

Road Log - Day Three

- 0.2
16.0 On left side, dark bay fill shales of the Breathitt Formation overlying red and green shales and siltstones of Nada and Cowbell Members of the Borden Formation.
- 0.3
16.3 On left and right sides, shales of the Breathitt Formation overlying shales and siltstones of Nada and Cowbell Members of the Borden Formation.
- 0.3
16.6 On right side, siltstones of Cowbell Member of the Borden Formation exposed in roadcut.
- 0.3
16.9 On right side, siltstones of Cowbell Member of the Borden Formation exposed.
- 0.4
17.3 Bridge; on left side, red and green shales and siltstones of Cowbell and Nada Members of the Borden Formation are exposed, which are overlain at the west end of cut by sandstones of the Breathitt Formation.
- 0.6
17.9 On left side, red and green shales of Nada Member of the Borden Formation are exposed; they in turn are overlain by sandstones of the Breathitt Formation at the west end of the cut.
- 0.5
18.4 On right side, distributary mouth bar sandstones and siltstones of the Breathitt Formation are exposed in large roadcut.
- 0.4
18.8 Rowan-Carter County line; on left and right sides are exposed distributary bay-fill shales and sandstones of the Breathitt Formation.
- 0.5
19.3 On left, red and green shales of Nada Member of the Borden Formation overlain by interdistributary bay-fill shales of the Breathitt Formation.
- 0.2
19.5 Westbound entrance ramp to weigh station.
- 0.7
20.2 On both left and right side of the interstate, tidal-flat deposits of St. Louis through Tygarts Creek Members of the Slade Formation are exposed.
- 0.6
20.8 On right side, tidal-flat carbonates of the Slade Formation.
- 0.3
21.1 On right side, carbonates of St. Louis through Tygarts Creek Members of the Slade Formation overlie silt-stones and green and red shales of Cowbell and Nada Members of the Borden Formation (see Chaplin, 1980, Perry Br. Section).
- 0.3
21.4 Overpass of Kentucky Highway 799; on both right and left sides, siltstones of upper Cowbell Member of the Borden Formation are exposed.

Road Log - Day Three

- 0.7
22.1 On right side, siltstones and shales of upper Cowbell Member of the Borden Formation (see Chaplin, 1980, Haney Br. Section 1A).
- 0.2
22.3 On right side, siltstones and shales of upper Cowbell Member of the Borden Formation.
- 0.5
22.8 On right side, siltstones and shales of lower Cowbell Member and upper Nancy Member of the Borden Formation.
- 0.2
23.0 On right side, siltstones and shales of lower Cowbell Member and upper Nancy Member of the Borden Formation.
- 0.2
23.2 On right side, siltstones and shales of lower Cowbell Member and upper Nancy Member of the Borden Formation, (see Chaplin, 1980, Haney Br. Section 1B).
- 0.1
23.3 On right side, siltstones and shales of Cowbell and Nancy Members of the Borden Formation.
- 0.5
23.8 On left side, gradational contact between Nancy (shale) and Cowbell (siltstones) of the Borden Formation.
- 0.7
24.5 On left side, shales of Nancy Member of the Borden Formation.
- 0.4
24.9 On left side, shales of Nancy Member of the Borden Formation with thin turbidite beds in its lower part.
- 0.5
25.4 On left side, gradational contact between the prodelta shales of Nancy Member and the distal turbidite beds of Farmers Member of the Borden Formation.
- 0.9
26.3 On left side, rest area.
- 0.3
26.6 On right side, rest area.
- 0.7
27.3 On left side, shales of Nancy Member of the Borden Formation exposed in roadcut.
- 0.6
27.9 On left side, shales containing layers of siderite nodules belonging to Nancy Member of the Borden Formation are exposed.
- 0.6
28.5 On both left and right sides, very fine-grained sandstone turbidite beds of Farmers Member of the Borden Formation are exposed.
- 0.3
28.8 On both the left and right sides of the interstate, the very fine-grained, sandstone, distal turbidite beds of Farmers Member of the Borden Formation are exposed.

Road Log - Day Three

- 1.2
30.0 Exit 137, (Morehead-Flemingsburg), junction of I-64 and Kentucky Highway 32. On both left and right sides of the exit ramp, turbidite beds of the Farmers Member are exposed. Turn left onto KY Highway 32 heading southeast towards Morehead.
- 0.9
30.9 On the left side, shales and siltstones of Cowbell Member of the Borden Formation are exposed in roadcut.
- 0.4
31.3 On the left side, shales and siltstones of Cowbell Member of the Borden Formation are exposed in roadcut.
- 0.5
31.8 On the left side, shales with zones of siderite nodules and siltstones of Nancy and Cowbell Members of the Borden Formation are exposed.
- 0.4
32.2 On the left side, shales and siltstones of Nancy and Cowbell Members of the Borden Formation are exposed in roadcut.
- 0.6
32.8 Junction of State Highway 32 and U.S. Route 60. Turn right onto U.S. Route 60 and proceed west.
- 0.6
33.4 Junction of U.S. Route 60 and State Highway 519 on the left. Proceed west on U.S. Route 60.
- 0.5
33.9 On right side, distal turbidite beds of Farmers Member and prodelta shales of Nancy Member of the Borden Formation are exposed.
- 2.4
36.3 On right side, black, fissile shales of the Sunbury Shale, (Lower Mississippian) are exposed.
- 1.0
37.3 Junction of Lakeview Heights access road and U.S. Route 60. Also on the right side, exposed in roadcuts, are the gray shales of the Bedford Formation. (Upper Devonian/Lower Mississippian?) and the overlying Sunbury Shale.
- 0.2
37.5 On the right side, the contact between black shales of Sunbury Shale and distal turbidite beds of Farmers Member of the Borden Formation are exposed.
- 0.2
37.7 Bridge over Chesapeake and Ohio Railroad Tracks.
- 0.3
38.0 Bridge over Triplett Creek.
- 0.4
38.4 On left side, black fissile shale of the Ohio Shale (Upper Devonian) is exposed..
- 1.2
39.6 Junction of Farmers airport access road on left with U.S. Route 60. Proceed west on US 60.
- 0.5
40.1 Junction of State Highway 801 and U.S. Route 60, on the right side, proceed west on US 60. Exposure of Ohio Shale on left side.

Road Log - Day Three

- 0.2
- 40.3 Junction of State Highway 801 and U.S. Route 60, on the left side. Turn left onto 801 and proceed south.
- 0.2
- 40.5 On left side is a large roadcut exposure of the Ohio Shale. Also note numerous slump features along the roadcut and hillside, as this unit presents many engineering problems locally.
- 1.1
- 41.6 View on right hand side of Minor E. Clarke Fish Hatchery. This is the largest hatchery in the state of Kentucky and one of the most advanced facilities in the country.
- 0.2
- 41.8 Junction of State Highway 801 and access road to Minor E. Clarke Fish Hatcheries on right, continue on 801.
- 0.3
- 42.1 On right side is a roadcut exposure of the Ohio Shale.
- 0.1
- 42.2 On right side, the Bedford Shale is exposed in roadcut.
- 0.1
- 42.3 On right side, the Sunbury Shale and sandstone beds of Farmers Member of the Borden Formation are exposed in the roadcut.
- 0.1
- 42.4 Junction of State Highways 801 and 826, turn right onto 826 and proceed south.
- 0.1
- 42.5 On the right side is the access road to the Cave Run Lake Project Office.
- 0.4
- 42.9 Cross Cave Run Lake Dam. Cave Run Lake is on the left side of the Licking River and on the right side at the base of the dam. Also note hatchery ponds to the far right.
- 0.2
- 43.1 Stop 4 - Junction of Cave Run Lake Spillway Access Road and SR 826. Turn left onto spillway access road.

Stratigraphy and depositional environments
of the Sunbury and lower Borden Formations (Lower Mississippian)
in northeastern Kentucky

- STOP 4 - CAVE RUN LAKE SPILLWAY SECTION -

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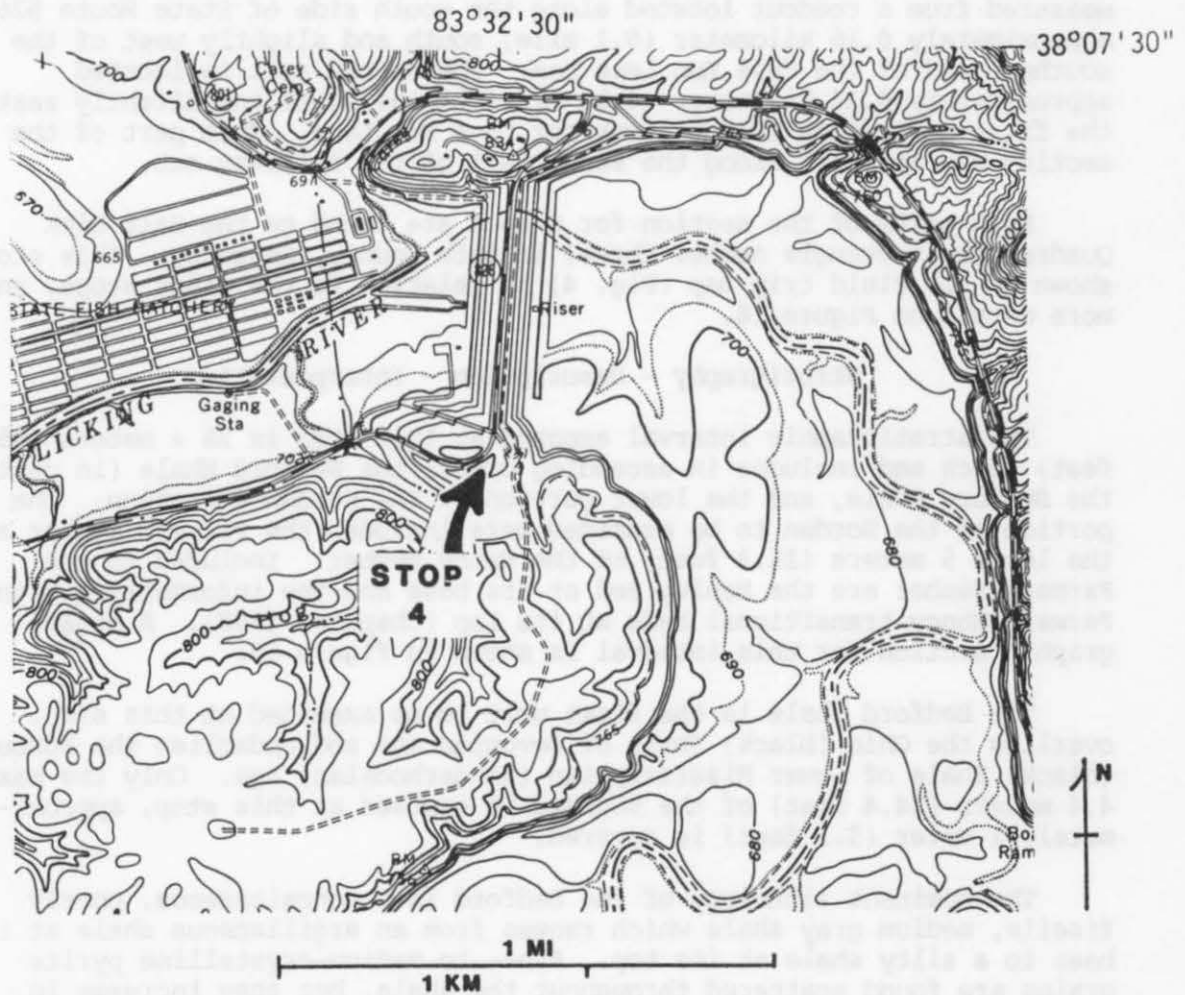


Figure 18. Location map for Stop 4. Location of Measured section is shown on a portion of the Salt Lick, Kentucky 7.5' Topographic Quadrangle Map.

Purpose

At this stop we will examine: 1) the upper part of the Bedford Shale, 2) the Sunbury Shale, and 3) the lower part of the Borden Formation which includes the Farmers Member and the lower 5 meters of the Nancy Member. Some of the more interesting features to observe and discuss include: 1) anaerobic, dysaerobic, and aerobic conditions in the marine environment, 2) distal turbidites with their associated sedimentary structures, 3) basin floor and prodelta deposits, and 4) a subaqueously derived lag deposit containing abundant fossils (especially conodonts).

Location

Stop 4 is a composite section made up of two parts. The first is measured from a roadcut located along the south side of State Route 826 approximately 0.16 kilometer (0.1 mile) south and slightly west of the southern end of the Cave Run Lake Dam. The second part is located approximately 0.24 kilometer (0.15 mile) to the south and slightly east of the first part along the spillway for Cave Run Lake. This part of the section was measured along the south wall of the spillway cut.

Both parts of the section for Stop 4 are found on the Salt Lick Quadrangle (rectangle number three) in Bath County, Kentucky. This stop is shown on the field trip map (Fig. 4) in relation to the other stops, and in more detail on Figure 18.

Stratigraphy - Description - Interpretation

The stratigraphic interval exposed at this stop is 26 + meters (85.3 + feet) thick and includes in ascending order; the Bedford Shale (in part), the Sunbury Shale, and the lower portion of the Borden Formation. The portion of the Borden to be examined here includes the Farmers Member and the lower 5 meters (16.4 feet) of the Nancy Member. Included in the Farmers Member are the Henley Bed at its base and the informally designated Farmers-Nancy transitional beds at its top (Chaplin, 1980). A stratigraphic section for this interval is shown in Figure 19.

The Bedford Shale is the first unit to be examined at this stop. It overlies the Ohio (black) Shale of Devonian age and underlies the Sunbury (black) Shale of Lower Mississippian (Kinderhookian) age. Only the basal 4.4 meters (14.4 feet) of the Bedford is exposed at this stop, approximately 1 meter (3.3 feet) is covered.

The dominant lithology of the Bedford is a noncalcareous, poorly fissile, medium gray shale which ranges from an argillaceous shale at its base to a silty shale at its top. Fine- to medium-crystalline pyrite grains are found scattered throughout the shale, but they increase in abundance up section. The unit here is homogeneous and lacking in primary sedimentary structures which implies homogenization from bioturbation. Fossils have thus far evaded us at this locality, however, to the north along I-64 a molluscan dominated marine fauna is found.

This unit locally contains thin (generally 5 centimeters (2 inches) or less) dolomitic siltstone beds especially in its upper part. The uppermost

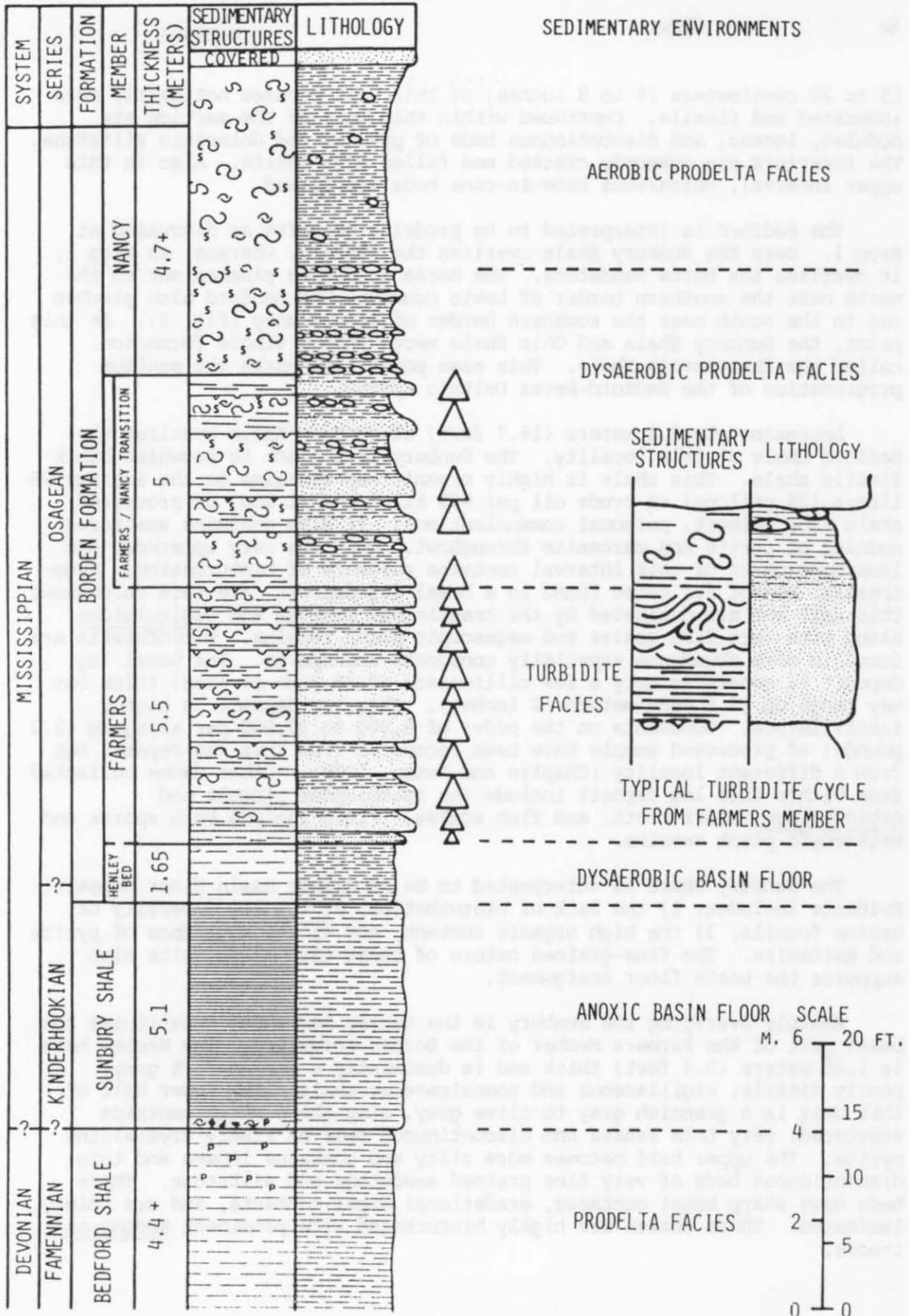


Figure 19. Stratigraphic Section for Stop 4.

15 to 20 centimeters (6 to 8 inches) of this unit becomes noticeably more indurated and fissile. Continued within this part of the section are nodules, lenses, and discontinuous beds of pyritic and dolomitic siltstone. The interiors are commonly cracked and filled with barite. Also in this upper interval, calcareous cone-in-cone beds are formed.

The Bedford is interpreted to be prodelta deposits as discussed at Stop 1. Here the Sunbury Shale overlies the Bedford, whereas, in Stop 1, it overlies the Berea Sandstone. The Berea Sandstone pinches out to the north near the southern border of Lewis county. The Bedford also pinches out to the south near the southern border of Bath county (Fig. 4). At this point, the Sunbury Shale and Ohio Shale merge into a single formation called the Chattanooga Shale. This same point also marks the maximum progradation of the Bedford-Berea Deltaic System.

Approximately 5.1 meters (16.7 feet) of Sunbury Shale overlies the Bedford Shale at this locality. The Sunbury is a black to brownish black fissile shale. This shale is highly organic and contains on the average 95 liters (25 gallons) of crude oil per 909 kilograms (1 ton) of processed shale (Joe Gilbert, personal communication). It also contains scattered nodules of pyrite and marcasite throughout. Only the very uppermost and lowermost parts of this interval contains evidence of bioturbation. Megafossils, except for those found in a basal lag deposit, are rare throughout this unit but are dominated by the brachiopods Lingula and Orbiculoidea along with rare fish scales and megascopic plant remains. Microfossils are found in more abundance especially conodonts and spores. The basal lag deposit is generally only a few millimeters (0.25 inch or less) thick but may range up to 5 centimeters (2 inches). This lag deposit is highly fossiliferous. Conodonts on the order of 8,000 to 10,000 per kilogram (2.2 pounds) of processed sample have been recovered from this lag deposit but from a different locality (Chaplin and Mason, 1979). Other fauna collected from within this lag deposit include the brachiopods Lingula and Orbiculoidea, shark teeth, and fish scales. Flora include both spores and megascopic plant remains.

The Sunbury Shale is interpreted to be an anoxic basin floor deposit. Evidence includes: 1) the lack of bioturbation, 2) the low diversity of marine fossils, 3) the high organic content, and 4) the abundance of pyrite and marcasite. The fine-grained nature of these clastic deposits also supports the basin floor assignment.

Sharply overlying the Sunbury is the Henley Bed which constitutes the basal part of the Farmers Member of the Borden Formation. The Henley here is 1.65 meters (5.4 feet) thick and is dominantly a medium dark gray, poorly fissile, argillaceous and noncalcareous shale. The lower half of this unit is a greenish gray to olive gray, clay shale which contains scattered, very thin lenses and discontinuous beds of finely crystalline pyrite. The upper half becomes more silty and contains lenses and thin, discontinuous beds of very fine grained sandstone and siltstone. These beds have sharp basal contacts, gradational upper contacts, and are thinly laminated. These shales are highly bioturbated with prominent Zoophycos traces.

Also present are scattered burrow-mottled siderite nodules. Body fossils are extremely rare in the Henley and have not been found at this locality. A diverse microfossil assemblage is present and includes conodonts, arenaceous foraminifera, and spores. Chaplin (1984) has placed the Kinderhookian-Osagean boundary of the Lower Mississippian in the basal 25 to 50 centimeters (10 to 20 inches) of the Henley Bed based on his work with conodonts from the Morehead (Kentucky) area.

The basal contact of the Henley Bed sharply overlies the Sunbury Shale and marks the base of the Borden Formation (PL-11B). However, burrows filled with the clay shales of the Henley extend for several centimeters into the underlying black shales of the Sunbury.

The Henley Bed is interpreted to be a basin floor deposit. At the time of deposition this area was basinward of the Borden delta and only the clay fraction was transported to this point. The silt and very fine sand are thought to have been deposited as the distal-most part of the turbidites or density flows. The accumulation of these hemipelagic deposits was very slow as indicated by its fine-grain nature, extensive bioturbation, and condensed faunal zones (regional studies by Mason in progress). Dysaerobic conditions are suggested by the extensive bioturbation, carbonaceous intervals, the abundance of pyrite, and the absence of a good open marine fauna.

Overlying the Henley Bed is 5.5 meters (18 feet) of interbedded sandstone and shale which typifies the Farmers Member of the Borden Formation. Tabular sandstone beds dominate the lithology of this interval (PL-11B). The sandstone is a light gray, moderately sorted, very fine-grained sublitharenite. These sandstones are cemented by siderite, limonite, and microcrystalline quartz. The sandstone beds average 48 centimeters (19 inches) in thickness with the shale beds averaging only 12 centimeters (4.8 inches).

The sharp lower contact of sandstone beds exhibits locally developed sole marks. Commonly encountered erosional sole marks include scour marks and tool marks. Small scale homogeneously distributed flute casts (PL-11E) are the most common scour marks observed. Tool marks include a variety of grooves (PL-11H), chevron, bounce or skip (PL-11C) and prod marks (PL-11C). Other features preserved on the soles of these beds include dewatering structures such as small scale load casts and a preturbidite trace fossil fauna (PL-11H). The most common form genus encountered here is Helminthopsis. Rarer form genera include: 1) Bifungites, 2) Paleodictyon and 3) Neonereites.

Internal sedimentary structures are abundantly preserved in the sandstone beds. These include: 1) parallel laminations (PL-11D), 2) small scale current ripple laminations (PL-11D, PL-11F), and 3) small scale trough cross-laminations (PL-11F). Dewatering structures such as convolute laminae and associated flame structures (PL-11G), though rare, are also present. The lower and middle portions of the thicker sandstone beds contain only the escape structures of the preturbidite fauna.

The upper portions of these sandstone and overlying shale beds are usually heavily bioturbated by a post turbidite fauna (PL-11A). The most

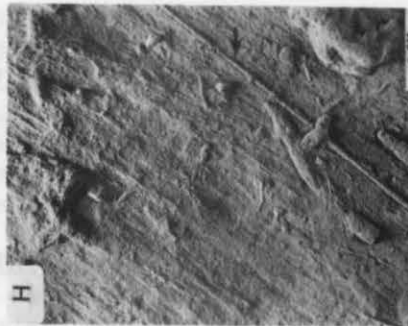
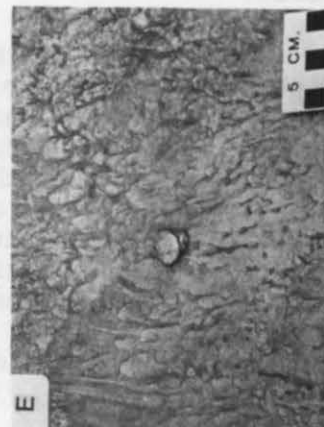
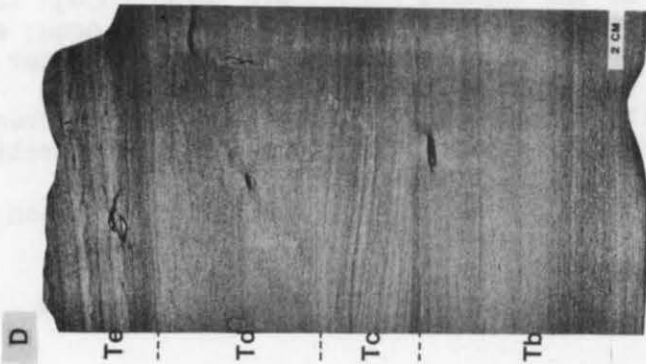
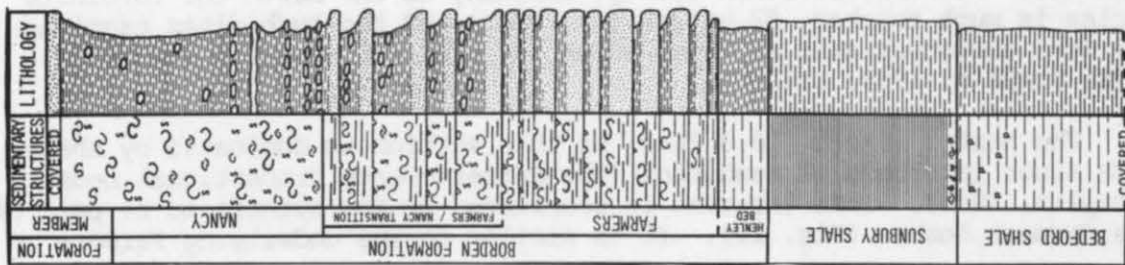
FIGURE CAPTIONS FOR PLATE 11

- Stop 4 -

- Figure A. Upper surface of a typical turbidite bed found within the Farmers Member of the Borden Formation; note extensive burrowing especially by Zoophycos.
- Figure B. Photo along S.R. 826 showing the contact between the Sunbury Shale and the Henley Bed of the Borden Formation as well as the contact between the Henley Bed and the even tabular turbidite beds that constitute the remaining part of the Farmers Member of the Borden Formation.
- Figure C. The undersurface of a turbidite bed from the Farmers Member exhibiting sole marks which include (a) drag marks and (b) tool marks; also note the linear orientation of the sole marks.
- Figure D. Polished slab showing the typical sequence of internal sedimentary structures found within a turbidite bed from the Farmers Member; Bouma Divisions Tb-Te are shown on the figure.
- Figure E. The underside of a turbidite bed from the Farmers Member exhibiting flute casts, again note their linear orientation.
- Figure F. Small scale trough cross laminae which are commonly found in the turbidite beds of the Farmers Member are typical internal sedimentary structures found in Bouma's Division Tc.
- Figure G. Convolute laminations and flame structures are both types of dewatering structures which are encountered in Bouma's Division Tc, however, these internal sedimentary structures, though present, are not common in the turbidite beds of the Farmers Member.
- Figure H. The sole of a turbidite bed from the Farmers Member exhibiting both inorganic and organic sedimentary structures; arrow points to a groove mark.

Note: All specimens shown on this plate, with the exception of that in Figure G, which is from the Berea Sandstone at the Rock Hill Chapel Section (Stop 1), are from Stop 4.

PLATE 11



abundant form genus is Zoophycos. Rarer form genera include Chondrites, Cylindrichnus, Helminthoida, Laevicyclus, Scalarituba, and Teichichnus.

The upper contacts of the sandstone beds are gradational into the overlying shales. These intervening shales are olive gray, poorly fissile, and noncalcareous. The shales in the lower part of this interval are argillaceous and lithologically similar to the underlying Henley Shale. In the upper part they become silty and more similar to the shales of the overlying Nancy Member. The shale intervals are extensively burrowed, but the burrows are deformed due to compaction. These shales also contain scattered siderite nodules. The nodules are light olive gray (fresh surface), silty, and generally ellipsoidal to oval in shape. Relict sediment layering and three dimensional burrows are preserved in these nodules which suggests their formation was prior to compaction of the shales.

Body fossils in this part of the Farmers Member are rare, though local concentrations are encountered within the sandstone beds. These occur as lag deposits in the basal part of the bed or occasionally, in its upper part. An individual fossil is sometimes encountered by itself in the sandstone beds or in the siderite nodules found within the shale intervals. Hexactinellid sponges are the most common fossil observed at this locality. The rarest is a Coelenterate interpreted to be a member of the class Hydrozoa, or more specifically the float of a chondrophorine (Yochelson and Mason, in press). Other fossils include: brachiopods, fenestrate bryozoans, conularids, crinoid detritus, cephalopods, pelecypods, gastropods, phyllocarid remains, Sphenothallus (worm tubes), and fish remains.

The tabular sandstone beds of the Farmers Member are interpreted to be distal turbidites, and the intervening shale beds as interturbidite pelagic deposits. A typical cycle from the Farmers Member would be a fining upward sequence beginning with the sharp contact at the base of a sandstone bed and ending at the top of the shale interval (Fig. 19). A sample from this locality is shown on Plate 11D with Bouma Divisions Tb-Te indicated.

The abundant and diverse trace fossil association found in the Farmers Member is placed in the Nereites ichnofacies by Chaplin (1980; 1982) and supports a relatively deeper water environmental (in an epicontinental setting) interpretation.

Of special note here, the boundary between the underlying basinal deposits (clay shales) of the Henley and overlying prodelta deposits (silty shales) of the Nancy is here interrupted by the turbidite facies of the Farmers. To the south this facies pinches out and this boundary cannot be observed. However, in Lewis County, Kentucky to the north the turbidite facies is much thicker, 82 meters (270 feet) and the turbidites examined are more characteristic of those which are proximal (Chaplin and Mason, 1978; Chaplin, 1980; 1982).

The next 5 meters (16.3 feet) of this section is dominated by shale with minor interbeds of sandstone (the Farmers-Nancy transitional beds (Chaplin, 1980). This interval is considered by the authors to be part of the Farmers Member (Fig. 19). It is similar to the underlying Farmers

except that the shale beds are thicker, 85 centimeters (2.8 feet) and the sandstone beds are thinner, 25 centimeters (10 inches).

The textural and compositional features, and sedimentary structures observed here are similar to those described in the underlying Farmers. Many features on the soles of individual sandstone beds are more apparent here owing to the greater undercutting of the thicker shale intervals. A mean paleocurrent direction of S 72° W was determined for the upper four sandstone beds of this interval.

The shales found in this part of the section are similar to the more silty shale found in the overlying Nancy Member. The shales in this interval are extensively bioturbated to the point of being totally homogenized. Siderite nodules and even lenses are more abundant, and locally are more fossiliferous than those of the underlying shale interval. Cephalopods and conularids are the most commonly encountered fossils in these nodules. Small phosphate nodules are sparsely scattered throughout but are more abundant in the upper shale beds of this interval. These nodules are light olive gray to olive gray in color and average 22.53% P₂O₅ in content (Todd Stewart personal communication, 1985). Relict laminations and three-dimensional worm burrows are preserved in these nodules. They sometimes contain body fossils of which conularids are the most abundant. Microfossils collected from the shale intervals include abundant conodonts and arenaceous foraminifera.

The fine-grained tabular sandstone beds are interpreted to be distal turbidite deposits with the shales representing prodelta deposits. The major difference between this interval and the underlying part of the Farmers Member is the longer period of time represented by the shale intervals. The evidence supporting these longer time periods include: 1) the increased thickness of the shale intervals, 2) the increase in the bioturbation of the shale, and 3) a marked increase in chemical sedimentation (i.e., siderite and phosphate nodule development).

The uppermost part of the section includes 4.7 meters (15.4 feet) of the basal Nancy Member of the Borden Formation. Here, the Nancy is a light olive gray, silty shale which is noncalcareous and poorly fissile. These silty shales are so extensively bioturbated that identification of individual traces is frequently impossible. Some trace fossils however, can be observed. They are listed here in order of decreasing abundance: Zoophycos, Scalarituba, Helminthoida, and Chondrites. Chaplin (1980; 1982) placed this trace fossil association of the Nancy into the Zoophycos ichnofacies.

Siderite nodules, lenses, and beds are abundant in the Nancy Member, especially in its lower part. These siderite nodules, lenses, and beds are olive gray in color (fresh surface). They contain relict laminations and three-dimensional trace fossils which suggests a formation prior to the compaction of the surrounding sediments. These siderite nodules are locally fossiliferous in the lower portion of the Nancy. Cephalopods including both ammonoids and nautiloids are the most commonly found fossils within the nodules from this interval. Other less commonly found fossils here include: conularids, phyllocarid remains, hyolithids, Sphenothallus (worm tubes) and fish remains. Nodules from the middle and especially the

upper part of the Nancy Member also contain brachiopods, gastropods, pelecypods, bryozoans, trilobites, and crinoid debris. The fossils found in the siderite nodules, lenses, and beds are most commonly preserved as both internal and external molds and casts. The void spaces found within the fossils, such as cephalopod chambers, are infilled with barite, sphalerite, and minor galena. Most of the fossils in the siderite nodules are well preserved and show little sign of compaction other than minor fractures. This also supports their early formation within the sediments, before much compaction of the sediment had taken place. In this scenario it is believed the fossil void spaces are next infilled with the barite, sphalerite, and galena. Then at some point following the infilling of the void spaces, the original shell material of the fossils is dissolved away. Following this, there occasionally is some precipitation of pyrite in the voids left by the skeletal material. This type of fossil preservation is found in the Farmers-Nancy transitional beds and throughout the overlying Cowbell Member of the Borden Formation. Regionally, this mineralization has been traced from Scioto County, Ohio in its northern extent to, Madison County, Kentucky in its southern extent (Fig. 4). This is an aerial distance of approximately 160 kilometers (100 miles).

The lower 2 meters (6.6 feet) of the Nancy Member (especially the upper 1.5 meters (4.9 feet) contains a juvenile molluskan fauna. This fauna is dominated by the ammonoid *Kazakhstania* and the archaeogastropod *Sinuitina*. The fauna is significant in that it is interpreted to be of a dysaerobic (oxygen-deficient) environment (Mason and Kammer, 1984). Evidence for the dysaerobic environmental setting of this fauna includes: 1) dwarfed individuals in some species (ammonoids), 2) a high percentage of juveniles, 3) a low species diversity, 4) the dominance by mollusks, 5) a trophic structure similar to living dysaerobic faunas, and 6) the replacement of skeletal material by pyrite and marcasite (Mason and Kammer, 1984). Recent examination of the dysaerobic interval for conodonts has been worthwhile, as conodonts on the order of 30 elements per kilogram (2.2 pounds) or more have been recovered. This is significant as biostratigraphically important ammonoids also occur in the same processed sample. Thus, here it will be possible to compare two biostratigraphically important fossil groups for the Lower Mississippian.

Also present in the upper half of the Nancy are small scattered phosphate nodules which are similar to those described from the underlying interval. Here the phosphate nodules are more abundant and overall slightly higher (22.91%) in P_2O_5 content (Todd Stewart personal communication, 1985). They are more fossiliferous, but conularids are still the most abundant fossils found in these nodules. Other fauna found less commonly include: 1) cephalopods (both ammonoids and nautiloids), 2) *Sphenothallus*, 3) *Lingula*, 4) phyllocarid remains, and 5) fish remains.

The top of the section here is marked by a mostly concealed fine-grained tabular sandstone bed, 40 to 50 centimeters (15 to 20 inches) thick. This sandstone bed is found throughout the region in the lower part of the Nancy Member, approximately 4.5 to 5 meters (14.7 to 16.4 feet) above the base. It is similar to the sandstone beds described in the underlying Farmers Member and is interpreted to be a distal turbidite deposit. The Nancy Member is gradational with the underlying Farmers Member. The upper contact with the overlying Cowbell Member (which is

not present at this section), is also highly gradational.

The Nancy Member is interpreted to be the prodelta deposits of the Borden delta. Evidence supporting this interpretation includes: 1) the silty nature of the shales, 2) the abundance of a good open marine fauna, 3) the dominance of horizontal feeding burrows and trails in an abundant but low diversity trace fossil fauna, 4) the high degree of bioturbation and resulting homogenization of the sediments, 5) the presence of siderite and phosphate nodules, 6) the presence of a dysaerobic fauna, 7) its contained turbidite deposits and gradational lower and upper contacts with basinal clay shales (Henley Bed) and delta front siltstone (Cowbell Member) respectively. For an interpretative reconstruction of this and the previously discussed Borden depositional environments showing their respective trace fossil ichnofacies associations see Figure 6.

Biostratigraphically significant ammonoids have been collected at this and nearby sections from the upper Farmers Member, the Farmers-Nancy transitional beds, and the lower part of the Nancy Member of the Borden Formation.

This abundant ammonoid fauna includes the following species: Muensteroceras parallelum (Hall), M. oweni (Hall), Kazakhstania colubrella (Morton), Protocanites lyoni (Meek and Worthen), Karagandoceras N. sp., and Imitoceras rotatorium (Koninck) Mason, 1981; Gordon and Mason, 1985). Based on the ammonoid fauna, this part of the Borden Formation in northeastern Kentucky is Fern Glen or lowermost Burlington (early Osagean or late Tournaisian) in age (Mason, 1981; Gordon and Mason, 1985).

Road Log - Day Three (Cont'd)

- 0.2
- 43.3 On both sides of the road, the Bedford Shale through the base of the Nancy Member of the Borden Formation is exposed in roadcuts (see stop 1, of Day 3).
- 0.1
- 43.4 Entrance to resident engineers office on right, continue west on State Highway 826.
- 1.1
- 44.5 On the left side, the black, fissile shales of the Ohio Shale are exposed along roadcut.
- 1.9
- 46.4 Junction of State Highway 826 and U.S. Route 60, turn left on 60 heading west.
- 1.7
- 48.1 Overpass of the Chesapeake and Ohio Railroad over U.S. Route 60.
- 1.1
- 49.2 Junction of U.S. Route 60 and State Highway 211, turn left onto 211 and proceed south through the town of Salt Lick.
- 0.2
- 49.4 Railroad crossing of the Chesapeake and Ohio Railroad.
- 0.5
- 49.9 Bridge over Salt Lick Creek.

Road Log - Day Three

- 2.9
- 52.8 Junction of State Highway 211 and Clear Creek Road (Forest Service Road 129) on left, turn left onto Clear Creek Road and proceed southeast.
- 0.3
- 53.1 Bridge crossing Salt Lick Creek.
- 0.9
- 54.0 On left side, in front of Adam's Bait Shop, black fissile shales of the Ohio Shale are exposed in roadcut.
- 0.3
- 54.3 Enter Daniel Boone National Forest. Also note exposures of the Ohio, Bedford and Sunbury shales on left side of the road.
- 0.1
- 54.4 On both left and right sides, sandstones and shales of Farmers and Nancy Members of the Borden Formation are exposed. Also note Clear Creek Lake on the right-hand side.
- 0.5
- 54.9 Access road to Clear Creek Lake and its boat ramp on the right-hand side.
- 0.4
- 55.3 Junction of Forest Service Road 129 and entrance to Clear Creek Furnace Picnic area (129-A) on the right side. Turn right into the picnic area and stop in the parking lot. We will have lunch here by the old iron furnace.
- 0.2
- Leave Clear Creek Furnace Picnic Area and turn right onto Forest Service Road 129 leading southeast.
- 55.5 Junction of Forest Service Road 129 with Forest Service Trail 129-B to Clear Creek Camping Area, on the right side.
- 0.3
- 55.8 Junction of Forest Service Road 129 with Forest Service Road 909 on the right; bear left and continue uphill on Clear Creek Road.
- 0.5
- 56.3 On the left side are exposures of siltstones of the Cowbell Member of the Borden Formation.
- 0.5
- 56.8 Junction of Forest Service Road with Forest Service Road 918 on left side; also enter Pioneer Weapons Hunting Area. Exposures of siltstones and red and green shales of Cowbell and Nada Members of the Borden Formation can be seen on the left, preceding the road junction. Continue on Forest Service Road 129.
- 0.5
- 57.3 On the right side is an exposure of shaly siltstone of Cowbell Member of the Borden Formation.
- 0.6
- 57.9 Junction of Forest Service Road 129 and Forest Service Road 914 on right side, continue on Forest Service Road 129.
- 0.2
- 58.1 Access road to Hunters Campground on right and entrance to Pioneer Weapons Hunting Area on the left side of the road.

Road Log - Day Three

1.5

- 59.6 Junction of Forest Service Road 129 and access road to Leatherwood Boat Dock (to the right) on Cave Run Lake. Bear left and continue uphill on Forest Service Road 129. Note exposure of Cowbell Member of the Borden Formation on left side of the road in roadcut.

0.5

- 60.1 Near the top of the hill is a small pull off on the right side. Pull over here for Stop 5a.

Stratigraphy and depositional setting
of the lower Slade Formation (Upper Mississippian)
in eastcentral Kentucky

- STOP 5a - LEATHERWOOD CREEK SECTION -

R. Thomas Lierman
The George Washington University and
Washington, D.C.

Charles E. Mason
Morehead State University
Morehead, Kentucky

83°32'30"

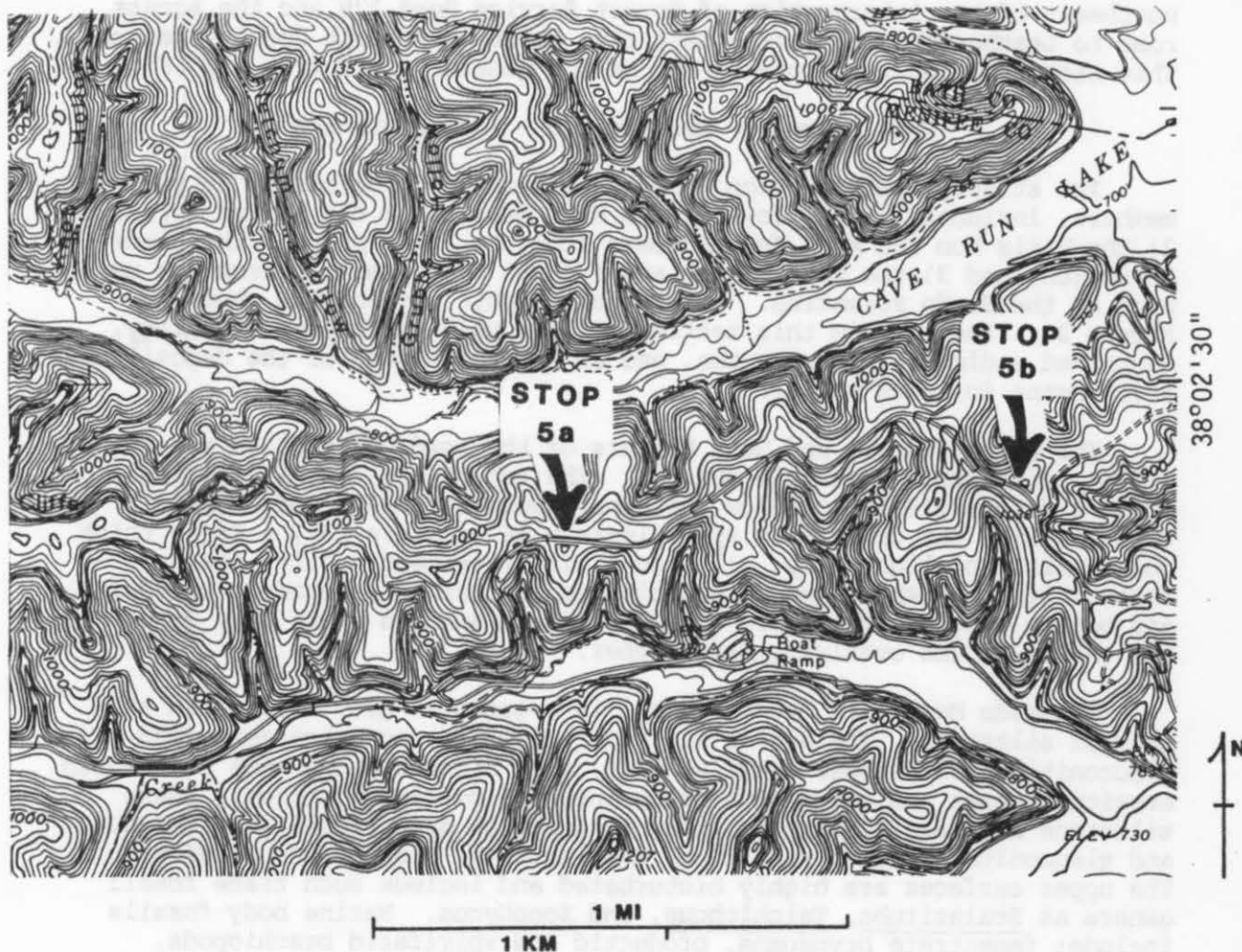


Figure 20. Location map for Stops 5a and 5b. Location of each measured section is shown on a portion of the Salt Lick 7.5' Topographic Quadrangle Map - eastcentral Kentucky.

Purpose

The purpose of this stop is to examine portions of the Slade Formation and the upper part of the subjacent Borden Formation. Approximately 25 meters (82 feet) of the Slade, and nearly 70 meters (230 feet) of the

Borden Formation are exposed along these roadcuts. We will spend this time examining the wide variety of primary and secondary sedimentary structures, as well as the vertical and lateral relationships between adjacent units. Some of the more interesting features to examine here are small scale paleokarst and paleosol zones, and a number of sedimentary structures and textures which suggest vadose zone diagenesis.

Location

Stop 5a is exposed in several roadcuts along Leatherwood Road (Forest Service Road 129). These cuts occur along an east-west trending ridge just north of Leatherwood Creek and are approximately 0.6 mile (1.0 km) northeast of the intersection of Forest Service Road 129 and the access road to Leatherwood Boat Ramp; Salt Lick Quadrangle, Bath County, Kentucky. This stop is shown in Figure 20 and on the general field trip map (Fig. 4).

Stratigraphy - Description - Interpretation

The stratigraphic section exposed at Stop 5a, from oldest to youngest members, includes: 1) the Cowbell and Nada Members of the Borden Formation, 2) the Warix Run and Mill Knob Members from the lower part of the Slade Formation, and 3) the Cave Branch and Tygarts Creek Members from the upper part of the Slade Formation. This stratigraphic sequence is shown in Figure 21. Included in this section will be unit thickness, lithology, contained sedimentary structures, and an interpretation of the depositional environment for each member.

The upper Cowbell and Nada Members of the Borden Formation are the oldest units exposed at this outcrop. The top of the Cowbell is placed about 4 meters (13 feet) below the conspicuous Warix Run/Nada Contact. At this locality the Cowbell is approximately 66 + meters (217 + feet) thick and consists of light gray, siltstones with interbedded silty shales. These siltstones show thin, discontinuous laminations, abundant burrowing and become progressively more argillaceous up section where they grade into the shales of the overlying Nada Member.

The Nada Member (4 meters thick) is a greenish gray shale with thin beds of siltstone. The shales are poorly fissile, noncalcareous, and glauconitic. Siltstones occur as thin, even discontinuous beds with sharp erosional bases and tops which grade into the overlying shales. These siltstone beds are light olive gray to greenish gray, locally calcareous, and glauconite streaked with thin, even to wavy, discontinuous laminae. The upper surfaces are highly bioturbated and include such trace fossil genera as *Scalarituba*, *Teichichnus*, and *Zoophycos*. Marine body fossils include: fenestrate bryozoans, productid and spiriferid brachiopods, pelecypods, gastropods, nautiloids, and echinoderm debris.

The Cowbell and Nada Members are seen as two genetically related units. The Cowbell is a series of delta front deposits including distal bar and interdistributary bay facies. The Nada is part of an open marine, delta destructional facies that occurs as active delta building ceases and delta front deposits are progressively reworked during marine transgression. This sequence is more thoroughly discussed in this volume, by Lowry-Chaplin and Chaplin (day 2) (Chaplin, 1980).

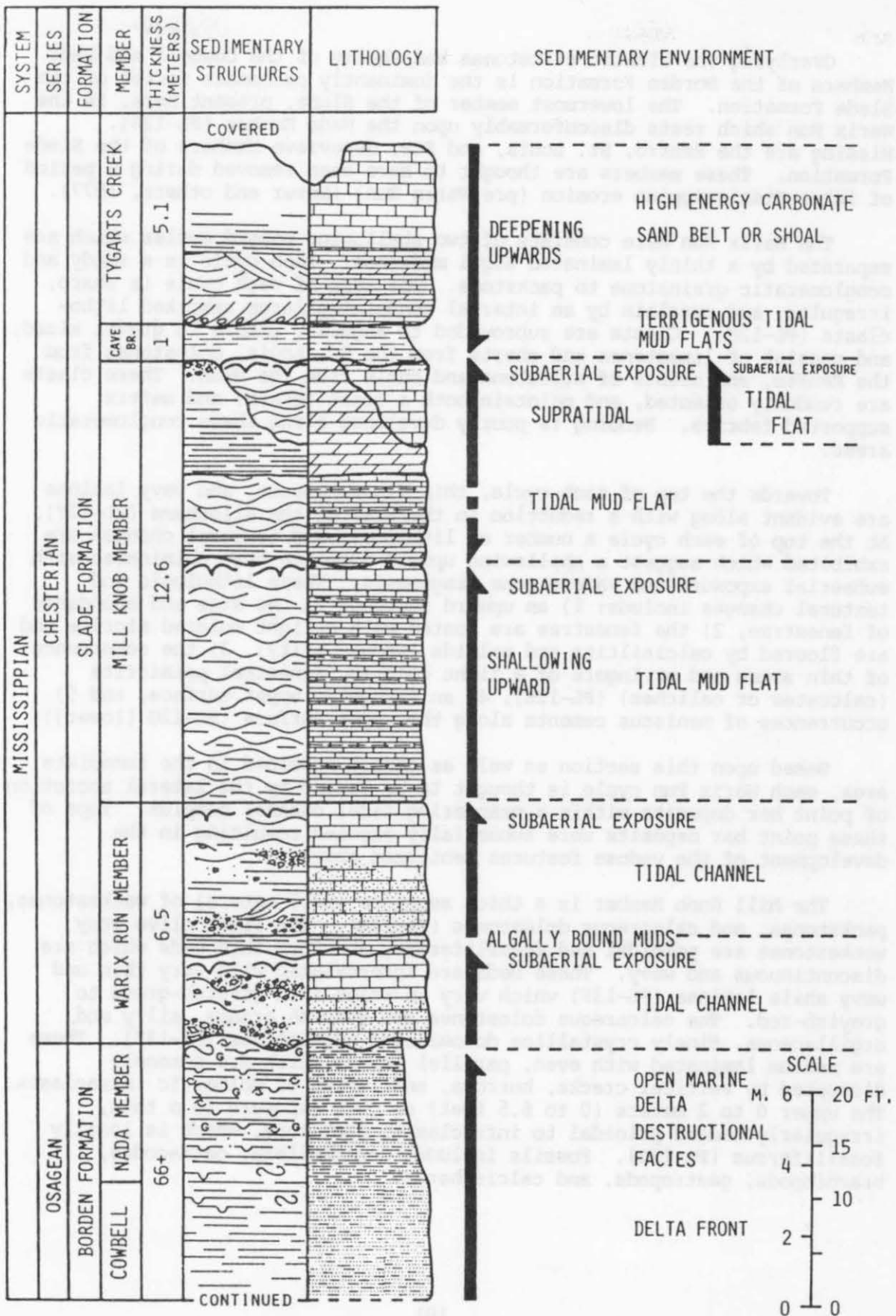


Figure 21. Stratigraphic Section for Stop 5a.

Overlying the clastic siltstones and shales of the Cowbell and Nada Members of the Borden Formation is the dominantly carbonate facies of the Slade Formation. The lowermost member of the Slade, present here, is the Warix Run which rests disconformably upon the Nada Member (PL-12B). Missing are the Renfro, St. Louis, and Ste. Genevieve Members of the Slade Formation. These members are thought to have been removed during a period of intra-Mississippian erosion (pre-Warix Run) (Dever and others, 1977).

The Warix Run here consists of two shallowing upward cycles which are separated by a thinly laminated algal mudstone. Each cycle is a sandy and conglomeratic grainstone to packstone. The base of each cycle is sharp, irregular, and overlain by an interval containing large reworked lithoclasts (PL-12C). Clasts are subrounded to angular, pebble to gravel sized, and consist of limestones and cherts from the St. Louis, dolostones from the Renfro, and clasts of siltstone and shale from the Nada. These clasts are randomly oriented, and maintain both a clast (grain) and matrix supported fabrics. Bedding is poorly developed along these conglomeratic areas.

Towards the top of each cycle, thin discontinuous, and wavy laminae are evident along with a reduction in the size of the allochems (PL-12F). At the top of each cycle a number of lithologic and textural changes are exhibited which suggest a shallowing upward sequence that culminates with subaerial exposure and vadose zone diagenesis. These lithologic and textural changes include: 1) an upward increase in the size and abundance of fenestrae, 2) the fenestrae are coated with a light colored micrite and are floored by calcisiltite and peloids (vadose silt?), 3) the occurrence of thin zones and stringers of a light colored, fenestral pelmicrite (calcretes or caliches) (PL-12E), 4) an irregular upper surface, and 5) occurrences of meniscus cements along the upper surface (PL-12G [lower]).

Based upon this section as well as others examined in the immediate area, each Warix Run cycle is thought to be formed by the lateral accretion of point bar deposits within a meandering tidal channel complex. Tops of these point bar deposits were subaerially exposed resulting in the development of the vadose features mentioned above.

The Mill Knob Member is a thick sequence (12.7 meters) of wackestones, packstones, and calcareous dolostones (PL-13A). The light olive gray wackestones are peloidal and fossiliferous, and form thin beds which are discontinuous and wavy. These beds are intercalated with very thin and wavy shale laminae (PL-13F) which vary in color from grayish-green to grayish-red. The calcareous dolostones are grayish orange, silty and argillaceous, finely crystalline dolomitized wackestones (PL-13E). These are medium laminated with even, parallel layers which are commonly disrupted by vertical cracks, burrows, and layers of dolomitic intraclasts. The upper 0 to 2 meters (0 to 6.5 feet) at this exposure is a thin, irregularly bedded peloidal to intraclastic packstone, which is locally fossiliferous (PL-13D). Fossils include: foraminifera, ostracodes, brachiopods, gastropods, and calcispheres.

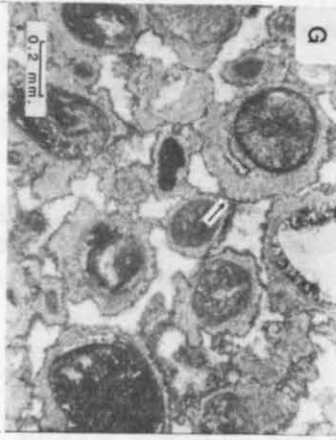
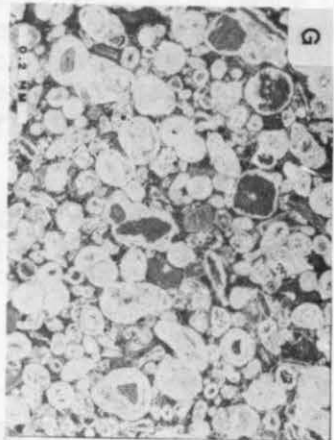
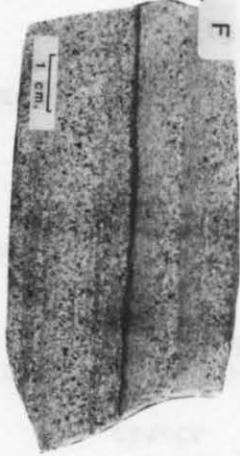
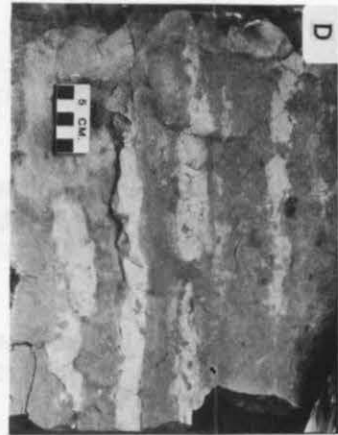
Three shallowing upward cycles are recognized at this stop. They are marked on Figure 21. The top of each of these cycles displays clear evidence of subaerial exposure. This includes: 1) a loss of characteristic bedding as one approaches these exposure zones, 2) upward increase in the size and abundance of fenestrae and shrinkage cracks, 3) zones or areas of in-situ breccia along the upper surface (PL-13B), 4) the brecciated areas tend to be locally dolomitized and silicified, 5) the occurrence of tepee structures along the top margins (PL-13C), and 6) the highly irregular upper surfaces (PL-13A).

FIGURE CAPTIONS FOR PLATE 12

- Stop 5a -

- Figure A. Photo of the Tygarts Creek Member of the Slade Formation overlying the Cave Branch Shale.
- Figure B. Photo of the Warix Run Member of the Slade Formation overlying the Nada Member of the Borden Formation. Arrow points to erosional and irregular contact between these formations.
- Figure C. Polished slab from the base of the Warix Run Member showing a clast-supported framework which contains a variety of clast types. Arrows point to the examples of this variety which include: (a) reworked lime clasts, (b) caliches, and (c) chert fragments from the St. Louis Member.
- Figure D. Hand specimens from the lower half of the Tygarts Creek Member showing the alternation of dolomitic (the darker layers) and calcareous layers. The dolomitic layers are very fine grained, and generally consist of a loose fabric of subhedral, ferrous dolomite crystals.
- Figure E. Polished slab from the top of the Warix Run Member showing areas of well developed fenestral caliche which tends to parallel primary layers in the rock.
- Figure F. Hand sample from the Warix Run Member showing normally graded laminae typically formed in this member.
- Figure G. Photomicrograph of a typical grainstone from the upper half of the Tygarts Creek Member showing ooliths, micrite-enveloped grains, and coated skeletal debris.
[upper]
- Figure G. Thin section from the Warix Run showing well developed meniscus cements (arrow) that are common along the top of this unit.
[lower]

BORDEN FORMATION		SLADE FORMATION			FORMATION	
COMBELL	NADA MEMBER	WARIX RUN MEMBER	MILL KNOB MEMBER	CAVE BR.	TYGARTS CREEK	MEMBER
COVERED						SEDIMENTARY STRUCTURES
LITHOLOGY						
CONTINUED						



[upper]

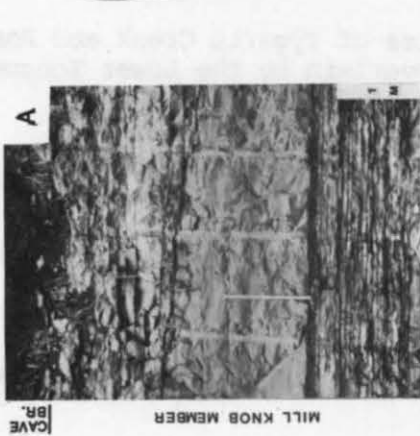
[lower]

FIGURE CAPTIONS FOR PLATE 13

- Stop 5a -

- Figure A. Photograph of outcrop showing the various lithologies of the Mill Knob Member of the Slade Formation at Stop 5a. Note the irregular upper contact of the Mill Knob with the Cave Branch Shale.
- Figure B. Polished slab from the top of the Mill Knob Member. Arrows point to several significant features found within this unit which are: (a) the breccia clasts, (b) the presence of internal sediment which has infilled between the breccia clasts and (c) the presence of fenestral caliche filling void space between clasts.
- Figure C. Close-up of a well developed tepee structure from the top of the Mill Knob Member. Note extensive brecciation along axis of tepee.
- Figure D. Polished hand specimen and thin section of a typical wackestone from the top few meters of the Mill Knob. Allochems include: foraminifera, calcispheres, and ostracods in addition to peloids.
- Figure E. Polished hand specimen and thin section of calcareous dolostone from the Mill Knob Member. Thin section shows a hypidiotopic fabric of ferroan dolomite crystals.
- Figure F. Polished hand specimen and thin section of the argillaceous limestone which comprises most of the Mill Knob Member at this stop.

FORMATION	MEMBER	SEDIMENTARY STRUCTURES	LITHOLOGY	
BORDEN FORMATION	COMBELL	2	FINELY CRYSTALLINE, CALCAREOUS DOLOSTONE	
	NADA MEMBER	2		
SLADE FORMATION	MILL KNOB MEMBER	2	DISCONTINUOUS, WAVY, PARALLEL BEDDED SHALY, WACKESTONE	
	CAVE BR.	2		
	TYGARTS CREEK	COVERED		DISCONTINUOUS, WAVY, NONPARALLEL BEDDED FOSSILIFEROUS
				CONTINUED



A

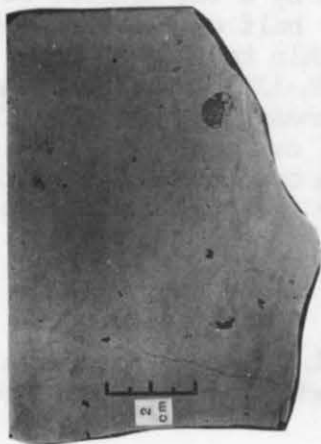
CAVE BR. MILL KNOB MEMBER



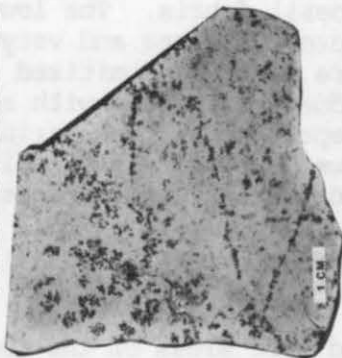
B



C



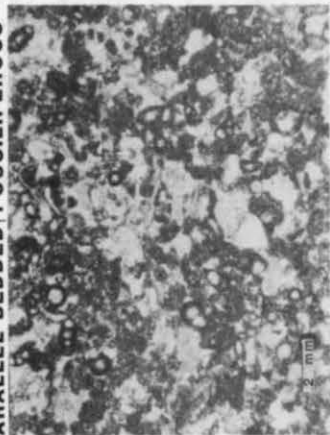
D DISCONTINUOUS, WAVY, NONPARALLEL BEDDED FOSSILIFEROUS



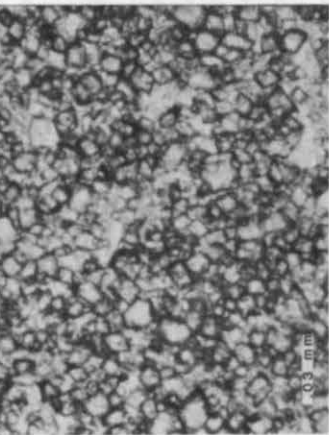
E FINELY CRYSTALLINE, CALCAREOUS DOLOSTONE



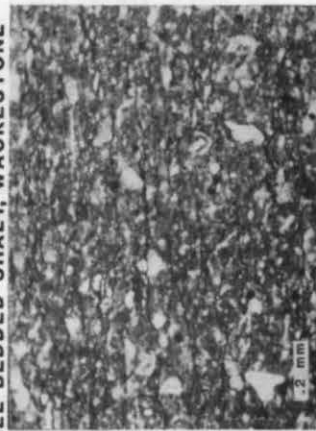
F DISCONTINUOUS, WAVY, PARALLEL BEDDED SHALY, WACKESTONE



G



H



I

At this locality, the Cave Branch Bed is approximately 1 meter (3.3 feet) thick and rests disconformably on the top of the Mill Knob Member (PL-13A). It is a greenish gray, poorly fissile shale which is noncalcareous and poorly fossiliferous. The lower portion is interpreted to be a partially reworked paleosol which rests upon the exposed surface of the Mill Knob. In places, it is gradational into the underlying limestones of the Mill Knob and tends to fill depressions or paleokarsts developed along the upper surface. The upper parts of the Cave Branch Bed very likely represents terrigenous deposition on intertidal mudflats (Dever and other, 1977).

The youngest Member exposed at this stop is the Tygarts Creek Member. Approximately 5 + meters (15 + feet) thick, the Tygarts Creek is dominantly a fine-to-coarse-grained, oolitic grainstone (PL-12G [upper]) which is white to yellowish gray. The lower surface is sharp (PL-12A) with abundant horizontal traces. This is immediately overlain by a lag deposit of rounded limeclasts and fossil debris. The lower half of the unit shows abundant bi-directional cross-laminae and very thin to thin bedded, irregular layers which are partly dolomitized (PL-12D). The upper half of the unit is a thickly bedded grainstone with abundant stylolites. This unit is interpreted to represent an open marine, carbonate shoal which developed following renewed marine transgression over the tidal mudflats of the Cave Branch. This unit will be more closely observed at Stop 5b.

Road Log - Day Three (Cont'd)

- 0.2
- 60.3 On both right and left sides of the road, carbonates of Mill Knob through Tygarts Creek Members of the Slade Formation are exposed in roadcuts.
- 0.3
- 60.6 On both right and left sides, carbonates of Tygarts Creek and Ramey Creek Members of the Slade Formation overlain by the Lower Tongue of the Breathitt Formation are exposed in roadcuts.
- 0.2
- 60.8 On left side, carbonates of Tygarts Creek Member of the Slade Formation are exposed.
- 0.25
- 61.05 Again on both right and left sides, carbonates of Tygarts Creek Member of the Slade Formation are exposed in roadcuts.
- 0.25
- 61.3 At the junction of small road on the left, pull off for Stop 5b, disembark from vehicle and observe exposures on both the left and right sides of road.

Stratigraphy and depositional setting
of the upper Slade Formation (Upper Mississippian)
and lower Breathitt Formation (Lower Pennsylvanian)
in eastcentral Kentucky

- STOP 5b - LEATHERWOOD CREEK SECTION -

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The George Washington University and
Washington, D.C.

Charles E. Mason
Morehead State University
Morehead, KY

Purpose

The purpose of this stop is to examine the upper portion of the Slade Formation (the Tygarts Creek and Ramey Creek Members) and its contact with the overlying Lower Tongue of the Breathitt Formation. Approximately 10 meters (32.5 feet) of the Slade Formation is exposed along the north side of this roadcut and roughly 1.6 meters (5.3 feet) of shale representing the Lower Tongue of the Breathitt Formation. The contact between these two formations is significant in that it represents the boundary between the Mississippian and the Pennsylvanian subsystems. Also of special note is the conspicuous development here of paleokarst and collapse features within the carbonate interval. Other significant features of this stop are the primary and secondary sedimentary structures found within the Tygarts Creek and the Ramey Creek Members of the Slade Formation. These include: 1) selective areas of secondary dolomitization in the lower half of the Tygarts Creek Member and parts of the Ramey Creek Member, 2) evidence of subaerial exposure and vadose zone diagenesis within the Ramey Creek Member, and 3) the occurrence of an abundant but low diversity marine fauna within the Ramey Creek Member.

Location

Stop 5b is exposed in a roadcut along Leatherwood Road (Forest Service Road 129). This exposure occurs along an east-west trending ridge just north of Leatherwood Creek approximately 2.9 kilometers (1.8 miles) northeast of the intersection of Forest Service Road 129 and the access road to Leatherwood Boat Ramp; Salt Lick Quadrangle, Bath County, Kentucky. This stop is shown in Figure 20 and on the general field trip map (Fig. 4).

Stratigraphy - Description - Interpretation

The stratigraphic section exposed at Stop 5b includes the Tygarts Creek and Ramey Creek Members of the Slade Formation (PL-14A) and the Lower Tongue of the Breathitt Formation. The stratigraphic interval exposed at this locality is shown in Figure 22.

The oldest unit to be examined at this stop is the Tygarts Creek Member of the Slade Formation. As observed at Stop 5a, the Tygarts Creek also rests upon the Cave Branch Shale here. A major difference does occur however, below the Cave Branch Shale where the underlying carbonate sequence (the Warix Run and Mill Knob Members; a total of 29 meters [95 feet] found at Stop 5a) is missing at this locality. The Cave Branch Shale at this stop lies directly upon the St. Louis Member of the Slade

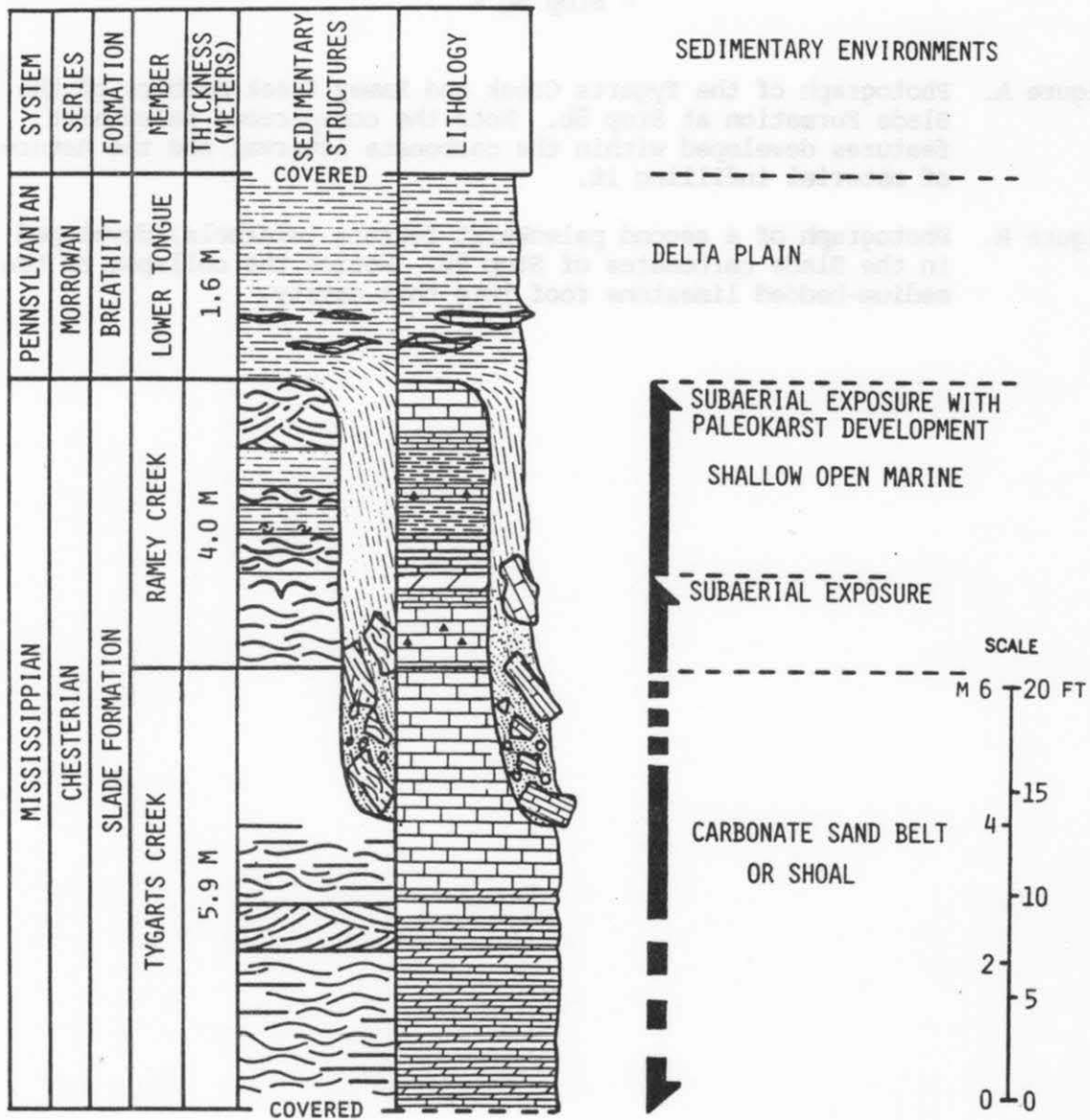


Figure 22. Stratigraphic Section for Stop 5b.

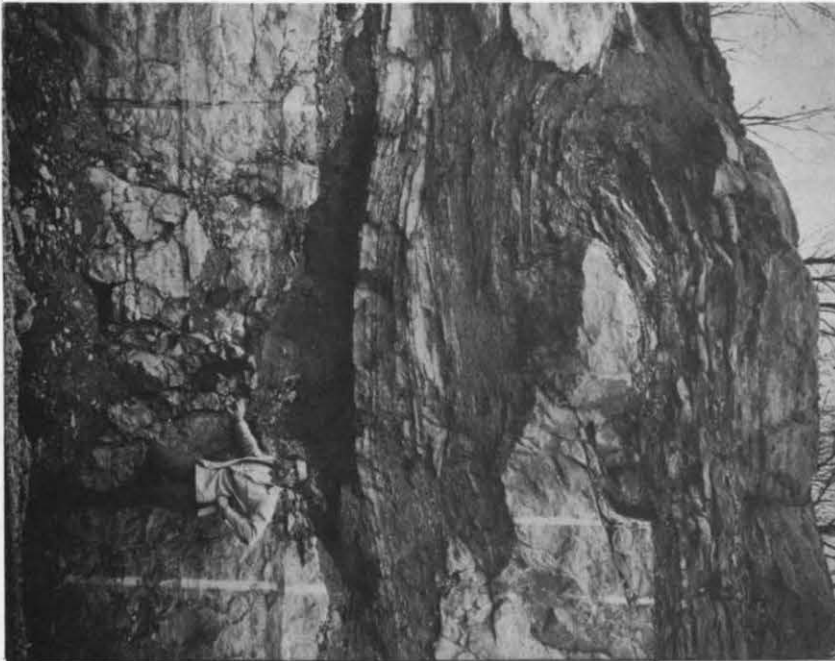
FIGURE CAPTIONS FOR PLATE 14

- Stop 5b -

Figure A. Photograph of the Tygarts Creek and Ramey Creek Members of the Slade Formation at Stop 5b. Note the conspicuous paleokarst features developed within the carbonate interval and the nature of material infilling it.

Figure B. Photograph of a second paleokarst feature (sinkhole) developed in the Slade carbonates of Stop 5b. Notice the collapse of the medium-bedded limestone roof into this cavity.





A

TYGARTS CR.	PALEO-KARST	TYGARTS CREEK	RAMEY CREEK
-------------	-------------	---------------	-------------

B



Formation. It is suggested by Dever and others (1977), that the Warix Run and Mill Knob Members occupy erosional lows which are cut into the underlying St. Louis and Renfro Members of the Slade Formation and the Nada and Cowbell Members of the Borden Formation. The maximum relief reported for these erosional lows is approximately 24 meters (80 feet). The Warix Run and Mill Knob Members attain their maximum thickness in the centers of these areas. Away from the centers these members thin and pinch out along the margin of each low area. This stop is situated along the edge of one of these low areas, whereas the previous stop was situated closer to the center. The St. Louis and Renfro Members which underlie the Cave Branch Bed are poorly exposed here, and will be examined at Stop 6 where they are more accessible and better exposed.

The Tygarts Creek Member is a fine- to coarse-grained, oolitic grainstone which varies from white to yellowish gray in color. The lower contact as indicated earlier, is sharp with the underlying Cave Branch Bed. The lower half of this unit has intervals with bi-directional cross-laminae and very thin to thin bedded irregular layers which are selectively dolomitized. This lower half is generally a packstone to grainstone with ooliths, micrite-enveloped grains and skeletal debris being less abundant here than in the upper half of this unit. Dolomitization appears to have occurred along the more muddy layers. The upper half of this unit is a thickly bedded, fossiliferous grainstone containing abundant ooliths and coated grains along with skeletal debris. Megafossils dominantly making up the skeletal debris are brachiopods, gastropods, echinoderms, and bryozoans. The unit also contains abundant, well developed stylolites.

All evidence encountered here suggests an open marine, high energy, subtidal setting for this unit. Possibly a carbonate sand shoal or tidal bar belt as described by Ball (1967).

The Ramey Creek Member here is a series of interbedded shales and limestones. The limestones vary from medium- to very fine-grained oolitic and fossiliferous packstones and grainstones. These limestones are irregular, thin to very thinly bedded with thin shale layers separating the beds. These layers are locally fossiliferous particularly towards the top of individual beds. The most abundant fossils found in this interval are solitary rugose corals, brachiopods, blastoids and crinoid debris. Red and gray chert nodules are quite common in these layers as well, with the chert apparently replacing areas of intense bioturbation. The shales in this interval are light olive gray, noncalcareous to calcareous and fissile. Generally they contain thin, discontinuous limestone beds and locally they are fossiliferous containing the above listed fauna.

An interval found in the lower third of the Ramey Creek Member, contains evidence of subaerial exposure and alteration. This evidence includes: 1) an irregular upper surface, 2) intense brecciation along the top of the unit, 3) an increase in the abundance of irregular fenestrae upwards, and 4) the replacement of the altered zone by dolomite.

In general, a subtidal, open marine setting is suggested for this interval with the development of poorly washed, skeletal sand shoals deposited within an overall muddy environment. Occasionally these shoals may be subaerially exposed.

Overlying this shallow marine carbonate interval are 1.6 meters (5.3 feet) of shales from the Lower Tongue of the Breathitt Formation which is considered to be Pennsylvanian in age. These shales are poorly fissile, olive gray, noncalcareous, and nonfossiliferous with the exception of plant detritus. The lower part of this interval contains rare, very thin lenses of argillaceous limestone. This sequence of strata is generally interpreted to be deposited within a delta plain setting.

The most conspicuous and interesting feature exhibited at this outcrop are the occurrences of paleokarst and collapse structures (PL-14A and 14B) within the carbonates of the Slade Formation. The section at this stop is missing the two uppermost members of the Slade Formation, as well as the entire Paragon Formation; an interval which could represent up to 40 + meters (130 + feet) of sediments (Ettensohn and others, 1984). The paleokarst features here are filled with sediments resembling those found in portions of the Lower Tongue of the Breathitt; shales, thin sandstone beds, and thin discontinuous seams of coal. It appears from examination of this section that an extensive period of karst development and erosion occurred before the deposition of the Lower Tongue of the Breathitt, and that its initial deposition occurred over a highly irregular surface.

This systemic contact between the Slade and the Lower Tongue of the Breathitt Formations, as seen here, should be compared with that of our next stop, Stop 6, as they are quite different in nature.

Road Log - Day Three (Cont'd)

- Return to vehicle, we will return long Forest Service Road 129 back to the junction with State Highway 211.
- 8.5
- 69.8 Turn right onto S.R. 211 and proceed south.
- 3.2
- 73.0 Junction of S.R. 211 and S.R. 36, turn left onto 36 and proceed southeast.
- 0.1
- 73.1 Bridge, over Clark Fork.
- 0.2
- 73.3 On right side are roadcut exposures of shales of Nancy Member of the Borden Formation.
- 0.3
- 73.6 On right side, shales of Nancy Member of the Borden Formation are again exposed.
- 0.2
- 73.8 Bridge over Salt Lick Creek.
- 0.4
- 74.2 Junction of S.R. 36 & Big Salt Lick Road on the right side at Judith, Kentucky; proceed southeast on S.R. 36.
- 0.6
- 74.8 Junction of State Route 36 with Stone Quarry Road on the right side; proceed on S.R. 36.
- 0.5
- 75.3 On right side of road are roadcut exposures of siltstones of Cowbell Member of the Borden Formation.

Road Log - Day Three

0.5

- 75.8 Pull off the road on the right side at the top of the hill for Stop 6, disembark from vehicle and observe exposures in road cuts along both left and right sides of the road.

Stratigraphic relationships of Mississippian delta
destructional deposits and transgressive carbonate shelf
deposits to overlying Pennsylvanian delta plain deposits
in northeastern Kentucky

- STOP 6 - HILLTOP CHURCH SECTION -

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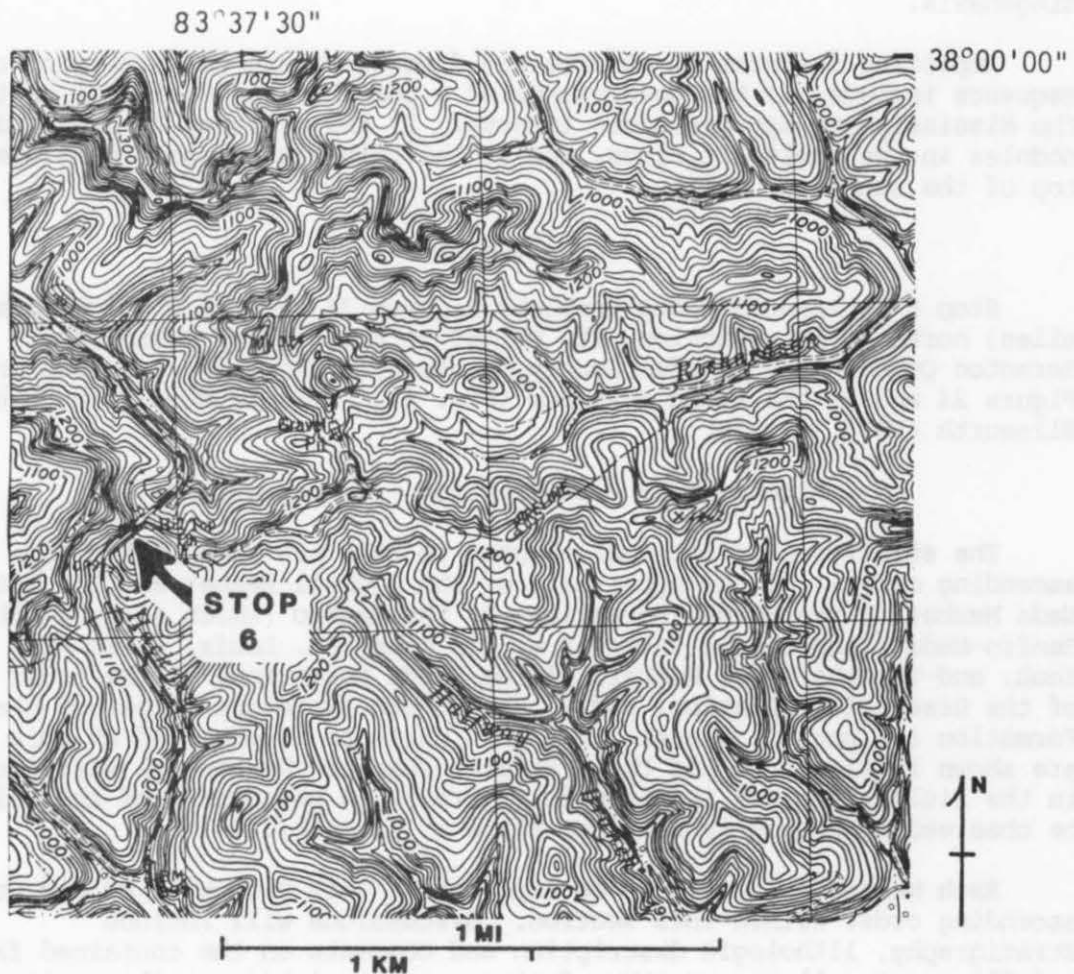


Figure 23. Location map for Stop 6. Location of measured section is shown on a portion of the Scranton 7.5' Topographic Quadrangle Map, Kentucky.

Purpose

At this stop we will examine: 1) clastic lithofacies characteristic of the destructive phase of Borden delta building, 2) carbonate lithofacies representing transgressive shelf deposits on the subsiding Borden delta platform, and 3) clastic deposits overlying the carbonate lithofacies, which resulted from renewed delta progradation.

Some of the more interesting features to observe and discuss within the Nada include: 1) possible submarine discontinuity surfaces, 2) fossil-bearing glauconitized and bored phosphate nodules, and 3) the marine fauna preserved in its upper part.

Notable features to observe and discuss within the carbonate sequence include: 1) various carbonate lithofacies, 2) the nature of the contacts between superjacent units in this sequence, and 3) the development of a number of sedimentary features suggesting subaerial exposure and vadose diagenesis.

Important features to observe and discuss within the overlying clastic sequence include: 1) the development of a possible residual soil on top of the Mississippian age carbonate interval, 2) the presence of residual chert nodules in the semiflint clays, and 3) the thin coal deposit developed on top of the semiflint clay.

Location

Stop 6 is located along Kentucky Highway 36 about 5.0 kilometers (3.1 miles) north of its junction with US 460 in the town of Frenchburg, Scranton Quadrangle, Menifee County, Kentucky. This stop is shown in Figure 23 and on the field trip map (Fig. 4). This is Stop 7 in Dever and Ellsworth (1977, p. 11).

Stratigraphy - Description - Interpretation

The stratigraphic interval exposed in this new roadcut includes (in ascending order): 1) the upper part of the Cowbell Member and the entire Nada Member of the Borden Formation, 2) the Renfro (which includes the Renfro-Nada transitional interval at its base, St. Louis, Warix Run, Mill Knob, and Tygarts Creek Members of the Slade Formation, 3) the Lower Tongue of the Breathitt Formation, and 4) the Corbin Sandstone Member of the Lee Formation (in part). The stratigraphic units to be observed at this stop are shown in Figure 24 and their relationship to the general stratigraphy in the field trip area is shown in Figure 5. A photograph of the units to be observed at Stop 6 is found on Plate 15 (PL-15A).

Each member (or unit) to be examined at this Stop will be discussed in ascending order within this section. Discussions will include stratigraphy, lithologic description and comments on the contained fauna and flora, as well as any other feature used to interpret the environmental setting of the member in question.

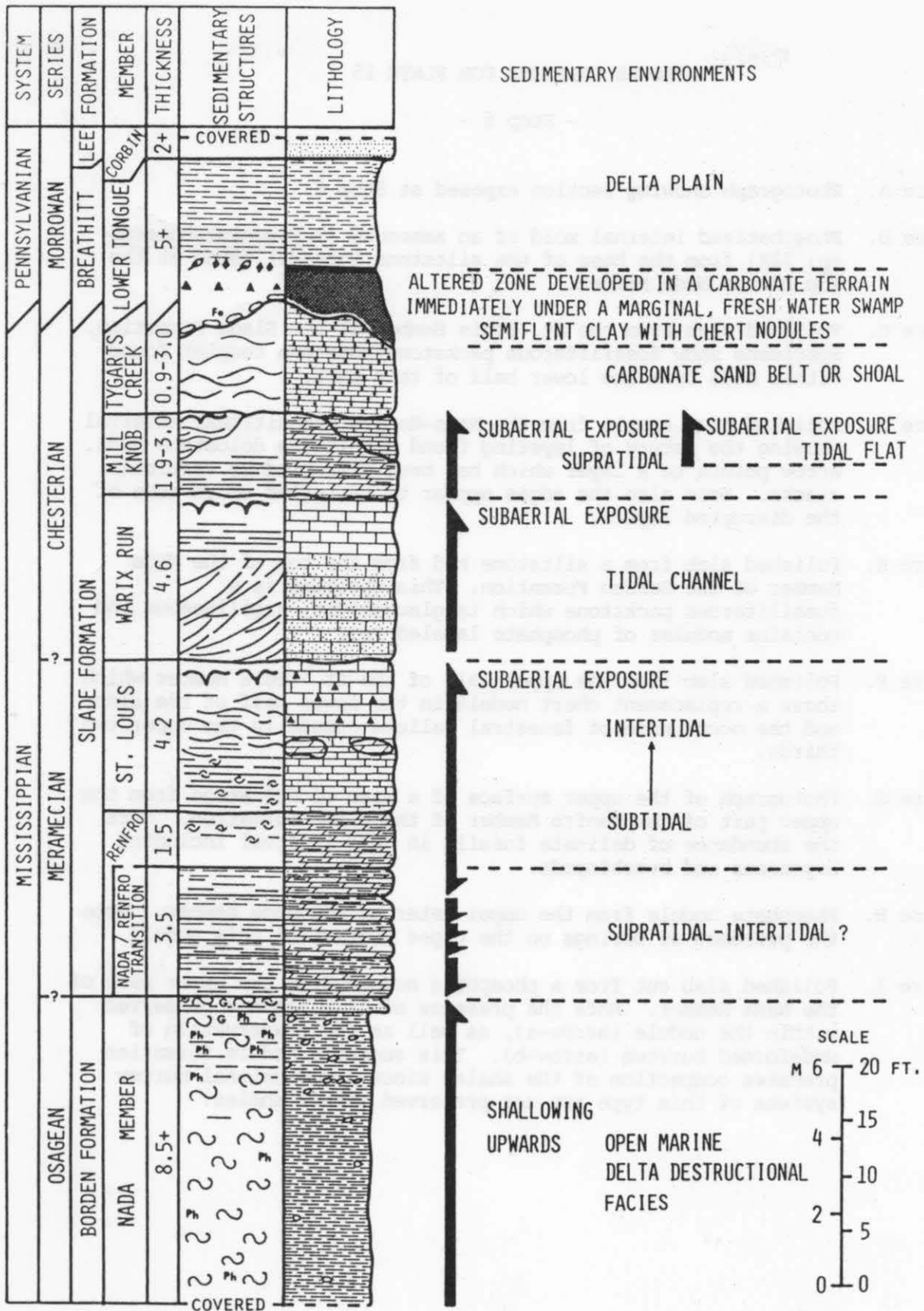


Figure 24. Stratigraphic Section for Stop 6.

FIGURE CAPTIONS FOR PLATE 15

- Stop 6 -

- Figure A. Photograph showing section exposed at Stop 6.
- Figure B. Phosphatized internal mold of an ammonoid (? *Eogonioloboceras* sp; 22X) from the base of the siltstone interval found at the top of the Nada Member.
- Figure C. Polished slab from the St. Louis Member of the Slade Formation. Specimens show fossiliferous packstone/mudstone couplet found within beds from the lower half of this unit.
- Figure D. Polished hand sample from the Nada-Renfro transitional interval showing the nature of layering found within the dolostone beds. Arrow points to a layer which has been disrupted by vertical cracks. Note also the edges appear to be curled up in some of the disrupted layers.
- Figure E. Polished slab from a siltstone bed from the top of the Nada Member of the Borden Formation. This specimen is a fossiliferous packstone which is glauconitic, argillaceous and contains nodules of phosphate labeled (a).
- Figure F. Polished slab from the upper half of the St. Louis Member which shows a replacement chert nodule in the lower half of the slab and the occurrence of fenestral caliche crusts in the upper two thirds.
- Figure G. Photograph of the upper surface of a slab of dolostone from the upper part of the Renfro Member of the Slade Formation. Note the abundance of delicate fossils in this interval including bryozoans and brachiopods.
- Figure H. Phosphate nodule from the upper meter of the Nada Member. Note the presence of borings on the upper surface of this nodule.
- Figure I. Polished slab cut from a phosphate nodule from the upper part of the Nada Member. Note the presence of fine laminae preserved within the nodule (arrow-a), as well as the preservation of undeformed burrows (arrow-b). This suggests nodule formation predates compaction of the shales since 3-dimensional burrow systems of this type are not preserved within shales.

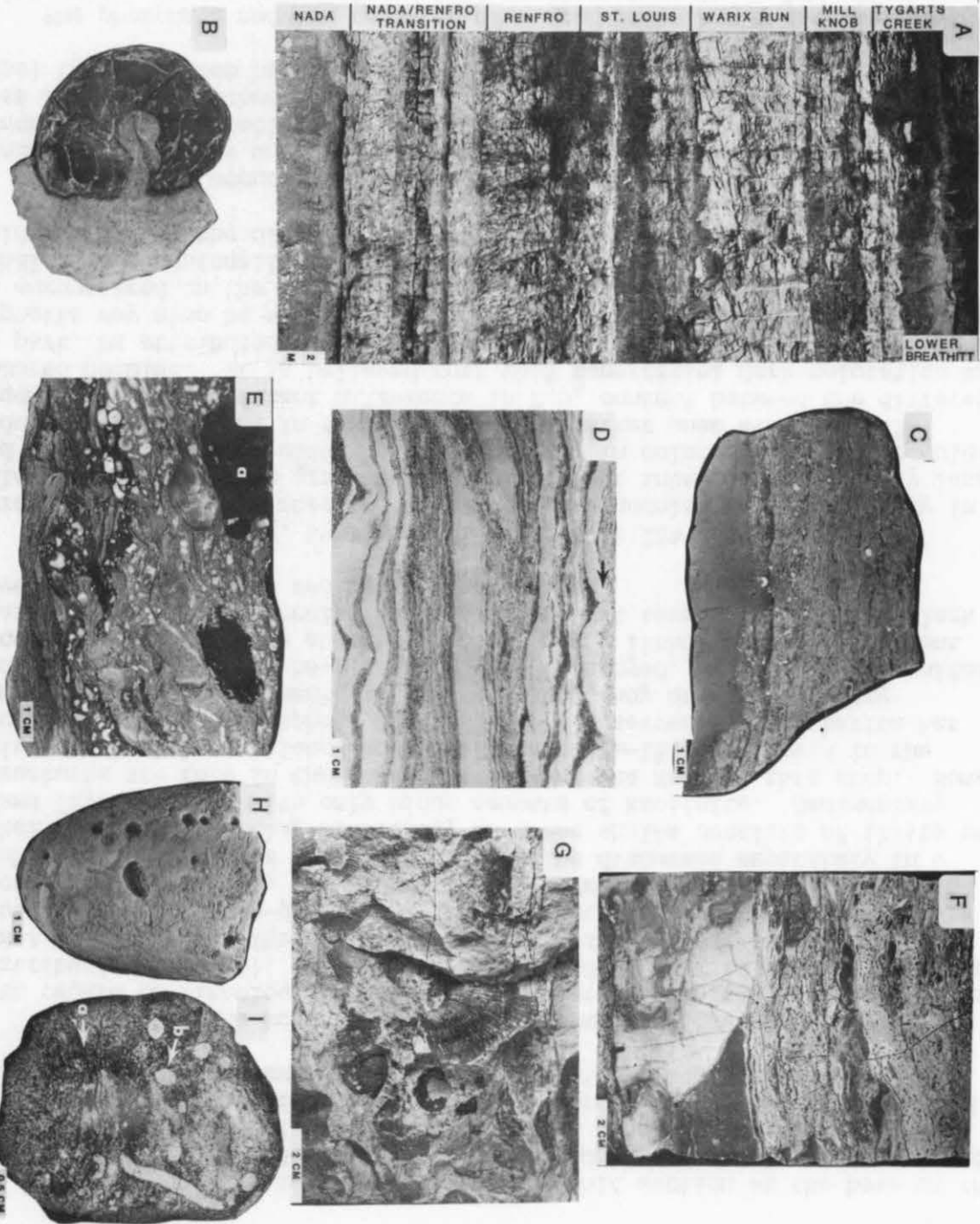
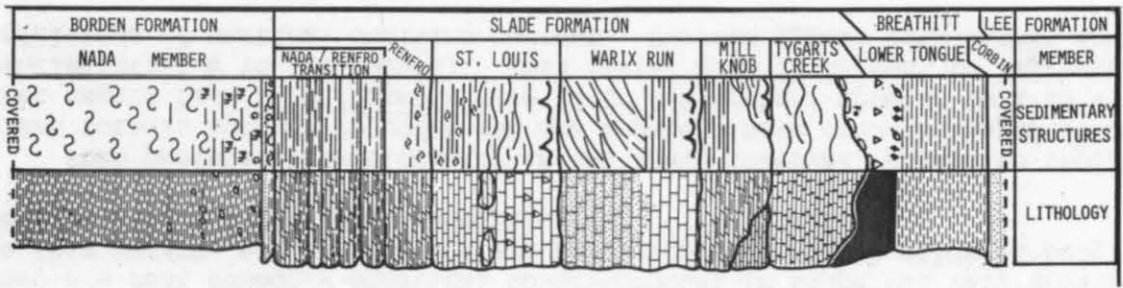


PLATE 15

We will begin examining this stratigraphic section at the base of the Nada Member of the Borden Formation. The Nada has recently been designated the uppermost member of the Borden Formation since Ettensohn and others (1984) removed the Renfro Member from the Borden Formation and made it the basal member of the newly established overlying Slade Formation.

The Nada is the most highly variable member of the Borden Formation with regard to lithologic character, stratigraphic thickness, and regional distribution (Fig. 5). At this stop, the Nada Member is about 8.5 meters (28.3 feet) thick. The dominant lithology is mixed dark-red (lower part of section) and greenish-gray (upper part of section), noncalcareous, platy to poorly fissile shales. The upper 50 to 60 centimeters (2 feet) of this member is dominantly a siltstone and will be discussed separately in a later section. The clay mineralogy of these shales consists of illite and mixed layered clays with only minor amounts of kaolinite. Sedimentary structures are rare in the shale interval of the Nada at this stop. Some faint parallel laminations and worm burrows (PL-15I) preserved in the secondarily formed phosphate nodules can be observed. Bioturbation has homogenized these sediments to the point that any original primary sedimentary structures have been largely destroyed. The extremely uniform fine-grain size and the absence of alternating lithologies of different grain sizes in this lithofacies is also in part responsible for the lack of development of primary sedimentary structures.

Phosphate nodules, averaging slightly over 23% P_2O_5 , are found throughout the Nada Member at this stop. The nodules vary externally in color from light olive gray to olive black, but internally they vary less and are most often an olive to greenish-gray in color. The lighter colored nodules average 23.5% in P_2O_5 , whereas the darker ones average 22.7% suggesting no significant difference in P_2O_5 content between the different colored nodules. It is believed that this superficial dark coloration may, in part, be attributed to the glauconitization processes and that manganese deposits may also be a significant contributor. Pyrite encrustations may be encountered on the surface of some nodules. Pyrite and more commonly sphalerite occasionally occur within the phosphate nodules as infillings of voids left from the dissolution of fossil material.

The nodules occur throughout the Nada and appear to be both scattered randomly within the unit, as well as concentrated in continuous and discontinuous layers, especially in the upper part. However, these nodules are less frequently encountered and smaller (generally a few centimeters or less) in the bottom half of the Nada.

The phosphate nodules range in size from less than a centimeter (0.4 inch) up to approximately 12 centimeters (5 inches) in maximum dimension. They are most commonly spherical to ellipsoidal in shape but vary greatly in this regard, as many nodules are phosphatized internal molds of body fossils and possibly fecal material.

Some phosphate, particularly in the shaly interval, appear to replace trace fossils such as Phycodes and one indeterminate conical-shaped form that tapers from 5 to 7 centimeters (2 to 2.8 inches) upwards to 2 to 4 centimeters (.8 to 1.6 inches). This latter form is thought to represent infillings of vertical dwelling burrows. Burrows appear both within and on

the surface of most phosphate nodules (PL-15H and 15I). Those burrows observed on the surface occur as depressions or molds and/or in raised relief as casts. These burrows also predate the formation of the phosphate nodules within which they are found.

Body fossils in the shales of the Nada Member occur either within the phosphate nodules or are the actual internal phosphatized molds of the fossils themselves (PL-15B). Megafossils found to date include cephalopods, gastropods, pelecypods, bryozoans, brachiopods, conularids, phyllocarid jaw structures, and fish teeth and plates. This fauna is dominated by mollusks and is thought to represent an open marine fauna. Ammonoid taxa of biostratigraphic value have been found in the Nada Member at this locality. These ammonoids are Winchelloceras allei (Winchell) and Eogonioloboceras sp. (PL-15B) from the upper 2 meters (6.5 feet) of the Nada Member and one specimen of Ammonellipsites sp. was found approximately 4.5 meters (14.7 feet) below the top of the Nada Member at this locality. Based on the identifiable ammonoids found to date, the Nada Member here is believed to be of Keokuk age (late Osagean and early Visean) (Gordon and Mason, 1985).

The upper 50 to 60 centimeters (1.7 to 2 feet) of the Nada Member at this stop consists dominantly of a greenish-gray, glauconitic, and shaly coarse-grained siltstone with minor amounts of a greenish-gray, platy, noncalcareous, and glauconitic shale. The siltstone is calcareous and locally grades into fossiliferous packstones (PL-15E). The siltstone beds appear undulatory to rubbly at a distance but on closer inspection, very thin laminations are quite evident. These laminae are caused by alternating glauconite-rich (dark colored) and glauconite-poor (light colored) layers. The glauconite here occurs as pelletal medium sand-size grains and less commonly, as infillings of ostracodes, foraminifera, bryozoan zooecia, and burrows.

One of the most interesting features of this interval is that it contains two separate layers of concentrated phosphate nodules. The lowest concentration occurs at the sharp contact between the siltstone of this interval and the underlying shales. Though found at the contact, the nodules are embedded in the base of the overlying siltstone. The next concentration of phosphate nodules occurs within the siltstone interval approximately 25 centimeters (10 inches) above its base. This nodule zone appears more sporadic than the first, but where observed the nodules are more abundant. The phosphate nodules from the siltstone interval are similar lithologically and in fossil content to those from the underlying shale interval. Variations include: 1) an increase in the overall size of the nodules and 2) a noticeable increase in the number of darker nodules observed in the siltstone interval. The most significant difference is that some of these phosphate nodules are bored to varying degrees on their upper surface (PL-15H). This supports the hypothesis that these nodules have been exhumed and concentrated on the seafloor by submarine erosion. No evidence to date has been found of epizoan encrustations on the surfaces of these nodules. This suggests the nodules did not remain exposed on the sea floor long enough for colonization by epizoans.

The siltstone interval contains a number of trace fossils especially in the upper 15 or 20 centimeters (6 to 8 inches) which is intensely burrowed by the following trace-making genera: Chondrites, Scalarituba, Teichichnus and Zoophycos. Another prominent trace found in this interval is a system of burrows. The individual burrows are 2 to 3 centimeters (approximately one inch) in diameter, silt-filled, and smooth-walled. The burrow systems occasionally show Y-shaped branching and are generally oriented horizontal to bedding. These burrow systems resemble those of the genus Thalassinoides and are herein tentatively assigned to that ichnogenus. Thalassinoides is identified as a trace made by arthropods and interpreted as a dwelling and/or dwelling feeding structure. This and the other ichnogenera described here from the Nada Member are associated with the Cruziana-Skolithos ichnofacies (Chaplin 1980, 1982) (Fig. 6). The trace makers, especially the deposit feeding forms, responsible for this trace fossil association were instrumental in churning the soft substrate and keeping the sediments soft and erodable. In addition, this churning action produced a zone of loose sediment which, along with the burrow systems, would have enhanced chemical exchange between this interval and the overlying water column. This activity possibly aided or encouraged the formation of phosphate nodules in the underlying sediment.

The body fossils found in the phosphate nodules or as phosphatized internal molds are similar to those of the underlying part of the Nada. However, the fossils found in the fossiliferous packstones vary significantly in type and preservation. Crinoid and bryozoan fragments (PL-15E) compose most of the skeletal debris along with a few gastropods and brachiopods. Recrystallization is the dominant type of fossil preservation. Residues from these fossiliferous packstones contain arenaceous foraminifera, sparse conodonts, glauconite infillings of ostracodes and bryozoan zoecia, pyritized burrows, and fish teeth and plates.

The basal part of the Nada Member is interbedded with the underlying Cowbell Member of the Borden Formation. The upper part of the Nada is interbedded with dolostones placed in the Renfro Member of the Slade Formation. Thus, both the lower and upper contacts of the Nada Member are gradational.

The Nada Member is interpreted to be a delta destructional facies of the Borden delta system. There is a noticeable decline in grain size during Nada deposition as is evident by the dominance of shale in this member. There are many factors which may have caused this reduction in grain size; one being the migration of distributaries. Another more plausible explanation is that erosion was nearing base level in the source area.

Phosphate nodules and phosphatized internal molds of fossils are encountered throughout but mainly in the upper half of the Nada Member, both scattered and in horizontal layers. The siltstone interval in the upper part of the Nada is highly glauconitic and contains concentrations of phosphate nodules; some of which are bored (PL-15H). This same interval is also highly bioturbated especially in its upper shaly part.

The above observations, along with the evidence presented in the previous discussion, suggests the following interpretation. Clastics were cut off to the point that even the deposition of suspended sediments was periodic. During periods of non-deposition, chemical activity in marine environments is high (i.e. carbonate deposition and manganese nodule formation (Tucker, 1981)). Thus it is felt phosphatization most likely occurred during these periods. It is believed the phosphate nodules formed within the sediments, below the sediment-water interface but before significant compaction had occurred. This is evident from the presence of preserved laminae and worm burrows with circular outlines within them. Worm burrows are normally flattened films, if preserved at all in the surrounding shales (Mason, 1981).

The origin of the nodules is currently unknown. Organic material (possibly decaying) may have acted as a nucleus. The high incidence of organic material associated with these and other phosphate nodules suggests organic material does play some important role in nodule formation. The amount of time involved in the deposition of the Nada Member is yet speculation, but is currently being investigated.

The nodules found in the Nada are both scattered and in layers. The scattered nodules may have formed during what was then normal deposition, whereas the layers may represent longer periods of nondeposition or possibly periods of submarine erosion where the nodules concentrated as in desert pavement.

The contact between the shale and the siltstone unit at the top of the Nada probably represents an extensive period of nondeposition and submarine erosion during which time a large number of nodules were concentrated. No erosional surface is found associated with the interval but studies have shown that significant discontinuities in the geologic record need not be characterized by discrete erosion surfaces (Baird, 1978). As pointed out earlier, the nodules concentrated at this contact are both light and dark in color, as well as bored in some cases. It is believed the darker nodules have been exhumed longer or possibly more often. This dark coloration is found to be mainly a thin coating on the outer surface of the nodules and may be partly attributed to the glauconitization process. The major cause of this coloration however is thought to be from manganese deposits as these deposits are commonly associated with both glauconite and phosphate (Tucker, 1981). These deposits and the borings occurred after the nodules were exhumed and exposed for periods of time at the sediment-water interface.

Features similar, in part, to those observed in the Nada at this stop, are described by Kennedy and Garrison (1975) in their study of nodular phosphates in the Cenomanian Glauconitic Marl of southeast England. In addition, features such as the glauconite/phosphate mineralization, borings, and the trace fossil assemblage in the Nada are similar to features described by Ekdale, Bromley, and Pemberton (1984) as characteristic of European chalk hardgrounds. A major difference of course, was that the prerequisite lithification carbonate cement was restricted principally to fossil infillings in the Nada, rather than forming extensive cemented surfaces on the sea floor as in the case of the chalk hardgrounds. The magnitude of this possible submarine discontinuity is not yet known but

hopefully paleontological studies now in progress will provide some evidence of its magnitude and regional extent in northeastern Kentucky.

The shaly interval of the Nada, based on the contained fauna (i.e. ammonoids), is thought to have been deposited in deeper (below wave base) marine waters. The overlying siltstone interval however may represent shallower conditions (storm base and above). The concentration of glauconite, a high degree of bioturbation, and the deposition locally of packstones (carbonates) in the siltstone interval, all indicate that clastic influx during this time was still restricted. The disarticulated and broken fossils of the skeletal packstones, especially the crinoids and bryozoans, attest to periodic high energy conditions. This same high energy may have enhanced the formation of glauconite as well as winnowed fines from the sediments to form siltstones and localized deposits of green sands.

Overlying the Nada Member is a series of interbedded dolostones and shales. Formally this sequence of strata is now placed in the Renfro Member of the Slade Formation as shown in the stratigraphic section (Fig. 24) for this stop. However, for discussion purposes this sequence is herein informally referred to as the Nada/Renfro transitional beds.

This interval consists of silty and argillaceous, fine- to medium-crystalline, calcareous dololutes. The dolostones have a yellowish gray color owing to the finely disseminated limonite. Texturally, these rocks have a hypidiotopic fabric of ferroan dolomite crystals. Megascopically, many of the beds exhibit thin, irregular laminae which are due to an alternation of packstone and mudstone layers. The muddy layers are commonly disrupted by vertical cracks (desiccation?) with the broken layers displaying a concave upward curvature (PL-15D). These beds also contain irregular fenestrae and veinlets of coarse, ferroan calcite.

The base of individual dolostone beds is sharp, whereas their upper surfaces are gradational with the overlying shales. These greenish-gray shales are noncalcareous, platy, and glauconitic. They are also very similar lithologically to the shales found in the upper part of the underlying Nada Member.

Based upon this set of observations, a supratidal origin is suggested for the dolostone beds with the shales representing a more marine component. The arrangement of supratidal dolostones overlain by marine shales suggests a series of rapid regressions along the base of individual dolostone units. This is followed by a more gradual transgression in which supratidal dolostones are overlain by marine shales.

The Renfro is the basal member of the Slade Formation and overlies the Nada Member of the Borden Formation. Stratigraphically this part of the Renfro is more closely related to the overlying St. Louis Member than to the Renfro/Nada transitional beds placed in its lower part. This latter statement will be explained more fully later in the discussion of the St. Louis Member.

The upper part of the Renfro is a fine- to medium-crystalline, argillaceous dolomite. It has grayish-orange color due to the presence of finely disseminated limonite. Texturally, the unit varies from a hypidiotopic fabric of subhedral dolomite crystals upwards to an idiotopic fabric of noninterfering, euhedral dolomite crystals scattered within a pelmicrite.

Megascopic sedimentary features are generally absent towards the base. Faint bedding becomes apparent up section and fossils become increasingly more abundant towards the top as well. The most commonly encountered fossils are spiriferid and productid brachiopods, fenestrate bryozoans, and echinoderm debris (PL-15G). This fossil association is very similar to that found in the overlying St. Louis Member.

It is thought that this part of the Renfro Member represents a dolomitized portion of the St. Louis which was originally deposited as a subtidal, fossiliferous pelmicrite.

The St. Louis is the second member of the Slade Formation, and wherever it is encountered, it is underlain by the Renfro Member.

The St. Louis Member is a fossiliferous packstone and wackestone to mudstone. The color is a very light gray to medium gray. The lower half of the unit contains thin irregular beds of limestone which are separated by thin shale partings. Individual beds have a sharp base overlain by a fossiliferous packstone in which fossil debris is horizontally oriented. This grades upward within each bed to a fossiliferous wackestone to mudstone with randomly oriented fossils (PL-15C). This in turn is overlain by a thin parting of shale. Commonly encountered fossils include: spiriferid and productid brachiopods, fenestrate bryozoans, and echinoderm debris along with more rare syringopodid and lithostrotionoid corals. The corals are concentrated in an interval slightly over one meter (3.3 feet) above the base of the St. Louis. The lower half of the unit also exhibits large "pods" of finely crystalline dolomite similar to that of the underlying Renfro. Irregular red to gray nodules of chert which are scattered within the unit or concentrated along distinct layers are also present (PL-15F).

The upper half of this unit exhibits a number of features suggestive of subaerial exposure and vadose zone diagenesis. These include: 1) an irregular upper surface, 2) the presence of calcrete or caliche crusts and stringers in the upper few meters, 3) an increase in the in-situ brecciation up section, 4) an increase in the insoluble residue content up section, 5) the presence of soil like "peds" along the upper surface, and 6) the development of broad, low amplitude tepees along the upper surface as well.

The St. Louis Member was originally deposited as an open marine, subtidal carbonate. The packstone/mudstone couplet is thought to be the result of periodic winnowing of subtidal muds probably during storm activity. The upper half of the unit where it has not been altered is primarily a micrite of shallow, quiet water origin. This unit prograded across a shallow open shelf during a regional marine regression. The upper half is extensively altered by subaerial exposure and vadose zone

diagenesis. The development of dolomite bodies within the St. Louis and the dolomitization of the Renfro probably occurred as fresh and marine waters mixed in a phreatic groundwater zone (Dorag model; Badiozamani, 1973) during this period of subaerial exposure.

Unconformably overlying the St. Louis is the Warix Run Member of the Slade Formation. This member is a sandy intraclastic grainstone to packstone. When previously observed, (Stop 5a), this member occupied the stratigraphic position of basal member of the Slade Formation. At this location (Stop 6) however, extensive erosion and removal of the St. Louis and Renfro Members did not occur. The stratigraphic position and lithologic nature of the Warix Run is here more typical of the unit.

The base of the unit is sharp and its lowermost part is composed of 1 to 2 centimeters (.4 to .8 inches) of calcareous sandstone which contains small rounded clasts of limestone and caliche from the underlying St. Louis. This in turn passes upward into large sets of trough cross-laminated grainstone (PL-15A). A mean paleocurrent direction of N60E was measured for the crossbeds found here. The upper 2 meters (6.6 feet) change abruptly into a horizontally laminated packstone with a noticeable decrease in quartz sand.

The upper 80 centimeters (2.6 feet) or so contains evidence of subaerial exposure and includes: 1) an irregular upper surface, 2) an increase in insoluble residue content, 3) an increase in the development of in-situ brecciation along the top of the unit, and 4) the presence of large areas which have been dolomitized.

This unit is thought to represent the lateral accretion of point bar deposits within a meandering tidal channel complex. The upper part of these point bar deposits were later subjected to extensive periods of subaerial exposure and vadose zone diagenesis.

The Mill Knob Member, which typically overlies the Warix Run Member of the Slade Formation here, is divided into two distinct lithologies. The first is a calcareous dolostone which composes the lower part of the unit, and the second is a peloidal wackestone to packstone composing the upper part. The dolostone interval is similar to that observed in this unit at Stop 5a. It is a silty and argillaceous, fine- to medium-crystalline, limonitic dololomite. The lower half of the unit exhibits thin irregular laminae which are disrupted by vertical cracks, burrow fenestrae, and rip-up clasts. The upper surface is irregular with a relief of 1.5 meters (4.9 feet). Areas of in-situ brecciation occur in the uppermost part of this portion of the member as well.

A supratidal origin with extensive subaerial exposure along the top is suggested here.

The limestone is a very light gray, peloidal wackestone to mudstone. Bedding is thin and separated by shale partings. The upper surface of this portion of the member also shows evidence of subaerial exposure which includes: 1) an irregular upper surface, 2) the presence of brecciation in its uppermost part, 3) an increase of insoluble residue content up section, and 4) the presence of calcrete stringers and crusts.

This sequence is thought to be primarily the result of vertical accretion and progradation of tidal-flat deposits which are later subaerially exposed.

The Mill Knob is overlain by the Tygarts Creek Member which constitutes the uppermost member of the Slade Formation at this locality. This member is a yellowish gray, thin to medium irregularly bedded calcarenite. The calcarenite is a well sorted, medium- to coarse-grained grainstone which is composed of micrite coated skeletal grains and oolites cemented by a clear drusy spar. The fossil grains consist of brachiopods, foraminifera, echinoderm debris, and occasional blastoid calices. The upper surface of this unit is highly irregular with a relief of 2.0 + meters (6.6+ feet).

A high energy subtidal sandbar or shoal is suggested for this unit.

The Lower Tongue of the Breathitt Formation overlies the Slade Formation. The Lower Tongue of the Breathitt here is a medium to dark gray shale. The shale is carbonaceous, noncalcareous, and poorly fissile. The lower third of this unit, however, is a semiflint clay. This semiflint clay varies from 2 to 5 meters (6.6 to 16.4 feet) thick and is directly overlain by a thin shaly bed of coal. This interval overlies the limestone and represents a leached and highly altered remnant of the upper Slade Formation which is missing at this locality. At the base of this unit is a thin, rubbly layer of ironstone ("bog iron") nodules and crusts which lie in direct contact with the limestone and represent a replacement of the carbonate by hematite. Also present in the semiflint clay interval are large scattered nodules of chert and thin seams of coaly shale.

Three samples from the semiflint clay interval were examined by x-ray diffraction. The first of these samples was taken from just above the ironstone layer at the base. This sample contained abundant quartz and kaolinite along with gibbsite and illite. The second sample came from the chert interval and contained abundant kaolinite along with gibbsite and illite. The third sample came from just below the small coal seam and contained only kaolinite.

From the above observations, it is suggested that the semiflint clay interval is all that remains of the limestones of the upper Slade Formation. The carbonate portion has been leached away under the highly acidic and reducing conditions of a marginal, freshwater swamp represented by the overlying coal bed. This is thought to have developed on an eroded carbonate terrain during the Lower Pennsylvanian (Patterson and Hosterman, 1964).

The remaining fissile shale overlying this altered zone is thought to have been deposited in a lower delta plain setting.

The Corbin Sandstone Member of the Lee Formation sits unconformably on top of the shales of the Lower Tongue of the Breathitt Formation. The Corbin sandstone is a quartzose and conglomeratic, fine- to coarse-grained quartz arenite. It is massive to medium or thickly bedded and yellowish gray in color. It is also highly crossbedded and locally contains abundant plant fossils preserved as molds or casts. Only the lower 2 meters (6.6

feet) is exposed in this roadcut section, though extensive cliffs of this member can be seen in the surrounding hillsides (especially on the south side at this stop). This unit is interpreted to be fluvial in origin (Hester and Taylor, 1977).

Road Log - Day Three (Cont'd)

Return to vehicle to proceed south along S.R. 36 to Frenchburg.

- 0.4
- 76.2 Cowbell Member of the Borden Formation is exposed in a roadcut along right side of the road.
- 0.35
- 76.55 Cowbell Member is exposed in a stream cut on right side of the road.
- 0.25
- 76.8 Cowbell Member is exposed in a stream cut along the left side of the road.
- 0.3
- 77.1 Junction of S.R. 36 with S.R. 1274 on left side of the road, continue south on 36.
- 0.8
- 77.9 Bethel Baptist Church on left side of the road.
- 0.5
- 78.4 Cowbell Member exposed on right side of the road behind buildings.
- 0.4
- 78.8 Bridge over Beaver Creek.
- 0.1
- 78.9 Junction of S.R. 36 with U.S. 460; turn left onto U.S. 460 and proceed southeast.
- 0.6
- 79.5 Note: Construction and rerouting of U.S. 460 for the next mile is currently in progress; roadcuts for this section of U.S. 460 will expose a section quite similar to that just examined at Stop 6 except for an increase in thickness of the Breathitt Formation. The long hill we are about to ascend is the Pottsville escarpment.
- 1.0
- 80.5 Junction of U.S. 460 with small black top road on right at the top of the hill, continue on U.S. 460.
- 0.3
- 80.8 Microwave tower on left side of the road.
- 0.1
- 80.9 Road sign for Natural Bridge State Park on right side of the road.
- 1.5
- 82.4 Shales of the Breathitt Formation exposed on the right side of the road behind the house.
- 0.4
- 82.8 Junction of U.S. 460 with S.R. 77 on right side of the road, turn right onto S.R. 77 and proceed south.
- 0.3
- 83.1 Laurel Spring Missionary Baptist Church on right side of the road.
- 1.9
- 85.0 Pecks Grocery on left side of the road.
- 0.2
- 85.2 Log cabin on left side of the road.

Road Log - Day Three

- 0.1
85.3 Tarr Ridge Union Church on right side of the road; a nice view of the Lexington Peneplain can be observed behind the church. (NOTE: PULL OFF TO RIGHT SIDE OF THE ROAD IN FRONT OF THE CHURCH FOR A BRIEF PHOTOGRAPHIC STOP)
- 0.1
86.0 Small sawmill on right side of the road.
- 3.6
89.6 Entrance sign to Daniel Boone National Forest on right side of the road, also on right side are several small oil wells.
- 0.3
89.9 Entrance to Civilian Conservation Center on right side of the road.
- 0.3
90.2 Tarr Ridge picnic area on right side of the road; sign for picnic area on left.
- 0.4
90.6 Red River Gorge Geological Area sign on left side of the road.
- 0.2
90.8 Enter into Red River Gorge; cliff-forming sandstone exposed along both sides of the road are outcrops of Corbin Sandstone Member of the Lee Formation which is Pennsylvanian in age.
- 1.4
92.2 Junction of S.R. 77 and 715, turn right (west) and stay on S.R. 77.
- 0.05
92.25 Sign stating Natural Bridge State Park 10 miles on right side of the road.
- 0.15
92.4 Red River on left side of the road, Cowbell Member of the Borden Formation is exposed in roadcut on right side of the road.
- 0.5
92.9 Turn left and follow S.R. 77, across iron bridge, over the Red River; gravel road straight ahead before left hand turn, goes to Raven Rock, a large Corbin Sandstone outcrop which can be observed when looking down river or west.
- 0.1
93.0 Powell County line and center of iron bridge over the Red River.
- 0.05
93.05 The Cowbell Member of the Borden Formation is exposed on left side of the road in roadcut.
- 0.15
93.2 The Cowbell Member exposed on right side of the road in a roadcut.
- 0.4
93.6 Lower part of the Slade Formation (Renfro and St. Louis (in part) Members) are exposed in roadcut on right side of the road.
- 0.1
93.7 Pennsylvanian age shales and sandstones of Lee and Breathitt Formations are exposed in a roadcut along right side of the road.
- 0.3
94.0 Enter Nada Tunnel which is cut out of the Corbin Sandstone Member of the Lee Formation.

Road Log - Day Three

- 0.2
94.4 Exit Nada Tunnel.
0.2
94.4 Shales from Lower Tongue of the Breathitt Formation are exposed in the roadcut on right side of the road.
0.5
94.9 The Nada Member of the Borden Formation is exposed behind house on left side of the road.
0.45
95.35 The Cowbell Member of the Borden Formation is exposed intermittently for the next 0.4 miles in creek on right side of the road.
0.6
95.95 The Cowbell Member is exposed in the roadcut along right side of the road.
0.35
96.3 Pass under Mountain Parkway.
0.05
96.35 Junction of S.R. 77 with S.R. 11 and 15, turn left and proceed southeast on S.R. 11 and 15.
0.05
96.4 The Cowbell Member is exposed in roadcut along right side of the road.
0.01
96.5 The Cowbell Member is exposed on left side along the north side of the Mountain Parkway.
0.3
96.8 The Cowbell Member is exposed in roadcut on right side of the road.
0.2
97.0 The Cowbell Member is exposed on left side along the north side of the Mountain Parkway.
0.2
97.2 Pass under the Mountain Parkway.
0.7
97.9 Junction of S.R.'s. 11 and 15, turn right and proceed along S.R. 11.
0.1
98.0 Pass under the Mountain Parkway.
0.1
98.1 The Cowbell Member is exposed in roadcut on left side of the road.
0.5
98.6 The Cowbell Member is exposed in roadcut along left side of the road.
0.3
98.9 Little Abner Motel on left side of the road.
0.25
99.15 The Cowbell Member is exposed in roadcut along left side of the road.
0.15
99.3 The Cowbell Member is exposed in roadcut along left side of the road.
0.45
99.75 The Cowbell Member is exposed in roadcut along left side of the road.
0.3
100.05 Entrance to Natural Bridge State Park, turn right into park and cross bridge; then turn left at "T" junction and follow blacktop road to Hemlock Lodge.

Road Log - Day Three

- 0.05
100.1 The Cowbell Member is exposed in roadcut along right side of the road.
0.2
100.3 The Cowbell Member is exposed in roadcut along right side of the road.
0.1
100.4 Enter Hemlock Lodge parking lot, note on right side of the parking lot exposures of the Cowbell and Nada Members of the Borden Formation, as well as Renfro and St. Louis Members of the Slade Formation.

END OF ROAD LOG DAY THREE.

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