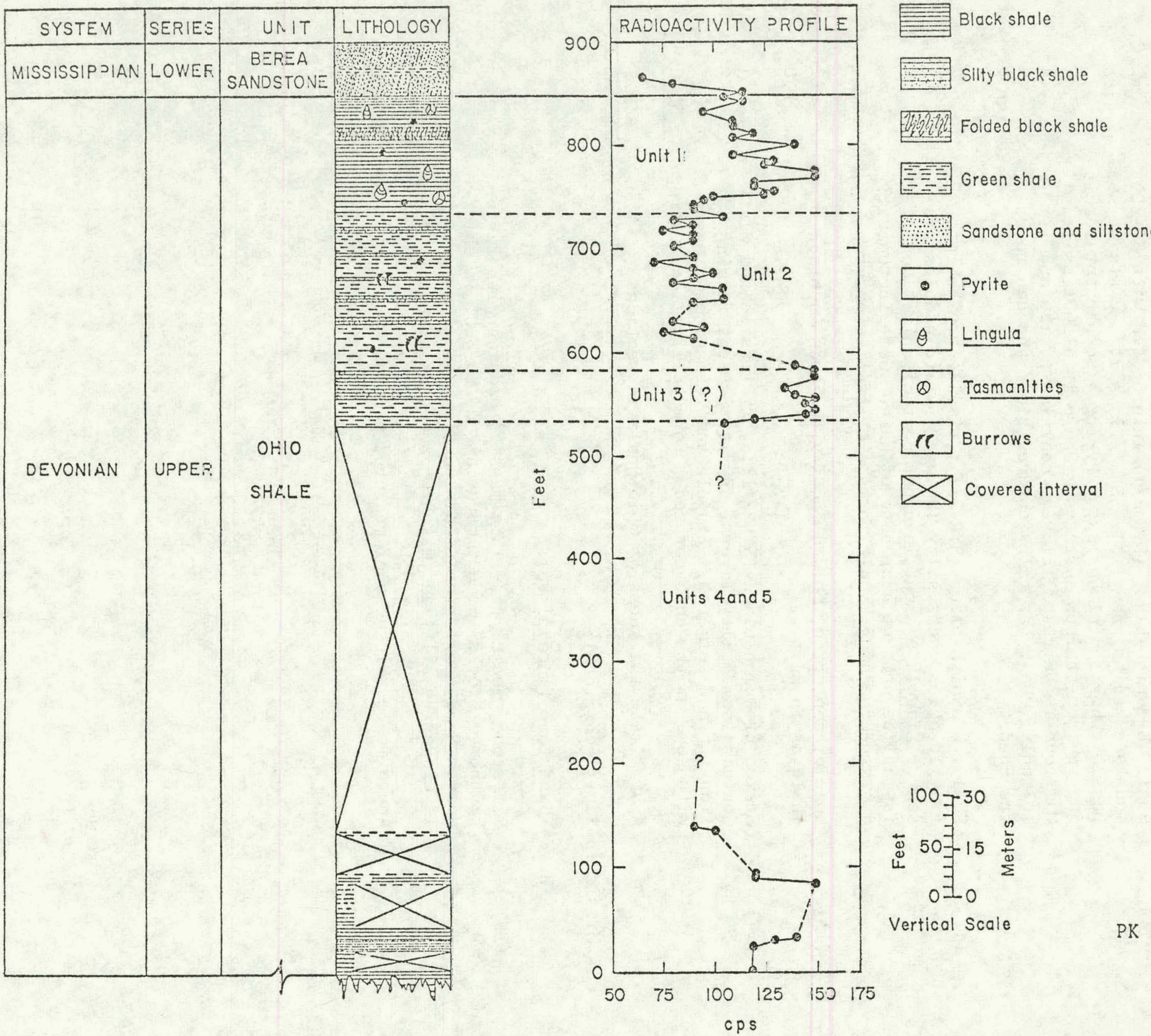
Ohio Shale (continued):

(11)	Shale, brownish-black (5YR 2/1) interbedded with 50-60% mudstone medium gray (N5). Shale is silty, contains some possible horizontal burrows. Pyrite also present resulting in iron-stained surfaces. Shale is also fissile. Mudstone is burrowed, clayey, contains pyrite and is moldable. Unit has talus covered slope and had to be trenched.	150
(12)	Shale, brownish-black (5YR 2/1), fissile-breaks into fragile chips, some silty laminae, pyrite nodules present. Lingula present in upper part of unit. Some Tasmanites present near base of unit. Some tectonically disturbed bedding. Unit forms a cliff-like outcrop.	67
(13)	Zone of contorted, folded and faulted beds in black shale as in unit 12.	7.0
(14)	Shale, brownish-black (5YR 2/1), very fissile and platy Contains some silty layers. Pyrite present forming iron-stained surfaces. Lingula and Tasmanites present with some of the unit covered. Forms cliff-like outcrop.	35.0
	Approximate thickness of Ohio Shale in section.	849.5

Mississippian (incomplete):

Berea Sandstone (incomplete):

(15)	Siltstone, medium gray (N3) massive bedding with large weathered blocks formed. Beds are up to 3.0' in thickness. Some small green shale partings in siltstone. Shale is clayey to silty and makes up about 5% of total volume.	25+
	Approximate thickness of measured section.	874.5+


SYSTEM
SERIES
UNIT
LITHOLOGY
MISSISSIPPIAN
LOWER
BEREA SANDSTONE
DEVONIAN
UPPER
OHIO SHALE
RADIOACTIVITY PROFILE
Unit 1
Unit 2
Unit 3 (?)
Units 4 and 5
?
Feet
900
800
700
600
500
400
300
200
100
0
50
75
100
125
150
175
cps
Black shale
Silty black shale
Folded black shale
Green shale
Sandstone and siltstone
Pyrite
Lingula
Tasmanites
Burrows
Covered interval
100
50
0
30
15
0
Feet
Meters
Vertical Scale

PK #1 Section

Geochemical Studies

1.0 Executive Summary--

The past quarter has seen the completion of development of all the routine analytic procedures including those for sample preparation. The developmental work was carried out on a set of samples collected around the Cincinnati Arch. Final conclusions as to chemical variance and expectations as to the usefulness of various chemical parameters were presented by Blackburn, Dennen and Davis at the Gas Shales Symposium in Morgantown.

Completed also was the development of techniques for mineralogical analysis of the Devonian shale. The report of these techniques, developed by Scott Huang, are presented in this document. Mr. Huang along with Mr. Robert Wook are continuing the mineralogical determinations on the Perry Co., Martin Co. and Pine Mountain cores. This work is including detailed mineralogic studies on the measured section studied in detail by the Stratigraphy Group and described elsewhere in this report.

Chemical determinations on these sections are well underway and the raw uranium and thorium determinations are presented as an appendix to this section of the report. Determinations of all chemical parometers deemed to be either of stratigraphic or economic significance will be complete for these sections by the end of February at which time they will be delivered *in toto*.

Sample preparation for x-ray spectrometry of the various cores available to this group is underway and the determination of uranium, thorium and potassium in these samples should be complete by the end of March. At that time, the data will be reported along with an analysis in light of the gamma-ray well logs and scintillation surveys.

2.0 Introduction--

The semi-quantitative analysis of various clay mineral contents in black shales is necessarily based upon the intensity of diffraction peaks of those minerals. The x-ray diffraction intensity of clay mineral is affected greatly by the homogenity of sample, by the amount of clay content, by temperature and by the particle size.

Sample preparation technique is considered in this report with regard to disintegration of the consolidated Devonian Black Shale. The purpose of this research work is to find out the easiest and the best disintegration method which can produce the best resolution for clay minerals in the shale sample.

2.1 Materials Used:

Three API standard clay samples were used in this study:

1) Montmorillonite, H-26, Clay Spur, Wyoming;
2) Kaolinite, H-4, Macon, Georgia;
3) Illite, H-35, Fithian, Illinois.

2.2 Disintegration Technique

Since grain size is a factor of x-ray diffraction intensity, all the clay samples should be prepared to include material of less than two microns. The common methods for pulverizing rocks which have systematically been studied include:

1) Na_2CO_3 Solution Method

Place 2 mg of clay standard into a 250 ml beaker and fill the sample with 25 ml 1N Na_2CO_3 and make the final volume up to 100 ml with D-H_2O. Gently swirl the beaker occasionally. The method takes about 10 days to disaggregate the sample. This method will be the standard in this research work and the data derived from it will also be compared with the other data of different methods.

2) Dry Grinding Method (DG)

Place 2 gm of sample in a small agate mortar and gently grind the sample for 2, 5, 10 and 20 minutes respectively.

3) Wet Grinding Method (WG)

Procedures are same as the dry grinding method, but a few drops of methanol alcohol were added to wet the sample thoroughly. Do not allow the sample become dry while grinding. Allow the alcohol to evaporate before storing the sample.

4) Ceramic Ball Mill Method (DBMC)

The Spex Industries MIXER/MILL (#8000), a high speed impact shaker, is capable of pulverizing 10-25 ml in a single load. The Ceramic Vial (#8003) is made of 96% alumina-ceramic with a capacity of 15 ml. It is designed for grinding hard materials. One ceramic ball, made of 99% alumina-ceramic with dia. ½" and weight 4.1232 gm, was used during pulverizing.

A 2 gm sample was pulverized for 5, 10, 20 and 30 minutes respectively.

5) Lucite Ball Mill Method (DBML)

Procedures are same as ceramic ball mill method. A lucite Grinding Vial (#8006) is used instead of ceramic vial. Lucite vial with grinding capacity about 20 ml is used for grinding brittle materials. Ona dia. 0.35" lucite ball (weight 0.47719 gm) has been used.

6) Steel Grinding Vial (WBMS)

Place 2 mg of sample in a stell grinding vial (#8001; 2" dia. x $2\frac{7}{8}$" long with O-ring sealed lid, 25 ml grinding capacity). Fill the vial with 20 ml methanol alcohol. Shake the vial for 5, 10, 20 and 30 minutes with one steel ball (¼" dia. and wt. 1.0205 gm). After shaking, transfer the suspension through 50 micron sieve into a beaker. If particles are larger than 50 micron, the method is repeated until the whole sample passes -60 mesh. Let all particles deposit and discard the clear supernatant liquid. Wash the sediment with D-water to prevent floculation.

7) Prop-type Ultrasonic Method (USP)

2 gm of clay sample are put into a 250 ml beaker. Fill the beaker with 25 ml 1N Na_2CO_3 and make the final volume up to 100 ml with D-H_2O.

A prop-type sonic instrument (Branson SONIC Power #S-75) was used to disperse clay sample for 5, 10, 20 and 30 minutes.

8) Tank Shape Ultrasonic Method (UST)

Procedures are same as USP method. Sonblaster (#200) tank shape sonic instrument was used.

9) <u>Method used by J. J. Renton at Univ. W. Va. (JJR)</u>

2 gm of sample is placed in the Spex steel grinding vial. Add 20 ml methanol alcohol into the vial and 300 1/8" steel balls. Grind the sample for 15 minutes then transfer the solution into a 250 ml bottle for future particle separation.

3.0 Particle Separation -- Pipette Method--

The sand fractions (larger than 50 micron) are removed from the suspension of dispersed clay sample by wet sieving. After the sands are separated from silt and clay, they are transfered to a 50 ml beaker and dried in an oven.

The suspension of silt and clay is next separated at the 2 micron limit. To do this, the suspension is stirred and then allowed to stand quietly for at least seven (7) hours for each 10 cm (4 inches) of depth at $25^{\circ}C$. It takes one to two weeks to separate all the particles less than 2 micron. The clay suspension is then transfered into a 250 ml bottle. The density of this suspension is determined by pipetting 5 ml into a pre-weighed 50 ml beaker and drying in an oven. After the clay fractions are separated, the suspension of silt is again separated at the 20 micron limit. The silt suspension is stirred and allowed to stand quietly for at least 4 minutes 40 seconds for each 10 cm of depth.

4.0 Preparation of Clay Specimens--

Transfer exactly 240 mg of clay size sample into a plastic centrifuge tube and fill about 2/3 full with 1N $MgCl_2$ solution. After shaking, the sample is centrifuged for 10 minutes at 1500 rpm. Let the centrifuge stop without using brake and discard clear supernatant solution. After the 5th Mg-saturation, the sample is washed with D-water until a negative test for chloride is obtained by using 1% $AgNO_3$ as the indicator. Shake the clay sample with 10 ml of 20% glycerol. Transfer suspension onto a ceramic tile and allow the suspending water to be sucked through the ceramic tile with a filtration rate of 5 ml of a 4% clay suspension in about 1 minute. According to the study of Gibbs, there is little or no segregation with the suction method. The chance for each mineral to deposit at the surface will be the same. Remove the tile from holder and air dry at least one day.

5.0 The Determination Of The Optimum Amount Of Clay Needed For x-Ray Diffraction Analysis--

From the basic equation reported by Cullity (1967), the following equation can be derived:

$$d\ (mg/cm^2) = \frac{-500\left(\ln\ (1-Gx)\right) \sin\ (2\theta/2)}{u^*}$$

where: d is the concentration of clay on a tile;
Gx is the amount of observed diffraction;
u* is the mass absorption coefficient.

The amount of sample required for getting 99.9% observed diffraction is listed in Table 1. Comparing the amount of sample required for 99.9% of Gx and the amount used in this work (240mg), the maximum amount of diffraction for all these three clay minerals should be attained.

Table 1

Amount of sample for 99.9% of Gx

Sample	u* for $Cu_{k\alpha}$	2θ(001)	amount of sample(mg/tile)
Mont.	42	4.7	57
Kaolinite	30	12.4	209
Illite	55	8.7	80

* The surface area of ceramic tile is 16.8 cm^2.

6.0 Measurement of Peak Intensity--

The area under the (001) peak is the desired intensity measurement. However, it is very difficult to calculate. The product of peak height times the peak width at half-height is used as the peak intensity. All lengths were measured in inches (accurate to 1/64 inch). Because of low angle diffraction, the background has different level on either side of a peak. The peak height is measured as the distance of peak top to a line connecting both background valleys. The peak width at half-height is measured along a line which is parallel to the line connecting the peak valleys. This measurement gives the best fit data to known materials. The total counts of the 001 reflection peak were also recorded for comparing the accuracy of peak area measurement.

Every sample was scanned forward and backward with a low scan rate (8 minutes per degree 2θ), a long time constant (10 seconds) and chart speed of 15 (2 inches per degree 2θ).

All samples of the same clay mineral were run at the same scale: 5k counts per second for montmorillonite; 1k counts per second for kaolinite and 500 counts per second for Illite.

7.0 Data and Results--

Raw data is given in tabular form as Tables 2, 3 and 4, As mentioned earlier, the "Na_2CO_3 method" is the standard in this research work. All the other values were compared with it taking the peak intensities of standard method as 1.00.

The reduced data is also presented as maps of relative peak intensity (peak area ratio) vs processing time of each method.

Three sets of data derived from dry grinding techniques are shown in Fig. 1. The intensity of montmorillonite increases at the 5-minute processing time and then decreases but almost maintained a constant intensity about 1.15. All the intensities obtained, however, have values which are higher than 1.00. This might be caused by breaking the wavy montmorillonite into finer particles and enhancing the intensity. The actual reason is not yet known. Evaluation of the actual sample by SEM might give some ideas, and this will be done in the near future. For kaolinite, the result is more or less the same as predicted. Reduction of intensity after a 5-minute processing time might be due to the creation of amorphous materials. There is no change for illite. The intensity was maintained at about 0.4 all the way.

Fig. 2 shows the variation of peak intensity after wet grinding processing. The relative intensities of kaolinite are rather high and are almost the same after a 5-minute treatment. The result is different from the DG method. Comparing the data of montmorillonite and illite in Fig. 1 and Fig. 2, the only difference is at the 30-minute processing time for montmorillonite and for a 10-minute for illite. It is obviously due to the effect of methanol alcohol.

Similar trends for montmorillonite and kaolinite under DBMC method (Fig. 3) may be observed. The intensities decrease with time. Instead of maintaining constant intensity as with the above methods, illite, however, shows an increasing trend and approaches the 1.25 line. This is most unexplainable at this time.

In Fig. 4, the relative intensity of kaolinite at 10-minute is the highest value observed. This sample is to be evaluated by SEM. There is no difference in the method except the weight of the ball. The ceramic ball is about 9 times the weight of lucite ball meaning that the impact force is 9 times different. The montmorillonite and illite, however, did not show any large change. Montmorillonite still has a decreasing trend and illite shows the same sig-zag pattern.

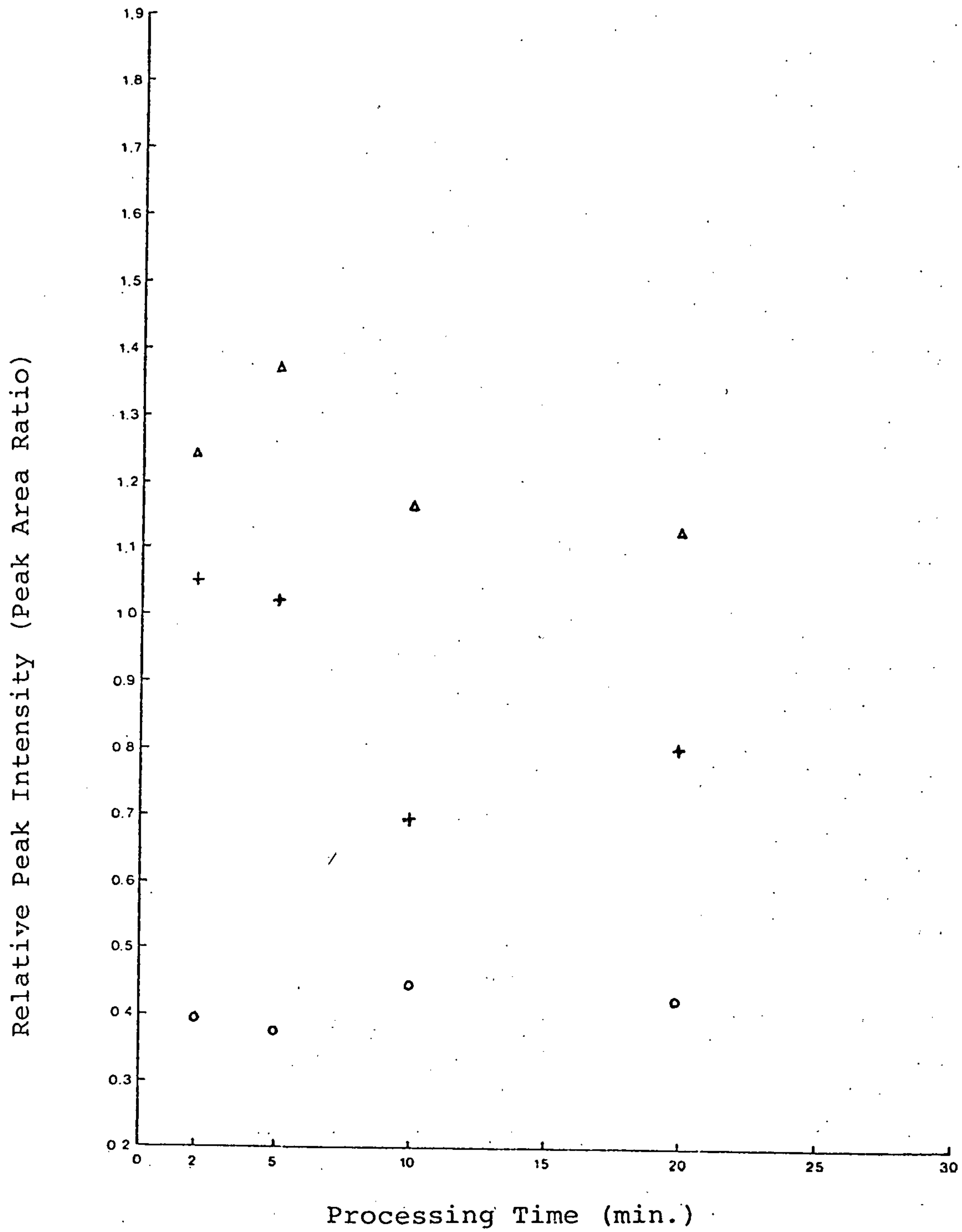


Figure 1.- Variation in peak intensity of three API standard clays with a dry grinding technique. (Δ: mont.; +: kaol.; o: illite)

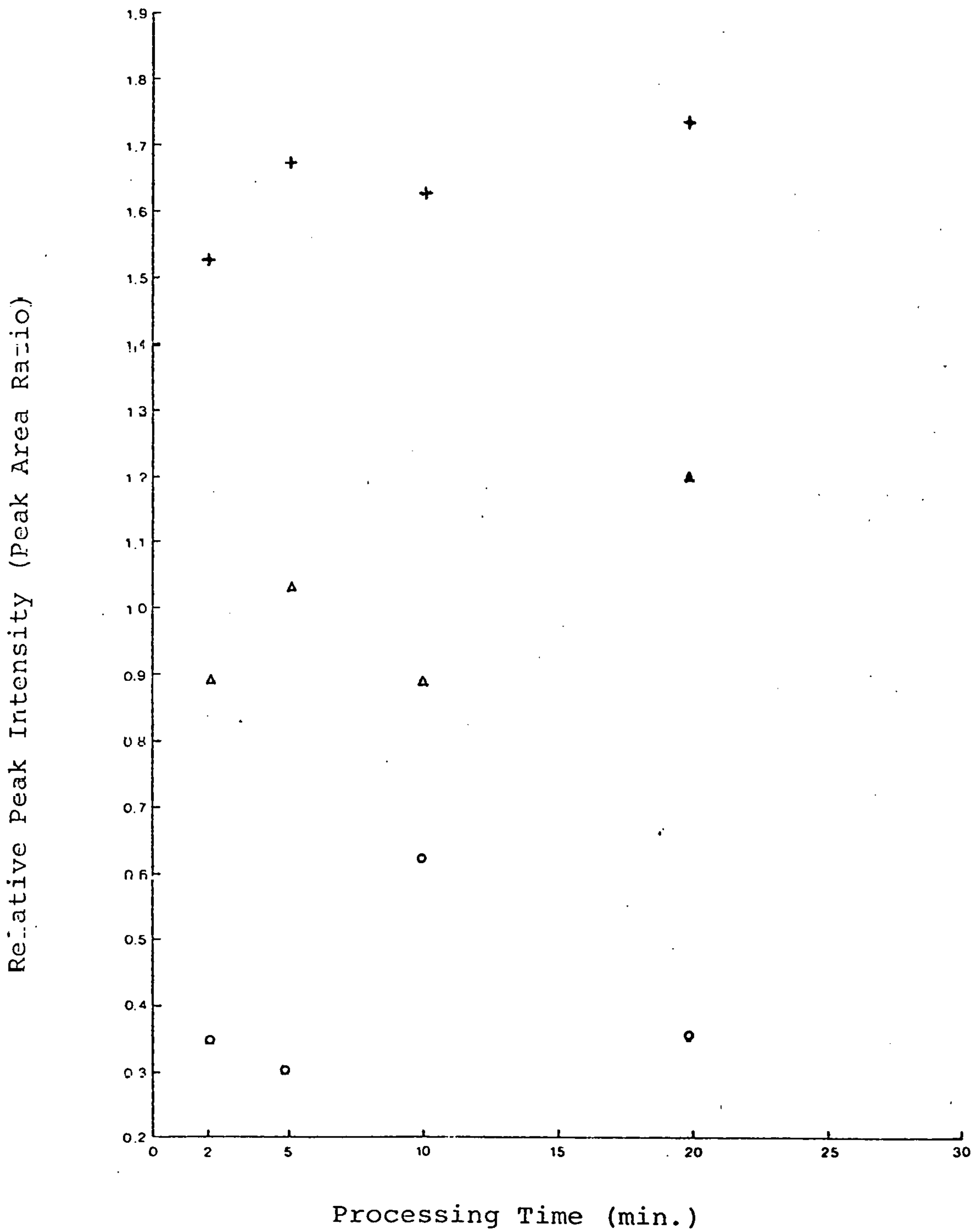


Figure 2.- Variation in peak intensity of three API standard clays with a wet grinding technique. (Δ: mont.; +: kaol.; o: illite)

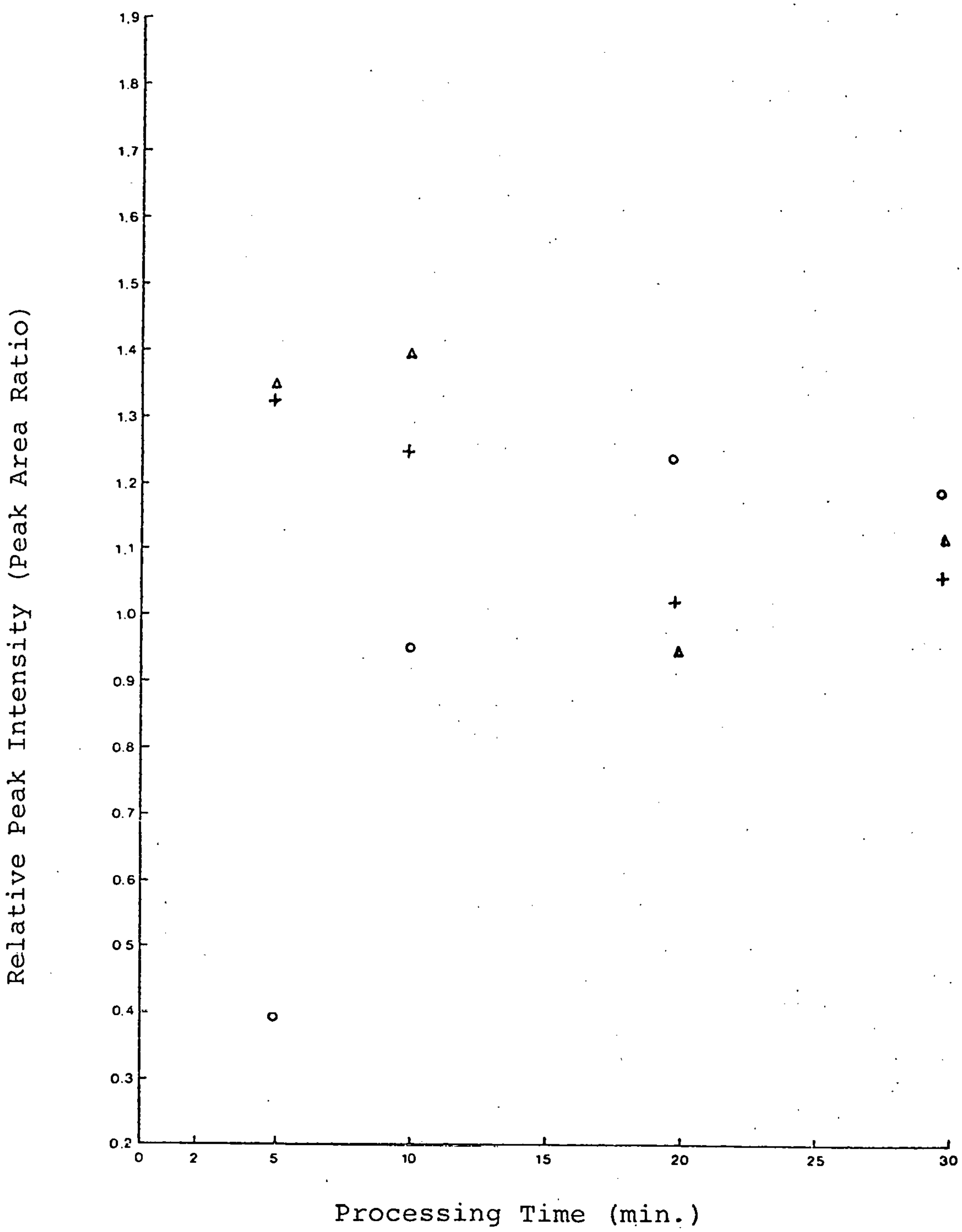


Figure 3.- Variation in peak intensity of three API standard clays with a ceramic ball mill technique (Δ: mont.; +: kaol.; o: illite)

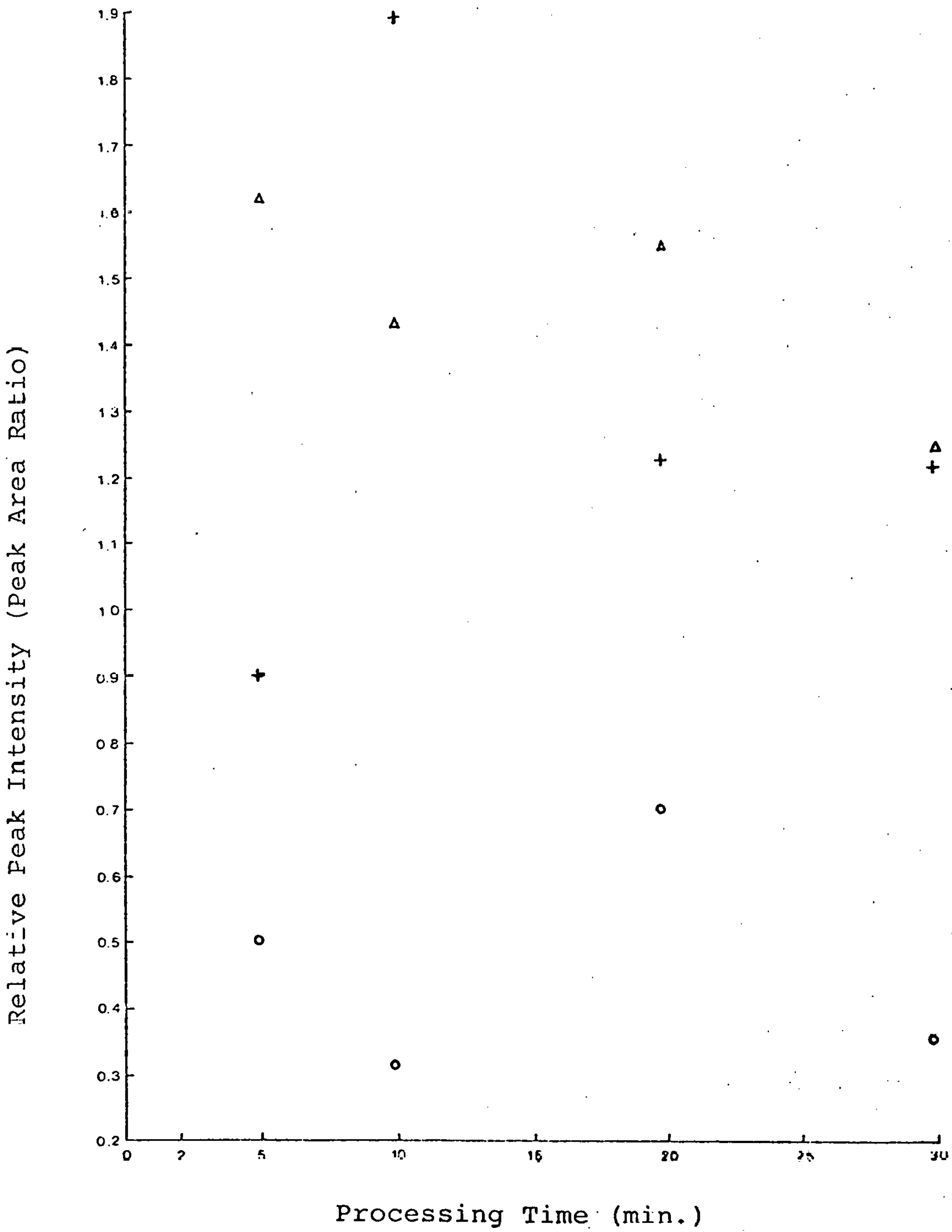


Figure 4.- Variation in peak intensity of three API standard clays with a lucite ball mill technique. (Δ: mont.; +: kail.; o: illite)

Kaolinite under the wet-impact method (WBMS) has same increase-rate of intensity as wet-grinding method (Fig. 5). It seems, however, that the wet impact method has less enhancing effect. The wet impact method has the more desirable result for both kaolinite and montmorillonite. Both data almost coincide except at 5-minute processing time. It is the only method to produce a decreasing result of illite.

Fig. 6 and 7 show the results of ultrasonic methods. Ultrasonic frequency may break clay particles along cleavage. Thus, the peak intensities are higher than the other pulverizing methods. The tank-shape sonic instrument affords even better results, especially for the 10-minute treatment. This method (UST-10) is strongly recommended as both the data for montmorillonite and kaolinite have same relative intensity ratio and illite has intensity about 0.8. This latter value is extraordinarily high. The advantages of this method include: easy calculation of the relative amounts of clay contents in black shale, higher resolution of diffraction pattern, and saving of sample preparation time.

The method proposed by J. J. Ranton whows all three relative intensities have less than 1.00 value. The values are shown in Table 2, 3 and 4.

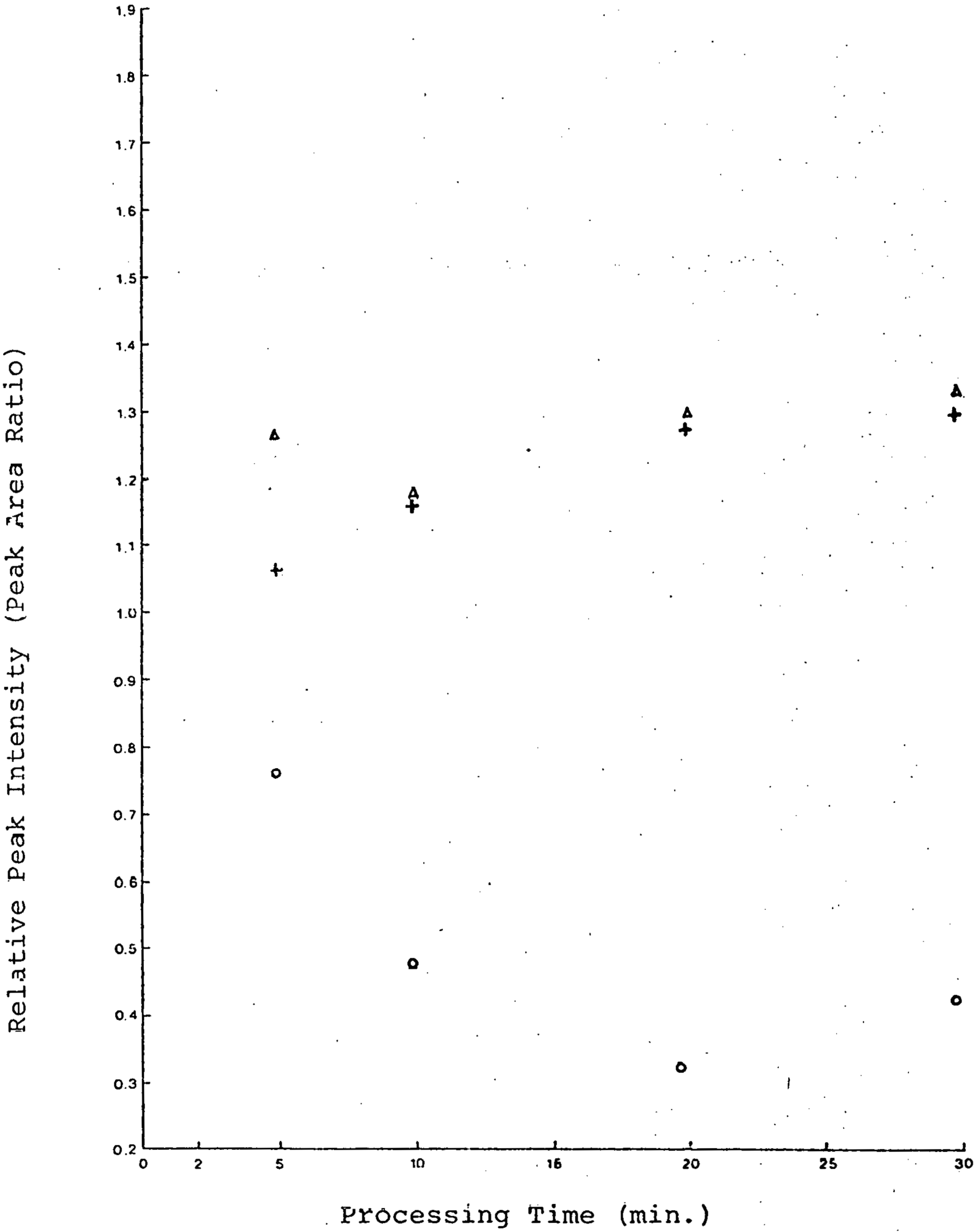


Figure 5.- Variation in peak intensity of three API standard clays with a steel ball mill technique. (Δ: mont.; +: kaol.; o: illite)

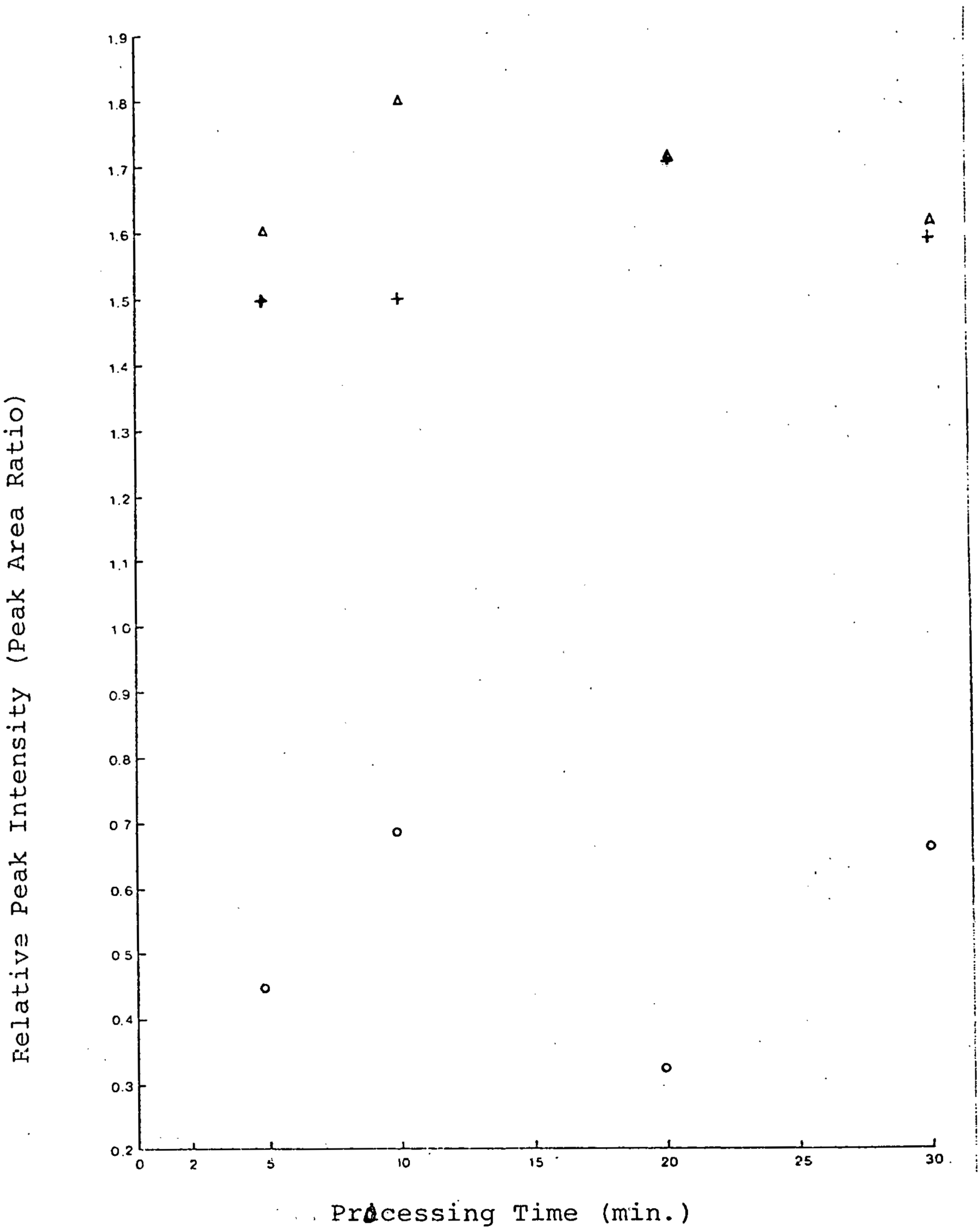


Figure 6.- Variation in peak intensity of three API standard clays with a prop-type ultrasonic technique. (Δ: mont.; +: kaol.; o: illite)

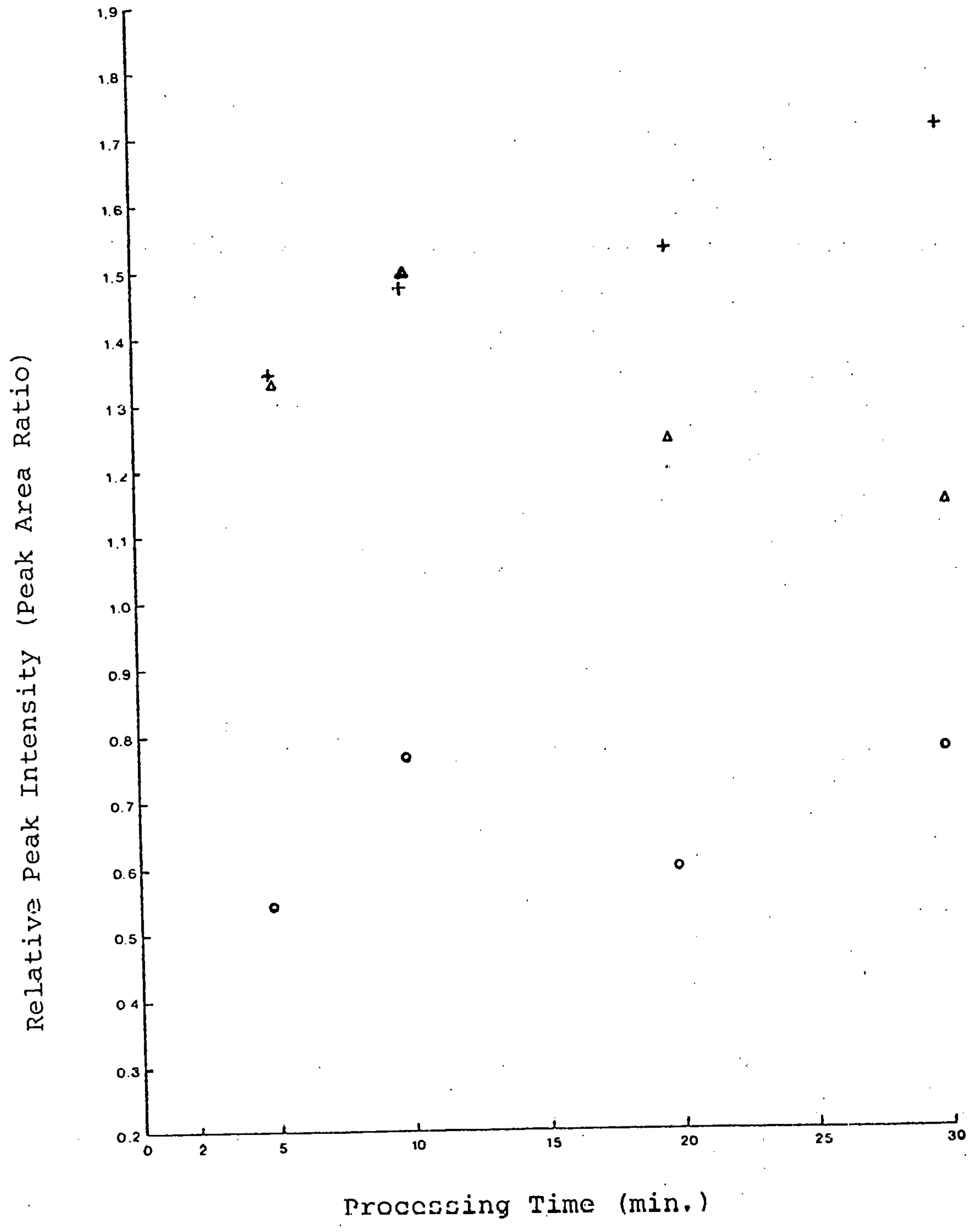


Figure 7.- Variation in peak intensity of three API standard clays with a tank-shape ultrasonic technique. (Δ: mont.; +: kaol.; o: illite)

Table 2

Montmorillonite Data

Sample	Peak Height (x1"/64)	Peak Width (x1"/64)	Peak Area x(1"/64)^2	Peak Area Ratio	Total Counts	Total Count Ratio
Na_2CO_3	401	49	19625	1.00	37017	1.00
DG-2	502	48.5	24347	1.24	47473	1.28
DG-5	534	50.5	26967	1.37	51595	1.39
DG-10	456	50	22775	1.16	42540	1.15
DG-20	466	47.5	22135	1.13	43032	1.16
WG-2	352	50	17600	0.90	34419	0.93
WG-5	421.5	48	20232	1.03	40104	1.08
WG-10	350	50	17500	0.89	33503	0.91
WG-20	466.5	50.5	23558	1.20	44877	1.21
DBMC-5	502	53	26606	1.36	50683	1.37
DBMC-10	524	52	27248	1.39	53258	1.44
DBMC-20	249	74	18426	0.94	31974	0.86
DMBC-30	264	83.5	22002	1.12	34317	0.93
DMBL-5	626	51	31926	1.63	60827	1.64
DMBL-10	552.5	51	28177	1.44	52893	1.43
DBML-20	636	48	30528	1.56	58856	1.59
DBML-30	518	47.5	24605	1.25	47953	1.30
WBMS-5	553	45	24885	1.27	48738	1.32
WBMS-10	514.5	45.5	23410	1.19	45961	1.24
WBMS-20	528	48.5	25608	1.30	51195	1.38
WBMS-30	524	50	26200	1.34	50091	1.35
JJR	421	44.5	18735	0.95	37951	1.03
USP-5	614.5	51.5	31647	1.61	60492	1.63
USP-10	723	49	35427	1.81	68860	1.86
USP-20	633	53	33549	1.71	62789	1.70
USP-30	583	54.5	31774	1.62	61053	1.65
UST-5	508	51.5	26162	1.33	50326	1.36
UST-10	602	49	29498	1.50	56240	1.52
UST-20	508	48	24384	1.24	47238	1.28
UST-30	472	48	22656	1.15	43880	1.19

Table 3

Kaolinite Data

Sample	Peak Height (x1"/64)	Peak Width (x1"/64)	Peak Area x(1"/64)^2	Peak Area Ratio	Total Counts	Total Count Ratio
Na_2CO_3	367	34	12461	1.00	9142	1.00
DG-2	386	34	13124	1.05	9843	1.08
DG-5	366.5	34.5	12645	1.01	9430	1.03
DG-10	244	35.5	8643	0.70	6378	0.70
DG-20	269	37	9939	0.80	7051	0.77
WG-2	529	36	19044	1.53	14412	1.58
WG-5	559	37.5	20963	1.68	15328	1.68
WG-10	566.5	36	20394	1.64	15142	1.66
WG-20	611.5	34.5	21097	1.69	16286	1.78
DBMC-5	470	35.5	16685	1.34	12502	1.38
DBMC-10	404	38.5	15554	1.25	11591	1.27
DBMC-20	323.5	39.5	12778	1.03	9514	1.04
DBMC-30	335.5	39.5	13252	1.06	10354	1.13
DBML-5	312	36	11232	0.90	8444	0.92
DBML-10	687	34.5	23702	1.90	18085	1.98
DBML-20	437	35	15295	1.23	11664	1.28
DBML-30	437.5	35	15210	1.22	11616	1.27
WBMS-5	418	32	13376	1.07	10713	1.17
WBMS-10	406	36	14598	1.17	11041	1.21
WBMS-20	455.5	35	15943	1.28	12229	1.34
WBMS-30	458	35.5	16241	1.30	12287	1.34
JJR	304	36.5	11096	0.89	8554	0.94
USP-5	551	34	18734	1.50	14618	1.60
USP-10	536	35	18760	1.51	14099	1.54
USP-20	627	34	21318	1.71	16402	1.79
USP-30	579.5	34.5	19993	1.60	14958	1.64
UST-5	482	35	16870	1.35	12699	1.39
UST-10	527	35	18445	1.48	13858	1.52
UST-20	529.5	36	19062	1.53	14234	1.56
UST-30	605.5	34.5	20390	1.68	16052	1.76

Table 4

Illite Data

Sample	Peak Height (x1"/64)	Peak Width (x1"/64)	Peak Area x(1"/64)^2	Peak Area Ratio	Total Counts	Total Count Ratio
Na_2CO_3	74	110	8140	1.00	2842	1.00
DG-2	45.5	69.5	3162	0.39	1213	0.43
DG-5	47	56.5	3050	0.37	1286	0.45
DG-10	34	106	3604	0.44	1480	0.52
DG-20	48	71	3408	0.42	1745	0.61
WG-2	27	104	2808	0.35	1043	0.37
WG-5	31.5	79	2489	0.31	1065	0.37
WG-10	45.5	111.5	5073	0.62	1484	0.52
WG-20	34	84	2856	0.35	1173	0.41
DBMC-5	42	75	3150	0.39	1315	0.46
DBMC-10	73	106.5	7775	0.96	2806	0.99
DBMC-20	90.5	112	10136	1.25	3342	1.18
DBMC-30	99	98	9702	1.19	3405	1.20
DBML-5	44.5	91	4049	0.50	1463	0.51
DBML-10	35.5	72	2556	0.31	1092	0.38
DBML-20	66	86	5676	0.70	2160	0.76
DBML-30	34	83	2822	0.35	934	0.33
WBMS-5	60	103	6180	0.76	2174	0.76
WBMS-10	42	90.5	3801	0.47	1161	0.41
WBMS-20	30.5	85	2593	0.32	1013	0.36
WBMS-30	35	96.5	3378	0.42	1137	0.40
JJR	42.5	101.5	4314	0.53	1505	0.53
USP-5	45.5	81	3686	0.45	1548	0.54
USP-10	46	121.5	5589	0.69	1668	0.59
USP-20	37	71	2627	0.32	1381	0.49
USP-30	59.5	91.5	5444	0.67	1925	0.68
UST-5	49	90	4410	0.54	1711	0.60
UST-10	61.5	102	6273	0.77	2269	0.80
UST-20	52.5	93	4883	0.60	1649	0.58
UST-30	59	106	6254	0.77	2215	0.78

Appendix

Uranium, Thorium and Potassium Values for Measured Sections in Kentucky. (See Fig.)

SECTION PU

Height in meters from base of section	ppm U	ppm Th	% K
Top	46.2	13.1	3.02
13.7	33.1	15.1	3.14
12.2	57.2	14.6	3.07
9.1	66.3	19.8	3.17
6.1	35.0	18.7	3.69
1.5	44.0	14.4	3.10
0	53.6	18.6	3.48

SECTION CL

45.1	26.7	10.2	2.82
43.6	29.1	9.9	2.64
42.1	12.6	7.1	2.95
40.5	32.5	10.6	3.16
39.0	29.8	14.4	3.00
37.5	29.6	12.0	3.29
36.9	13.6	12.4	4.27
33.7	17.1	11.7	4.32
32.9	11.0	12.4	4.20
32.8	32.5	9.5	3.58
31.2	25.9	12.1	3.61
30.5	25.2	11.7	3.80
28.9	19.2	9.9	2.53
24.4	25.3	10.1	3.17
22.9	21.6	8.7	3.05
21.3	8.0	8.5	2.31
19.8	33.4	10.7	3.27
16.8	15.9	8.8	3.24
15.2	36.2	11.3	3.56
13.7	46.2	4.6	3.54
12.2	60.4	9.7	2.82
10.8	56.3	11.6	3.25

SECTION RU

10.7	40.1	7.9	3.60
7.6	44.4	8.8	3.07
3.0	58.9	5.1	2.76
1.5	14.9	8.0	2.73

SECTION FL

Height in meters from base of section	ppm U	ppm Th	% K
Top	3.3	11.0	3.98
54.9	57.7	10.0	2.93
44.9	3.7	13.4	3.91
44.2	14.6	16.5	3.30
38.1	30.4	10.4	3.13
36.6	13.9	27.6	2.82
35.1	12.2	16.9	3.60
33.5	18.4	8.5	2.14
32.0	24.3	15.6	4.21
28.9	19.5	12.2	4.01
27.4	15.3	11.8	3.51
24.4	15.7	11.2	3.36
22.9	14.2	9.2	4.29
16.8	22.1	11.7	3.27
6.1	19.5	12.2	4.01
4.6	13.5	8.3	3.21
0	6.5	12.6	4.11

SECTION BR

13.8	15.8	5.8	4.47
13.7	40.4	15.9	3.85
13.4	44.4	13.9	3.57
13.3	22.4	5.9	4.55
13.0	24.4	14.7	4.79
12.4	37.8	12.3	3.91
12.2	39.8	12.2	4.05
7.6	25.3	5.3	3.19
6.1	39.1	4.7	3.63
3.0	12.5	5.2	3.71
1.5	21.0	0.5	2.78

SECTION LE

27.4	19.0	7.4	2.89
25.3	13.9	9.2	2.57
22.9	9.7	8.3	2.78
21.3	29.7	8.8	3.49
18.3	24.3	7.9	3.52
16.8	21.1	9.3	3.53
15.2	32.8	6.9	3.22
13.7	31.2	6.3	2.68
12.2	51.7	8.7	2.75
7.6	25.1	10.5	3.35

SECTION CU

Height in meters from base of section	ppm U	ppm Th	% K
7.6	28.2	7.4	3.26
6.1	104.4	11.4	4.04
4.6	116.1	13.5	4.43
1.5	60.6	8.7	3.42
0.9	11.3	10.4	4.77

SECTION CA

Height in meters from base of section	ppm U	ppm Th	% K
11.7	31.9	9.5	3.67
10.7	25.4	9.2	3.42
9.1	63.4	10.6	3.42
7.6	58.3	9.4	3.90
6.1	39.2	8.7	3.75
4.6	38.1	7.0	3.18
3.0	34.1	6.5	2.63
1.5	45.2	7.3	3.72

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