2. Road Log and Stop Descriptions

by
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with contributions from
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Road Log - Saturday 25, 2004

Total mileage
0.0
Departure from Holiday Inn Express, 411 West Spring Street, New Albany, Indiana.

31.0
Stop 1: I-65, Exit 112, Bernheim Forest, Kentucky (Illinois Basin): Roadcut exposure of the New Albany Shale on the west side of the I-65 South at the intersection with KY-245 (37° 55' 26"N, 85° 41' 22"W (WGS84/NAD83), USGS Shepherdsville Quad; Fig. 2.1.1).

125.0
Stop 2A: KY-52, between Richmond and Irvine, Kentucky (Appalachian Basin): Roadcut exposure of the Ohio Shale on the north side of the road, approximately 6 miles west of Irvine, across from the Emmanuel Baptist Church (37° 42' 12"N, 84° 02' 01"W (WGS84/NAD83), USGS Panola Quad; Fig. 2.2.1).

0.4
Stop 2B: KY-52, between Richmond and Irvine, Kentucky (Appalachian Basin): Convenient roadcut exposure of the upper portions of the Ohio Shale on the north side of the road (37° 42' 04"N, 84° 02' 24"W (WGS84/NAD83), USGS Panola Quad; Fig. 2.2.1).

65.6
Stop 3A: Junction City, Kentucky (Cincinnati Arch): Spectacular roadcut exposure of shales that exhibit a combination of aspects of the Chattanooga, New Albany, and Ohio Shales on the east side of US-127, approximately 3 miles south of Junction City (37° 32' 54"N, 84° 48' 18"W (WGS84/NAD83), USGS Junction City Quad; Fig. 2.3.1).

0.2
Stop 3B: Junction City, Kentucky (Cincinnati Arch): Roadcut exposure of the upper portion of the Devonian black shale succession (37° 33' 23"N, 84° 48' 01"W (WGS84/NAD83), USGS Junction City Quad; Fig. 2.3.1).

97.8
Return to Holiday Inn Express, 411 West Spring Street, New Albany, Indiana.

The location of well 1-3 Kavanaugh and field stops 1-3 is shown in Figure 2.1 and in the overview road map on the back cover of this guidebook.

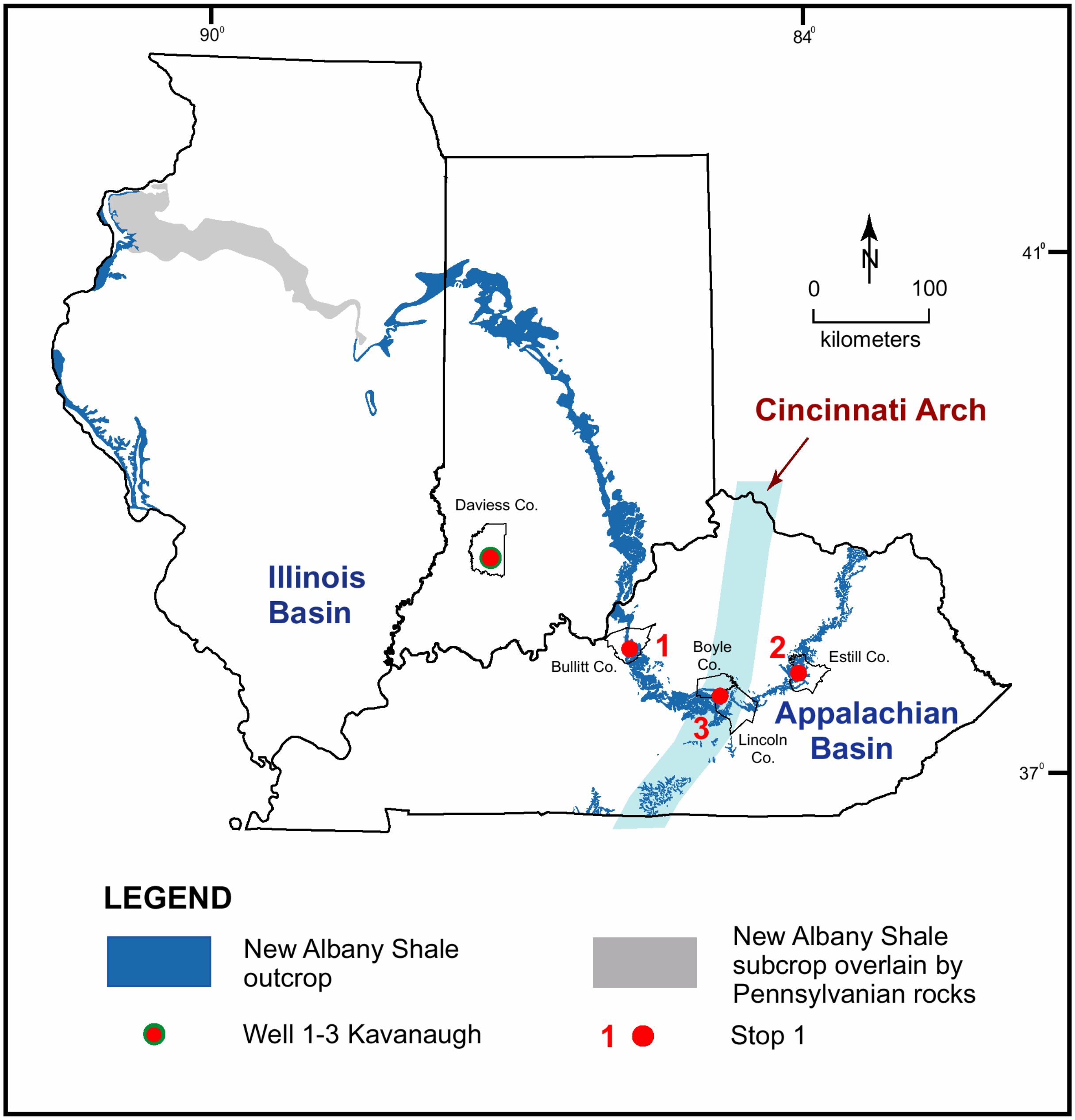


Figure 2.1: Map showing the location of well 1-3 Kavanaugh and field stops 1-3.

2.1: Stop 1, I-65, Exit 112, Bernheim Forest, Kentucky

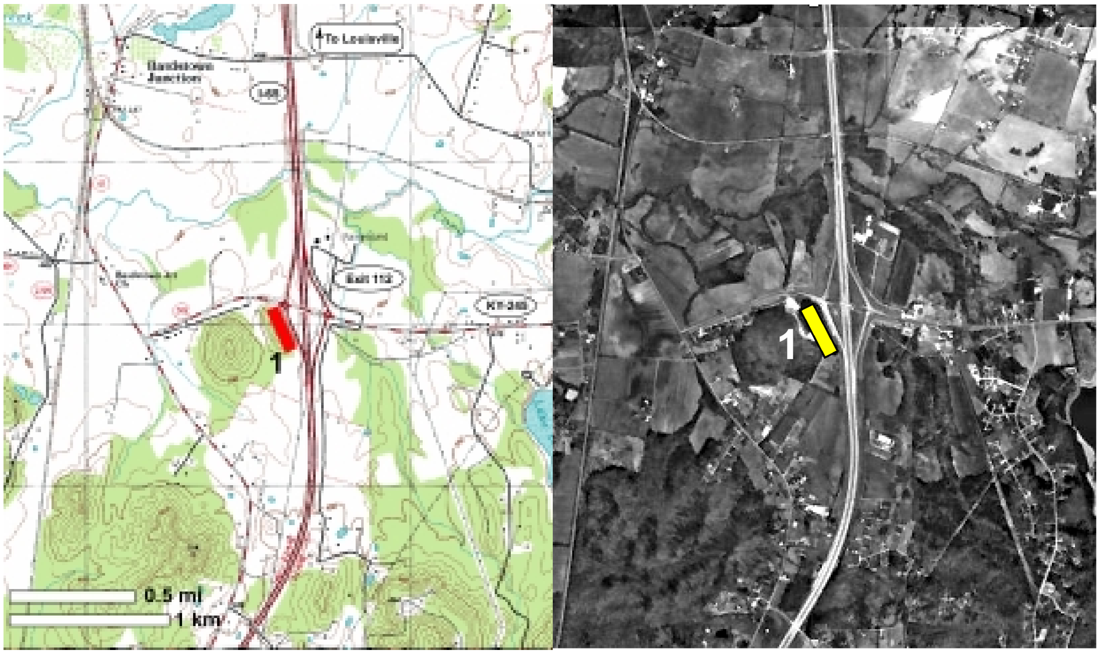


Figure 2.1.1: Stop 1 is a roadcut along the southbound entrance ramp to I-65 at the intersection with KY-245 (Exit 112). The outcrop is marked in red on the topographic map at left and yellow on the air photo at right.

Stop 1: This outcrop exposes a succession of the Devonian New Albany Shale that was deposited in the eastern part of the Illinois Basin (Fig. 2.1). The Middle Devonian Beechwood Limestone outcrops at the base of the exposure (Fig. 2.1.2) and is unconformably overlain by the Middle to Upper Devonian New Albany Shale. The latter is approximately 22 m thick at this location and consists in ascending order of the Blocher, Morgan Trail, Camp Run, and Clegg Creek Members (Fig. 2.1.2). These members were proposed by Lineback (1970) in his classical study of the New Albany and have been in use ever since. Lineback (1970) and subsequent researchers (e.g., Hasenmueller, 1993, Hasenmueller et al., 2000) assumed that black shale deposition in the area commenced sometime during the Middle Devonian and “continued without significant interruptions until the middle of Kinderhookian time” (Lineback, 1970). What is curious in this context is that this supposedly continuous black shale deposition produced members so distinctive that they can be traced over large areas in the subsurface as well as in outcrop. Several boundaries between members are literally knife-sharp and suggest in this day and age of sequence stratigraphy that they in fact represent an erosional break. That this is indeed the case was first demonstrated in the Chattanooga Shale of Tennessee, the southern equivalent of the New Albany Shale (Schieber, 1994, 1998a, 1998b). Tracing erosion surfaces northwards from Tennessee shows that they continue into the New Albany Shale (Johri and Schieber, 1999; Schieber, 2000), and that the most significant ones coincide with the member boundaries established by Lineback (1970) for the New Albany Shale. To illustrate these bounding surfaces in outcrop, and to show how they provide the connection between regionally different stratigraphic and lithological expressions of Late Devonian black shales is one of the focal points of this field conference. In Figure 2.1.2, the erosion surfaces that have been identified with confidence are marked with numbers in white circles (in ascending order). The same numbering scheme is also used in stratigraphic overviews for Stops 2 and 3. In earlier work on the Chattanooga Shale of Tennessee and southern Kentucky (Schieber, 1998b), additional erosion surfaces were recognized, probably because of closer proximity to the Cincinnati Arch. In stratigraphic overviews for this field guide, approximate positions of some of these additional erosion surfaces are marked with numbers in grey circles. Future research may in some cases confirm these surfaces, and in other cases identify their correlative conformities.

Starting at the south end of the exposure we see, at the base, the Beechwood Member of the Middle Devonian North Vernon Limestone (Sandberg et al., 1994), a lateral equivalent of the Boyle Formation of eastern Kentucky (see Stop 2). The Beechwood is a light to dark-gray crinoidal limestone that weathers tan to medium brown (Fig. 2.1.3). A thin pyritic lag marks the unconformable contact between the Beechwood Limestone and the overlying Blocher Shale (Fig. 2.1.3).

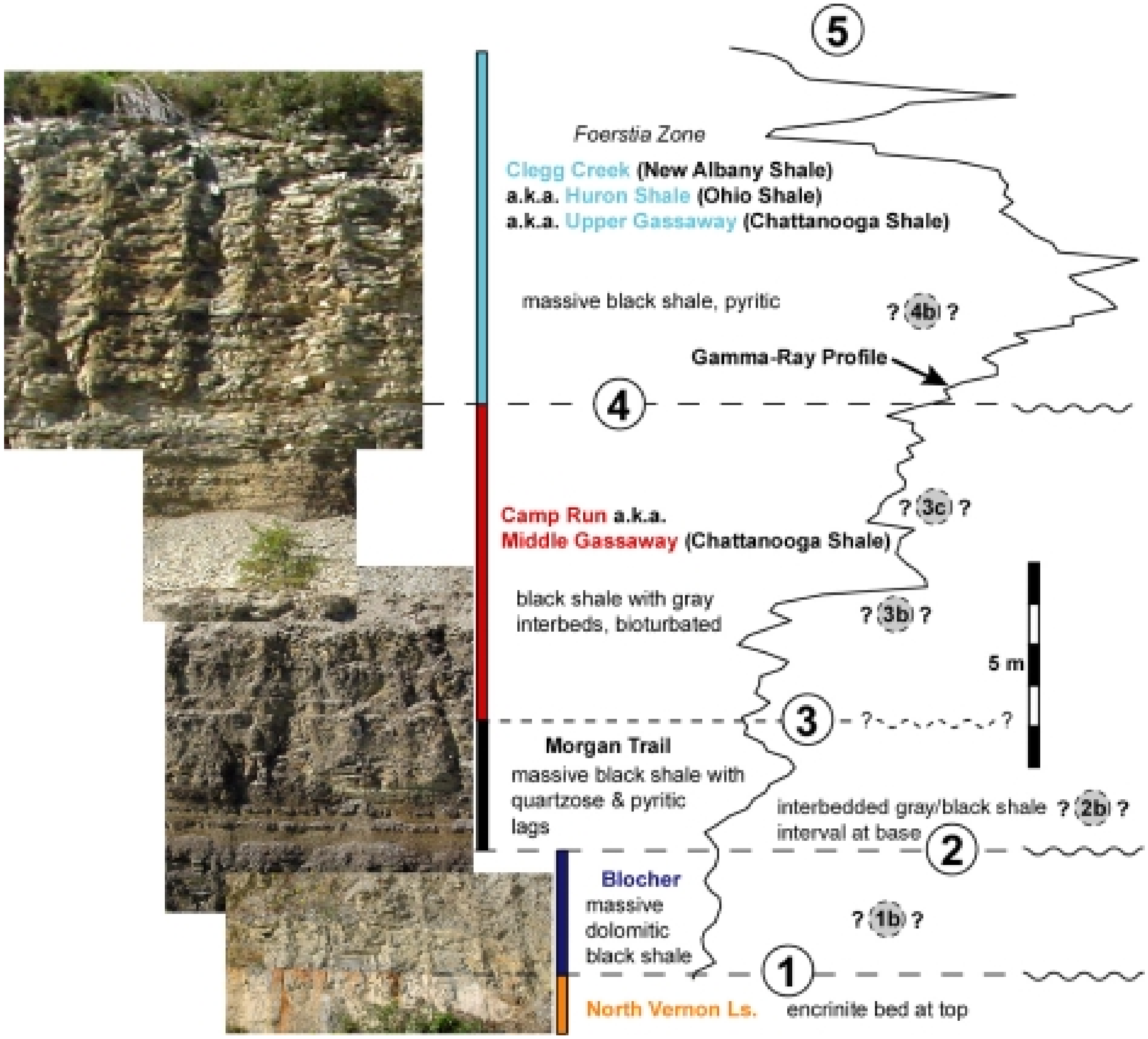


Figure 2.1.2: Stratigraphic overview of Stop 1. Wavy lines are known or suspected erosion surfaces (sequence boundaries). The numbers in white circles serve to match these surfaces to those observed in other stops. The numbers in gray circles mark the approximate location of erosion surfaces that are suggested from studies in other areas but have not yet been positively identified.

Figure 2.1.3: *Left*: Outcrop detail photograph of encrinite at the top of the Beechwood Limestone (crinoid stems pointed out be yellow arrows). *Right*: Irregular-undulose nature of Beechwood paleotopography. Red arrow points at cm-thick pyritic lag at the base of the Blocher.

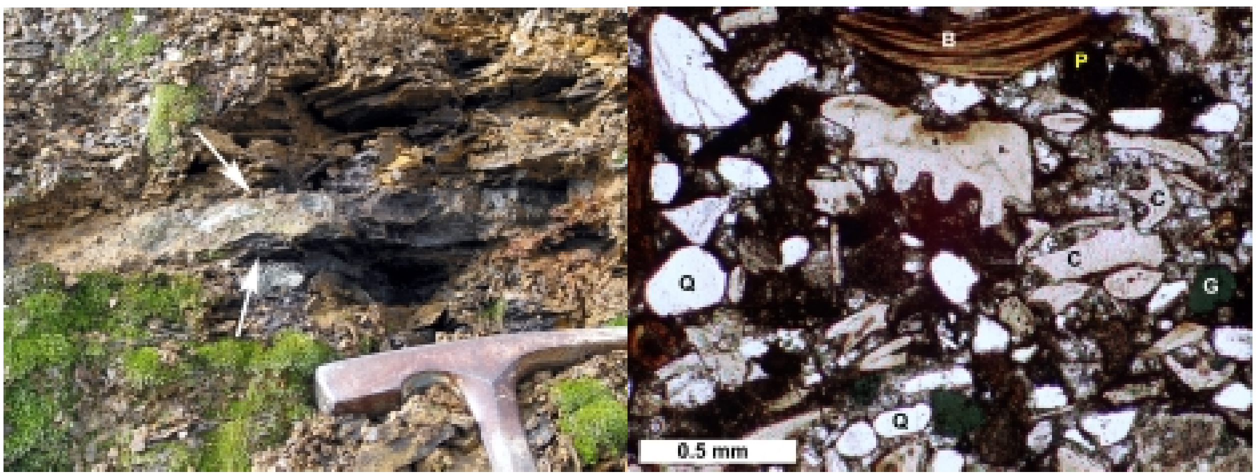


Figure 2.1.4: *Left*: The lag deposit (white arrows) at the Blocher-Morgan Trail contact. *Right*: Photomicrograph (transmitted light) of lag deposit. Shows rounded quartz (Q), pyrite (P), glauconite (G), conodonts (C), and shell fragments of linguloid brachiopods (B).

Figure 2.1.5: Interbedded gray and black shale (ledge-forming) in basal portion of Morgan Trail. Shows sharp base of black shale bed in center.

Blocher Member: In this exposure, the Blocher Member, a massive dolomitic black shale with mm- to cm-thick lenticular-wavy beds of dolosiltite is visibly draped over the North Vernon paleotopography (Fig. 2.1.3). Brownish-black when freshly exposed or examined in cores, it weathers into cm-thick blocky slabs having a brownish-bluish tint (Fig. 2.1.3). According to Over (2002), the top of the Blocher at this location is of mid-upper Frasnian age, and the top may be of uppermost Givetian or early Frasnian age, based on the presence of the encrinite bed (Fig. 2.1.3) at the top of the Beechwood (Sandberg at al., 1994).

The next unit above the Blocher would typically be the *Selmier Member*, a unit of alternating gray and black shales (Lineback, 1970). At this locality, however, the Selmier is missing (most likely due to erosion), and the Blocher is directly overlain by the Morgan Trail Member.

Morgan Trail Member: A 1- to 2-cm thick pyritic lag with rounded quartz grains, glauconite, *Lingula* shells, and abundant conodonts (Fig. 2.1.4) separates the Blocher from the shale unit that overlies it. The conodonts indicate a lower Famennian (lower *crepida* zone) age for the base of the next shale package (Over, 2002). This age assignment indicates that this black shale unit should be assigned to the Morgan Trail Member of the New Albany Shale (Sandberg et al., 1994; Over, 2002). Depending on how one calibrates the Late Devonian conodont record (Sandberg et al., 1994; Klapper, 1997; Tucker et al., 1998) there may be 3 to 7 million years of rock record missing between the Blocher and the base of the Morgan Trail at this location. Thus, although the erosion surface between Blocher and Morgan Trail is subtle and superficially conformable at the outcrop scale, it is nonetheless a very significant break in the stratigraphic record.

The basal meter of the Morgan Trail in this exposure is atypical in that it consists of interbedded black and gray shales, thus inviting mistaken identification as Selmier or Camp Run. These black-gray cycles may reflect a “shallow” water Morgan Trail facies that has been eroded (or never been deposited) elsewhere. Examined more closely, the black shale beds have sharp and potentially erosive bases (Fig. 2.1.5), and have gradational contacts with overlying gray shales. These decimeter-scale black-gray cycles may reflect minor sea level variations during Morgan Trail deposition and could represent parasequences. Above this basal interval the remainder (±2m) of the Morgan Trail Member is massive and variably pyritic due to thin lags enriched in pyrite-filled *Tasmanites* cysts.

Camp Run Member: The Camp Run consists of interbedded black (a few cm’s to several m’s thick) and gray shale (a few cm’s to 30-cm-thick) beds. The gray beds are fully bioturbated, and the black beds are visibly bioturbated from the top (burrows filled with gray shale) and have in addition very subtle indications of early depositional bioturbation (Schieber, 2003a). The presence of less-resistant gray shale beds is a basic field criterion for distinguishing the Camp Run from the underlying and overlying shales (Morgan Trail and Clegg Creek, respectively), and as we can see from the base of the Morgan Trail in this exposure, it is not a failsafe criterion. Elsewhere, for example in central Tennessee, the Camp Run equivalent (Middle Gassaway) is in erosive contact with underlying black shales. Although we can see here a sharp contact in form of the first gray shale bed above the Morgan Trail, whether this contact is indeed erosive at this location has not yet been established with certainty. It is likely that as we go further westward away from the Cincinnati Arch, erosive contacts found on and in vicinity of the arch will turn into their “correlative conformities” (sensu Vail). The upper boundary of the Camp Run, its contact with the overlying Clegg Creek Member, is knife-sharp (Fig. 2.1.6) in this exposure (and in many others as well) and represents an erosion surface. Although the Camp Run and Clegg Creek appear conformable on the outcrop scale, the erosion surface is visible regionally through progressive truncation of the Camp Run gamma-ray log motive (Schieber, 2000; Barrett, 2002). The black-gray shale cycles in the Camp Run are suggestive of intermittent improvement of bottom water oxygenation and, depending which brand of magic one prefers, may be a byproduct of sea level variations, change in basin circulation patterns, drop in surface productivity, or climate variations.

Clegg Creek Member: Massive in appearance and pyritic, the Clegg Creek Member has a sharply contrasting outcrop expression than the underlying Camp Run Member (Fig. 2.1.6). The presence of a pyrite-enriched interval with *Foestia/Protosalvinia* in the top portion of the Clegg Creek is significant because it facilitates correlation with the other two stops of this field trip, as well as with well 1-3 Kavanaugh (introduced yesterday). *Foerstia* is a useful biostratigraphic marker for correlations with other portions of the Devonian black shale succession (Kepferle, 1981; Hasenmueller et al., 1983; Roen, 1993). The Clegg Creek itself is truncated on top and overlain in places by a bed with reworked phosphate nodules, the so-called Falling Run Bed (Campbell, 1946).

Cross-cutting Veins: At the northern end of this outcrop occur more or less vertical veins, filled with quartz, dolomite, and locally some bitumen (Fig. 2.1.7). These veins may extend for up to 5 meters vertically through the outcrop, are from a few cm’s to 15 cm wide, and have been contorted and telescoped because of the compaction of the surrounding shale after vein emplacement. These features indicate that vein emplacement took place while their shale host was still not fully compacted. “Backstripping” the contortion and telescoping of these veins suggests that they were emplaced when their shale host still had between 20 to 30 percent porosity. Judging from shale compaction models, this would imply at a minimum a burial depth of several hundred meters when the veins were emplaced. Although, the very slow accumulation of these black shales could have allowed the package to reach the indicated porosities at somewhat shallower depth. In any case, injection of fluids to force open these veins would have required overpressured fluids and may well be related to the trapping of deeper formation waters beneath the Devonian shale seal. These veins are oriented in NW-SE direction, the same as other comparable veins in Devonian black shales of the region, and coincident with the preferred orientation of lineaments mapped at the surface and fracture orientations in the New Albany Shale (Carr, 1981).

Figure 2.1.6: Knife-sharp erosional contact (white arrows) between Camp Run and Clegg Creek Members. Red arrows at the top of the exposure mark a soft weathering interval (due to abundant pyrite) that coincides with the *Foerstia/Protosalvinia* Zone.

Figure 2.1.7: Vertical vein filled with quartz and dolomite, cutting essentially vertical through the Camp Run Member (north end of exposure). Vein is contorted and telescoped because of shale compaction after vein emplacement.

2.2: Stop 2: On Route 52 between Richmond and Irvine, Kentucky, ~3.5 miles east of Estill County line

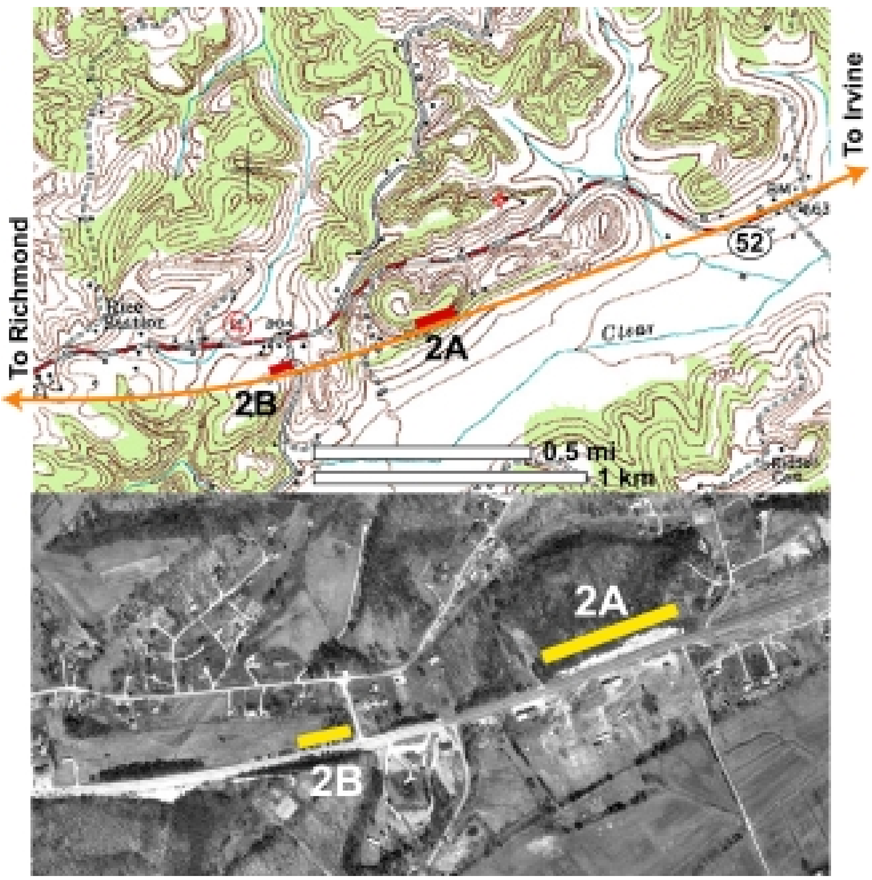


Figure 2.2.1: The exposures we will visit at Stop 3 are in roadcuts along KY-52, approximately 6 miles west of Irvine. They are marked in red on the above topographic map and in yellow on the air photo below.

This exposure differs from Stop 1 in that we are now to the east of the Cincinnati Arch and thus have moved from the Illinois into the Appalachian Basin (Fig. 2.1). Consequently, we can not expect the rocks to look exactly the same as at Stop 1, and we also have to be prepared to encounter stratigraphic units that we did not see previously. Nonetheless, our rocks of interest still are of the same comforting black color as previously. The total thickness of black shales exposed here is about 36 meters, almost twice as much as in the previous exposure.

Although the entire section is exposed at Stop 2A, the portions in the upper part of the cut are difficult to reach and will be examined at Stop 2B instead. In combination, the two cuts show a section of Devonian black shales that begins in the Middle Devonian and essentially reaches to the top of the Devonian. Whereas the lowermost black shale at Stop 1, the Blocher, is quite possibly mostly Frasnian (Sandberg et al., 1994; Over, 2002), here we will see Middle Devonian black shales that predate the Blocher and have not been found (yet) in the Illinois Basin.

Stop 2A: Stratigraphic units in this exposure are discussed from the bottom upwards (Fig. 2.2.2). For the lowermost units (Boyle and Portwood), the paper by Brett et al. (this guidebook) should be consulted for details.

Boyle Dolomite: At the very base of the exposure, we see nicely exposed the Middle Devonian Boyle Dolomite (Fig. 2.2.2), a medium-gray, orange-buff weathering dolostone and dolomitic limestone, with layers of irregular pale cream-colored chert nodules. Its age is Middle Devonian, probably Givetian. It has an unconformable (low-angle) contact with the overlying Portwood. The angular contact is best seen in large Boyle outcrops several miles to the west (towards Richmond) along KY-52.

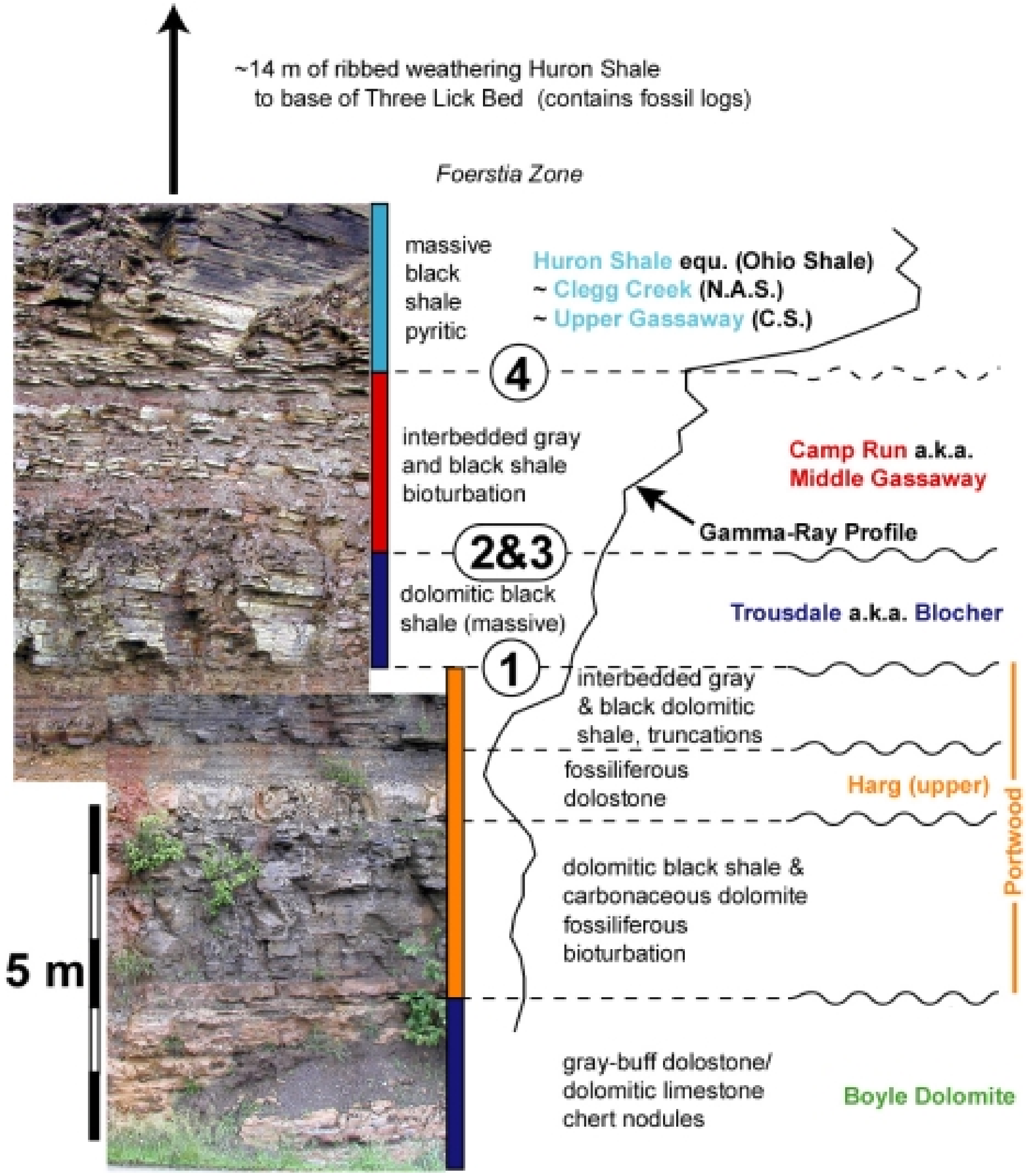


Figure 2.2.2: Stratigraphic overview of Stop 2A. Wavy lines are known or suspected erosion surfaces (sequence boundaries). The numbers in circles serve to match these surfaces to those observed at other stops.

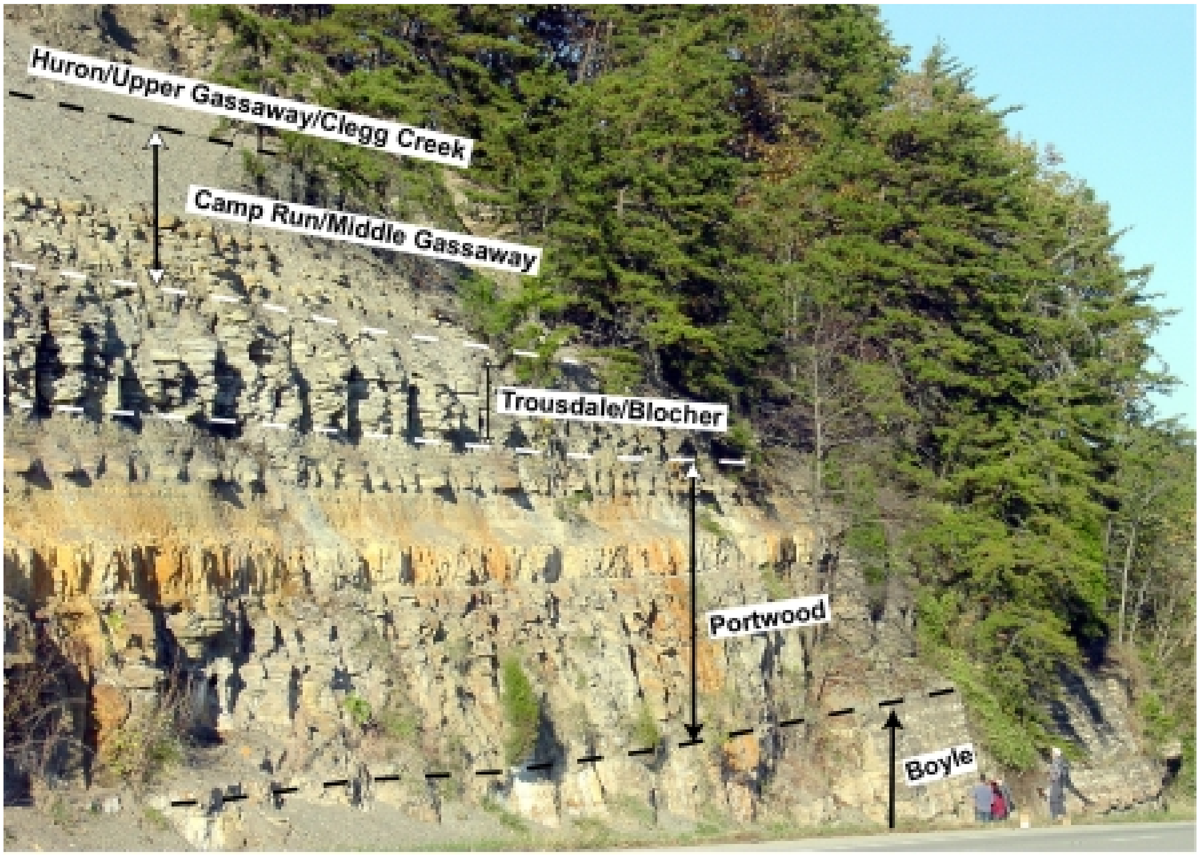
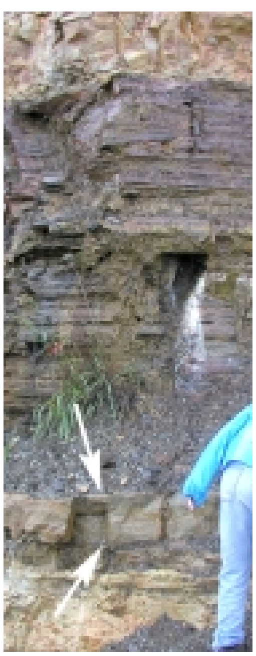


Figure 2.2.3: East end of exposure at Stop 2A. Shown are the major subdivisions discussed at this stop, marked with arrows (thickness) and dashed lines (contacts).

Portwood: The Boyle is separated by a thick lag horizon (up to 50 cm thick) from the overlying Portwood Formation (Figs. 2.2.3, 2.2.4). The lag is a fine to medium sandstone that is dominated by detrital dolomite grains overgrown by interlocking clear dolomite cement. In addition to dolomite the lag also contains well-rounded quartz grains, well-rounded glauconite grains, and bone debris. The Portwood is a unit that is characterized by strong lateral variability and has long defied attempts at lateral correlation of subdivisions visible in given outcrops. At first glance it seems to vary so strongly from outcrop to outcrop that correlations seem all but impossible. At the base of this Portwood section (see also Fig. 2.2.2) we see an interval of strongly dolomitic black shales that is quite fossiliferous in thin section, contains glauconite grains, and shows bioturbation (Fig. 2.2.4). It is considered a lateral equivalent of the Tully Formation (Givetian) in New York (Brett et al., this volume). This carbonaceous interval is overlain by a buff colored dolomite bed (10 to 50 cm thick) with an undulose erosive base, probably a sequence boundary (Carl Brett considers it the middle/upper Tully sequence boundary). Above this dolomite bed follow about 1.6 meters of interbedded black and gray dolomitic shales to the top of the



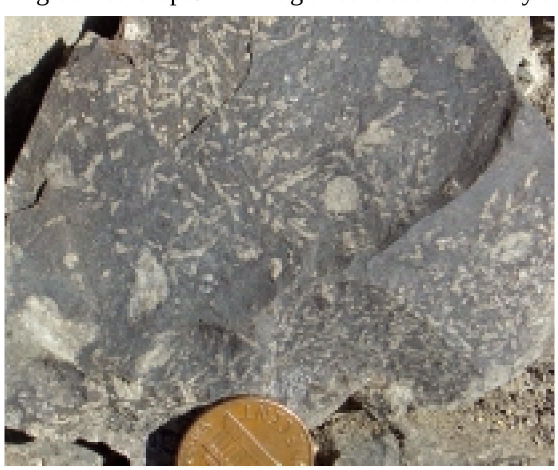


Figure 2.2.4: *Left:* Boyle-Portwood contact, boundary lag marked with white arrows. *Above:* Bioturbation in Portwood dolomitic black shale unit. Larger tubes (light circles) as well as *Chondrites*.

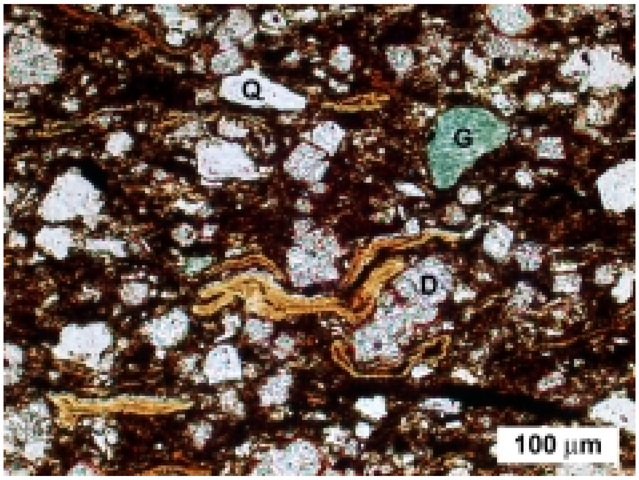


Figure 2.2.5: Photomicrograph from the dark dolomitic shale interval in the striped interval at top of Portwood. Yellow deformed streaks are *Tasmanites*, dolomite marked D, quartz marked Q, glauconite marked G.

Portwood. In the middle of this 1.6-m interval, a more resistant black shale bed seems to overlie yet another truncation (erosion) surface. Thin sections from the upper half of this 1.6-m interval show that these shales are still strongly dolomitic, contain glauconite pellets, and are mottled due to bioturbation (Fig. 2.2.5).

Trousdale/Blocher: The next higher unit is a dolomitic black shale that contains phosphatic shells of inarticulate brachiopods and abundant *Tasmanites*. It is significantly less dolomitic than the black shales in the underlying Portwood (Fig. 2.2.6), and very similar petrographically to the Blocher and Trousdale examined elsewhere in the region. Campbell (1946) reported Geneseo style fauna from this unit, and Brett et al. (2003) report conodonts that suggest an uppermost Givetian age, further suggesting that it overlaps in age with the Blocher in Indiana.

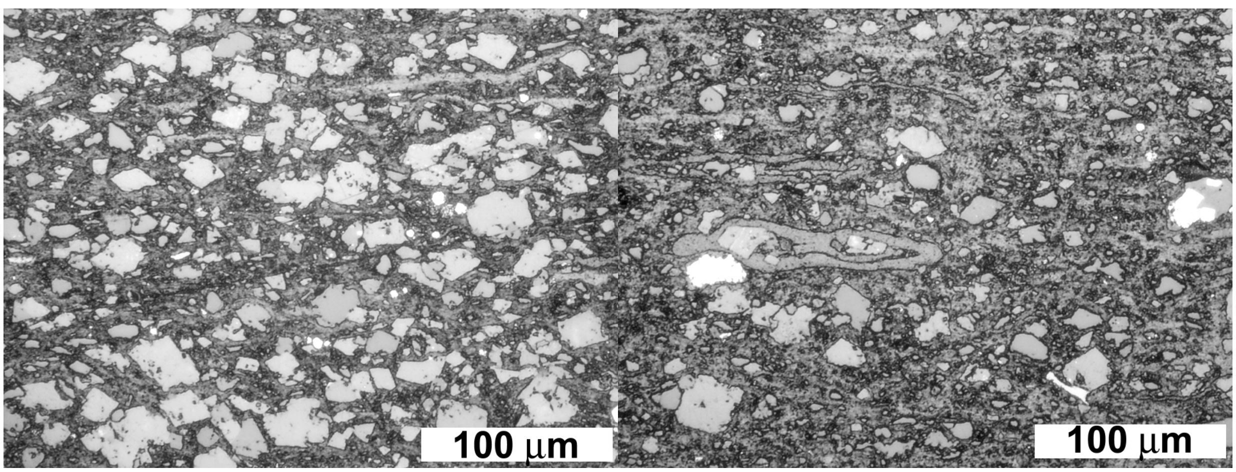


Figure 2.2.6: *Left:* Photomicrograph (reflected light) of Portwood black shale (above Boyle). *Right:* Photomicrograph of Trousdale black shale. The light-gray euhedral grains are dolomite, elongate horizontal features are *Tasmanites*; the remainder consists of clay, quartz silt, organic matter, and some pyrite (bright spots).

Middle Gassaway/Camp Run: The next interval above the Trousdale/Blocher consists of interbedded black (resistant ledges) and gray shales (soft, recessive) that vary in thickness from 4 to 20 cm (Fig. 2.2.7). The black shale beds show nice burrows (*Chondrites, Planolites, Zoophycos*) filled with gray shale from above (Fig. 2.2.7). This interval bears close resemblance to the Middle Gassaway as observed in central Tennessee, and also the Camp Run in Indiana in exposures/cores along the eastern outcrop belt.

We currently have no conodont data from this interval, but by comparison with sections further east (Morehead, I-64) that place comparable strata into the Camp Run bracket (Over, 2002), and by sheer lithologic similarity, we assume that these beds are correlative to the Camp Run in Indiana/western Kentucky and the Middle Gassaway in central Tennessee. We should also note that there is a lag deposit at the base of this interval, as well as a low-angle truncation of underlying Trousdale/Blocher beds.

Figure 2.2.7: *Left:* Outcrop of interbedded black and gray shale of the Middle Gassaway/Camp Run interval. *Right:* Macroscopically visible bioturbation in black shale beds. Shows mainly *Chondrites* and *Planolites*.

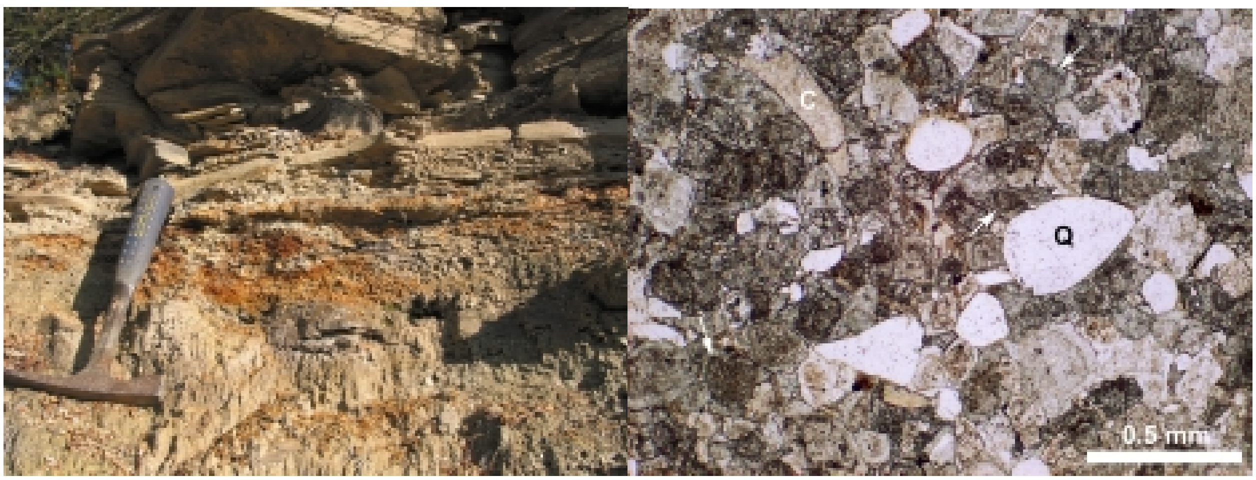


Figure 2.2.8: *Left:* Rusty-colored resistant lag at base of the Camp Run interval. *Right:* Photomicrograph of the lag that shows rounded quartz (Q), conodont fragments (C), and rounded detrital dolomite grains (white arrows) with overgrowth cement.

Figure 2.2.9: Disturbed zone in Portwood. To the left and right, we see the Harg dolomite bed at the same elevation (vertical arrows), and in between there is an area with deformed beds, jumbled stratification, and pods of dolomite (inclined arrows) that are deformed (Fig. 2.2.10) and clearly at a lower elevation.

In detail, the lag in Figure 2.2.8 is separated from the underlying Trousdale by a 15-cm-thick, poorly exposed interval of interbedded black (1- to 2-cm beds) and gray shales (2- to 4-cm beds). This kind of lithology is atypical for the Trousdale and whether it is in erosive contact with the Trousdale is presently not known. There is a possibility that those 15 cm are all that is left of what once might have been a Selmier/Dowelltown equivalent in this area. Careful evaluation of photomosaics showed that the Trousdale thins about 15 percent over that portion of the outcrop where both top and base are exposed, and that the thinning is due to erosion on top.

Upper Gassaway/Clegg Creek/Huron: Following above this interbedded interval is a massive weathering shale unit that, together with the remainder of the outcrop above, has the look and feel of the Huron Shale Member of the Ohio Shale as seen further to the northeast (Morehead, I-64), but is about half as thick. This correlation is supported by the strong gamma-ray signature of the basal massive black shale of this unit (characteristic also of Clegg Creek and Upper Gassaway) and confirmed by the fact that this unit contains the *Foerstia* Zone, as do Upper Gassaway and Clegg Creek. These shales were deposited more slowly than other black shales in the succession, and contain abundant diagenetic pyrite, in part, possibly because of bottom current reworking of the black shale substrate and consequent pyrite enrichment (as observed in the Upper Gassaway) in thin (sub-mm) lag deposits. The abundant pyrite causes these shales to produce efflorescences of variably hydrated ferrous/ferric sulfates associated with pyrite oxidation--melanterite, szomolnokite, copiapite, coquimbite, and jarosite. These efflorescences can form whitish to yellowish crusts on the outcrop and may wax and wane in response to precipitation. The base of this shale interval is marked by a knife-sharp contact with the underlying black/gray interbedded unit, and may well be erosive. We have not yet located a lag at this location, but this may in part be due to the inaccessibility of this contact at this location. There is evidence of erosion prior to deposition of this black shale unit at the base of the Upper Gassaway (in Tennessee) and the Clegg Creek (in Indiana), and it is also observed at Stop 3, located on the Cincinnati Arch (and thus more likely affected by sea level drops). The transgression marked by this massive black shale unit could be the second transgressive pulse of TR cycle IIe of Johnson et al. (1985), a transgression which led to the most extensive flooding recorded by the Late Devonian black shale succession of the eastern U.S. The remainder of the section will be examined at Stop 2B.

It should be pointed out here that the base of the Huron Shale, as found in Ohio, is approximately at the base of the Famennian (*triangularis* zone). In northeastern Kentucky, however, earlier deposited Famennian strata (approximately the lower third) were completely removed by erosion (Over, 2002), and the first Famennian black shale unit that is preserved is several conodont zones younger (*rhomboidea* zone) than its lithostratigraphic equivalent in Ohio. Thus, although we use the term “Huron Shale” in reference to this unit during our field trip, we must keep the biostratigraphic difference between Ohio and Kentucky in mind. This variable age of the Huron base, due to progressive onlap of black shales onto the Cincinnati Arch as sea level rose, has been the cause for considerable confusion and head-scratching in the past. Technically speaking, the underlying interval of black/gray interbedded shales could also be called Huron because if we are correct with our Gassaway/Camp Run assignment, then these shales are also Famennian and thus of (type) Huron age (Such are the joys of stratigraphy).

Deformed Beds in the Portwood: Just about in the middle of the roadcut at Stop 2A, there is a zone where the prominent dolomite bed (Harg) in the Portwood is displaced downward (Fig. 2.2.9), separated into deformed pods, and surrounded by deformed shale (Fig. 2.2.10). These pods can resemble ball and pillow structures and suggest that the dolomite bed sank into the underlying shale unit, implying liquefaction of the shale. The overlying stratigraphic units are not affected, pointing to soft sediment deformation during Portwood time. Because the shale liquefaction affected only a narrow area, the suggestion is of a localized energy release, such as one would expect from movement of deeper seated faults. Had the energy source been an earthquake that affected a large surface area, or perhaps a tsunami, we should expect a correspondingly larger lateral extent of the liquefaction zone as well. The paper by Brett et al. (this guidebook) contains additional information on deformed beds in the Portwood, some thoughts about possible causes, and also argues for fault movements as a possible cause.

Stop 2B: To have a more convenient look at the upper portion of the Devonian section we drive westward (uphill) on KY-52 for approximately 0.4 miles. A nice exposure of Devonian black shales on the north side of the road (Fig. 2.2.11) shows the top portion of the Huron Shale, the Three Lick Bed, and an overlying more massive and weathering-resistant black shale that correlates with the Cleveland Shale of Ohio (Kepferle and Roen, 1981). Both the Huron Shale and the Cleveland Shale are members of the Ohio Shale, and the Three Lick Bed (TLB) is a convenient marker to separate them (Provo et al., 1978). The TLB extends as a marker over large portions of the Appalachian Basin, but its origin is a bit of a mystery. We can see that the black shale beds between the three gray shale beds that define the TLB have a well-defined sharp base, suggesting that we actually have black-gray couplets that mark depositional events or cycles. The TLB has been interpreted as a distal tongue of the Chagrin Shale, a more proximal deltaic succession, but that does not explain the triplet nature of this bed that stays so constant over such a large area.

Figure 2.2.10: Closeup of a pod of dolomite in the disturbed zone in the Portwood. Note shale wrapping around pod at left.

The Huron Shale shows “ribbed” weathering on the dm scale in this exposure, related to rhythmically varying contents of clay and organic matter (Jaminski et al., 1998) that lead to resistant ledges of carbonaceous shale and softer portions that are enriched in clay (but still carbonaceous). Of interest here are thin discontinuous beds of cone in cone calcite that are probably testament to a (time) increment of very slow sediment accumulation. Measuring up from the base of the Huron as defined at Stop 2A, we have here a total of 17 m of Huron Shale. Going just 70 km to the NE (Morehead, Kentucky) we would find that this portion of the section has more than doubled (36 m) in thickness.

The overlying Cleveland Shale is more massive and resistant looking because of an overall higher TOC content. It still shows cycles of resistant versus softer beds, but the cycle thickness is now on the sub-dm scale. If we assume that the cycles reflect some kind of periodic forcing mechanism (e.g., climate, Milankovitch, etc.), we have two options to interpret the difference in cycle thickness between the Huron and Cleveland Shale:

1) Sedimentation rates dropped drastically from Huron to Cleveland.
2) The periodicity of the forcing mechanism or the forcing mechanism itself changed.

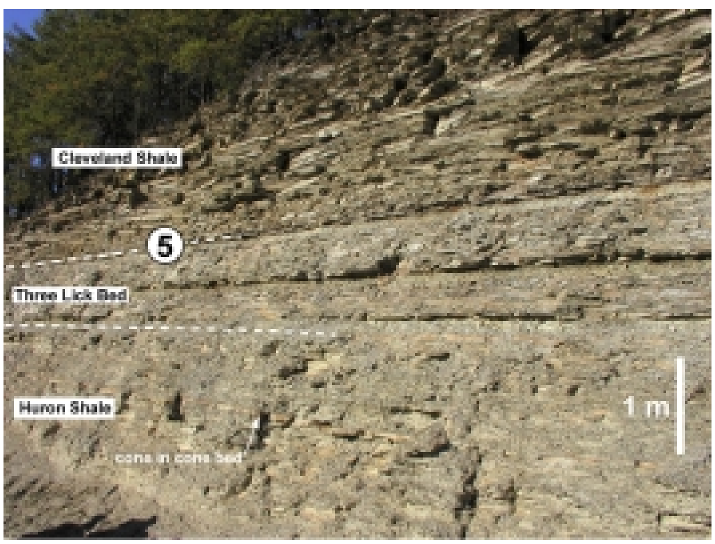


Figure 2.2.11: Stratigraphic units at Stop 2B. Three Lick Bed separates Huron and Cleveland Shale. Arrow points to cone in cone calcite bed. The circled number 5 serves to match this surface to its equivalent at Stop 3.

Option 1 seems more likely for the reason that, at this particular horizon (Cleveland base), there is evidence for an erosive interlude prior to Cleveland deposition, with localities ranging from southern Tennessee to northeastern Ohio. In that sense, the knife-sharp Cleveland base is clearly representative of a sequence boundary, possibly corresponding to the transgression associated with TR cycle IIf of Johnson et al. (1985). This boundary is marked as a circled number 5 in the stratigraphic overview for Stop 3 (Fig. 2.3.2). Even where we do not find direct evidence for erosion in the form of lags and scours, the sharp basal contact of the Cleveland and its high TOC content are suggestive of its deposition during a transgression and sea level rise. In that case, clastics would have been held back in estuaries and on coastal plains, leading to smaller clastic input and (all else staying the same) thinner cycles.

We will see the Huron-Three Lick Bed-Cleveland interval again at Stop 3, another 70 km to the west, where it will be thinner still because of greater distance from the clastic source (the Huron will be ~10 m thick, versus 17 m at Stop 2).

2.3: Stop 3, ~3 miles south of Junction City, Kentucky

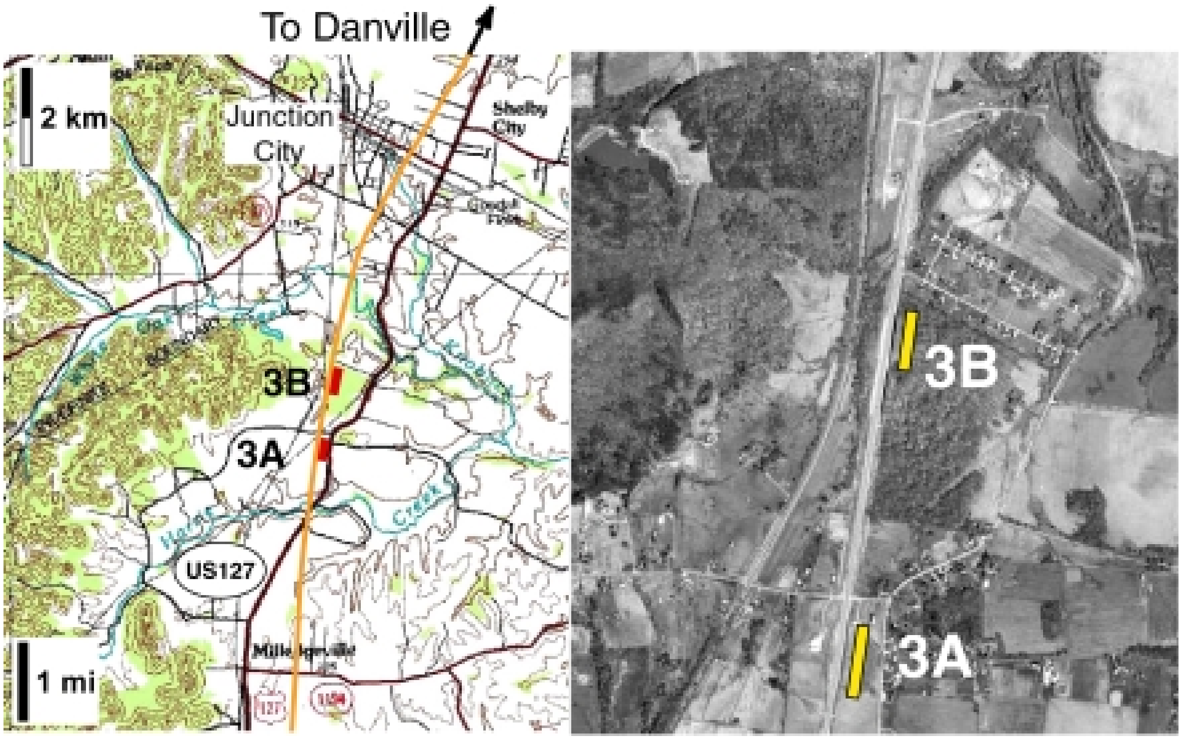


Figure 2.3.1: The exposures we will visit are in roadcuts along US-127, approximately 3 miles south of Junction City. They are marked in red on the topographic map at left, and in yellow on the air photo at right.

The two marked roadcuts show, in combination, a fairly complete section of Devonian black shales. Stop 3A shows the lower part of the section, and Stop 3B shows the upper part. The strata exposed here were deposited near the crest of the Cincinnati Arch (Fig. 2.1), and as such, constitute the connection between the Appalachian and the Illinois Basins. The total thickness of Devonian black shales is about 17 meters, less than in the previous two exposures. We will again see the erosion surfaces that we already inspected in the previous two stops. The exposed strata, although in "legal" terms belonging to the Chattanooga Shale (de Witt, 1981), show a combination of aspects of the Chattanooga Shale, the New Albany Shale, and the Ohio Shale.

Stop 3A: Stratigraphic units in this exposure are discussed from the bottom upwards (Fig. 2.3.2).

Boyle and Duffin: The Middle Devonian Boyle (a foot or less) and Duffin carbonates (60 to 80 cm thick) occur at the base (south end) of this exposure. Similar to Stop 2A, the Boyle consists of medium-gray, orange-buff weathering dolostone and dolomitic limestone with layers of irregular pale cream-colored chert nodules. Conodonts suggest that it is Middle Devonian, probably Givetian in age (see paper by Brett et al., this volume). The Duffin carbonates are a facies of the Middle Devonian Portwood Formation, a unit that is characterized by strong lateral variability. Recent work by Carl Brett and Gordon Baird suggests that it will finally be possible to unravel its complex facies patterns and to see stratigraphic order in this unit (see paper by Brett et al., this guidebook).

Although in places sufficiently coarse to have earned the name "breccia", at this locality the Duffin is a crudely bedded calcareous/dolomitic sandstone (Fig. 2.3.3) with variable amounts of silicified fossil debris and large vugs that can contain nice clusters of calcite crystals. The origin of these vugs is problematic. Comparable vugs occur elsewhere (e.g. around Nashville, Tennessee) in carbonates beneath the Devonian black shale succession, and in really fresh outcrops they are actually filled with gypsum. They probably formed when acidic formation waters were squeezed out of the sedimentary stack that accumulated in the Appalachian and Illinois Basins, migrated through the carbonates beneath the seal of Devonian shales, and dissolved part of the carbonate matrix. Quartz-dolomite-bitumen veins similar to those seen at Stop 1, also occur in the Trousdale Shale of this outcrop (Fig. 2.3.4), and may well be related to the movement of overpressured fluids underneath the Devonian shale seal.

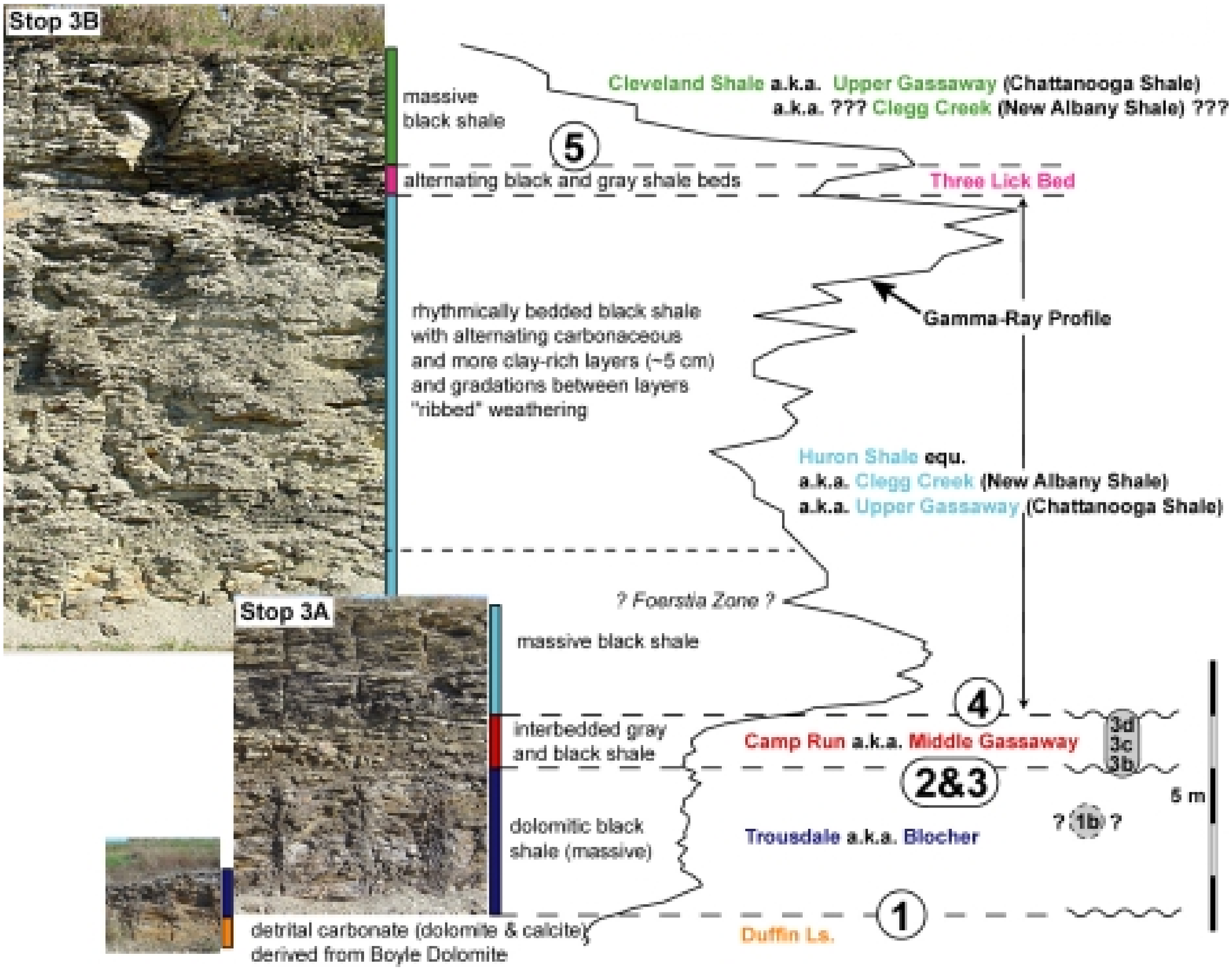


Figure 2.3.2: Stratigraphic overview of Stop 3. Wavy lines are known or suspected erosion surfaces (sequence boundaries, numbers in circles match surfaces to those seen at other stops). Gray circled numbers mark approximate location of erosion surfaces that are suggested from studies in other areas but have not yet been positively identified.

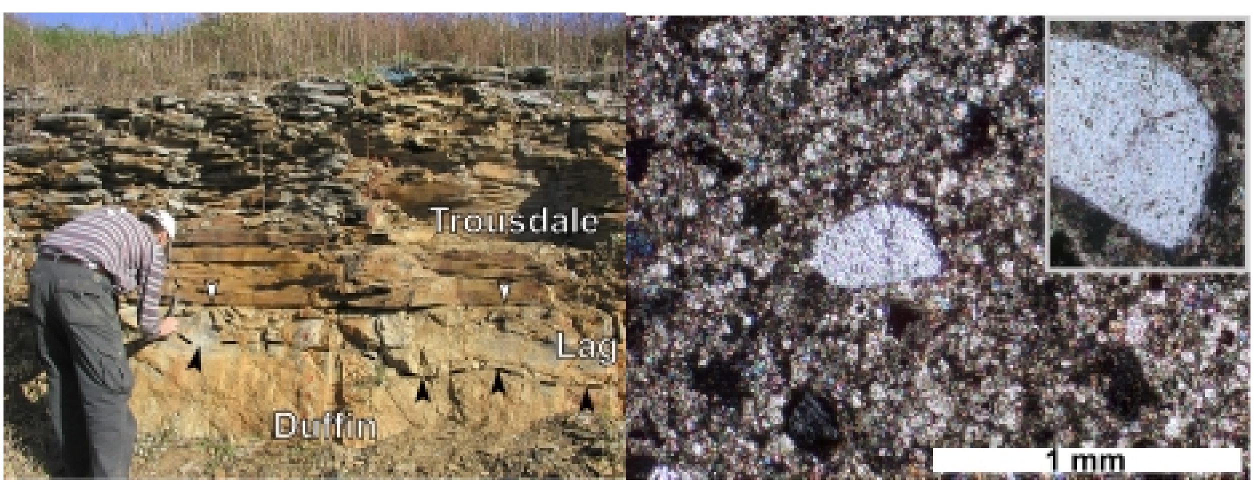


Figure 2.3.3: *Left:* Base of succession at stop 3A (south end), with buff weathering Duffin overlain by platy rusty weathering Trousdale Shale. A lag deposit (up to 40 cm thick) separates the two units. Base of lag (black arrows, dashed line) is undulose and fills in surface irregularities on the Duffin. Upper surface of lag is even and forms a sharp contact (white arrows) with overlying Trousdale. *Right:* Lag consists of abundant dolomite grains with interlocking overgrowth cement and scattered grains of chert (from silicified fossils) and well-rounded quartz sand.

Figure 2.3.4: At left, quartz-dolomite-bitumen vein (white arrow) in Trousdale contorted because of compaction.

Trousdale/Blocher: Dolomitic black shales assigned to the Trousdale/Blocher interval overlie the Duffin carbonates and are separated from them by a thick lag deposit (Fig. 2.3.3). The stark contrast between the probably shallow water (within wave base) Duffin deposits and the overlying and the deeper (but not too deep) deposited Trousdale Shale (Campbell, 1946) probably reflects sea level rise and flooding in association with the Taghanic onlap (Late Givetian, Johnson et al., 1985), a time of maximum highstand that prompted widespread dysoxic/anoxic (?) conditions and correlates with the Geneseo black shales in New York (Kirchgasser et al., 1997). The black, platy Trousdale contains phosphatic shells of inarticulate brachiopods, *Tasmanites* cysts, scattered dolomite grains, and scattered pyrite framboids and small pyrite concretions (Fig. 2.3.5). It also contains discontinuous-lenticular dolomitic laminae (a few mm thick) that consist of cemented detrital dolomite grains (silt to sand size). Bioturbation is not obvious, but subtle traces and lamina disruptions have been observed. The total thickness of Trousdale in this outcrop is approximately 2 m (varies along outcrop). The similarity between the Trousdale and the Blocher as seen at Stop 1 is readily apparent. Although the names differ between eastern and western Kentucky, it seems fairly certain that it is a contiguous unit that reaches across the Cincinnati Arch. Latest Givetian conodonts (*disparalis* Zone) have been reported from the Trousdale near Clay City, Kentucky, also supporting a Blocher-Trousdale equivalency (Brett et al., 2003) and association with Taghanic flooding.

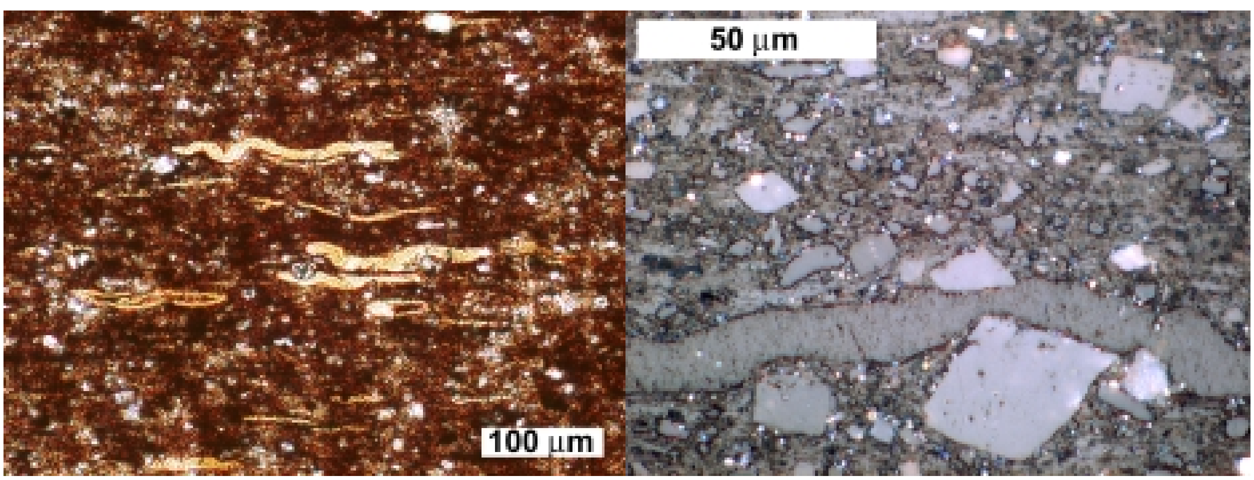


Figure 2.3.5: Photomicrographs of Trousdale carbonaceous shale. *Left:* transmitted light, shows brownish matrix of clay minerals and organic matter (kerogen). Horizontal-wavy yellowish streaks are compacted *Tasmanites* cysts, light (white) spots are dolomite grains. *Right:* reflected light, shows fine quartz silt (dark-gray irregular grains, a few microns in size), dolomite rhombs (light-gray, euhedral and tens of microns in size), and deformed *Tasmanites* in lower half. Although there is horizontal alignment of *Tasmanites*, there is no clear lamination. This suggests disruptions of initial surface stratification of the probably quite soupy sediment by surface and shallow infauna (polychaete worms, nematodes, meiofauna, etc.) that was able to tolerate low benthic oxygen levels and disrupted the sediment sufficiently to prevent preservation of “nice” primary laminae.

Although dolomite can form during diagenesis in carbonaceous shales, there is probably too much dolomite to be accounted for by extraction from overlying seawater. It is more likely that dolomite was derived from distant outcrops of underlying Middle Devonian carbonates, forming islands in the Trousdale-Blocher sea. Because the underlying relief of the pre-Trousdale erosion surface seems quite muted (judging from large exposures), one would have to conclude that the water between "islands" could not have been excessively deep. Although difficult to pin down without more detailed information, the water depth during Trousdale deposition was probably on the order of tens of meters at best. That, in essence, the same black shale facies is found from Indiana (Blocher) to eastern Kentucky (Trousdale) during the Late Givetian-Middle Frasnian time interval suggests that the later differentiation into discrete basins (Illinois versus Appalachian) was not well developed (if at all) at that time.

Middle Gassaway/Camp Run - **The highlight of this outcrop** is the next interval above the Trousdale. It consists of interbedded black shales (resistant ledges, 5 to 15 cm thick) and gray shales (soft weathering, 5 to 15 cm thick), and varies in thickness across the exposure (1.1 m at the north end, 0.6 m at the south end). In terms of facies, these shales are a very good match for the middle Gassaway (Chattanooga Shale) in Tennessee and also show considerable resemblance to the Camp Run (New Albany Shale) in cores and exposures along the outcrop belt in Indiana. Comparable shales near Liberty (20 miles south along US-127) have been examined for conodonts by Over (2002), and yielded an age that is compatible with the middle Gassaway and Camp Run intervals.

Although this interval is quite thin, it shows a most interesting feature --inclined truncation surfaces (Fig. 2.3.6) that attest to intermittent sea level drop that brought previously deposited shales within the reach of wave erosion, followed by again rising sea level and renewed shale deposition (Schieber, 1998a,b). There are at least four transgressive-regressive (TR) episodes recorded here and four prominent lag deposits that are associated with them (Fig. 2.3.7). What is curious here is that these lags sit somewhat above the actual truncation surface that marks the regressions. A possible explanation could be that these lags represent the maximum flooding surfaces of the associated TR cycles. This is somewhat counterintuitive, but has been observed elsewhere (e.g., Swift et al., 1987). It could mean that during maximum flooding, extreme sediment starved conditions allowed occasional strong storms to still leave a preservable imprint in the rock record. In this sense, these lags probably record multiple reworking episodes (amalgamation lags), a viewpoint that is supported by the observation of discontinuous shale drapes and shale streaks within samples from these lags.

Thin sections of lags show that euhedral dolomite grains that form an interlocking fabric with adjacent grains are their main component (Fig. 2.3.8). In addition to dolomite, we find glauconite pellets, abraded phosphatic bone debris, *Lingula* shells, and well-rounded quartz grains (sand size). The dolomite grains, although typically euhedral in outline, contain rounded cores of detrital dolomite (cloudy, sand to silt size) that have a clear rim of overgrowth cement (Fig. 2.3.8). Although one might at first think that the dolomite is derived from erosion of the underlying Trousdale, the grains are generally too large to be of that source. It is more likely that they were derived from "knobs" or islands of Middle Devonian carbonates (Boyle, Portwood) that projected above the Middle Gassaway/Camp Run surface and were subject to wave erosion during low stands of sea level. This particular question will probably require some careful geochemical fingerprinting for its resolution. *Lingula* shells in these lags may have been derived from the underlying Trousdale. The source of the well-rounded quartz grains is probably more distal and will, as well, require more investigation.

The observed thinning of this unit towards the south end of the outcrop is due to yet another episode of sea level drop followed by a major transgression, probably the second transgressive pulse of the IIe TR cycle of Johnson et al. (1985) (see Stop 2).

Upper Gassaway/Clegg Creek/Huron: The black shales that result from this transgressive pulse are highly enriched in organic matter and are variably known as Upper Gassaway (Tennessee/southern Kentucky), Clegg Creek (Indiana/western Kentucky), and upper Huron Shale (Ohio/northeastern Kentucky). This is also the most prolific gas-producing interval in the Devonian black shale succession. Extreme sediment starvation during maximum flooding (coincident with the *Foerstia/Protosalvinia* Zone) has locally led to highly pyritic shales that may contain up to 40 wt. percent sulfur. The erosion surface that is associated with this TR cycle is distinct and clearly visible in cores, gamma-ray profiles, and outcrops of the New Albany and Chattanooga Shales, and is a very valuable marker for sequence stratigraphic purposes. Statements made at Stop 2 with regard to the age of the Huron base apply here as well.

Figure 2.3.6: Outcrop photo of truncation surfaces in the interbedded black/gray shale interval above the Trousdale. Figure 2.3.7 (below) shows a tracing of truncation surfaces and bedding planes from a photo

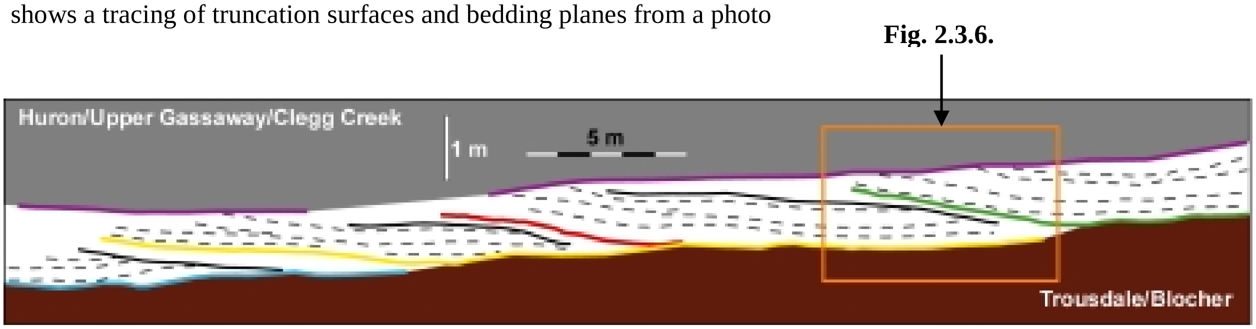


Figure 2.3.7: Truncation surfaces in the Middle Gassaway/Camp Run equivalent (vertical exaggeration by a factor of 2). Lag deposits are marked with solid colored lines, and traced beds are marked with dashed black lines. Erosion surfaces within the interval are marked with solid black lines. The basal lag is marked in blue and separates the underlying Trousdale/Blocher from the overlying Middle Gassaway/Camp Run. Three additional lags are associated with the following three TR cycles (marked in yellow, red, and green).

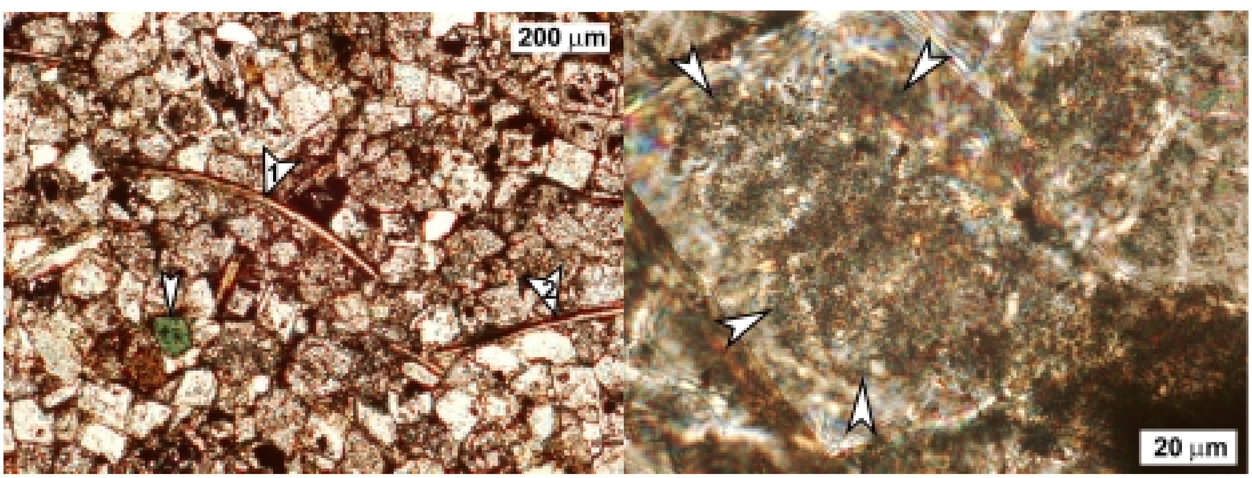


Figure 2.3.8: Photomicrographs from lag deposits in the Middle Gassaway/Camp Run interval. *Left:* Fabric overview with interlocking euhedral dolomite grains, rounded quartz grains, *Lingula* shells (arrows 1 and 2), glauconite pellets (narrow white arrow), and brownish phosphatic grains (bone debris). *Right:* Closeup of dolomite crystal that shows a cloudy detrital core (arrows) and a clear overgrowth rim with rhombohedral margins.

More than any of the other exposures that we have seen today, this one vividly and unmistakably drives home these messages:

1) Intermittent erosion does occur in Devonian black shale successions.
2) This is due to lowering of sea level.
3) These erosion surfaces can be the basis for sequence stratigraphic subdivision.
4) Sequences in black shales do not have to be very thick.

As a case in point, in the Camp Run/Middle Gassway interval of this outcrop, we have four sequences over a vertical distance of about one meter, indicating that only detailed analysis of cores and outcrops will be able to resolve these important stratigraphic markers. In the context of this outcrop (Fig. 2.3.2), the associated parasequences may well be the black/gray couplets that make up the succession between erosion surfaces.

It is also worth noting that at some distance from the Cincinnati Arch, in western Indiana, the Camp Run is quite a bit thicker (measures on the order of 10 meters or more as compared to barely a meter at Stop 3A) and lacks obvious erosion surfaces. This is evidently a reflection of deeper water conditions in Indiana that reduced the likelihood that shales suffered serious wave erosion during sea level drops. One can, however, (with some imagination) see multiple depositional cycles (at least three) in the Camp Run of Indiana, probably a distal reflection of the sea level changes that caused erosion in Cincinnati Arch locations.

Stop 3B: We already passed this exposure on our way down from Junction City (Fig. 2.3.1). It represents the upper portion of the Devonian black shale section at this location. The outcrop is a continuation of the succession seen at Stop 3A and slightly overlaps with it at road level (the match-up was done with gamma-ray profiles).

Huron Shale: What we see here at the base are a few more feet of massive Huron (high radioactive interval) that pass upwards into less resistant shales that weather in a characteristic ribbed fashion. This “ribbing” is due to periodic changes in clay and organic matter content (high clay = softer weathering; high TOC = harder weathering) that probably reflects climatic cycles (Jaminski et al., 1998). The resulting couplets of softer and harder shale are in this location a decimeter or less in thickness, but further east (for example in exposures on I-64 west of Morehead, Kentucky) they measure in decimeters and the respective interval can be hundreds of meters thick. The difference is a reflection of higher sedimentation rates in the Appalachian Basin and smaller sedimentation rates on the Cincinnati Arch.

Three Lick Bed: This outcrop also shows the Three Lick Bed that we saw at Stop 2B in the upper third of the exposure. The Three Lick Bed is thinner now and the gray shale beds are less pronounced, again a reflection of smaller sedimentation rates on the Cincinnati Arch. Like elsewhere in Kentucky and Ohio (Walker Hellstrom and Babcock, 2000), the Three Lick Bed is also marked by a sharp drop in gamma-ray activity (Fig. 2.3.2).

Cleveland Shale equ.: Above the Three Lick Bed follows again a more massive weathering black shale interval that we consider correlative with the Cleveland Shale of Ohio. It is the uppermost Devonian black shale unit in the Appalachian Basin and partial laterally equivalents occur in the Upper Gassaway Member of the Chattanooga Shale in Tennessee and southern Kentucky. Whether its lateral equivalents are also preserved at the top of the New Albany Shale is presently not known.