Appendix 3-A. Utica and equivalent outcrop descriptions by state

Kentucky field trip guide book

Geology and Stratigraphy of Utica Formation Equivalent Strata in Northeastern Kentucky

Utica Shale Consortium Field Trip

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Introduction

This one-day field excursion was designed to provide a visual outcrop reference for lithologic units examined, and analyzed, by participants of the Utica Shale Consortium. The field guide developed for this trip borrows extensively from a 1999 field trip guidebook by Algeo and Brett (2001). These authors provide a very detailed subdivision of the Kope Formation (Utica-equivalent, in part) exposed in the Cincinnati, Ohio area, and discuss this at length in a contributed article to the 1999 field trip guidebook (Brett and Algeo, 2001). The table below from the 1999 guidebook provides a brief reference for nomenclature used by these authors.

FAIRVIEW FORMATION

Fairmount Member (Upper Fairview)

Mt. Hope Member (Lower Fairview

1) Wesselman sub-member
    a) "A. Miller shell bed"
2) North Bend sub-member
    a) *Strophomena beds*

KOPE FORMATION

McMicken Member

1) Taylor Mill sub-member
    a) upper Taylor Mill shale ("Two-Foot Shale")
    b) *Orniella* limestone ("Z bed")
    c) *Diplocraterion* beds ("Reidlin Road beds")
    d) Jenette's gutter cast bed
    e) "Y bed"
    f) "X bed"
    g) graded *Diplocraterion* beds ("W beds")
    h) basal Taylor Mill shale ("Big Shale #7")
2) Grand Avenue submember
    a) upper Grand Avenue beds
    b) lower Grand Avenue beds
    c) basal Grand Avenue shale ("Big Shale #6")

SOUTHGATE MEMBER

1) Grand View sub-member
    a) "I-471 beds"
    b) "Grandview big bed"
    c) basal Grandview shale ("Big Shale #5)
2) Alexandria sub-member
    a) "Alexandria Pike twin beds"
    b) "River Road triplet beds"
    c) "black *Orniella* beds"
    d) basal Alexandria shale ("Big Shale #4")
3) Snag Creek sub-member
    a) "Snag Creek twin beds"
    b) "Snag Creek triplet beds"
    c) lower Snag Creek shale ("Big Shale #3")
4) Pioneer Valley Sub-member ("*Sowerbyella* beds")
    a) "upper White Castle beds"
    b) "middle White castle beds"
    c) Nigel Hughes' "trilobite beds"
    d) "lower White Castle beds"
    e) Newport Plaza hiatus concretion bed
    f) lower limestone beds
    g) basal shale/calcisiltite beds ("Big Shale #2")

ECONOMY MEMBER

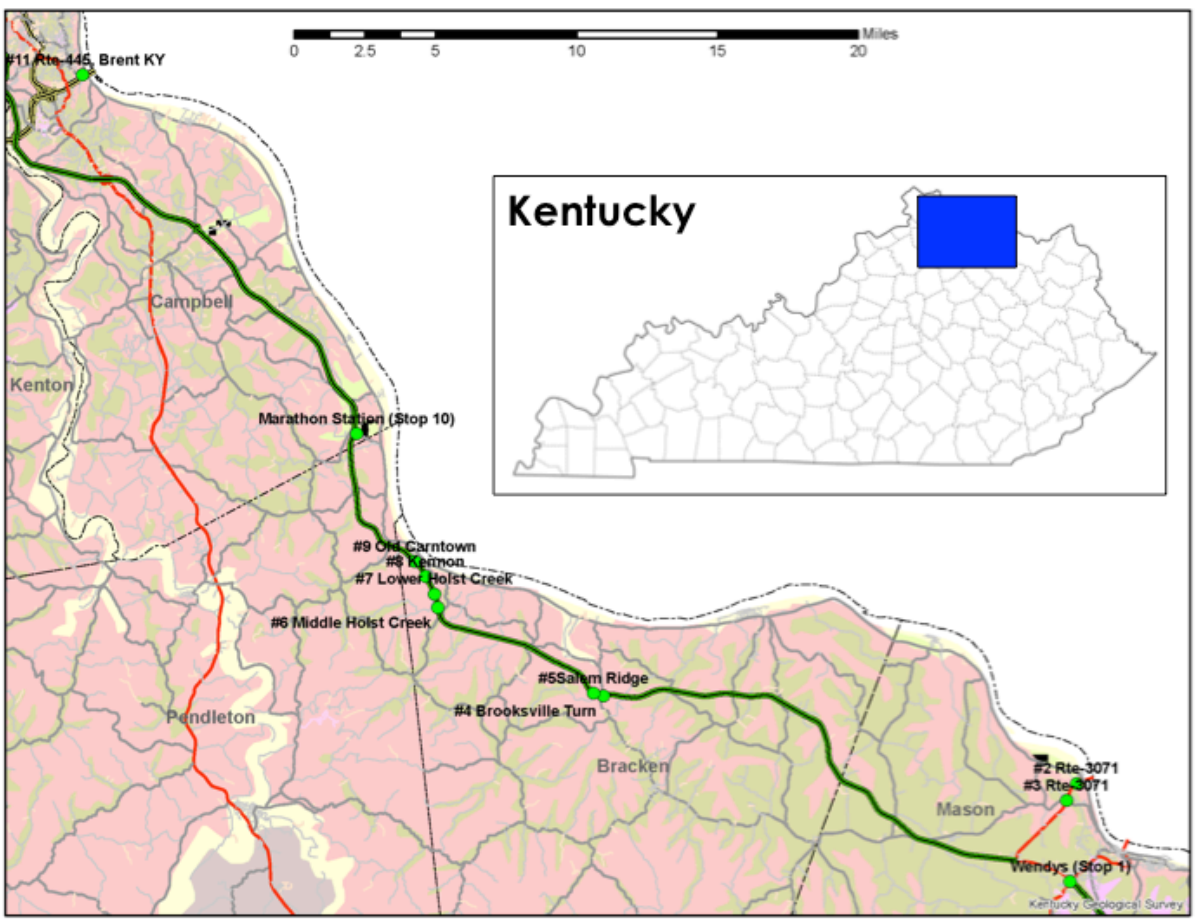
1) Brent Sub-member

a) “3rd Brent twins”
b) “2nd Brent twins”
c) “1st Brent twins”
d) lower Brent limestone
e) basal Brent shale (“Big Shale #1”)

2) Fulton Sub-member
   a) A through G limestone beds
   b) Lower *Triarthrus* shales
   c) *“Glyptocystites fultonensis”* beds

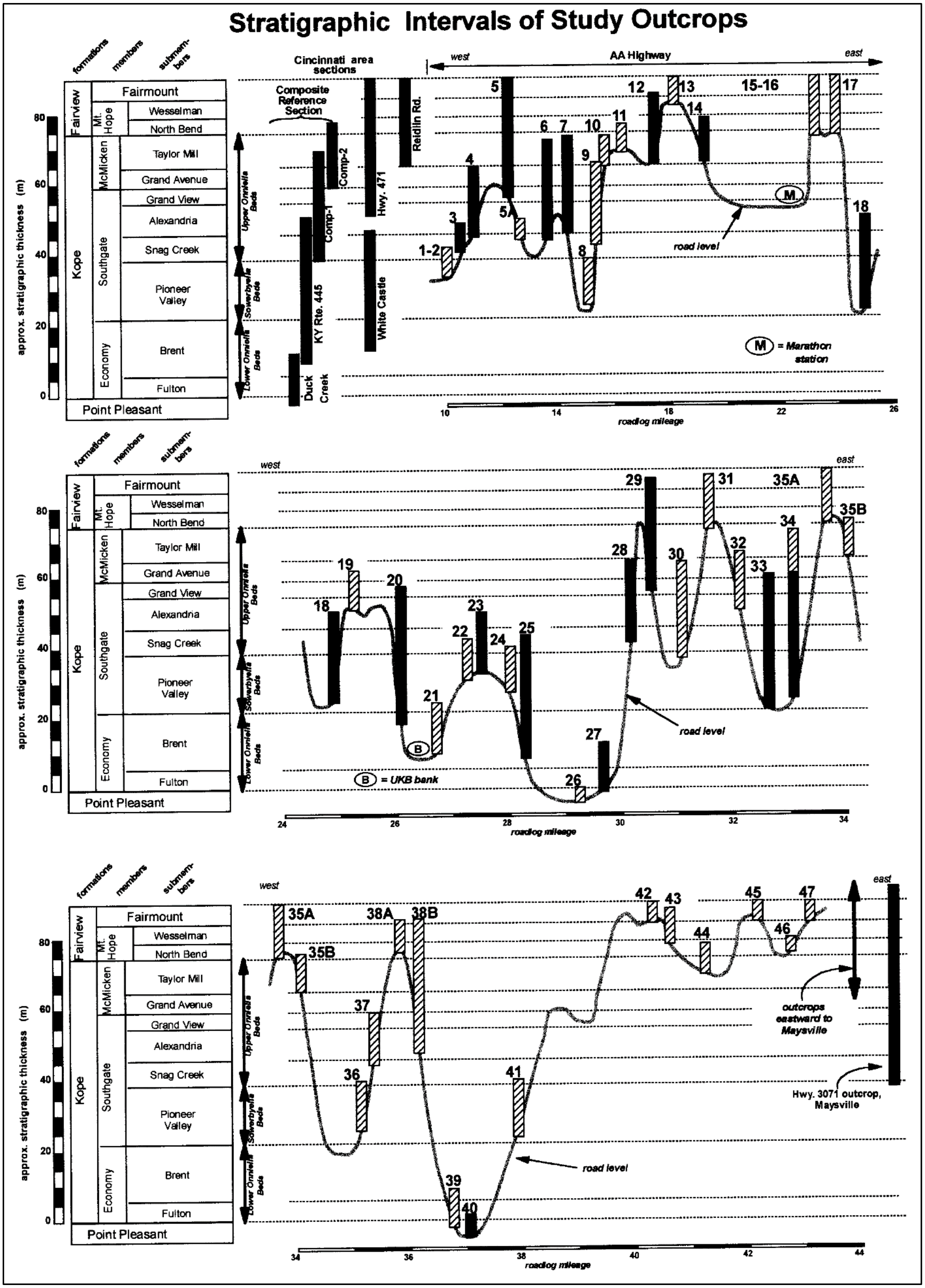
Itinerary

The trip will depart from, and return to, the Embassy Suites hotel on Newtown Pike in Lexington, Kentucky. The map below shows the location of the field trip area in NE Kentucky, and is accompanied by tables showing a list of field trip stops, with geographic coordinates, and equivalent stop numbers from the 1999 field trip guidebook by Algeo and Brett (2001). On the next page (p. 5), a series of road level diagrams illustrates the interval of strata exposed at the stops we will be making along the AA (Alexandria – Ashland) highway (Kentucky Route 9), and adjacent roadways.



Stop	Name	County	Road	Mile Pt	Lon	Lat
1	Wendys	Mason	US-62	14.3	-83.796596	38.631718
2	KY-3071 (lower)	Mason	US-68	17.8	-83.791169	38.682206
3	KY-3071 (upper)	Mason	US-68	17.1	-83.797974	38.673625
4	Brooksville Turn	Bracken	KY-1159	4.3	-84.100887	38.732078
5	Salem Ridge	Bracken	KY-9	10.6	-84.107093	38.733547
6	Middle Holst Creek	Bracken	KY-9	17.2	-84.208324	38.778947
7	Lower Holst Creek	Bracken	KY-9	17.8	-84.210478	38.785993
8	Kennon	Bracken	KY-9	18.4	-84.216207	38.795142
9	Old Carntown	Bracken	KY-9	19.1	-84.223029	38.802829
10	Marathon Station	Campbell	KY-2828	0.1	-84.260024	38.869243
11	KY-445, Brent, KY	Campbell	KY-445	0.1	-84.436593	39.056000

Stop	Original Field Guide Description
1	Bathroom Stop @ US-62/KY-9
2	10/9/99 Stop #4A: Middle Kope
3	10/9/99 Stop #4B: Upper Kope
4	10/9/99 Stop #3/Outcrop 40: Upper PTPL/lower Kope (Utica equiv), @KY-9 MP10.2
5	10/9/99 Outcrop 39: Rubbly exposure of upper PTPL/lower KOPE
6	10/9/99 Outcrop 28: Middle Kope
7	10/9/99 Stop #1/Outcrop 27: Kope-Pt Pleasant
8	10/9/99 Outcrop 26: PTPL-KOPE contact
9	10/9/99 Outcrop 25: Brent Submbr of Economy Mbr of Kope (upper Utica equiv)
10	Bathroom Stop, @ KY-9 MP 0.5
11	10/10/99 Stop #1: Middle Kope (via US-27, KY-1998, KY-8)



Stratigraphic Intervals of Study Outcrops
formations
members
submembers
Fairmount
Fairview
Mt. Hope
Wesselman
North Bend
McMicken
Taylor Mill
Grand Avenue
Grand View
Alexandria
Snag Creek
Southgate
Pioneer Valley
Kope
Economy
Brent
Fulton
Point Pleasant
approx. stratigraphic thickness (m)
Upper Onniella Beds
Sowerbyella Beds
Lower Onniella Beds
Cincinnati area sections
Composite Reference Section
Duck Creek
KY Rte. 445
Comp-1
Comp-2
Hwy. 471
White Castle
Reidlin Rd.
west
AA Highway
east
road level
M = Marathon station
B = UKB bank
roadlog mileage
outcrops eastward to Maysville
Hwy. 3071 outcrop, Maysville

STOP 1. Bathroom/rest stop at intersection of US-62 and KY-9 (AA Highway)

STOPS 2&3. Roadcuts on KY Route 3071, near Maysville, KY

These new roadcuts (late 1990s) provide an excellent reference section of the upper half of the Kope Formation, the overlying Fairview, and much of the Grant Lake Formation. Approximately 90 meters of section are exposed in this outcrop.

KY-3071 Loop (Total Mileage)	**Description**
0.0	Intersection of AA Highway and KY-3071
2.0	Small outcrop in shaly upper Fairview Formation
2.2-2.5	Large three-tiered outcrop in Fairview Formation; note following features:
2.33	Upper Fairview deformed zone; ball and pillow structure
2.38	Small thrust faults in Fairview appear to die out locally onto bedding planes
2.52	Channel-like feature appears at the same horizon as deformed beds
2.6	Road sign for KY-8
2.65	Bridge over large creek valley
2.85	Junction KY-3056 is at upper end of a huge new roadcut that extends from the middle Kope Formation at its base upward to the Bellevue and Corryville members of the Grant Lake Formation at its top
3.15	Bench on top of Grand Avenue submember of Kope Formation
3.2	Grand Avenue submember; at Dover sign
3.3	Big Shale #5 (base of Grand View submember) seen just above benches
3.6	Road sign for Maysville, KY-8 near base of section
3.8	Pull off on shoulder; disembark to examine middle Kope Formation beds

STOP 2. Lower Exposed Beds Along Route 3071 (Figs. 1 and 2)

Exposures at the lower end of this extended outcrop show the Snag Creek, Alexandria, and Grand View submembers of the middle Kope Formation (Southgate Member). Through these intermediate outcrops, beds of the Southgate Member exposed along Rte. 3071 can be correlated with equivalents in the Cincinnati area.

Near the base of the outcrop, the upper boundary of the *Sowerbyella*-rich zone occurs in a 40-cm-thick grainstone at the top of Pioneer Valley submember. This is followed by a 1.5-m-thick shale-rich interval, corresponding to Big Shale #3, of the Snag Creek submember. The bundle of limestones overlying this shale form the top of the Snag Creek submember, at about the level of the first bench. This is overlain by the thickest shale in the outcrop, Big Shale #4, at the base of the Alexandria submember. This shale is sharply overlain by the next cluster of limestones, which is rich in reddish *Onniella* grainstones and exhibits a characteristic spacing of layers that is traceable to the Cincinnati area; the top of this bundle occurs slightly above the second bench on the east side of the road. The next major shale interval (Big Shale #5) is generally obscured by talus; this forms the base of the Grand View submember, the top of which is identifiable as a "polka-dotted" bryozoan-rich limestone. Higher still, the closely packed thin limestones of the upper Grand Avenue submember form the top of the third bench on the east side.

Return to vehicles, turn around, and retrace route back south toward AA Highway.

3.8 First bench on west side of KY-3071 is on top of Alexandria beds (above Big Shale #4)

4.0 Second platform on top of Grand Avenue submember

4.3 Sign for KY-3066

4.35 Third bench is developed on the top of Grand Avenue submember

4.4 Junction of KY-3056; upper end of large outcrop; pull off and park just before intersection

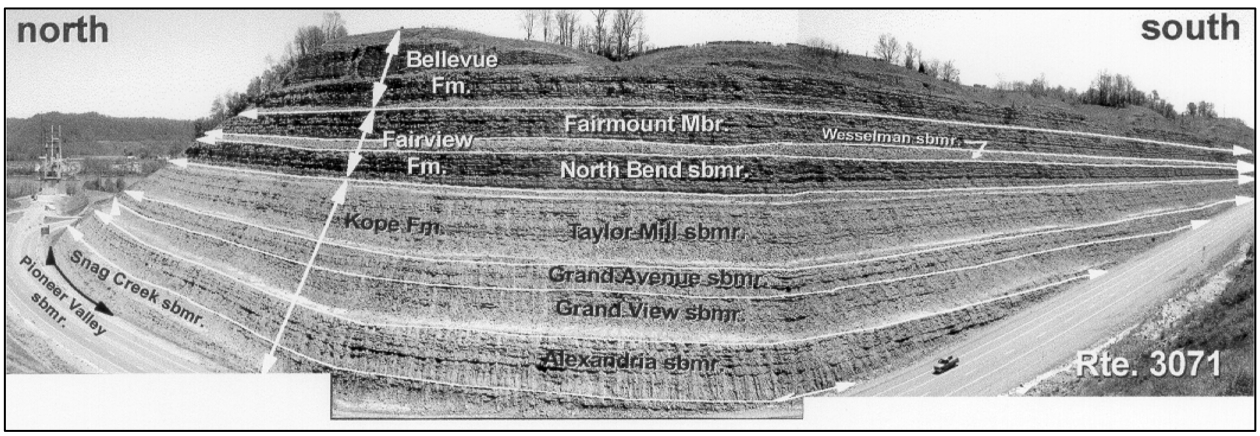


Figure 1. Route 3071 outcrop, Maysville, Kentucky (Algeo and Brett, 2001). The view of the section is at the northern end of highway, looking eastward. The lowest exposed beds, at road level on far left side of photo, are the upper Pioneer Valley beds. These are easily identified by the abundance of *Sowerbyella* contained therein. Overlying this is the full thickness of the Southgate and McMicken members of the Kope Formation, as well as the Fairview, Bellevue, and Grant Lake formations. The main seismite horizons are found in the upper Fairview Formation (Fairmount Member), but these are better seen on the west side of the highway than on the east side.

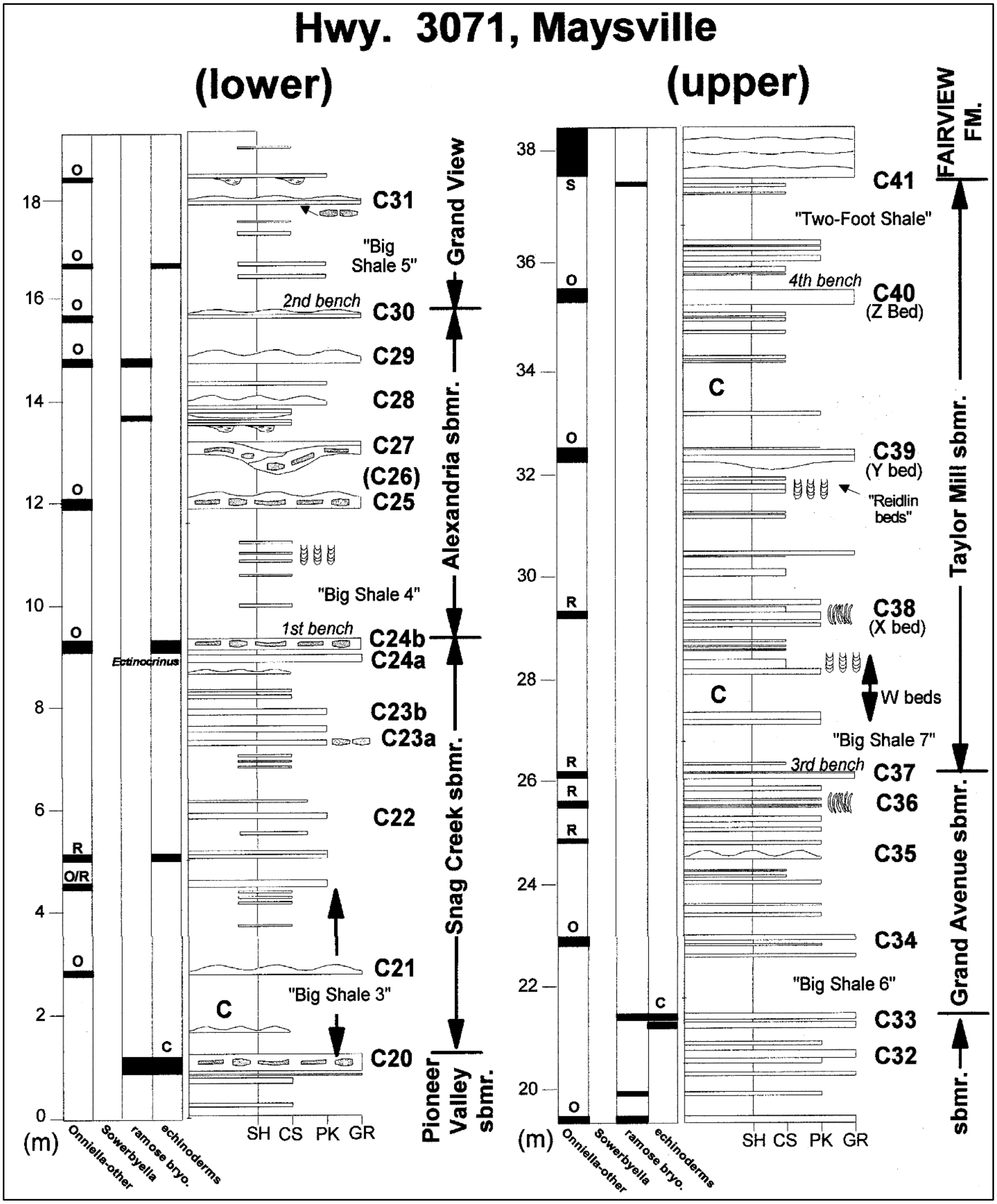


Figure 2. Measured section of KY 3071 outcrop, near Maysville, Kentucky Algeo and Brett, 2001).

Stop 3. Upper Exposed Beds along KY-3071

In the upper portion of the roadcut near the road level, the topmost beds of the Kope Formation are well exposed. Just below the Kope-Fairview contact (in the Taylor Mill submember of the Kope Formation), note the compact, 50-cm-thick *Onniella*-rich Z bed, which forms the fourth bench near the upper end of the roadcut. This is overlain by about one meter of shale that corresponds with the last bed of the Kope Formation ("Two-Foot Shale") seen elsewhere. At this level, there is an abrupt shift from the underlying shale- and siltstone-dominated Taylor Mill submember of the upper Kope to amalgamated grainstones of the Fairview Formation. Schumacher (1992) placed the base of the Fairview Formation in this area at or near the base of the overlying compact limestone ledge, which is rich in the brachiopod *Strophomena.* Holland (1998) also considered this to be the boundary between the first two sequences of the Cincinnatian Series (C1 and C2). However, recently Holland and others (2001) argued that the sequence boundary should perhaps be placed higher, above the *Strophomena*-bearing limestone, at the position of incursion of supposedly shallower water faunas in the "Wesselman shaly tongue." A case could also be made for placing a sequence boundary below the Z bed of the upper Kope. This *Onniella*-rich limestone shows a sharp base and an abrupt change to shallow compact limestone facies from the underlying shales. Fairview Formation beds are especially rich in the brachiopod *Strophomena,* which may represent the abrupt incursion of this species.

The seventh bench is just below the relatively sharp lower contact between shaly beds of the upper Fairview (possible Miamitown equivalent) and lighter gray, closely spaced, thin wavy packstone beds of the Bellevue Member of the Grant Lake Formation. About 30 cm below the contact is a distinctive, rusty weathering laminated siltstone with a channeled discontinuity surface along its top; this bed is extensively exposed along higher portions of the bench surface. Local pockets of shale filling hollows on this surface contain very abundant columns and crowns of the crinoid *Glyptocrinus decadatylus.* Basal Bellevue beds, immediately overlying this level, carry a series of hardgrounds with *Trypanites* borings and encrusting holdfasts of *Anomalocrinus.*

The next level of interest occurs about 150 cm below the eighth or second-to-last bench in this roadcut. The highest beds here are rubbly to wavy-bedded packstones and grainstones of the Bellevue Formation Its basal contact with the Fairview Formation is rather sharply defined and is located about 8 m above the highest seismites. These beds are full of well-preserved brachiopods, particularly *Platystrophia ponderosa* and *Heertella.* A number of bedding planes within this interval also show evidence of early lithification as hard-grounds.

Proceeding upward, a small, quarried area immediately below the uppermost bench in the outcrop was the site of excavation of a large (~5 m^2) hard-ground surface (Sumrall et al., 1999). This hard-ground was developed on the upper surface of relatively thin packstone beds rich in the brachiopod *Platystrophia ponderosa.* The surface itself was nearly planar with minor relief of a few millimeters. It is marked by large mounded colonies of bryozoans that are clearly cemented to the surface. Both the bryozoans and portions of the limestone surface itself had abundant encrusting edrioasteroids of four different species. Interestingly, the edrioasteroids occur in greatest density in elongate rows a few centimeters wide and up to a meter long; this pattern suggests that narrow portions of the surface were swept clean of mud coating and thereby were accessible to colonization by these crinoids. The hard-ground itself has been traced to all corners of this outcrop and in the nearby roadcuts potentially correlates also with the previously described hard-ground on a nearby railroad.

The uppermost beds exposed above the hard-grounds up to the distinct platform of the ninth bench are rubbly limestones. This bench is overlain by light gray, thin, wavy-bedded limestones of the upper Grant Lake Formation. (possible Corryville equivalent). Notable features include a mass of large domal bryozoans at a level of about 2 meters above the platform and a distinctive whitish-weathering amalgamated marker bed. Specimens of cyclocrinitids (small ball-like green algal) have also been obtained from shaly beds slightly below this level.

Return to vehicles, turn around and continue south on KY-3071

4.6 Large Fairview outcrop with thrust fault(s)
4.8 Channelized siltstone bed with ball-and-pillow structure
5.0 Outcrop with Fairview-Bellevue contact
7.2 Junction of KY-3071 and AA Highway;

END OF KY-3071 LOOP

Stop 4. Outcrop 40, Brooksville Turn (AA Highway – KY 1159 intersection)

At this stop, exposures along south side of KY 1159 just west of junction with AA Highway (Fig. 3) will be examined. This somewhat weathered road cut shows upper Point Pleasant limestones (about 7 m) and the lower Kope, Fulton submember. Note strongly deformed interval in Point Pleasant fine-grained grainstone beds near the base of the outcrop; folded and thrusted calcisiltite beds sharply and discordantly overlain by skeletal grainstone bed.

The bench at the top of the exposure shows the Point Pleasant-Kope. Certain unusual fossils are found in this basal 1-m-interval, including the rare cystoid *"Glyptocystites" fultonensis* and the crinoid *Merocrinus typus.* The brachiopod *Sowerbyella* and the trilobite *Cryptolithus* both make an appearance in these lower levels. Certain of the shales are rich in gastropods and clams, as are the basal shale beds of several higher Kope submembers.

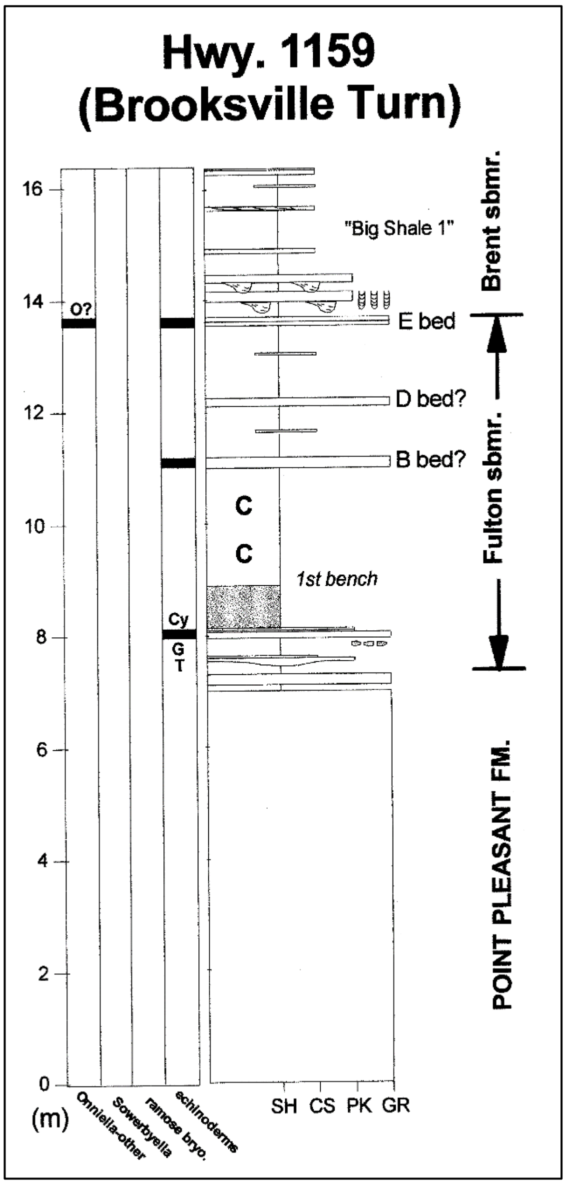
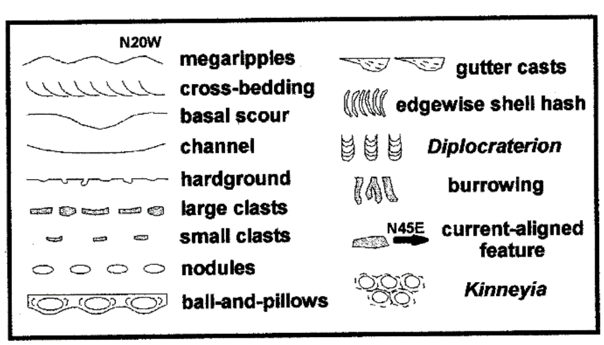


Figure 3. Measured section of the KY-1159 outcrop (Algeo and Brett, 2001). Columns on the left show dominant components of skeletal grainstones and packstones: O = *Onniella*, R = *Rafinesquina*, S = *Sowerbyella*, Z = *Zygospira* (cols. 1-2), ramose bryozoans (col. 3), and echinoderms (col. 4). In stratigraphic column on right, column width represents lithology: SH = shale, CS = calcisiltite, PK = packstone, and GR = grainstone. Beds labeled per stratigraphic nomenclature of Brett and Algeo, 2001. Beds inferred to be correlative with capping beds of cycles in Holland et al. (1997) are designated by "C" followed by the cycle number; uncertain cycle assignments are indicated by "?", and missing or covered cycle cap beds are enclosed in parentheses.



Stop 5. Outcrop 39, Salem Ridge (optional)

This optional stop is a rubbly outcrop of upper Point Pleasant and lower Kope Formations, comparable to outcrop 27 at Holst Creek.

Stop 6. Outcrop 28, Middle Holst Creek

This stop is a large outcrop of middle Kope Formation, showing the top of the Snag Creek beds, with Big Shale #3 and upper limestones (beds 24a, 24b) near the lower bench. Big Shale #4 and the "red *Onniella* beds" of the Alexandria submember are opposite the sign for KY-1019. The upper part of the roadcut is in the Grand Avenue submember. The Snag Creek beds form a distinctive succession; note particularly the cluster of about five beds of limestone that underlie a relatively thick nearly pure shale interval.

Stop 7. Outcrop 27, Lower Holst Creek

The roadcut on right side exposes the upper Point Pleasant, and lower Kope Formations with a contact that appears conformable. In the lowermost Kope, about ten thick crinoidal grainstones are present in lower 10 m of shale; these are rich in nautiloids and contain the crinoid *Merocrinus* and the trilobite *Cryptolithus.* At the level of the 1st bench, very large gutter casts occur in a siltstone bed; just above this, the outcrop becomes very shaly (Big Shale #1), and thin siltstones exhibit excellent trace fossils and sedimentary structures. Beds with well-developed *Kinneyia* iccur at the level of the 2nd bench. Also present are "log jams" of *Ectenocrinus;* the outcrop culminates in a few thicker limestones apparently belonging to the Brent submember.

This outcrop provides an exposure of one of the lowest units of the Cincinnati Arch region, due to the presence of a small anticline (the Moscow-Carntown anticline; Potter, 1996). The Middle Ordovician Point Pleasant Limestone, and its contact with the overlying Kope Formation, is well exposed here. The Point Pleasant consists of medium- to thick-bedded crinoid, brachiopod, and bryozoan packstones and grainstones, alternating with fine-grained, pelletal grainstones or calcisiltites, and medium gray shales.

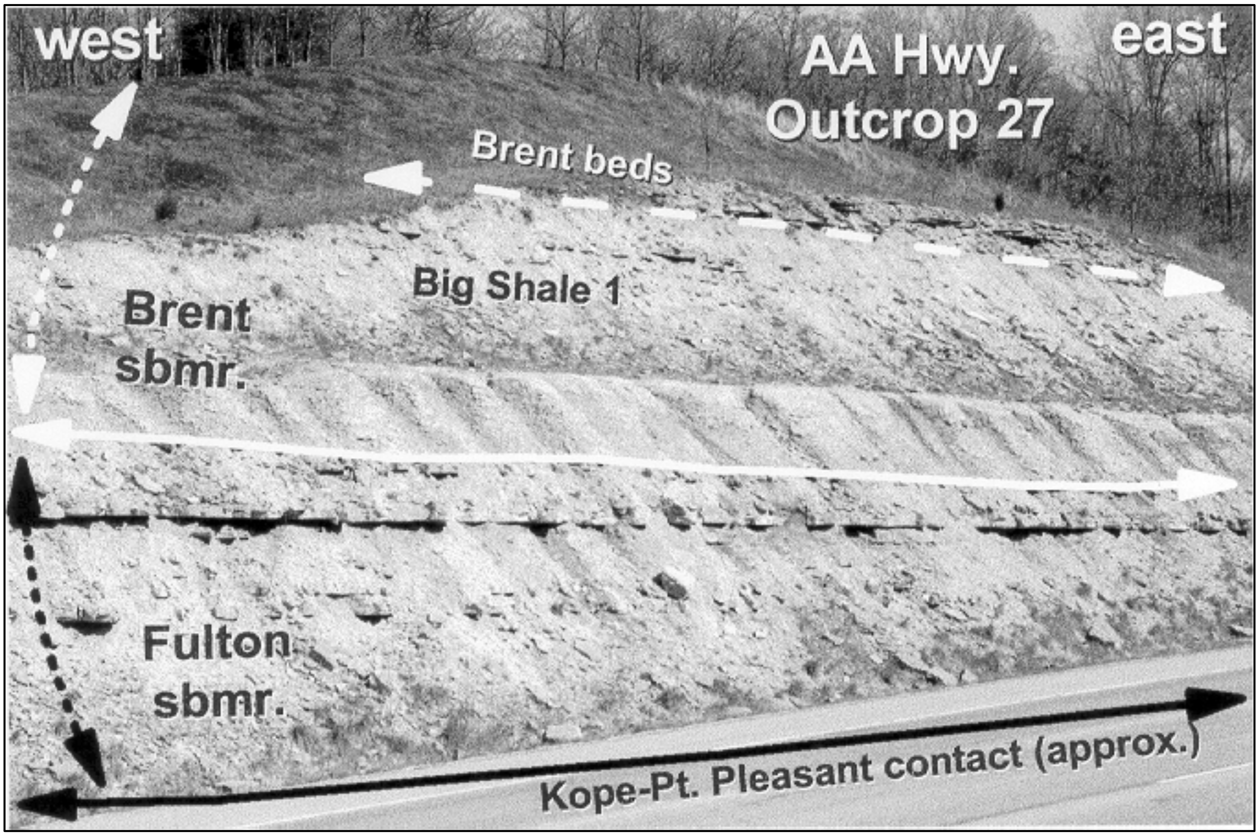


Figure 4. AA Highway Outcrop 27 (Algeo and Brett, 2001).

The contact with the overlying Kope Formation appears interbedded and gradational at this locality, but it is drawn at the base of the first substantial (0.5 m) shale interval. The basal shale (base of Fulton submember) is relatively dark grey, but is not the dark brownish gray shale that characterizes the basal Fulton beds farther to the northwest near Cincinnati. The Middle-Upper Ordovician boundary coincides approximately with this level, as does the base of the Cincinnatian Series. The lower 4 meters of the Kope Formation consists of an alternation of shales, and relatively massive crinoidal limestones (mainly grainstones). Certain unusual fossils are found in this interval including the rare cystoid *"Glyptocystites" fultonensis* and the crinoid *Merocrinus typus.* The brachiopod *Sowerbyella* and the trilobite *Cryptolithus* both make an appearance in these lower levels. Certain shales are rich in the gastropods and clams, as are the basal shale beds of several higher Kope submembers. The limestone ledges are strikingly set off from the underlying shales at sharp erosional boundaries and the beds contain large yellowish clasts of dolomitic mudstone, evidently eroded from the underlying beds. Above the highest major limestone, the upper 10 meters of Kope in this outcrop consists primarily of shale or mudstone with thin- to medium-bedded, planar to hummocky laminated calcisiltites or siltstone beds. This represents most of the thickness of the first major shale unit of the Kope, and most of the Brent submember.

A small gully on the east end of this outcrop displays an interesting limestone bed near the top of the basal Kope (Fulton) interval, with the top of this bed being cut by shale-filled scour channels. The sides of the larger channels have been extensively burrowed by epichnial tracemakers. These features may be comparable to large gutter casts that have been cut into the top of a limestone bed and infilled with shale. Approximately one meter above this horizon is a relatively thick hummocky cross-laminated calcisiltite bed with large (up to 20 cm across and 10 cm deep) gutter casts. The bed sole also shows excellent preservation of tool marks and trace fossils. This gutter cast horizon is readily traceable along the outcrop just below the first bench in the roadcut.

The second bench also shows some interesting features. Toward the top of the Brent shales are a series of thin siltstones, the upper surface of one of which shows a low relief, pitted, or furrowed, topography identifiable as *Kinneyia.* These features are of enigmatic origin. Once considered a trace fossil, they are relatively common in some Proterozoic deposits and have therefore been interpreted as an inorganic structure. Pfleuger (1999) inferred that *Kinneyia* are commonly associated with dysoxic conditions that might inhibit burrowing, and that these features developed as a result of expulsion of gas bubbles along the interface between a silt layer and an overlying bacterial mat. *Kinneyia* is commonly associated with millimeter-scale ripples, i.e., a series of parallel, slightly sinuous, furrows and ridges typically about three to five cm across. These are also present in the Kope Formation, and may be observed at this location where they penetrate through multiple laminae of calcisiltite beds. Both features have been considered as possible evidence of seismicity.

Another interesting feature present in the upper portion of the Holst Creek outcrop are "log-jams" of long crinoid stems, primarily of *Ectenocrinus;* clusters of parallel-oriented articulated crinoid stems sometimes with small crowns intact. These were obviously buried rapidly as they have been interpreted as the effect of mass mortality of uprooted crinoids and their orientation by basal work flowing gradient currents.

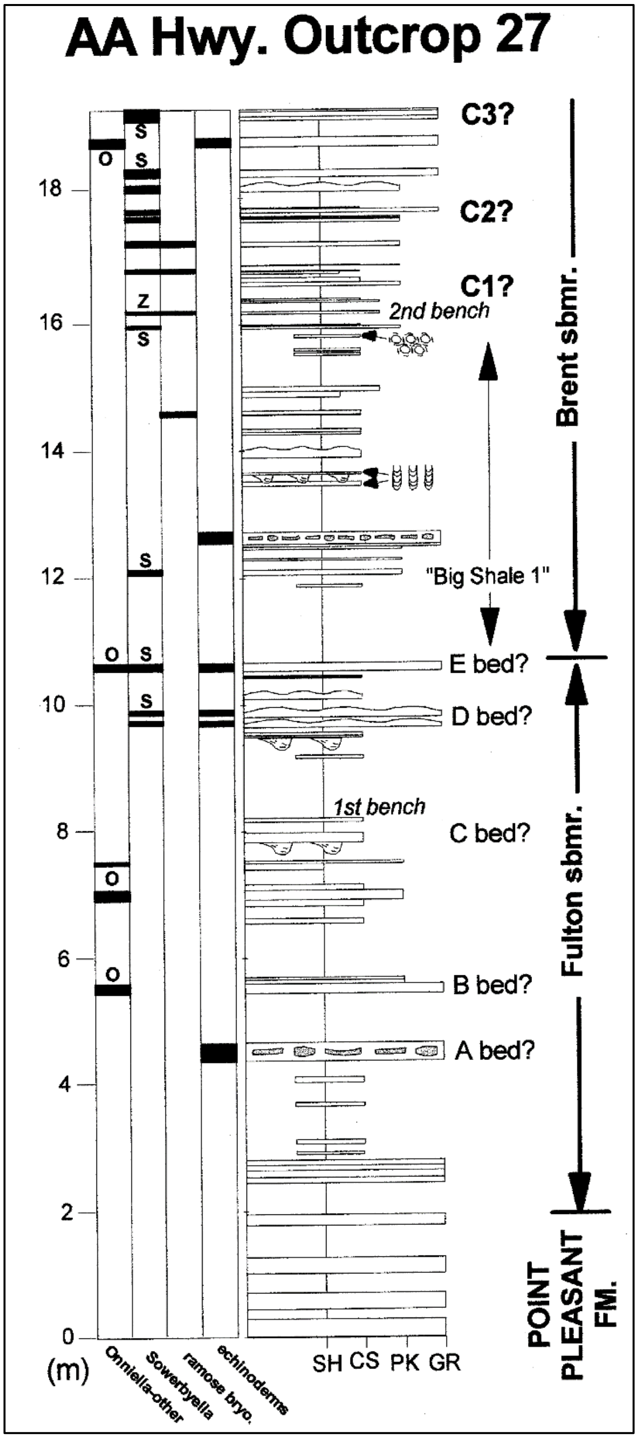
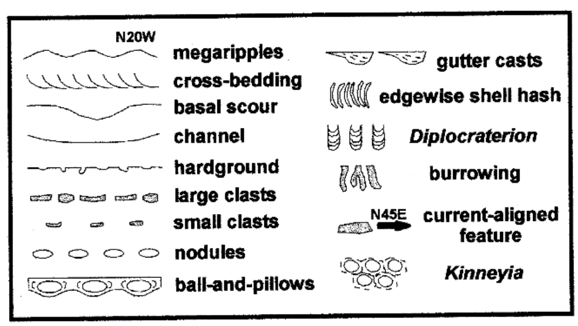


Figure 5. Measured section of Outcrop 27 on the AA Highway (Algeo and Brett, 2001). Columns at left show dominant components of skeletal grainstones and packstones: O = Onniella, R = Rafinesquina, S = Sowerbyella, Z = Zygospira (cols. 1-2), ramose bryozoans (col. 3), and echinoderms (col. 4). In stratigraphic column on right, column width represents lithology: SH = shale, CS = calcisiltite, PK = packstone, and GR = grainstone. Beds labeled per stratigraphic nomenclature of Brett and Algeo, 2001. Beds inferred to be correlative with capping beds of cycles in Holland et al. (1997) are designated by "C" followed by the cycle number; uncertain cycle assignments are indicated by "?", and missing or covered cycle cap beds are enclosed in parentheses.



Stop 8. Outcrop 26, Kennon (Fig. 6)

This stop is a small outcrop on the SW side of road in the Point Pleasant Formation. The contact with the overlying Kope Formation can be observed at the top of the outcrop.

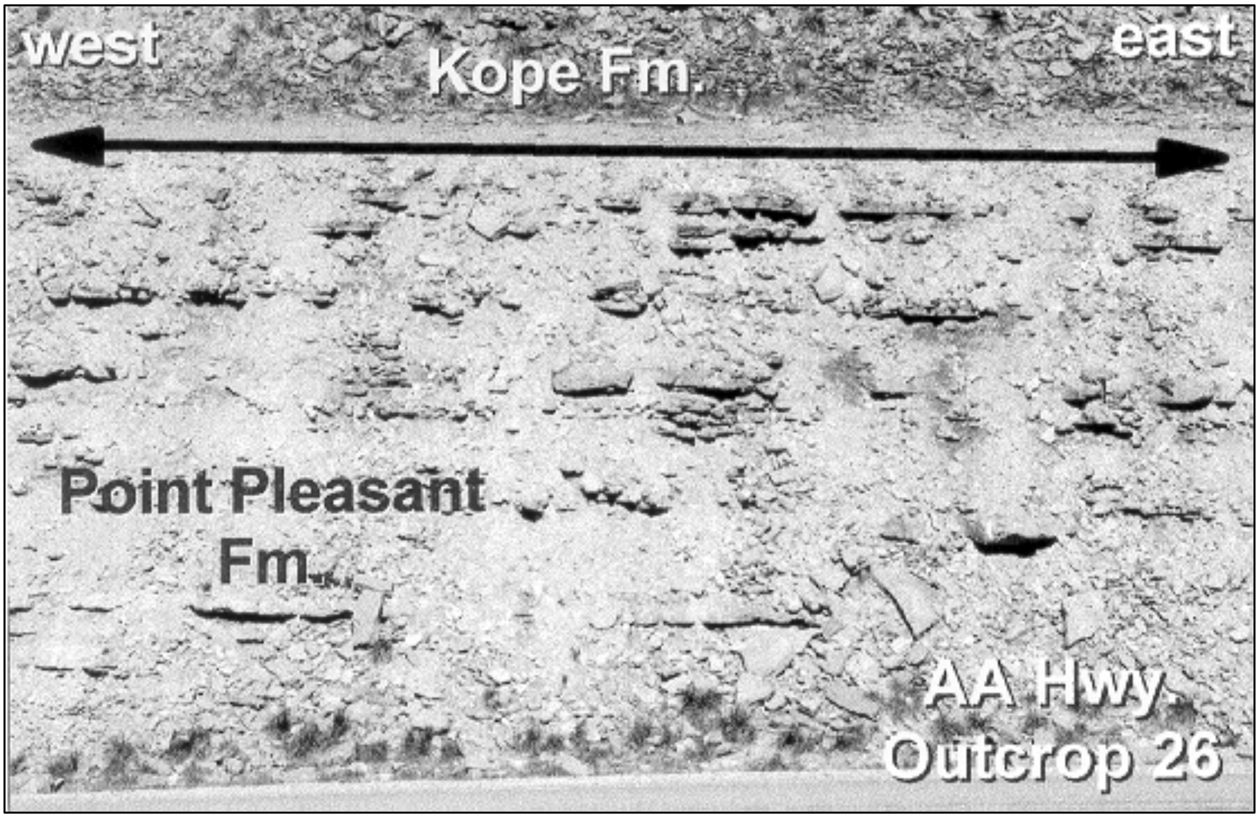


Figure 6. AA Highway Outcrop 26. Base of Kope Formation, and underlying Point Pleasant Formation Note the very dark gray shales at the base of the Kope (Algeo and Brett, 2001).

Stop 9. Outcrop 25, Old Carntown (Fig. 7)

This outcrop exposes a large section in the lower to middle Kope Formation, near crest of Moscow-Carntown anticline (Potter, 1997). Note the minor anticlinal fold apparent at outcrop scale. The lowest, prominently rippled, beds in ditch are in the Brent submember of the Economy Member. Excellent gutter casts, and pyritic hardground, are present on top of the first bench. Shale and overlying cycles 10-20 of the Pioneer Valley submember of Economy Member are well exposed in small gully on NE side of road; the uppermost bench is in Snag Creek submember.

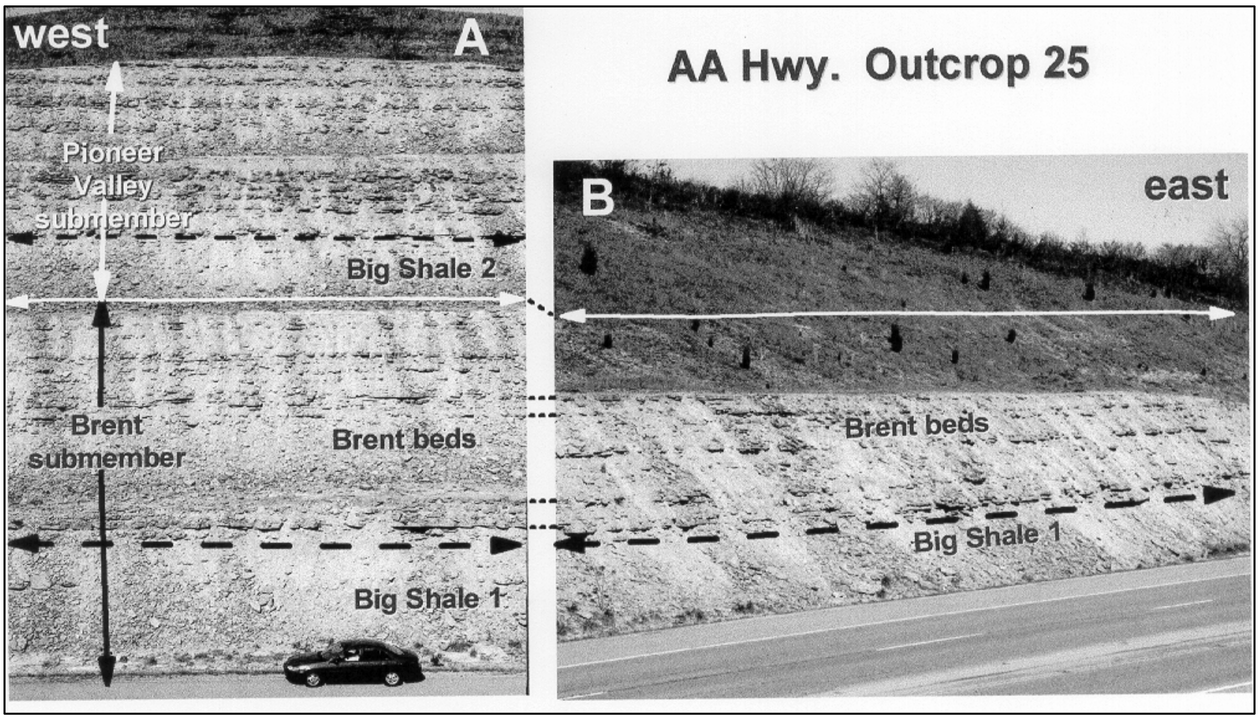


Figure 7. AA Highway Outcrop 25 (Old Carntown). (A) Center part of north side of highway; (B) East end of north side of Highway. Photo B shows better the development of the lower Brent beds of Algeo and Brett (2001), which are concealed in the covered interval above the first bench in Photo A.

Stop 10. Bathroom/rest break at Marathon Station

Stop 11. KY 445 near Brent, KY

This outstanding roadcut exposes about 41 m of the lower to middle Kope Formation on the north side of KY-445; the upper portion of this cut overlaps with sections exposed on adjacent I-275. Together these sections form a key composite reference section that has been studied extensively from the standpoint of graptolite biostratigraphy (Mitchell and Bergstrom, 1991). Recently this cut has been measured in considerable detail and divided into about 40 meter-scale cycles (Holland et al., 1997). It is also part of our Composite Reference Section for the Kope Formation (Figs. 9 and 10)

Bundling of limestones and shales that may be interpreted as cyclicity is apparent at two scales: (1) the outcrop is divisible into four decameter-scale intervals, which correspond approximately to the four tiers in the roadcut. Each of these larger cycles, which are equivalent to the submembers of the Kope Formation named by Brett and Algeo (2001), commences with a thick shale-rich interval, and passes upward into a cluster of thicker limestone beds. These clusters show abrupt tops (about at the level of each bench in the outcrop). A more careful inspection of these clusters shows that they in turn are divisible into smaller, meter-scale packages of shales, calcisiltites and fossil-rich packstones and grainstones, which are the meter-scale cycles of Holland and others (1997). The caps of these cycles are prominent, sharp-based limestone beds that form projecting ledges. Note that these smaller cycles appear to become more closely spaced toward the top of each decameter-scale cycle.

The base of this roadcut is within the middle Brent submember of the Economy Member and is estimated to be some 11 or 12 m above the base of the Kope. This interval can be examined in detail in the ditch at the base of the north (high) side of the cut. Particularly distinctive are three smaller bundles of ledge-forming limestones. Note the sparsely fossiliferous mudstones with thin siltstones and shell- and bryozoan-rich packstones. Observe also the concretionary beds that lie close below the major limestones (near the tops of putative cycles). These are overlain by limestone-rich intervals, each of which comprises two or three major grainstone beds (beds 5-8). Pairing of the major limestone ledges is distinctive and typical of this portion of the Kope. Limestone ledges show sharp, erosional bases and distinct, heavily burrowed tops that appear to be omission surfaces, possibly hardgrounds. Typical fossils include the brachiopods *Onniella* and *Sowerbyella,* and abundant small ramose bryozoans, fragments of *Cryptolithus* trilobites, and crinoidal debris. These assemblages are found in both the shales and the limestones, but are much more densely packed and typically more fragmented in the limestones. At the level of the first bench, an abrupt change to shales and siltstones is apparent.

Notice the thick siltstone beds with hummocky cross-lamination and sharp soles with tool marks and gutter casts. This is the base of the next decameter-scale cycle (the Pioneer Valley submember). "Log jam" clusters of articulated *Ectenocrinus* occur within these shales.

If time permits, climb carefully up the slope on the west end of the outcrop to view thick rusty-weathering limestones composed of intraclast-rich *Sowerbyella* grainstones (beds 16 and 18); these form the top of the Pioneer Valley submember, about 3 m above the second bench. Higher still are two thick shales capped by limestone bundles corresponding to the tops of the

Snag Creek and Alexandria submembers (decameter-scale cycles) at the tops of the third and fourth benches, respectively. The shales above bed 20 are particularly rich in graptolites (commonly current aligned), and an important zonal boundary, i.e., the base of the *Geniculograptus pygmaeus* Zone, has been located above bed 24 (base of the Alexandria submember), about 33 m above the base of the outcrop.

Figure 8. Photo of KY 445 outcrop (middle portion of Kope Formation). The height of outcrop is ~ 35 m. Note decameter-scale alternations (cycles) of thick shales and bundles of ledge-forming limestones. The Brent submember occurs at the base of photo, and the overlying Pioneer Valley submember, or "*Sowerbyella* zone", is shown in the upper half of photo.

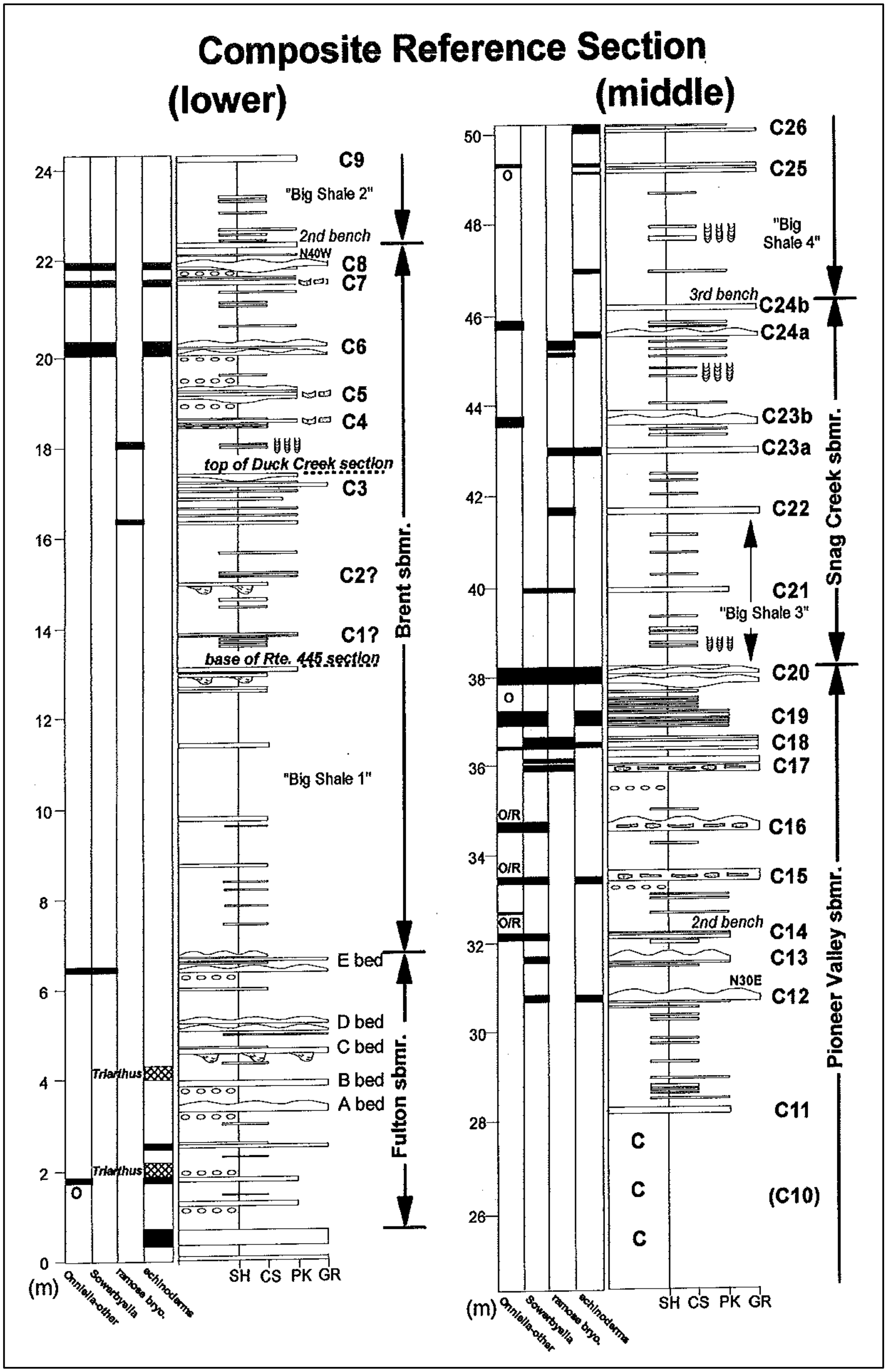


Figure 9 – Bottom portion of a composite reference section designed by Brett and Algeo (2001) for the Kope Formation in the Cincinnati, Ohio area

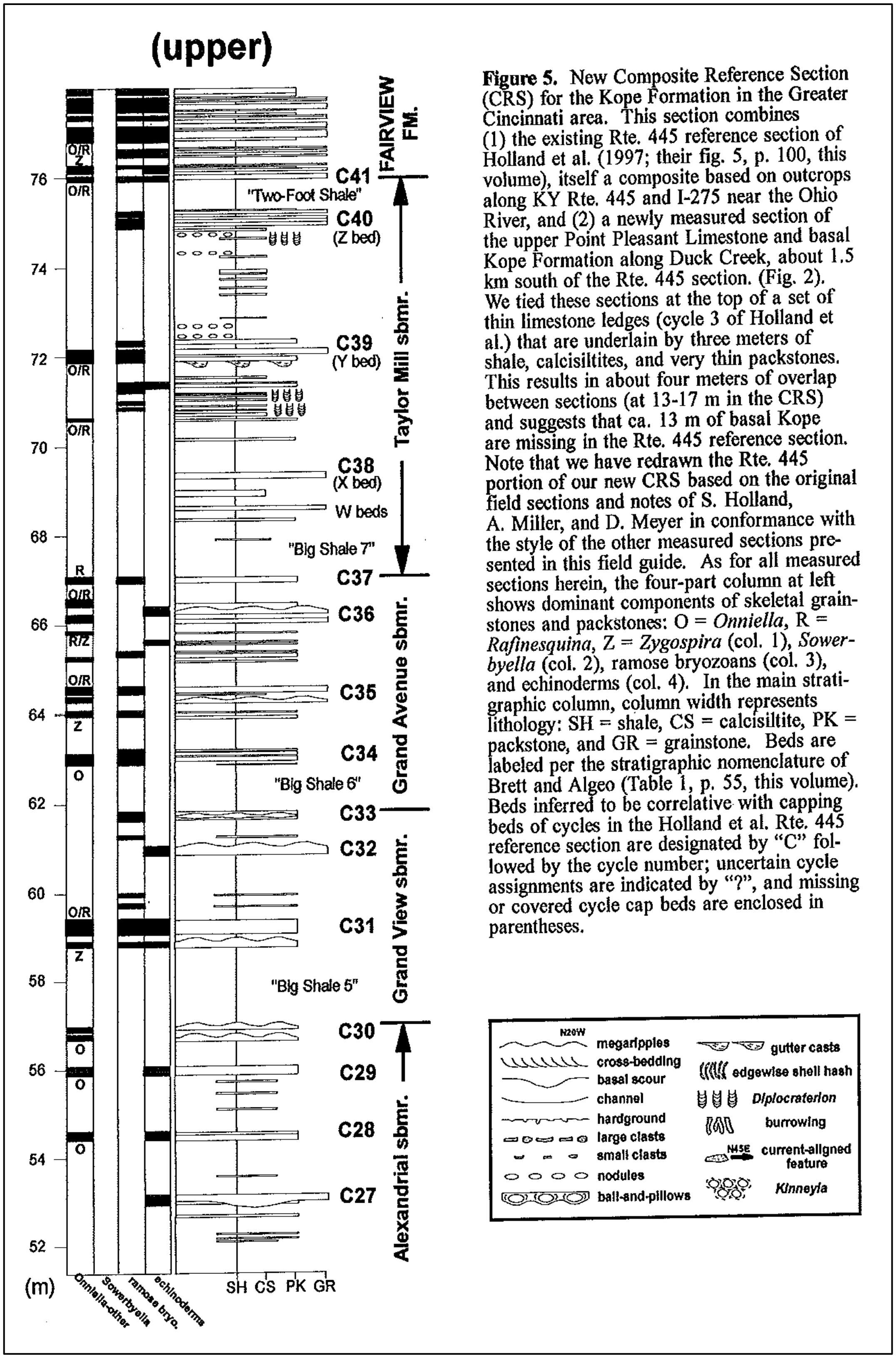


Figure 5. New Composite Reference Section (CRS) for the Kope Formation in the Greater Cincinnati area. This section combines (1) the existing Rte. 445 reference section of Holland et al. (1997; their fig. 5, p. 100, this volume), itself a composite based on outcrops along KY Rte. 445 and I-275 near the Ohio River, and (2) a newly measured section of the upper Point Pleasant Limestone and basal Kope Formation along Duck Creek, about 1.5 km south of the Rte. 445 section. (Fig. 2). We tied these sections at the top of a set of thin limestone ledges (cycle 3 of Holland et al.) that are underlain by three meters of shale, calcisiltites, and very thin packstones. This results in about four meters of overlap between sections (at 13-17 m in the CRS) and suggests that ca. 13 m of basal Kope are missing in the Rte. 445 reference section. Note that we have redrawn the Rte. 445 portion of our new CRS based on the original field sections and notes of S. Holland, A. Miller, and D. Meyer in conformance with the style of the other measured sections presented in this field guide. As for all measured sections herein, the four-part column at left shows dominant components of skeletal grainstones and packstones: O = *Onniella*, R = *Rafinesquina*, Z = *Zygospira* (col. 1), *Sowerbyella* (col. 2), ramose bryozoans (col. 3), and echinoderms (col. 4). In the main stratigraphic column, column width represents lithology: SH = shale, CS = calcisiltite, PK = packstone, and GR = grainstone. Beds are labeled per the stratigraphic nomenclature of Brett and Algeo (Table 1, p. 55, this volume). Beds inferred to be correlative with capping beds of cycles in the Holland et al. Rte. 445 reference section are designated by "C" followed by the cycle number; uncertain cycle assignments are indicated by "?", and missing or covered cycle cap beds are enclosed in parentheses.

Figure 10 – Top portion of a composite reference section designed by Brett and Algeo (2001) for the Kope Formation in the Cincinnati, Ohio area.

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Field trip stop photographs

The following pages contain images taken by John Hickman from several of the outcrop locations visited on this field trip. They are arranged by field trip stop location.

Plate 1

Stop 4. Brooksville Turn

Plate 2

Stop 7. Lower Holst Creek

Plate 3

Stop 8. Kennan

Plate 4

Stop 11. KY Route 445, near Brent, Kentucky

Ohio, West Virginia, Pennsylvania and New York

1.0 UTICA AND EQUIVALENT OUTCROP DESCRIPTIONS

1.1 Ohio

The Point Pleasant Formation, Utica Shale-equivalent rocks, and overlying Cincinnati Group, including the Kope Formation, are the oldest Upper Ordovician rocks exposed in Ohio (Figure 1-1). The Cincinnati Group is comprised of thirteen formations and seven members or beds, and ranges in thickness from 700 to 1000 feet (ft) (Schumacher, 1998). This stratigraphic interval is characterized by interbedded fossiliferous limestone and shale with varying ratios of each within individual units. In Ohio, these Upper Ordovician units are exposed only in the southwestern part of the state along the Cincinnati Arch region. These rocks are best exposed in stream cuts along the Ohio, Great Miami and Little Miami River valleys and tributaries. Bedrock exposures are generally poor in the upland areas and are covered by glacial sediments. Numerous papers have been published with detailed discussions and general overviews of the stratigraphy and deposition of Upper Ordovician rocks outcropping in the Cincinnati Arch region of southwestern Ohio and northern Kentucky. These include Hay and others (1981), Schumacher and others (1987), Holland (1993), Holland and others (1997), Davis and others (1998), Schumacher (1998), Holland (1998), Brett and Algeo (1999), Brett and Algeo (2001), Brett and others (2003), Potter (2007), and Brett and others (2008).

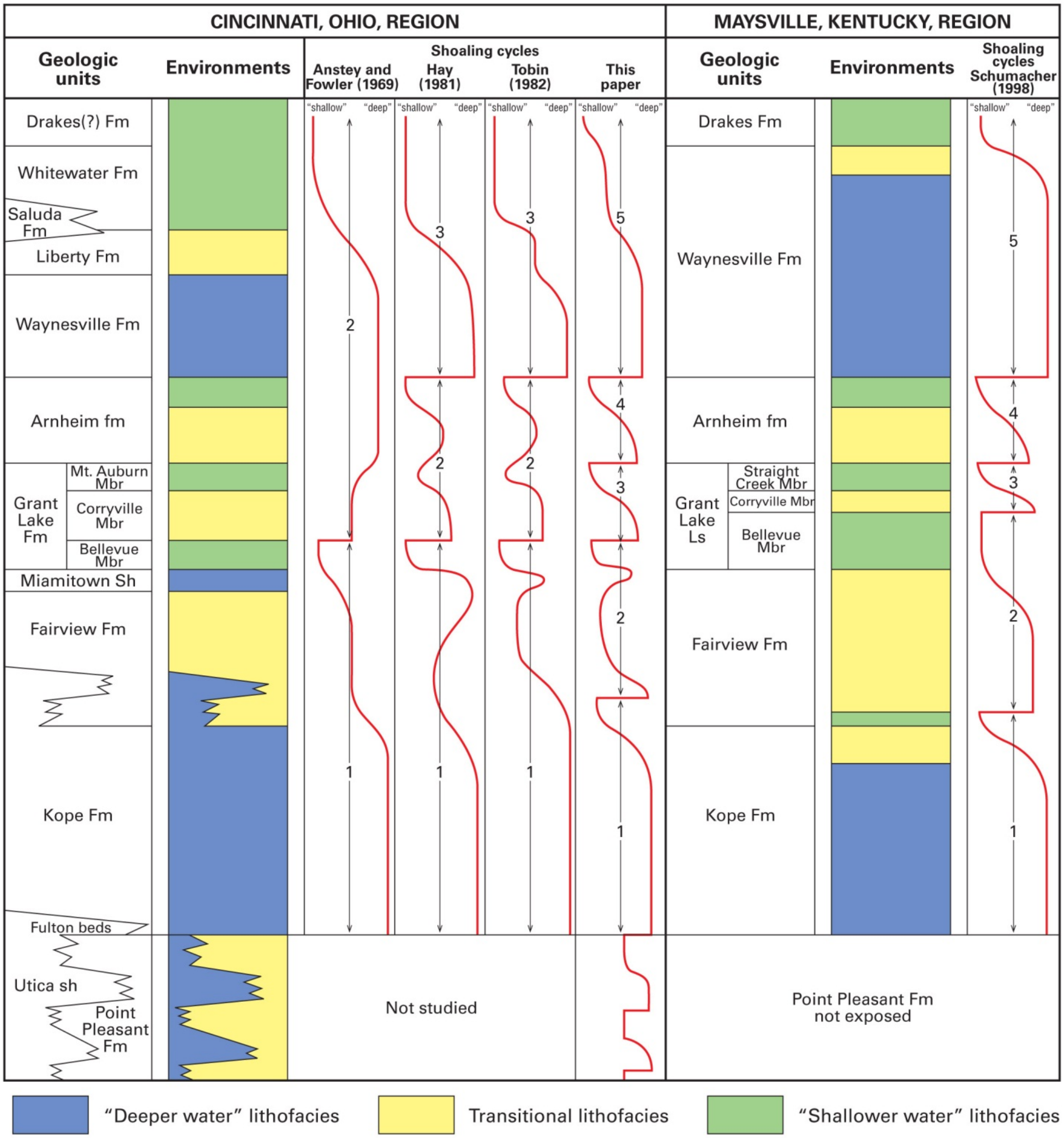

Figure 1-1. Stratigraphic column showing Upper Ordovician geologic units, depositional environments, and shoaling cycles in the Cincinnati, Ohio and Maysville, Kentucky region (from Schumacher and others, 2013).

1.1.1 Point Pleasant Formation Distribution and Characteristics

The Point Pleasant Formation is exposed along the Ohio River valley walls and associated tributaries in four counties in southwestern Ohio (Figure 1-2). The unit was named for outcrop exposures near the city of Point Pleasant in Clermont County. Thickness ranges from 50 to 150 ft (Schumacher, 1998). Point Pleasant exposures that have been examined or had measured sections in Ohio are shown in Figure 1-2. Exposures also are present in the Licking Valley in Campbell and Kenton counties and outcrops in southwestern Boone and Gallatin counties in

Kentucky. The Point Pleasant is resistant to weathering and forms cliffs and steep slopes along stream and river valleys. The accessibility and exposures along the Ohio River allowed it to be easily quarried and shipped by boat in the early twentieth century. Small pockets of natural gas also have been encountered in the Point Pleasant Formation in the Cincinnati area, but not in commercial quantities (Potter, 2007).

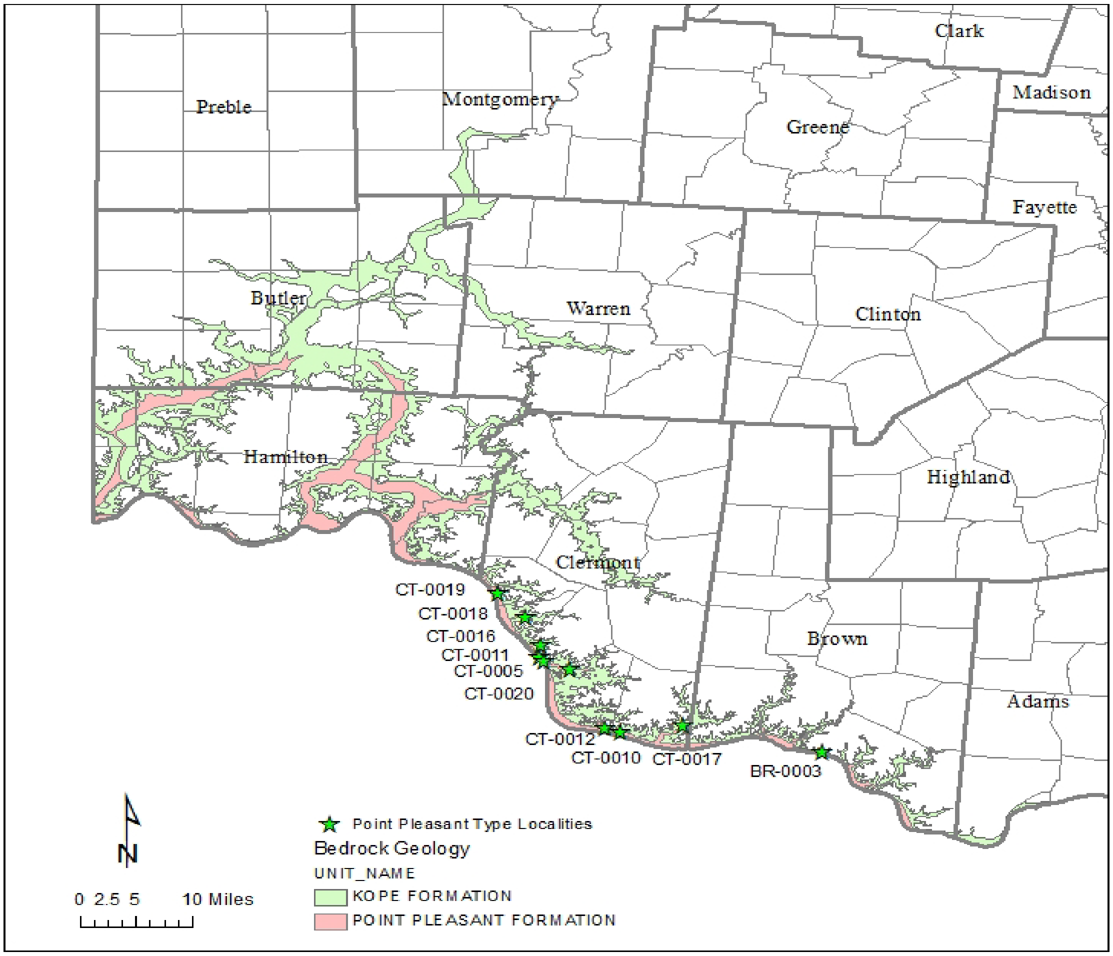

Figure 1-2. Bedrock geologic map showing the Kope Formation (includes Fulton beds, a facies of the Utica Shale) and Point Pleasant Formation exposures in southwestern Ohio. Also shown are type localities for these formations (from Davis and others, 1998). Descriptions of these are provided in Section 1.1.4.

The Point Pleasant underlies and has a sharp contact with the overlying Kope in outcrop exposures (Schumacher, 1998). It overlies the Lexington/Trenton Formation beds of the subsurface and has a gradational contact based on core and wireline logs. In outcrop, the Point Pleasant is characterized by variable amounts of thin- to medium-bedded, medium- to coarse-grained, fossiliferous wackestones and packstones that are interbedded with medium gray shales. The limestone units are gray to bluish gray in color and averages about 60% of the Point Pleasant interval. Graded bedding and ripple marks are common in some limestone beds. Cross bedding and soft sediment deformation also has been observed (Potter, 2007). The Point Pleasant Formation, as exposed along many of the stream beds in Clermont County, exhibits planar- to irregular-bedded limestone and shale (Figure 1-3). Limestone beds in this unit exhibit a diverse and abundant fossil content and consist primarily of brachiopods, bryozoans, crinoids and trilobites (Schumacher, 1998). Bivalves, cephalopods, gastropods and trace fossils also are present, but are less common. Biostratigraphic studies of the Point Pleasant indicate that it belongs to the superbus conodont Zone, suggesting a latest Shermanian age (Sweet and Bergstrom, 1984).

Figure 1-3. Outcrop photograph of the Point Pleasant Formation exposed along the Big Run stream in Clermont County, Ohio (from Schumacher and others, 2013).

Northward from the outcrop, lithologic variations occur in the subsurface as these rocks become a thinner bedded, laminated, fine-grained limestone interbedded with brown to black shale. The limestone bed thickness decreases and the amount of shale increases to the north in the subsurface. The shale changes color from primarily gray in the outcrop to a more organic-rich brownish gray to brown as the unit grades into and intertongues with the Utica Shale in the subsurface.

1.1.2 Utica Shale Distribution and Characteristics

The Utica was named for its type section at Utica in Oneida County, New York. In Ohio, it ranges in thickness from 0 to 390 ft in the subsurface. The organic-rich, dark brown to black Utica Shale, which is characteristic of the type section and the subsurface, is not exposed at the surface in Ohio. However, a facies of the Utica is present within the lower Kope Formation and is exposed in southwestern Ohio. The Utica intertongues, and is in facies transition with, the

Point Pleasant Formation and overlying Kope Formation (Figure 1-12). One of these tongues is named the Fulton beds of the basal Kope, and is exposed along the Ohio River and its tributaries in Hamilton and Clermont counties. Bedrock exposures of the Kope Formation are present along the Ohio River and its tributaries in seven counties in southwest Ohio (Figure 1-13).

The Utica Shale has a gradational upper contact with the Kope Formation and a sharp contact with the underlying Point Pleasant Formation. In outcrop exposures, the Fulton beds are characterized by thick bedded, dark-gray to brown shale that is interbedded with thin- to medium-bedded, fine- to coarse-grained limestone (Schumacher and others, 2013). Shale is the dominant lithology and constitutes about 80% of the total unit in the Fulton beds. Limestone beds are sparsely to highly fossiliferous. Dominant fossils include graptolites and trilobites (Schumacher and others, 2013). An exposure of the Fulton beds is present along 12 Mile Creek near New Richmond, Clermont County, Ohio, where thin (less than one ft), more resistant limestone beds are separated by a thicker shale interval (Figure 1-4).

Figure 1-4. Photograph of exposure of the Fulton beds along 12 Mile Creek near New Richmond, Clermont County, Ohio (from Schumacher and others, 2013). The Fulton beds are in the basal Kope and are considered to be an intertonguing facies of the Utica Shale.

Northward from the outcrop on the Lexington Platform, in the subsurface the Utica thickens into the “Sebree Trough” and has an intertonguing relationship with the Kope Formation, the Point Pleasant Formation, and the Lexington Limestone (Figure 1-16). The subsurface stratigraphy of the Utica-Lexington/Trenton interval is illustrated by regional stratigraphic cross-sections in the Trenton-Black River study by Patchen and others (2006). To the north, the Utica becomes a dark brown to black, organic-rich shale in the subsurface. The Utica to Lexington/Trenton interval reaches a maximum thickness of more than 390 ft in Champaign County, Ohio, in the “Sebree Trough” based on subsurface mapping (Patchen and others, 2006).

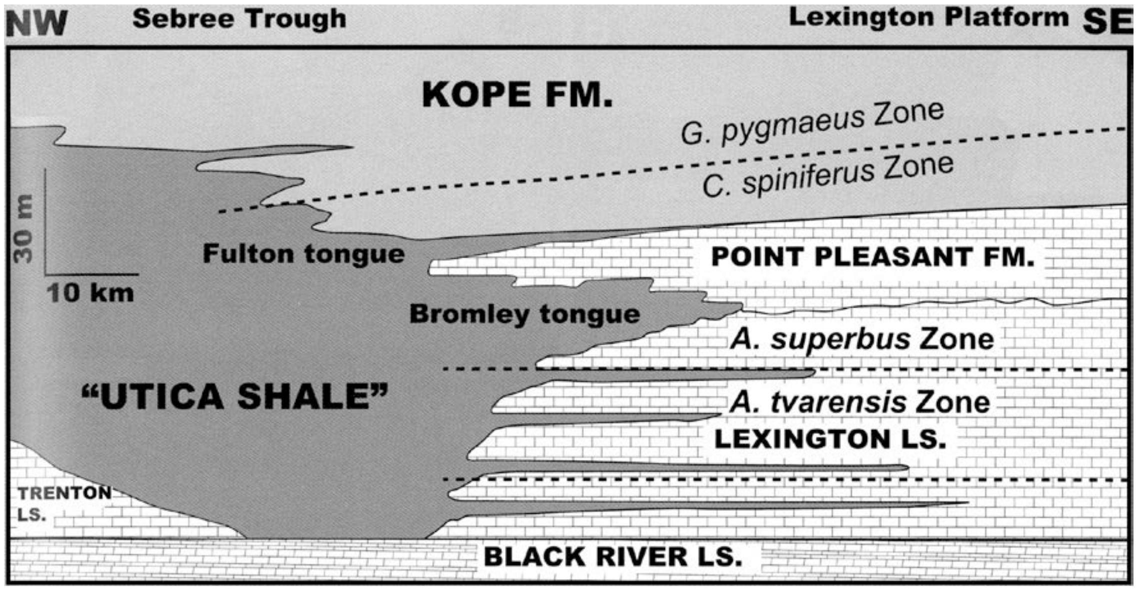

Figure 1-5. Northwest-southeast cross-section depicting the stratigraphy and facies relationship of Upper Ordovician strata from the "Sebree Trough" to the Lexington platform in southwestern Ohio and northern Kentucky (from Potter, 2007).

1.1.3 Depositional Environment and Setting

The lithofacies of the Upper Ordovician strata is the result of interactions among eustacy, basinal tectonics and biological productivity. Upper Ordovician sediments in southern Ohio and northern Kentucky were deposited in a shallow-marine subtropical environment approximately 20-25 degrees south of the paleoequator (Scotese and McKerrow, 1990; Brett and Algeo, 2001). Middle to Late Ordovician Black River time marked an important change in basin architecture as the region transformed from a passive/extensional regime to a compressive regime with collision of eastern Laurentia to the island arc system from the east-southeast. This resulted in the formation of the Blountian highlands and later the Taconic highlands. During this time, the architecture evolved into a broad, stable, shallow-water carbonate ramp as epeiric seas transgressed much of the region (Keith, 1989). The central Appalachian basin architecture continued to evolve during Lexington/Trenton time, with the appearance of low-relief carbonate buildups of the Trenton and Lexington Platforms surrounding the Utica/Point Pleasant sub-basin (Patchen and others, 2006). The Utica/Point Pleasant sub-basin includes the narrow, northeast-southwest trending "Sebree Trough" feature, whose origin is uncertain. Brett and Algeo (2001) suggest the Lexington Platform is a forebulge and the "Sebree Trough" is a backbulge related to the Taconic orogeny. Another interpretation is that the Sebree feature may be a result of rejuvenated faulting from pre-existing deep-seated basement faults (Ettensohn, 1992).

The appearance of dark brown and black shales of the Utica marked a significant change in paleogeography during late Ordovician time (Kolata and others, 2001). These siliciclastic muds and silts were probably sourced from the upland areas of the Taconic highlands to the east and northeast. During deposition of the Utica Shale, the intensity of the Taconic Orogeny once again increased causing a rapid rise in sea level or increased subsidence of the region resulting in the Utica Shale replacing carbonate deposition on the platforms. The Point Pleasant and Utica interval thickness map shows the in-fill of the Utica-Point Pleasant sub-basin, and the eventual drowning of the carbonate platforms (Patchen and others, 2006). The Utica Shale has been interpreted to represent a major transgression with a large influx of organic material, restricted circulation and low energy conditions (Bergstrom and Mitchell, 1992; Ryder, 1992, Wickstrom, 1996). Traditional models indicate the Utica was deposited in offshore, deeper-water, anoxic environments. More recently, workers have questioned the deep basinal model for black shale deposition, instead suggesting that these widespread shales form in more oxygenated waters on the order of 10 to 50 meters (m) deep (Smith and Leone, 2014).

Numerous authors (Davis and others, 1998; Brett and Algeo, 2001; Potter, 2007) have explained the occurrence of limestone-shale interbeds in the Upper Ordovician outcrop region by an interaction of quiet water deposition punctuated by periods of storm activity (tempestites). Evidence for tempestites include coarse, shell-rich limestone beds (turbulent water) interbedded with shale (quiet water), cross bedding, gutter casts, shallow channels and megaripples (Potter, 2007). Seismites also have been interpreted to explain the occurrence of deformed strata in restricted intervals throughout the Middle and Upper Ordovician in southwestern Ohio and northern Kentucky (Schumacher, 2001; Potter, 2007). These features include ball and pillow structures and convolute laminations observed in the Lexington/Trenton Formation, the Clays Ferry Formation, the Point Pleasant Formation, the Kope Formation, the Fairview Formation and the Grant Lake Formation.

Cyclicity in the Upper Ordovician Cincinnatian Series was recognized in early studies by Orton (1873). More advanced stratigraphic work defined in more detail the number of cycles that could be identified (Hay and others, 1981; Holland, 1993, Holland, 1998; Brett and others, 2003). Schumacher (1998) recognized that five shoaling cycles within the Cincinnati Group in the Maysville, Kentucky region also are present in the Cincinnati, Ohio region (Figure 1-12). Lateral facies changes indicate an increase in water depth northward from Maysville, Kentucky to Cincinnati, Ohio.

Holland (1993, 1998) and Holland and others (1997) applied sequence stratigraphy to the Upper Ordovician interval and recognized six sequences, named C1 to C6, that are dominantly shoaling upward and contain thin transgressive intervals at their base. Five of these sequences are exposed in the Cincinnati region, and the sixth has been removed by pre-Silurian erosion at the Cherokee Unconformity. Sequence boundaries are identified by subtle, thin, phosphatic, skeletal-rich limestone beds that represent transgressive systems tracts (TST). Southward in the upramp areas of north-central Kentucky, these sequences become thinner and contain greater thicknesses of transgressive deposits. Sequence C1 is the thickest of Holland’s sequences and initiated with an abrupt flooding surface near the base of the Kope Formation. This abrupt deepening above the Point Pleasant Formation coincides with Utica Shale deposition. The dark brown to black, organic-rich shales of the Utica were deposited coevally in the “Sebree Trough” and change by facies southward to a shale tongue of the Fulton beds at the base of the Kope onto the Lexington Platform (Brett and Algeo, 2001).

1.1.4 Type Cincinnatian Localities in Ohio (from Davis and others, 1998)

BR-0003 KOPE HOLLOW

Exposures in Kope Hollow starting about 0.5 kilometers (km) (0.3 mile [mi]) east of Levanna, north of U.S. Route 52; mostly Russelville, Ohio–Kentucky 7.5 minute

quadrangle; but also Higginsport, Ohio–Union Twp., Brown County, Ohio; 38^{0}46’00”N, 83^{0}52’40”W; elevation of base: 151 m (495 ft), in culvert under U.S. Route 52
Units.–Kope (151 ft/46.0 m), Point Pleasant (32 ft/9.8 m)
OGS measured section no. 13100

CT-0005 WILLIAM LIGHT PAVING COMPANY QUARRY
Abandoned quarry south of Indian Creek, 0.25 mi (0.4 km) east of junction of Ohio Route 232 and Big Indian Road; this intersection is 1.5 mi (2 km) east of U.S. Route 52 at Point Pleasant; Laurel, Ohio–Kentucky, 7.5 minute quadrangle; Clermont County, Ohio; 38^{o}53’17” N, 84^{o}12’13”W
Units.–Kope, Point Pleasant

CT-0010-BEAR CREEK
Quarry on east side of Bear Creek, adjacent to U.S. Route 52; Moscow, Ohio–Kentucky, 7.5 minute quadrangle; Washington Twp., 38^{0}48’00”N, 84^{0}09’20”; elevation: 497 ft (151.5 m)
Units.–Eden (70ft/21.3m), Point Pleasant (69ft/21 m), basal 12 ft/3.7 m covered).

CT-0011 BOAT RUN
Stream exposures above Clermontville Road bridge (at east edge of New Richmond 7.5 minute quadrangle) and up left fork toward Mt. Zion Church; Laurel, Ohio–Kentucky, 7.5 minute quadrangle; Monroe Twp., Clermont County, Ohio: 38^{0}55’25”N, 84^{0}08’15”W; elevation at base: 488 ft (149 m)
Units.–Kope (72 ft/21.9 m), Point Pleasant (52 ft/15.8 m)
OGS measured section no. 14934

CT-0012 CHILO
Stream exposures along creek parallel to Ohio Route 222, 0.2 mi (0.32 km) from U.S. Route 52: Moscow, Ohio–Kentucky, 7.5 minute quadrangle; Franklin Twp., Clermont County; 38^{o}75’45”N, 84^{o}08’15”W; elevation at base: 590 ft (179.8m)
Units.–Kope (30 ft/9.1 m), Point Pleasant (11 ft/3.4 m)
OGS measured section no. 13098

CT-0016 NORTH POINT PLEASANT
Unnamed ravine 0.3 mi (0.5 km) northwest of Opossum Hollow, 1.1 mi (1.7 km) west from Point Pleasant; base adjacent to U.S. Route 52; Laurel, Ohio–Kentucky, 7.5 minute quadrangle; Monroe Twp., Clermont County, Ohio; 38^{o}54’25” N, 84^{o}14’35” W, elevation at base: 505 ft (153.9 m).
Units.–Kope (65 ft/19.8 m), Point Pleasant (53 ft/16.2 m)
OGS measured section no. 13096

CT-0017 SLICKAWAY RUN
Stream exposures along creek from Cedron to Felicity beginning with lowest rock in run; Felicity, Ohio–Kentucky, 7.5 minute quadrangle, Franklin Twp., Clermont County, Ohio; 39^{o}48’15” N, 84^{o}03’00” W, elevation at base: 55.1 ft (167.9 m)
Units.–Kope (171 ft/52.1 m), Point Pleasant (4 ft/1.2 m); upper Point Pleasant also exposed on Bullskin Creek below mouth of Slickaway Run.

OGS measured section no. 13099

CT-0018 TWELVE MILE CREEK

Stream exposures along creek beginning at bridge of Ohio Route 132 where Fagin Run branches to the north; New Richmond, Kentucky–Ohio, and Laurel, Ohio–Kentucky, 7.5 minute quadrangles; Ohio Twp., Clermont County, Ohio; 38°58’00” N, 84°15’40” W; elevation at base: 496.5 ft (151.3 m)
Units.–Kope (108.5 ft/33.1 m), Point Pleasant (6.5 ft/2.0 m)
OGS measured section no. 13095

CT-0019 BECKJORD

Road cuts on north side of eastbound U.S. route 52, just west of Beckjord Coal Plant, 0.6 mi (1 km) east of Ohio Route 749; Withamsville, Ohio –Kentucky, 7.5-minute quadrangle; Clermont County, Ohio; 39°00’07” N, 84°17’49” W
Units.–Kope, Point Pleasant

CT-0020 POINT PLEASANT

Stream exposures on north side of U.S. Route 52, 0.3 mi (0.5 km) west of western city limits of Point Pleasant; Laurel, Ohio–Kentucky, 7.5-minute quadrangle; Clermont County, Ohio; 38°54’02” N, 84°14’13” W
Units.–Kope, Point Pleasant

1.2 West Virginia

Ordovician strata in West Virginia are well exposed in Germany Valley, to the east of the Allegheny front in Pendleton County. These exposures are described in detail in the Southeastern Section of the Geological Society of America Centennial Field Guide (Diecchio, 1986), and all following locations and descriptions are taken from that guide.

Germany Valley cuts through Middle Ordovician limestones and exposes the core of the Wills Mountain Anticline, which parallels the Allegheny structural front in the westernmost Valley and Ridge province. Exposures of the Wills Mountain anticline range from the Upper Ordovician Reedsville Formation through the Lower Silurian Tuscarora Sandstone (Figure 1-6) and comprise the Taconian, or Queenston, clastic sequence.

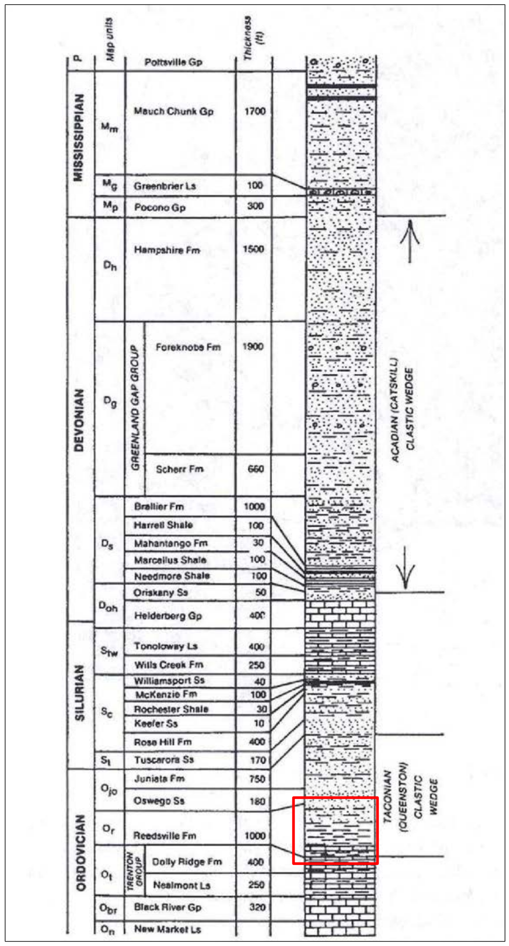

Figure 1-6. Stratigraphic column showing Upper Ordovician units exposed in Germany Valley, West Virginia (outlined in red box).

Four exposures of Upper Ordovician strata are accessible via U.S. 33, northwest of Franklin, West Virginia (Figure 1-7). These exposures, labeled as Stops 1, 2, 3a and 3b in Diecchio (1986) are generally adjacent to the highway, with the exception of Stop 1, which is accessed via a smaller road (Bland Hills Road). The stops expose progressively younger strata, beginning with the Dolly Ridge Formation (upper Lexington/Trenton Formation equivalent in West Virginia) and ending in the upper Reedsville Formation.

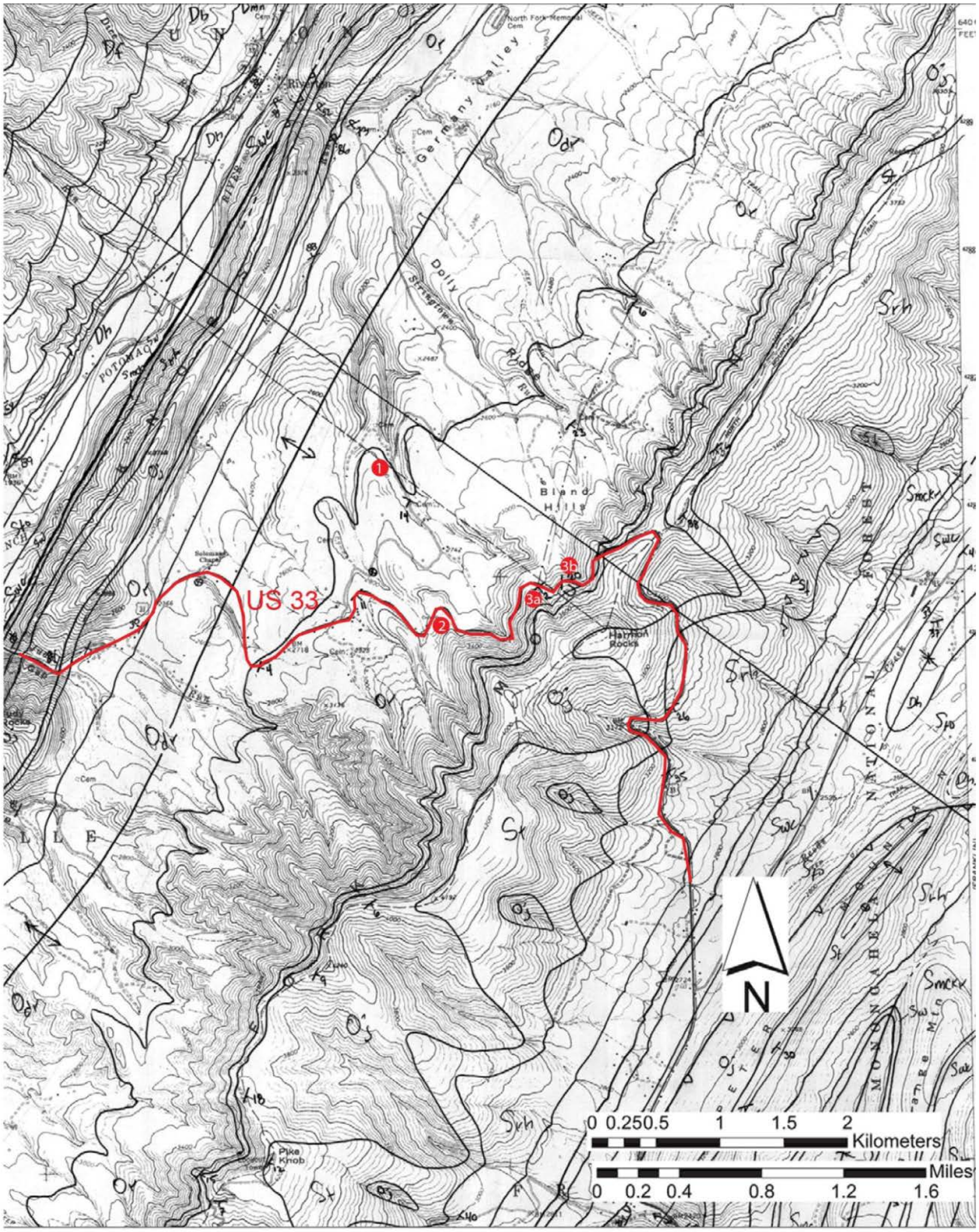

Figure 1-7. Outcrop locations in Germany Valley, West Virginia. Numbers refer to field trip stops described in text and taken from Diecchio's (1986) field guide. Geology from McDowell and others (2003).

Stop 1 is located about 2.5 mi east of Judy Gap on Bland Hills Road. The exposure is situated on Dolly Ridge, approximately 1.6 mi north of the intersection of U.S. 33 and Bland Hills Road. At this location, the Dolly Ridge Formation (map symbol Ot) is comprised of dense, dark gray, fine-grained, medium- to thin-bedded limestone. The limestone beds weather to yellow brown and are interbedded with olive gray shales. The Dolly Ridge is also known to contain bentonites; however, no bentonite beds have been identified at this location. The limestone beds are interpreted by Rodgers (1968) to have been deposited in the latter part of the formation of an extensive carbonate bank, formed during the Cambrian and Ordovician on the eastern margin of North America prior to the onset of Taconian clastic sedimentation. The shale beds in the Dolly Ridge are thought to represent the beginning of this Taconian clastic sedimentation and the end of carbonate deposition.

Stop 2 is located along U.S. 33 about 0.8 mi east of the intersection with Bland Hills Road. At this location, the lower part of the Utica-equivalent Reedsville Formation (map symbol Or) is exposed. The basal Reedsville is characterized by calcareous shale interbedded with laminae to thin beds of bioclastic calcarenite and rare, thin beds of calcareous siltstone. The calcareous shale is dominated by medium-gray to grayish olive sediments that weather to light gray. Fresh surfaces of the thinly interbedded bioclastic calcarenite and calcareous siltstone are medium gray, and weather to moderate yellow brown and light olive gray, respectively. Fossils are present in this part of the section and include brachiopods (*Rafinesquina*, *Sowerbyella*, and *Zygospira* sp.), graptolites (*Diplograptus* and *Climacograptus* sp.), trilobites (*Cryptolithus* sp.), cephalopods (*Orthoceras* sp.), gastropods (*Sinuites* sp.) and crinoid stalks and columnals. The bioclastic debris is interpreted to have been deposited as parts of storm event beds, which represent the transition from older carbonate sedimentation to Taconian clastic-dominated deposition.

The third Upper Ordovician outcrop exposed in Germany Valley (Stop 3a) is located approximately 0.7 mi east of Stop 2. This outcrop is comprised of the middle portion of the Reedsville Formation and is primarily light olive-gray shale. The shale is thinly interbedded with medium gray, calcareous siltstone that weathers grayish orange. Rarely present are thin interbeds of medium gray, bioclastic calcarenite and medium to thin interbeds of fine-grained, yellow-brown sandstone. The percentage of sandstone beds increases upsection as the percentage of carbonate sediments decreases, demonstrating the progressive formation of a clastic wedge that precludes carbonate sedimentation.

The uppermost portion of the Reedsville Formation is exposed at the final Reedsville outcrop in Germany Valley (Stop 3b), located approximately 0.2 mi from Stop 3a. At this location, the Reedsville is characterized by medium gray, fossiliferous, bioturbated mudstone that weathers to light gray. The faunal assemblage of the upper Reedsville differs completely from the biota observed lower in the section and is included in the *Orthorhynchula* assemblage biozone. The *Orthorhynchula* biozone, described by Bretsky (1969, 1970), contains shallow-water fauna. Examples of fauna of the *Orthorhynchula* biozone that have been described at this location include brachiopods (*Orthorhynchula* and *Lingul*a sp.), bivalves (*Ambonychia*, *Ischyrodonta*, *Modiolopsis*, and *Tancrediopsis* sp.), trilobites (*Isotelus* sp.) and phosphatized gastropods (*Plectonotus* sp.). Phosphate is also present in nodules in the uppermost Reedsville. This dramatic change in lithologic character and fossil content between the lower and upper parts of the Reedsville is thought to represent a eustatic sea-level drop associated with Late Ordovician glaciation (Diecchio, 1985).

Sediments of the upper Reedsville pass gradationally into the Oswego Sandstone at the top of the section exposed at Stop 3b. The Oswego sandstone marks the upper portion of the overall coarsening-upward cycle of clastic wedge sedimentation that starts at the base of the Reedsville. The contact between the two units is marked arbitrarily at the base of the lowest cross-bedded sandstone located above the *Orthorhynchula* assemblage biozone.

In addition to the Germany Valley outcrops, additional Upper Ordovician exposures are located to the southwest (near Hardscrabble, WV) and to the northeast in the Lost River area. Maps of the exposures are provided (Figures 1-8 through 1-10), but the outcrops have not been extensively described and are less accessible than the section exposed in Germany Valley.

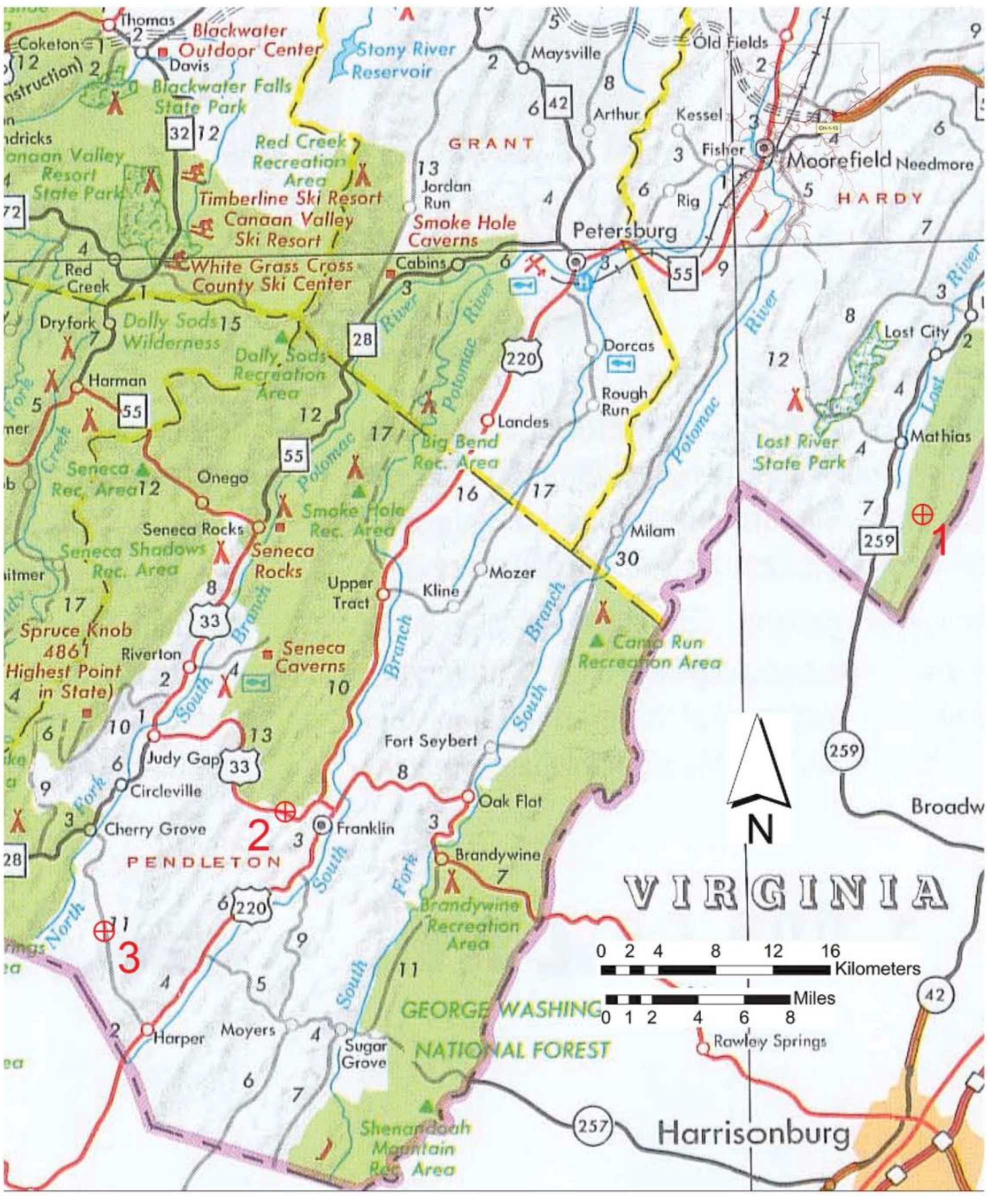

Figure 1-8. Ordovician outcrop locations in eastern West Virginia. 1: Lost River area, 2: Germany Valley, 3: Hardscrabble, West Virginia.

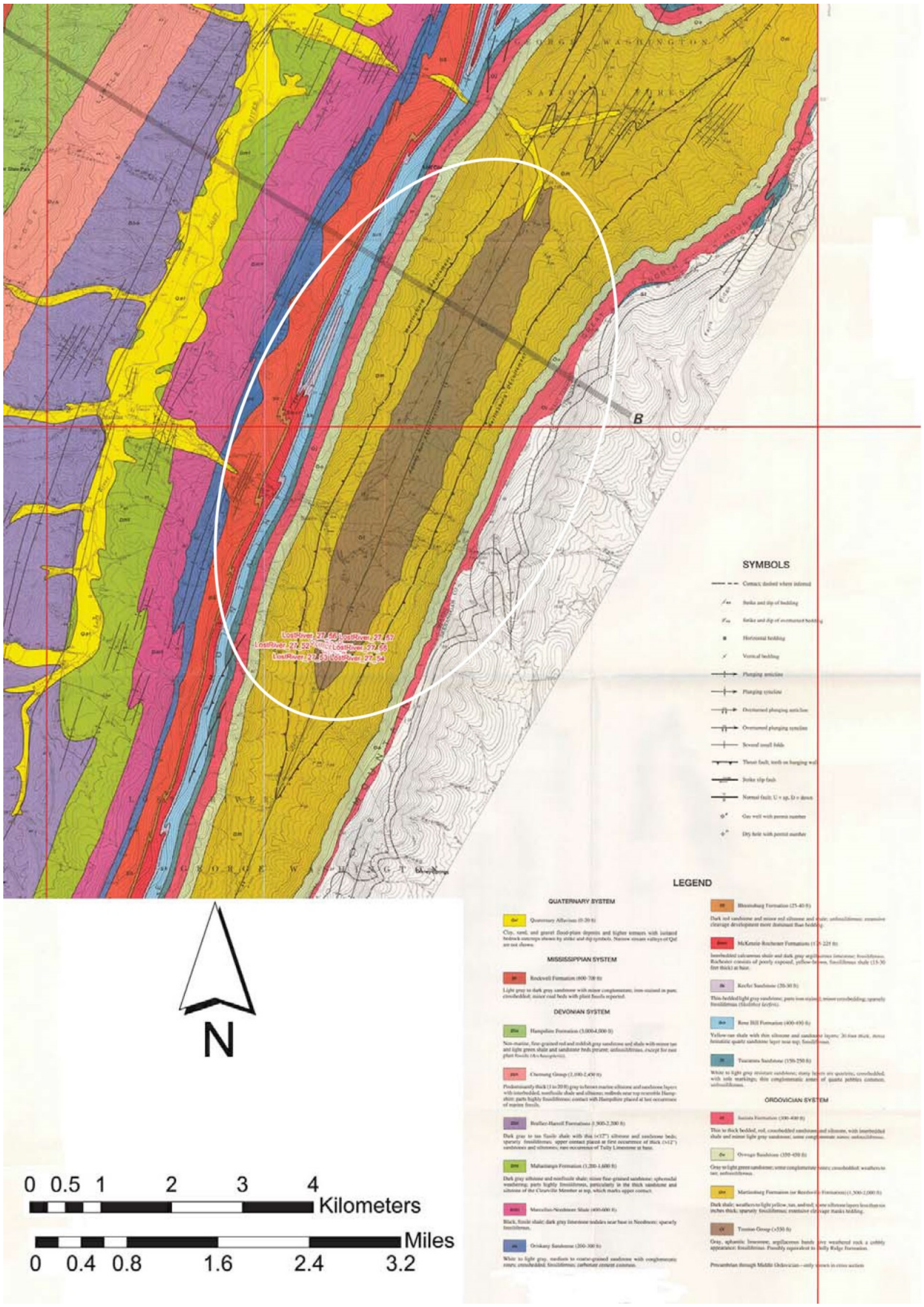

Figure 1-9. Ordovician exposures near Lost River, West Virginia. Exposures are thought to be of the Martinsburg Formation and may be incorrectly mapped as Trenton Group (=Lexington/Trenton Formation of this Study).

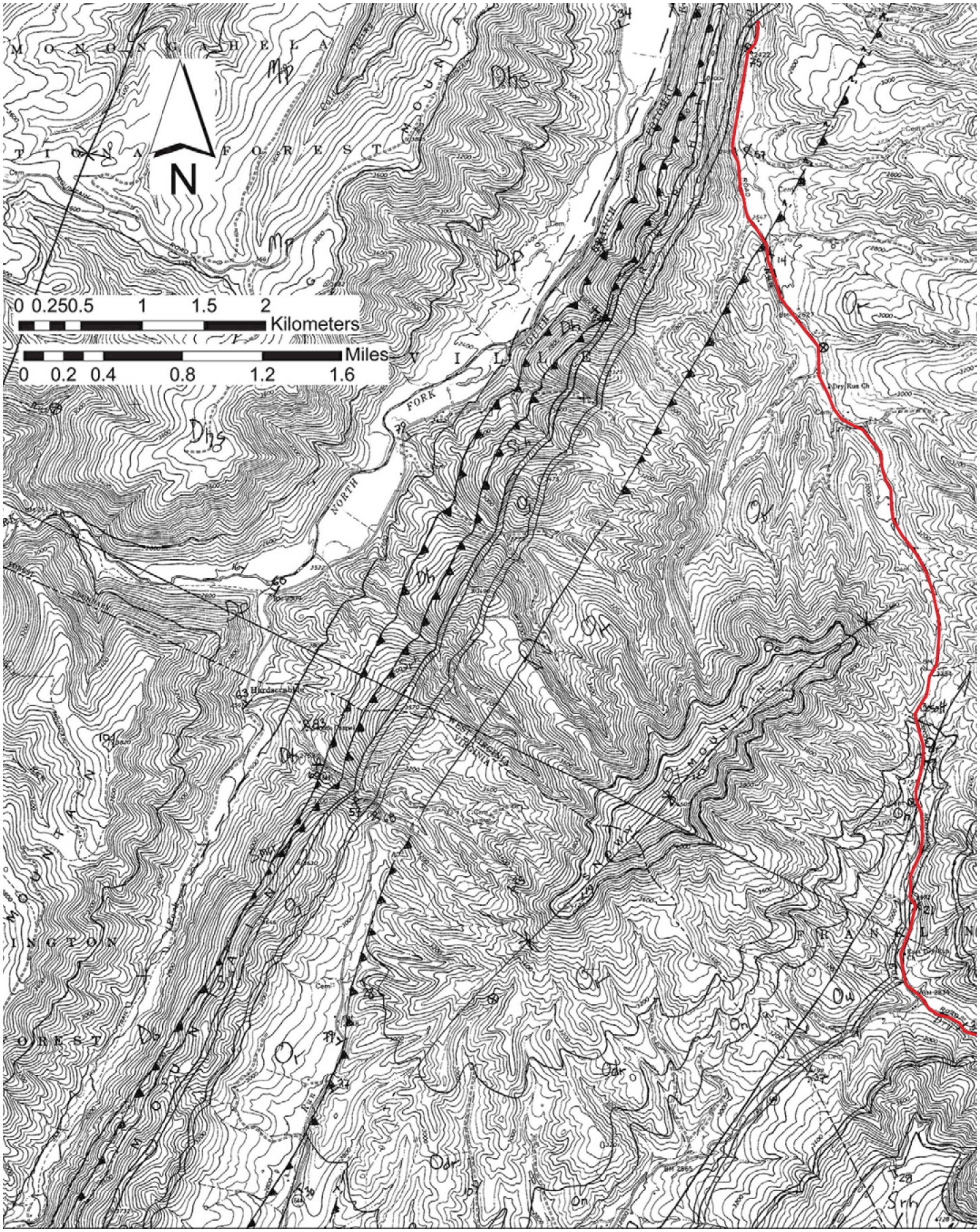

Figure 1-10. Reedsville Formation (map symbol Or) exposures near Hardscrabble, West Virginia. Also exposed in the area are older, Ordovician carbonates as well as Eocene intrusives. Geology from McDowell and others (2001).

1.3 Pennsylvania

Emmons (1842) named the Utica Shale for 75 ft of black shale lying between the Lorraine shales and the Trenton limestones (=Lexington/Trenton Formation of this Study) exposed near the town of Utica, New York. Over the years, the term "Utica" came to mean different things to different geologists. Today, the name is used in New York alternately as a group (i.e., Brett and Baird, 2002) and as a facies name (i.e., Baird and Brett, 2002; Lehmann and others, 1995, used the old Ken Caster term "magnafacies"). In this outcrop description, we follow the example of Baird and Brett (2002) in using the term Utica facies because it includes a variety of formation/member names across the state and across the Appalachian basin (Figure 1-11).

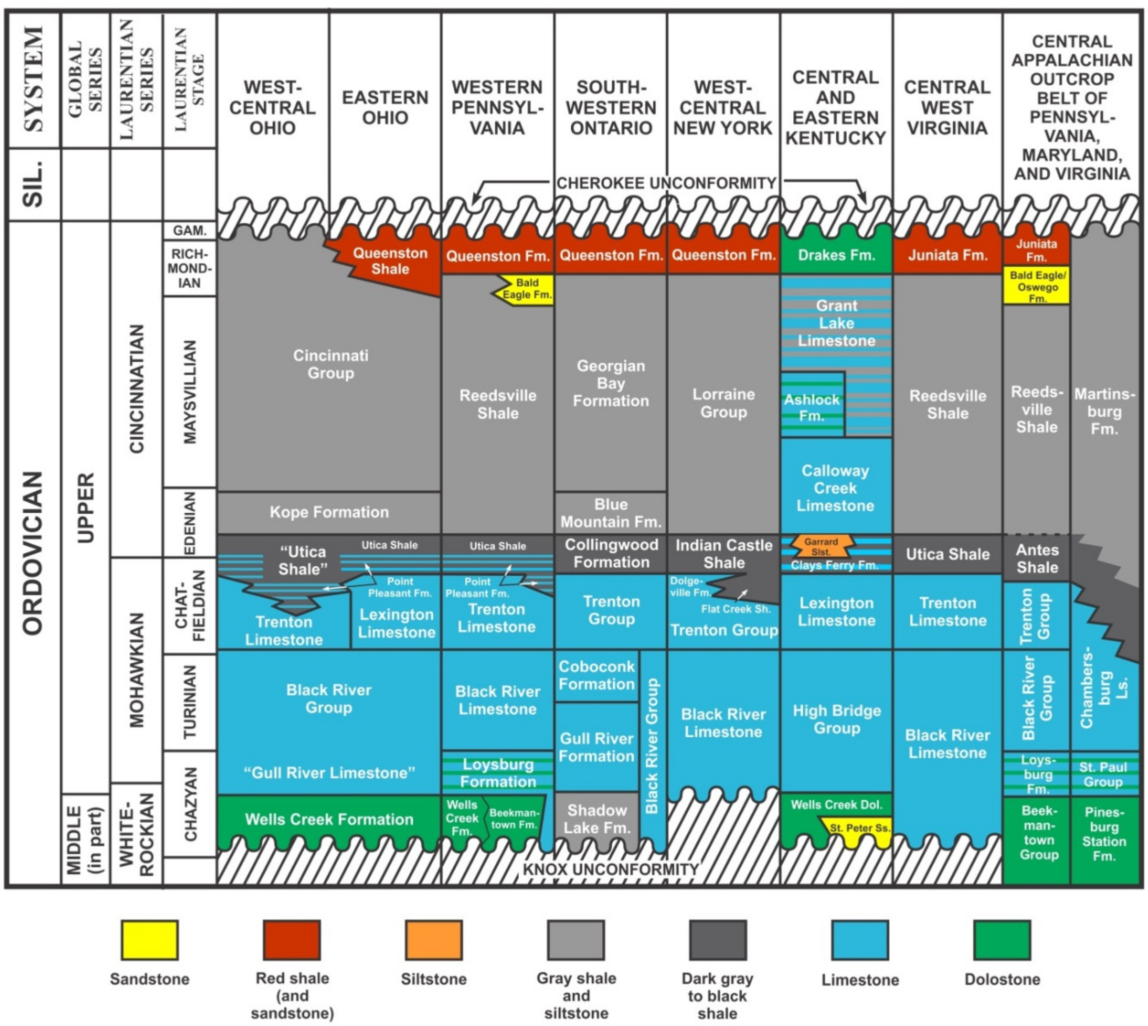

Figure 1-11. Correlation of Utica facies rocks in the subsurface of the Appalachian basin, and in the outcrop belt of Pennsylvania, Maryland and Virginia. Modified from Harper (2013a).

1.3.1 Utica Facies in Pennsylvania

The Utica facies in Pennsylvania is represented in the subsurface of the Appalachian Plateau by the Utica Shale and, in most of the Plateau, the underlying Point Pleasant Formation. In outcrop in central and eastern Pennsylvania, however, the Utica facies goes by a variety of names, depending on the overall stratigraphy of the area (Figure 1-12) and the philosophy of the geologist(s) working the outcrops.

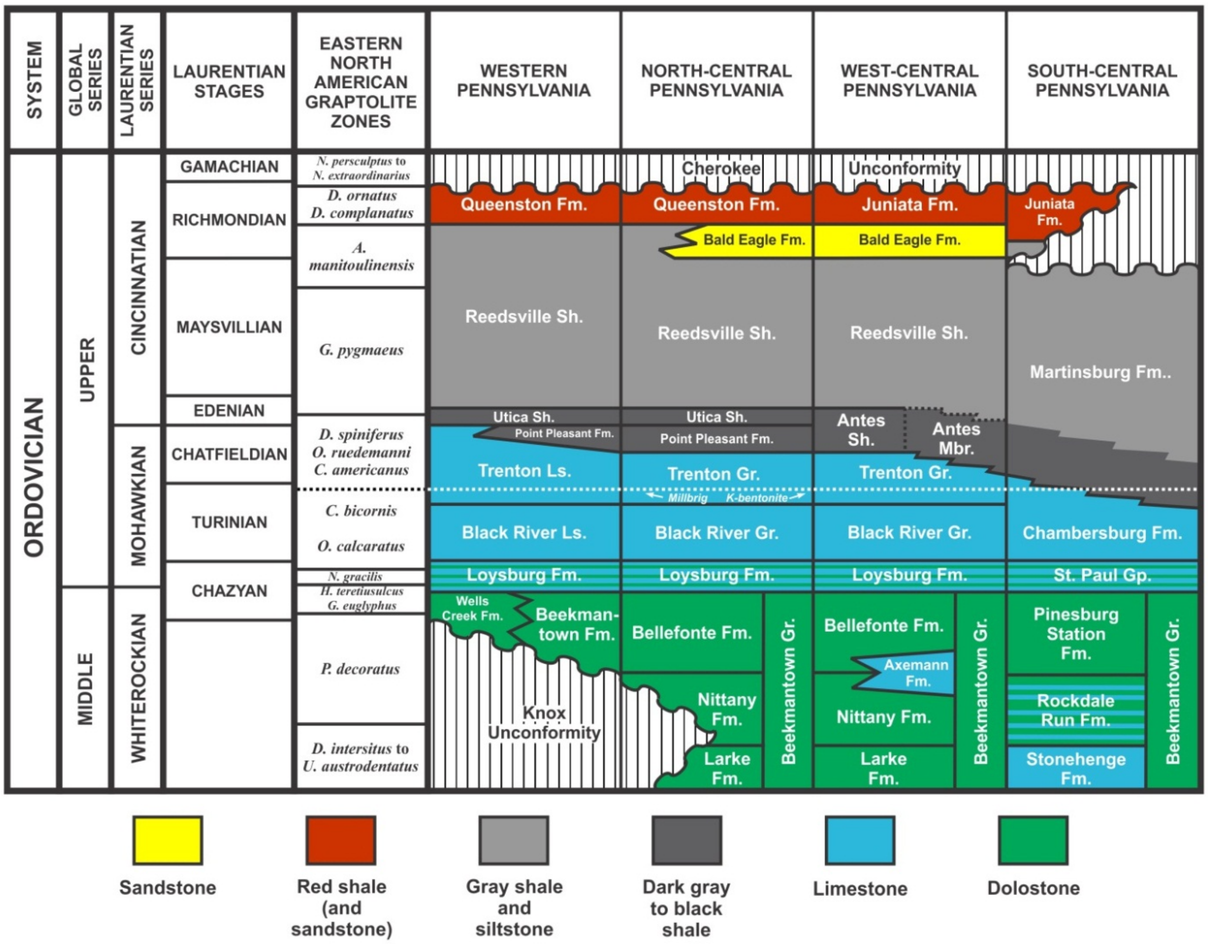

Figure 1-12. Correlation of Middle and Upper Ordovician strata in western and central Pennsylvania (modified from Harper, 2013b).

1.3.2 North-Central Pennsylvania Outcrop

Arguably, the most classic exposure of Utica facies rocks in north-central Pennsylvania occurs at Antes Gap in Lycoming County (Figure 1-13), a water gap formed where Antes Creek carved an entrenched, meandering channel through Bald Eagle Mountain on its way north to the Susquehanna River. It was here that Kay (1944) named the Antes Shale for about 400 ft of dark-gray to black shale lying between the dark-gray siltstone and shale of the Reedsville Formation and the limestone of the Coburn Formation (uppermost Lexington/Trenton Formation). Gross (1955), in documenting the lithology and paleontology of the Antes Shale and the overlying Reedsville Formation at this locality, disagreed with Kay's (1944) consideration of the Antes as a separate formation. Instead, following the lead set by generations of geologists mapping in central Pennsylvania, he placed both lithologies in the Reedsville Shale but divided the formation into an upper "Antes Creek Shale and Siltstone Member" and a lower "Antes Black Shale Member" (Figure 1-14).

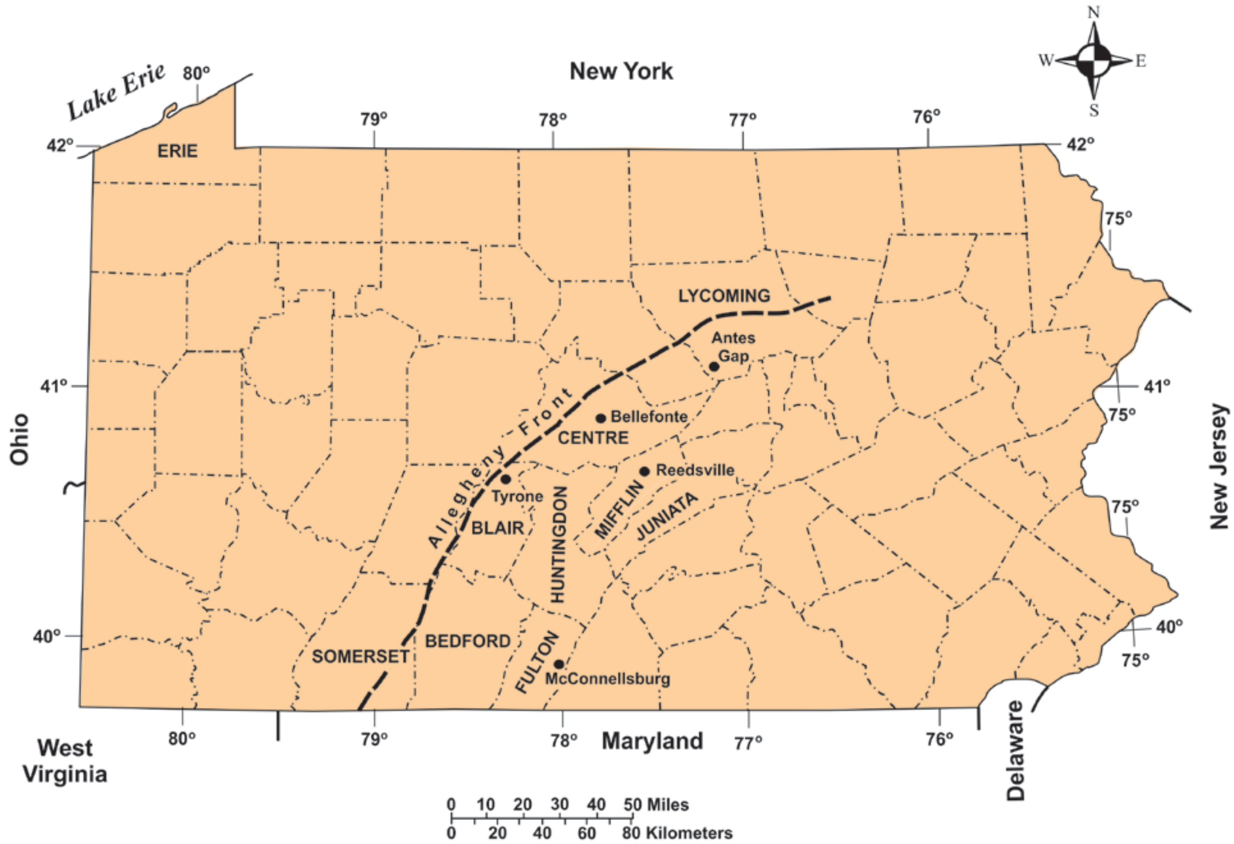

Figure 1-13. Locations of outcrops and other features in Pennsylvania discussed in this section. Names in all caps are county names.

Faill and Wells (1977) determined that, lithologically, the Antes comprises about 330 ft (somewhat less than thickness measured by Kay, 1944) of dark gray to black, fissile, massive- to thin-bedded, calcareous shale with interbeds of calcilutites, calcisiltites and slightly fossiliferous calcarenites in the area of the type locality in north-central Pennsylvania. Limestone beds are concentrated in the middle of the formation where they comprise about 25 percent of the lithology. Only about 10 percent of the lower Antes consists of limestone, and the upper beds have hardly any at all. Faill and Wells (1977) found that the contact with the underlying Lexington/Trenton Formation was gradational over approximately 50 ft, unlike in New York where the contact in distinctly disconformable; the upper contact with the overlying Reedsville Shale occurs more rapidly as a change through about 10 ft from black calcareous shale to olive-gray, non-calcareous, silty shale (Faill and Wells, 1977).

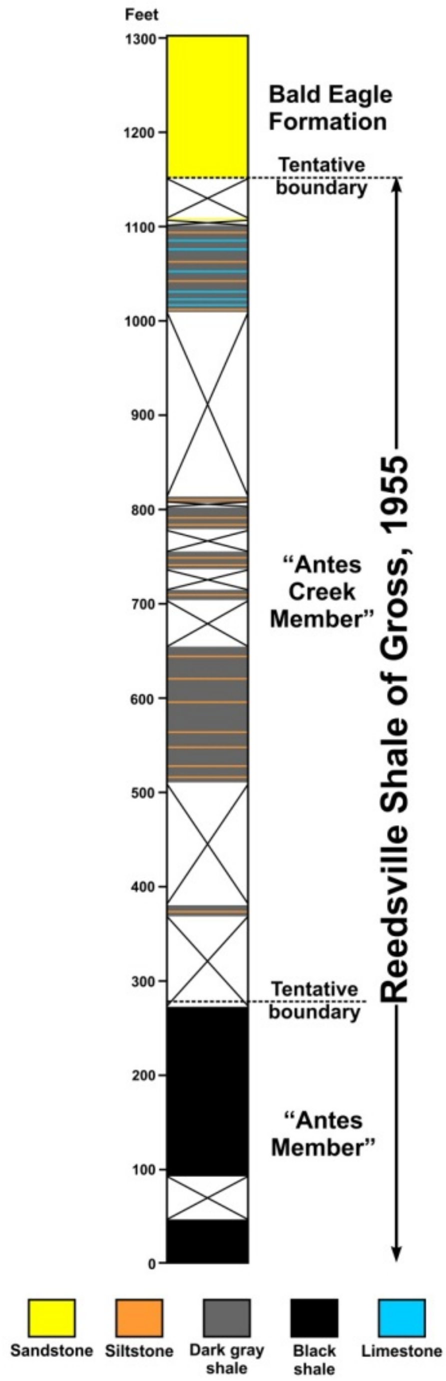

Figure 1-14. Stratigraphic section at Antes Gap measured by Gross (1955). Modified from Harper (2013b).

Figure 1-15 shows the lowermost exposure of Antes Shale in an abandoned borrow pit across Antes Creek from the intersection of PA 44 and PA 880. Gross (1955) determined that the rocks that crop out at Antes Gap dip 31°NE and strike N58°E.

Figure 1-15. Photograph of the Antes Shale type locality at Antes Gap, Lycoming County, Pennsylvania.

The Antes Shale at Antes Gap represents just one small exposure of the sequence of dark colored, fine-grained, often calcareous mudstones that carry an indisputable Late Ordovician fauna – the Utica facies. Tracing the Utica lithology around the outcrop in Pennsylvania is quite challenging because these rocks are easily deformed tectonically and rarely crop out. They weather easily into clayey loam with a few shale chips (Pierce, 1966; Faill and Wells, 1977), and on the slopes of mountains they tend to be covered by colluvium. The following section reflects the general concept of the Utica (and Lorraine) facies around central Pennsylvania.

1.3.3 West-Central Pennsylvania

Throughout most of central Pennsylvania, the Utica facies is considered to be merely the basal subset of rocks that make up the Reedsville Formation, although in a few places geologists have used the term "Antes Member" for these rocks. The Reedsville Formation comprises a thick sequence of dark gray shales and thin interbedded siltstones with calcareous black shales at the base. Originally, the First and Second Geological Surveys of Pennsylvania (Rogers, 1858; Lesley, 1892) had mostly followed New York's terminology, calling the upper dark gray shales "Hudson River shales" (or slates) and the lower black shales "Utica shales" (or slates). (The term "slate" referred to the equivalent Martinsburg Formation in eastern Pennsylvania where this sequence of rocks provided a lucrative business in roofing slates.) Ulrich (1911) eventually named the Reedsville for exposures at Reedsville, Mifflin County, Pennsylvania (Figures 1-13 and 1-16). Since that designation, 20th-century geologists working in central Pennsylvania have used the name Reedsville for the entire sequence, and this name has even found its way into some publications relating to subsurface formations (e.g., Fettke, 1961). The Reedsville is equivalent to the Lorraine Shale of New York, the Kope Formation and lower part of Cincinnati

Group of Ohio, and most of the upper Martinsburg Formation of southeastern/south-central Pennsylvania, Maryland, Virginia, West Virginia and eastern Tennessee (Figure 1-11).

Figure 1-16. Photograph of the outcrop of basal black shale and interbedded limestone of the Reedsville Formation and underlying Coburn Formation (uppermost Lexington/Trenton Formation) near the Reedsville type locality, Reedsville, Mifflin County, Pennsylvania.

Butts and Moore (1936; also Butts and others, 1939; and Butts, 1945), described the Reedsville as about 1000 ft of dark calcareous shales with thin layers of fossiliferous limestones. Gross (1955) and Washington (2009) included thin sandstones or siltstones that increase in thickness and coarseness upward. Like most geologists working the Appalachian Ordovician in Pennsylvania, Butts and Moore (1936) and Butts and others (1939) did not separate the lower, very thin, brown to black shale containing the trilobite *Triarthus eatoni* (Hall) (see Figure 1-17) and graptolites from the upper sandy shales when describing the Reedsville Formation in the Bellefonte and Tyrone areas of Centre, Blair and Huntingdon counties (Figure 1-13). Butts and Moore (1936) did, however, describe portions of the formation as being so highly carbonaceous and graphitic that it was once prospected for coal.

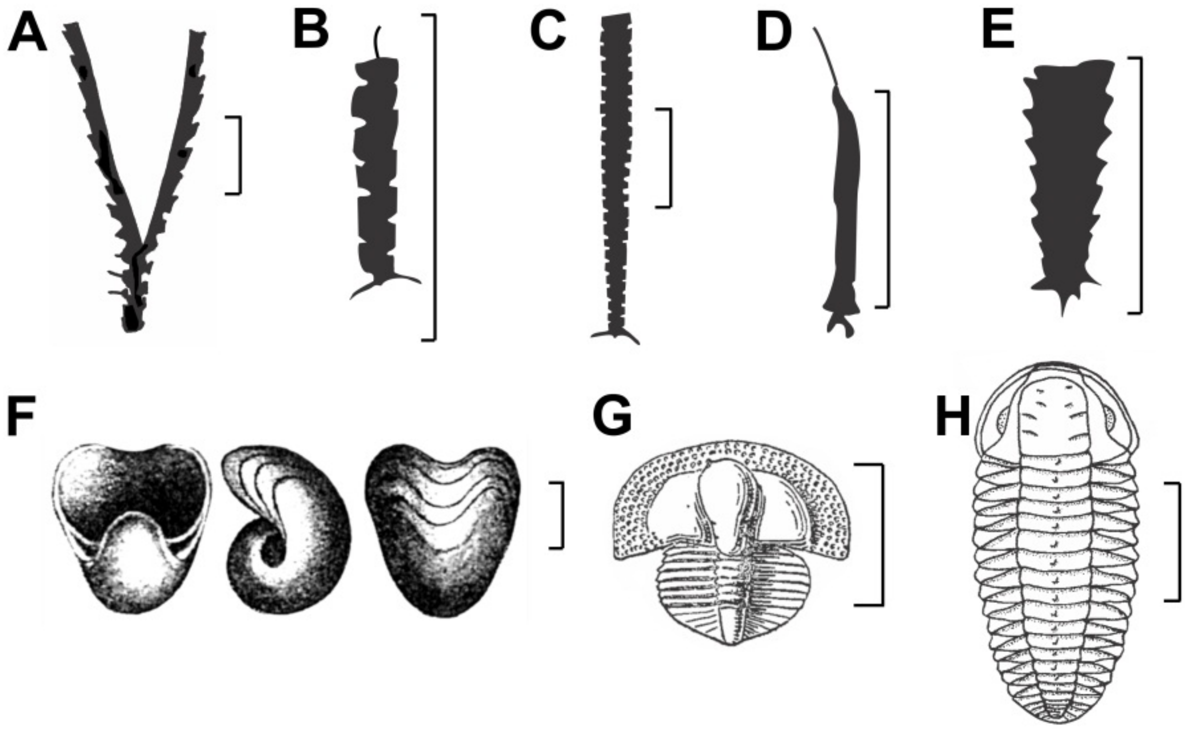

Figure 1-17. Representative Utica facies fossils found in Pennsylvania. A – *Dicranograptus nicholsoni* Hopkins; B – *Diplacanthograptus spiniferus* (Ruedemann); C – *Climacograptus bicornis* (Hall); D – *Corynoides americanus* Ruedemann; E – *Orthograptus ruedemanni* Ruedemann; F – *Sinuites cancellatus* (Hall); G – *Cryptolithus bellulus* (Ulrich); H – *Triarthus eatoni* (Hall). All scale bars = 10 mm, except D and E, scale bars = 5 mm.

Based on outcrop studies published since 1945, it appears that the Reedsville thickens toward the south and east. It ranges from roughly 1230 ft thick in Lycoming County (Faill and Wells, 1977) to about 2500 ft in northwestern Fulton County (Pierce, 1966, although there is some question as to whether these rocks should be called Reedsville or Martinsburg – see Figure 1-18 and discussion below). The Reedsville thickens from about 1000 ft near the Allegheny front (Butts and Moore, 1936; Butts, 1945; Doden, 2005; Doden and Gold, 2008) to about 1800 ft in the central depocenter of Huntingdon, Mifflin and Juniata counties (McElroy and Hoskins, 2007; 2008). In contrast, the Reedsville in the subsurface of the Plateau thickens from approximately 800 ft in the northwestern corner of Erie County (Fettke, 1961) to more than 2000 ft in Somerset and Bedford counties (data from Pennsylvania Geological Survey files; see Figure 1-13 for locations of place names).

1.3.4 South-Central Pennsylvania

The Martinsburg Formation, which is the south-central and eastern Pennsylvania equivalent of the Reedsville Formation, was named for exposures in the vicinity of Martinsburg, West Virginia (Geiger and Keith, 1891; Darton, 1892). It consists of as much as 2400 ft of shale and sandstone in south-central Pennsylvania and adjacent Maryland and gets progressively thicker to the southeast (Woodward, 1951). The lower 650 ft of the Martinsburg consists of black carbonaceous and calcareous shales that are interbedded with limestones containing a distinctly "Trenton" fauna in the basal 100 ft (Bassler, 1919). Based on the lithology alone, this lower 650 ft is unmistakably representative of the Utica facies of the Martinsburg. From top to bottom, the Utica facies consists of: (1) more than 500 ft of black, carbonaceous, fissile, unfossiliferous shale; (2) more than 100 ft of black, platy to fissile, calcareous shale containing a fauna of trilobites (*Cryptolithus*; see Figure 1-17) and graptolites (Woodward, 1951); and (3) about 10 ft of black, muddy, rubbly to slabby limestone and shale that has been called the "*Sinuites* bed" or "*Sinuites* zone" for the characteristic gastropod fossils (Figure 1-17) that occurs in it (Bassler, 1919; Craig, 1949; Woodward, 1951).

Pierce (1966) and Beares and others (2002), working in the area around McConnellsburg, Fulton County, Pennsylvania (Figure 1-13), called the Ordovician clastic sequence above the Lexington/Trenton Formation carbonates "Reedsville" rather than "Martinsburg." Pierce (1966) had deferred to the existing Geologic Map of Pennsylvania for nomenclatural use while mapping in the McConnellsburg area, and Beares and others (2002) followed suit. Although the question of accurate nomenclature needs to be resolved, the name Martinsburg is being used in place of Reedsville for this region of Pennsylvania.

1.3.5 Significance of the Utica Facies in Pennsylvania

Graptolites, which comprise the majority of the fauna in the Utica facies in Pennsylvania, are one of the major faunal groups used for Ordovician biostratigraphy. Kay (1944) found the graptolite *Dicranograptus nicholsoni* Hopkins and the trilobite *Triarthus eatoni* (Hall) (Figure 1-23) are common at the Antes type locality in Lycoming County. Butts and others (1939) reported *D. nicholsoni* and other graptolites in the basal black shale of the Reedsville in the Tyrone area of Blair County. Goldman and others (1994) considered *D. nicholsoni* to be part of the constituent fauna of the *Diplacanthograptus spiniferus* graptolite zone, which falls within the upper Chatfieldian Stage (upper Mohawkian Series) and/or lower Edenian Stage (lower Cincinnatian Series) of the Upper Ordovician (Figures 1-18 and 1-23). The occurrence of *D. nicholsoni* in the Antes Shale/basal Reedsville Formation (Utica facies) in north-central and west-central Pennsylvania means the Utica facies in those areas correlates to the Lower Indian Castle Shale of New York (Figure 1-11).

Beares and others (2002) placed the lower black shale beds (Utica facies) of the Martinsburg at McConnellsburg in south-central Pennsylvania in the *Climacograptus bicornis* graptolite zone, which falls within the upper Turinian Stage (middle Mohawkian Series) (Figures 1-12 and 1-17).

The entire Utica facies of eastern West Virginia and northern Virginia contains numerous K-bentonite beds (Craig, 1949), including one at the base of the Martinsburg that Kolata and others (1996) used chemical fingerprinting to identify as the Millbrig K-bentonite. The Millbrig is a significant ashfall that has been used for isochronous correlation throughout eastern North America and northern Europe. The Millbrig correlates with the top of the C. bicornis zone throughout eastern North America (Kolata and others, 1996), which places it within the upper Turinian Stage (middle Mohawkian Series) (Figure 1-12). Therefore, the Utica facies in south-central Pennsylvania, eastern West Virginia, and northern Virginia falls within that stage as well. Parris and Cruikshank (1992) also acknowledge that the basal beds of the Martinsburg in New Jersey and eastern Pennsylvania fall within the *C. bicornis* graptolite zone. Therefore, it appears that the basal black shales/slates (Utica facies) of the Martinsburg Formation correlate to the lower Lexington/Trenton Formation and/or upper Black River Limestone.

In the classic Union Furnace section adjacent to the Juniata River on the Centre-Huntingdon County border, the Millbrig K-bentonite occurs about 20 ft above the contact between the Nealmont and Salona formations (lower Lexington/Trenton Formation) (Laughrey and others, 2004). At this locality, the Millbrig lies approximately 300 ft below the base of the Antes Shale. This means that the Utica facies of the Martinsburg is significantly older than the Antes Shale in Centre and Lycoming counties. As such, the Martinsburg's Utica facies is actually older than the Flat Creek Shale of New York State (Figure 1-11), which is in the lower Corynoides americanus and Orthograptus ruedemanni zones (Goldman and others, 1994) (Figures 1-18 and 1-23). The basal black shales of the Martinsburg, in fact, are most likely the oldest Utica facies rocks in the Appalachian basin.

1.4 New York

New York has prepared outcrop descriptions for three localities in New York, two describing the Flat Creek Formation (Logana Member equivalent in New York) (Outcrops 1 and 2) and a third describing the Dolgeville (Upper Lexington/Trenton member equivalent) and Indian Castle formations (Utica and Point Pleasant equivalents) (Outcrop 3). These narratives are provided in Section 1.4.1 through 1.4.3 below.

1.4.1 NY Outcrop 1 - Route 5S Amsterdam, NY – Flat Creek Formation (Utica)

This is a road cut and creek exposure (Figure 1-18) in the upper part of the Flat Creek Formation (Utica), which tends to be slightly less enriched in total organic carbon (TOC). Mineralized fractures and small faults are visible and some show clear evidence of strike-slip movement. Pyrite occurs in some laminations. A small sandstone dike can be observed, which likely formed during syn-depositional faulting.

Figure 1-18. Satellite image of Stop 1 (Route 5S and along creek).

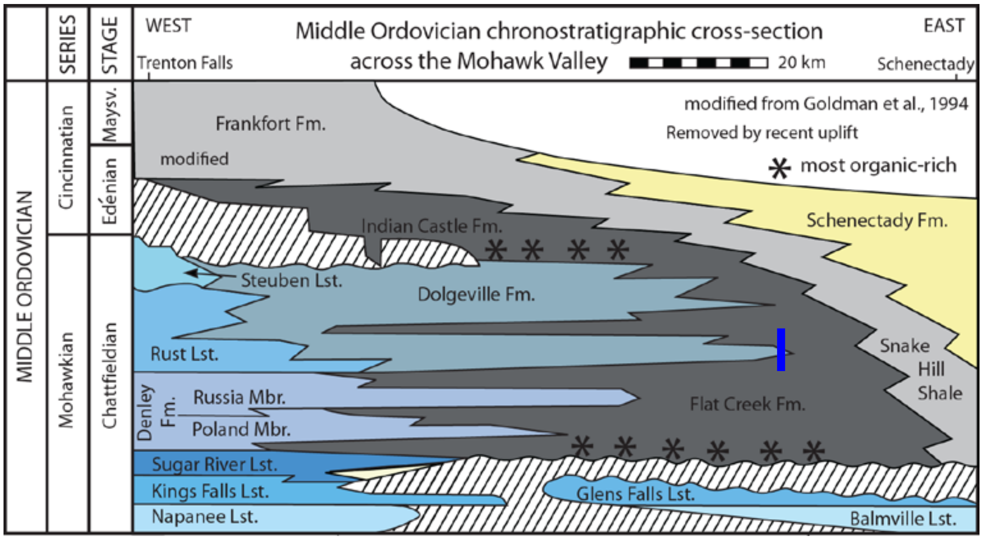

Figure 1-19. The geographic location and stratigraphic position of Stop 1 are shown within the regional facies diagram. Outcrop is in Flat Creek Member of Utica Shale. The vertical blue line indicates approximate stratigraphic interval. Waterfall under bridge is on limestone-rich interval.

1.4.2 NY Outcrop 2 – Wintergreen Park, Canajoharie Creek – Flat Creek Formation (Logana Member Equivalent)

The Flat Creek section is in a beautiful canyon where an almost complete section is preserved. Samples yield TOC values of 1-3%. The main purpose of this stop is to familiarize attendees with the Flat Creek, which is a calcareous shale (20-50% calcite), with mineralized fractures common. In the southeastern part of the basin, the Flat Creek has the thickest section of relatively high-TOC organic-rich mudrock. Both mineralized and un-mineralized fractures are present. The mineralized fractures commonly show evidence for multiple episodes of movement on faults. Slickensides suggest both strike-slip and extensional faulting occur in the Flat Creek Shale. The Flat Creek Shale was deposited during a period of tectonic activity, mainly in an area that was a tectonic high immediately prior to deposition. In fact, the Flat Creek sits directly on the Knox Unconformity or a very thin section of basal Lexington/Trenton Formation in places. Normal faulting that was mainly down to the east created the space for Flat Creek deposition. There are multiple bentonites in the Flat Creek Shale, which suggests significant volcanic activity to the east.

Figure 1-20. Aerial photograph of Stop 2.

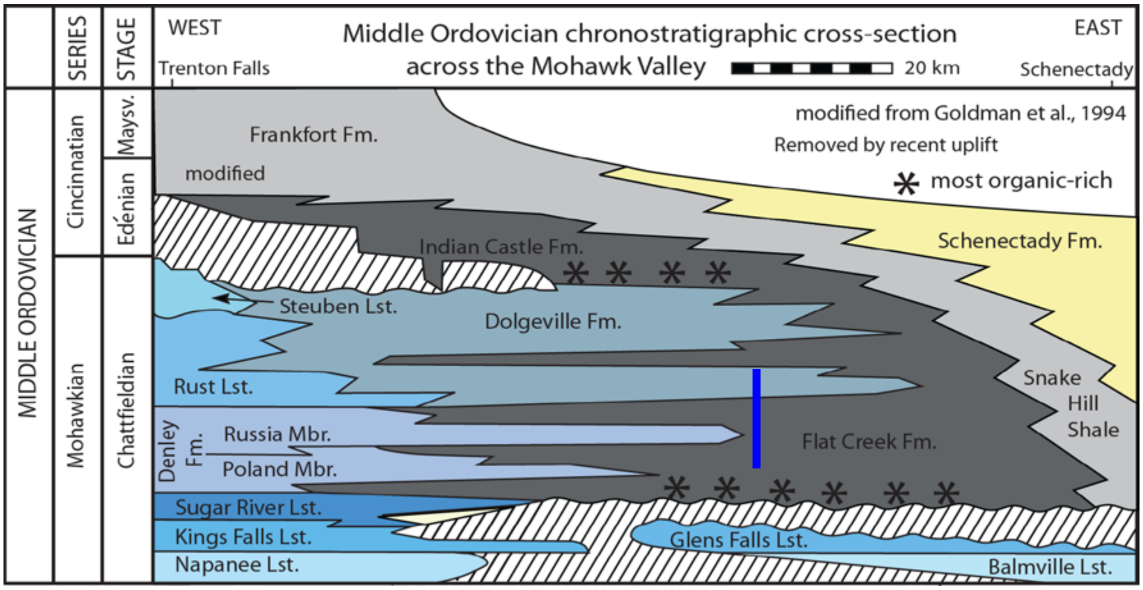

Figure 1-21. Flat Creek stratigraphic section represented by blue line (from Goldman and others, 1994).

Figure 1-22. Photograph of Flat Creek Shale in Canajoharie Creek.

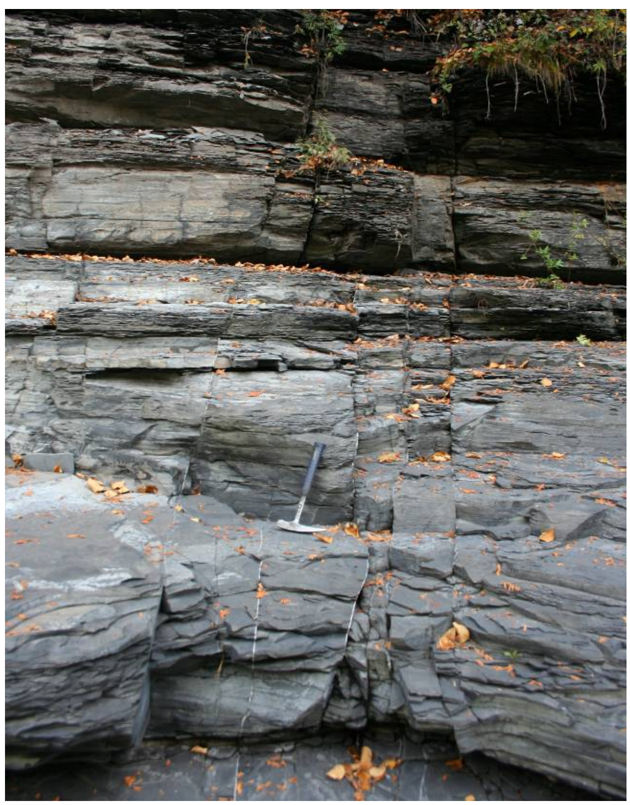

Figure 1-23. Photograph of fractures in the Flat Creek Shale.

1.4.3 NY Outcrop 3 - Paradise Road Overlook of NYS Thruway Road Cut–Dolgeville Formation (upper Lexington/Trenton member equivalent) and Indian Castle Shale (Utica and Point Pleasant equivalent)

This impressive outcrop viewed from an overlook above the New York State Thruway is probably the best exposure of the Dolgeville and Indian Castle formations. This outcrop is where the "Thruway Disconformity" was named.

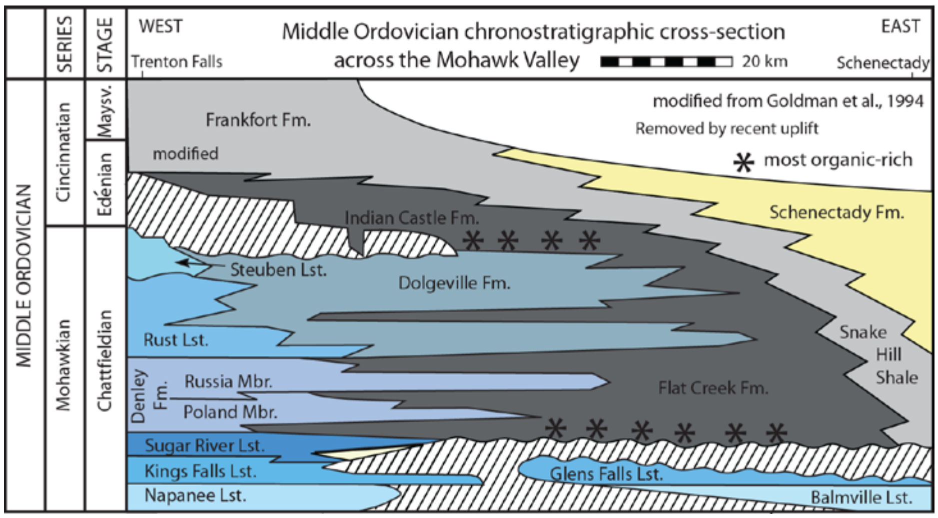

Figure 1-24. Thruway stratigraphic section (from Goldman and others, 1994).

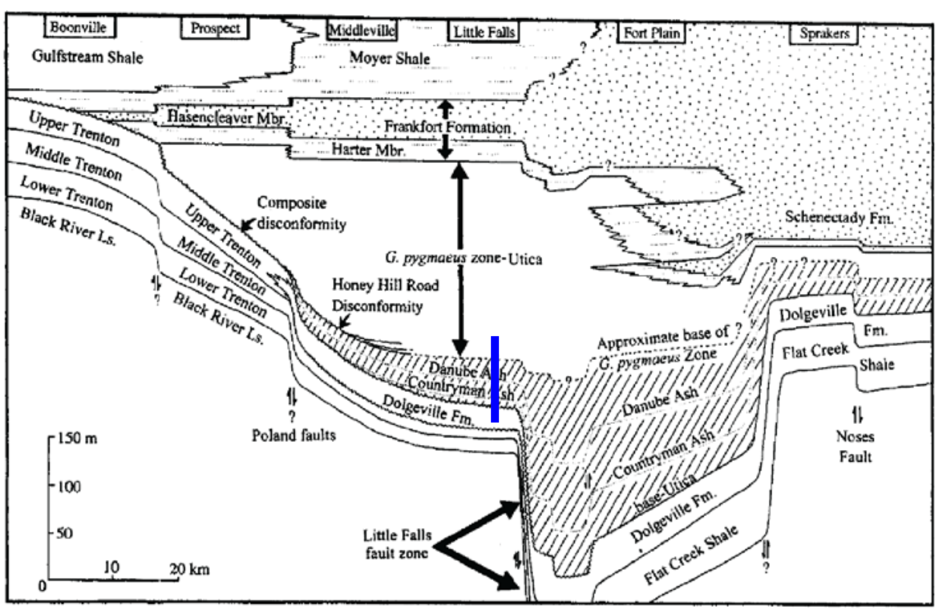

Figure 1-25. Section (blue line) on upthrown side of Little Falls Fault – dramatic thickening of Indian Castle on downthrown side to east (from Baird and Brett, 2002).

Figure 1-26. Photograph of folded interbedded Dolgeville at base overlain by Lower Indian Castle.

1.4.3.1 Dolgeville Formation

The Dolgeville Formation has centimeter-scale beds of limestone with low TOC and black shale with TOC values up to 3%. Shows of gas commonly are encountered when drilling through the Dolgeville and similar-looking facies within the Lexington/Trenton Formation. There commonly are folds in the Dolgeville facies that don't appear to affect the overlying Indian Castle. This facies has been interpreted as a downslope facies between the Lexington/Trenton Formation and Utica Shale. There are clear high-frequency changes in depositional conditions, probably higher frequency than Milankovitch-band eustatic sea-level changes.

There may be hundreds of thousands or a million years of rock record missing at the contact between the Dolgeville and the overlying Indian Castle at the Thruway Disconformity. This disconformity can be traced far to the west. It is likely a subaerial disconformity to the west, where there is no overlying organic-rich shale.

Figure 1-27. Photograph of close-up of folded Dolgeville capped by Thruway Disconformity and Indian Castle Shale.

1.4.3.2 Indian Castle Formation

There is a thin interval of the calcareous to transitional lower Indian Castle Shale (Point Pleasant equivalent) overlain by the more fissile, clay-rich upper Indian Castle (Utica equivalent). There are commonly benthic fossils in the lower Indian Castle Shale, suggesting at least partially oxygenated water. The calcareous and transitional zones generally have higher TOC values. There are some bentonites that are iron-rich and weather to an orange rust color. The Indian Castle is not folded and has longer fractures than the underlying Dolgeville.

Figure 1-28. Photograph of common fossil debris in the basal Indian Castle Shale.

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