Olsen, P. E., Schlische, R. W., and Gore, P. J. W. (and others), 1989, Field Guide to the Tectonics, stratigraphy, sedimentology, and paleontology of the Newark Supergroup, eastern North America. International Geological Congress, Guidebooks for Field Trips T351, p. 35-45.

2. DAN RIVER-DANVILLE BASIN, NORTH CAROLINA AND VIRGINIA

GEOLOGY OF THE DAN RIVER-DANVILLE BASIN

(by P.J.W. Gore and P.E. Olsen)

Introduction

The Dan River-Danville basin, approximately 167 km long and from 3 to15 km wide, is an exceptionally narrow and long basin (Figure 2.1). The basin is bounded on the northwest by a southeast-dipping normal fault system, referred to as the Chatham fault zone, toward which the sedimentary rocks in the basin steeply dip (20°-45°). The fault zone strikes approximately N30E°-N35°E, and dips approximately 44° SE (S.E. Halladay, unpublished manuscript). The southeastern edge of the basin is predominantly an unconformity, but a northwest-dipping normal fault is present locally (S.E. Halladay, unpublished manuscript). The basin straddles the North Carolina-Virginia state line, and the rocks in each state have been described in separate publications. Meyertons (1959, 1963) mapped the rocks in Virginia (Danville basin), and Thayer (1967, 1970) and Thayer *et al.* (1970) mapped the rocks in North Carolina (Dan River basin). Although there is only one basin, a dual system of nomenclature arose, and the basin is referred to as the Dan River-Danville basin (Robbins and Traverse, 1980). The rocks in the basin have been defined as the Dan River Group (Thayer, 1970), but lithostratigraphic nomenclature changes across the state line. Late Triassic (late middle and late Carnian) pollen, spores, and vertebrates have been found in the Cow Branch Formation of the Dan River Group (Olsen *et al.*, 1978, 1982; Robbins and Traverse, 1980; Thayer *et al.*, 1982). The total stratigraphic thickness of sedimentary rocks in the basin is estimated at 1100 m in the narrowest part of the basin, and may be more than 4000 m in the widest part (Henika, 1981).

Lithostratigraphy

In Virginia, three formations are recognized: (1) the mostly lacustrine Leakesville Formation, (2) the fluvial Dry Fork Formation, and (3) the fluvial and lacustrine Cedar Forest Formation (Table 2.1A; Meyertons, 1963). These formations are differentiated primarily on the basis of grain size. The Leakesville Formation is dominated by shale and siltstone, the Dry Fork Formation is dominated by sandstone, and the Cedar Forest Formation is dominated by conglomerate. As originally defined, these three formations all intertongue with each other and are at least in part lateral equivalents (Thayer, 1970). In North Carolina, a three-part stratigraphy is also present, but the nomenclature differs. Thayer (1970) divided the rocks into the following units: (1)

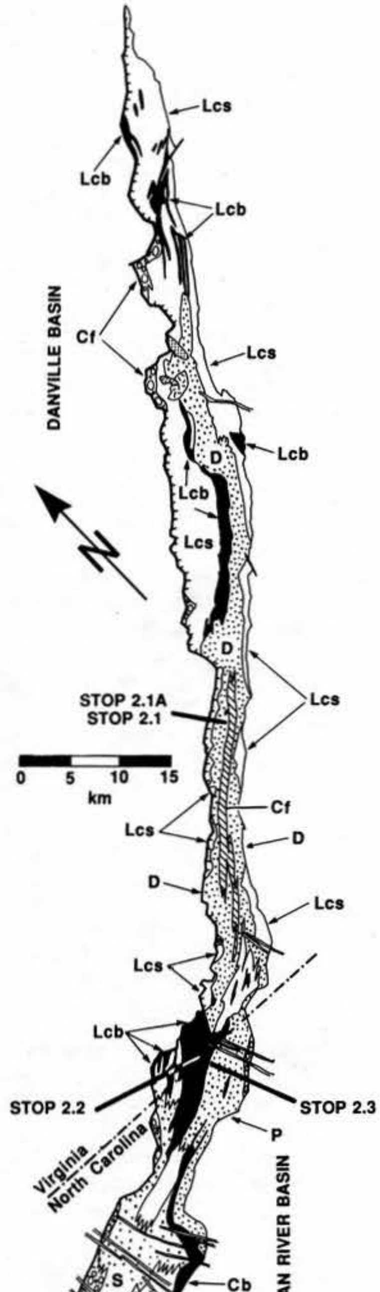

Figure 2.1: Geologic map of the Dan River-Danville basin, North Carolina and Virginia. Thin, double lines are dikes; regular stipple represents diabase intrusions; and black indicates predominantly lacustrine deposits. Abbreviations are: in Dan River basin—P, Pine Hall Formation; Cb, Cow Branch Formation; S, Stoneville Formation; in Danville basin—D, Dry Fork Formation; Lcs, Cascade Station Member of the Leakesville Formation; Lcb, Cow Branch Member of the Leakesville Formation; and Cf, Cedar Forest Formation. Modified from Meyertons (1963) and Thayer (1970).

Table 2.1A: Stratigraphy of the Dan River basin, North Carolina (after Thayer, 1970; Cornet, 1977a)

Units	*Thickness (m)*	*Age*	*Description*
Stoneville Fm.	?	Norian	Coarse to fine fluvial and alluvial clastics
Cow Branch Fm.	183	M.-L.Carn.	Gray to black, fine to coarse cyclical lacustrine clastics; thin coal seams at base
Pine Hall Fm.	2133	Carnian	Mostly tan, brown and red, coarse to fine fluvial and alluvial clastics

Table 2.1B: Stratigraphy of the Danville basin, Virginia (after Meyertons, 1963; Cornet, 1977a)

Units	*Thickness (m)*	*Age*	*Description*
Cedar Forest Fm.	?	Norian	Red, coarse to fine, basin margin, alluvial and fluvial clastics
Dry Fork Fm.	2438	?Car.-Nor.	Red to gray/green, fine to coarse fluvio-lacustrine graywackes and arkoses
Leakesville Fm.	?	L. Carnian - ?Norian	Red (Cascade Station Mb.) and gray to black (Cow Branch Mb.), fine to coarse, fluvial and cyclical shallow-water lacustrine clastics

the fluvial Pine Hall Formation, (2) the lacustrine Cow Branch Formation, and (3) the fluvial Stoneville Formation (Table 2.1B). The Pine Hall Formation is the lowermost unit and crops out along the southeastern basin margin. The Cow Branch Formation conformably overlies the Pine Hall but interfingers with it near the state line (Stop 2.3). The Stoneville Formation conformably overlies and interfingers with the Cow Branch-Pine Hall sequence (Thayer, 1970). We suspect that part of the rather choppy distribution of units apparent on the map (Figure 2.1) is due to intrabasinal faults, not interfingering, as does Weems (1988).

mileage

0 Begin mileage at 3020 Riverside Drive (US 58), Danville, VA.

0.8 At cloverleaf intersection of US 58 and US 29, get onto US 29 North.

10.5 Continue past VA 863 on left.

11.4 Entering Dan River-Danville basin. The basin is only about 3.2 km wide here. White Oak Mountain, just ahead, is a large northeast-trending ridge underlain by lithic arkoses and feldspathic litharenites (Thayer *et al.*, 1970). This is the mountain made famous in the ballad "Wreck of the Old 97". The railroad is less than a mile west of US 29 at this point.

12.1 Note roadcut on the left near top of White Oak Mountain off US 29. Pull off the road and park in dirt lot on the right side of the road. Cross the road with caution.

OPTIONAL STOP 2.1A: WHITE OAK MOUNTAIN NEAR DRY FORK, VA (by P.J.W. Gore)

Highlights: Coarse-grained fining-upward cycles in Dry Fork Formation

The outcrops on the west side of US 29 at White Oak Mountain, north of Danville, Virginia, are primarily red beds, which belong to the Dry Fork Formation, but they may be lateral equivalents of the Cow Branch Formation, which we will see later today. This locality was described by Meyertons (1963) in his report on the Triassic formations of the Danville basin and is also described by Thayer *et al.* (1970) in his field guide on the Dan River basin (Figure 2.2). The descriptions of this outcrop are from Meyertons (1963) and Thayer *et al.* (1970).

This site is located approximately in the narrowest part of the Dan River-Danville basin, and coarse-grained clastics extend across the basin here. These rocks are predominantly lithic arkoses and feldspathic litharenites, and they are arranged in thick, well-indurated, fining-upward cycles (7-10 m thick) consisting of sandy pebble conglomerates grading up to sandstone and in places capped by thin siltstone beds. The sandstones are characteristically poorly-sorted, have angular grains, and are commonly in grain-to-grain contact, with suturing and concavo-convex contacts (Thayer *et al.*, 1970), suggesting high pressures or temperatures. The high contact index and abundance of secondary overgrowths of calcite, chlorite, quartz, and albite are responsible for the hardness of these rocks (Thayer *et al.*, 1970).

An ideal fining-upward cycle at this locality consists of poorly-sorted pebble and cobble conglomerate overlying an erosional contact. The conglomerate, which actually consists of gravel lenses with low-angle cross beds to large trough cross beds (J.P. Smoot, pers. comm.), fines upward into dark gray, massive-appearing or trough cross-bedded, very coarse-grained sandstone, commonly containing scattered pebbles and cobbles (Thayer *et al.*, 1970). This sandstone grades upward into red or gray fine-grained sandstone, and the top of the cycle consists of red, massive, very fine-grained sandstone or siltstone (Thayer *et al.*, 1970). The presence of fining-upward cycles, possible channel lag conglomerates, and dune-scale cross bedding suggests fluvial deposition (Thayer *et al.*, 1970). The cycles are interpreted as the result of channel filling and migration in a braided stream environment because of the high ratio of coarse-to fine-grained rock, the wide range of grain sizes, and the presence of fining-upward sequences (Thayer *et al.*, 1970).

Leave Optional Stop 2.1A and continue north on US 29 for 0.6 miles.

12.7 Turn left into Vulcan Materials Corporation (first left going down the mountain from roadcut).

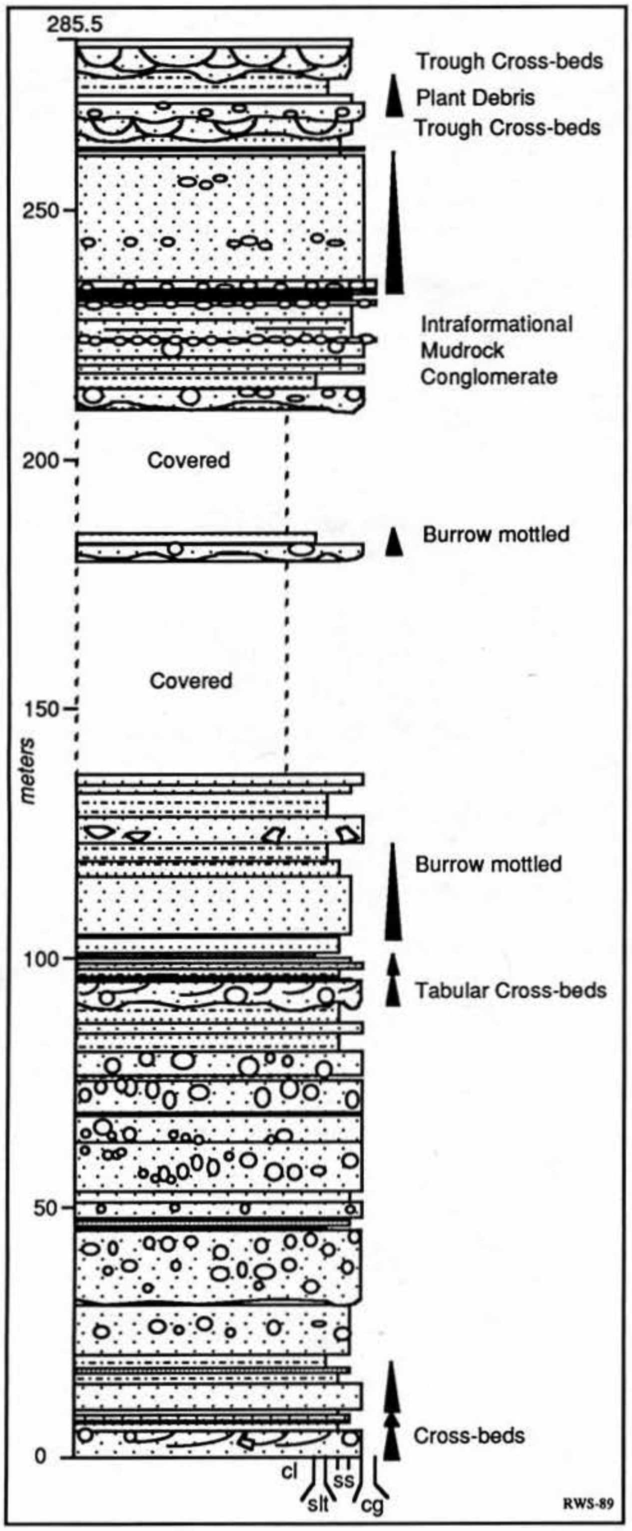

Figure 2.2: Measured section of the Dry Fork Formation along US 29, Stop 2.1A, showing several fining-upward cycles. Data for stratigraphic section from Thayer *et al.* (1970).

STOP 2.1: DRY FORK FORMATION AT CHATHAM QUARRY, CHATHAM, VA

(by P.E. Olsen and P.J.W. Gore)

Highlights: Large scale fluvial channels, intense bioturbation, conglomerates with unweathered feldspar.

The rocks exposed in this quarry are similar to those exposed in the White Oak Mountain roadcut on US 29, less than a mile away (see description of Optional Stop 2.1a). Note that the bedding is irregular and difficult to trace laterally due to large-scale channeling and faulting. Some of the conglomerates contain remarkably fresh pink feldspar (or feldspar overgrowths), suggesting deposition in an arid climate, rapid uplift and downcutting by streams, or retrograde weathering due to diagenesis.

The Chatham Quarry of the Vulcan Materials Corporation exposes more than 100 m of Dry Fork Formation. These beds lie stratigraphically below the Cow Branch Formation and are equivalents of the outcrops along US 29 described by Meyertons (1963) and Thayer *et al.* (1970). Large-scale tilted surfaces and large channel-form lenses can be seen in the quarry wall; however, small-scale sedimentary structures appear to be mostly obliterated by intense bioturbation or diagenetic overprints. Little detailed study has been made of these outcrops.

13.7	Leave Chatham Quarry. Turn right onto US 29 (heading south).
22.1	Follow US 29 South Truck Route. At the intersection of US 29 Bypass (Truck Route South 29) to US 58 West, fork to the right by cemetery (exiting basin).
25.8	Turn right onto US 58 West.
29.9	Crossing southeastern border and re-entering Dan River-Danville basin.
30.9	Turn left onto VA 863 to Eden, N.C. Note exposures of Dry Fork Formation on both sides of road. Ridges on right (northwest) for the next several miles are underlain by lithic arkoses and feldspathic litharenites of the Dry Fork Formation.
38.4	North Carolina state line. Road becomes NC 770.
40.7	Webster Brick Company quarry on right, lower Cow Branch Formation.
41.1	Cross the railroad tracks and turn right immediately into the Solite Quarry.

STOP 2.2: SOLITE QUARRY, LEAKSVILLE JUNCTION, VA (by P.E. Olsen and P.J.W. Gore)

Highlights: Cyclical lacustrine sequence; insect and reptile fossils; bedding plane shear zones; "syneresis cracks".

Quarries of the Virginia Solite Corporation on the border between North Carolina and Virginia expose a substantial portion of the Cow Branch Formation laterally equivalent to the type section of that unit. At these outcrops, the Cow Branch is highly cyclical and exceptionally fossiliferous. These exposures constitute one of the most important paleontological sites in North America.

This quarry and plant produce lightweight aggregate from shales in the Cow Branch Formation. Lightweight aggregate is any lithic substance that has been expanded by heating and can be used in place of sand, gravel, or crushed stone in mixtures of portland cement or in construction materials (Kirstein, 1970).

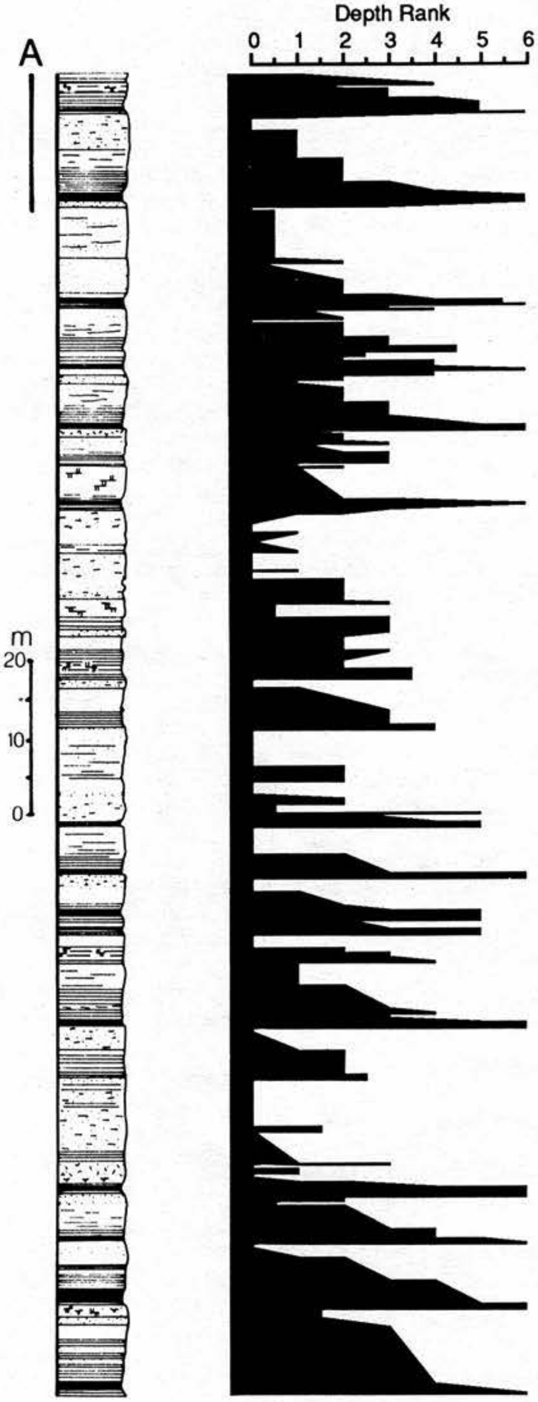

Figure 2.3: Measured section and depth ranks of the cyclical lacustrine Cow Branch Formation at the Solite Quarry, Stop 2.2. Black represents gray to black, finely-laminated calcareous siltstones; thin black lines represent gray, laminated siltstones; white represents gray, massive siltstone; and irregular stipple represents gray sandstone. Upper two lacustrine cycles labeled A are detailed in Figure 2.4. Modified from Olsen (1984a).

Cyclostratigraphy

One hundred and sixty meters of section, which dip at 30° NW (Kirstein, 1970), are exposed in the southern quarry (Figure 2.3) (not active at the time of writing). The main rock types present are: 1) black to gray, calcareous, laminated, clayey siltstone; 2) gray, mudcracked, massive mudstone; and 3) gray, ripple cross-laminated sandstone to cross-bedded conglomerate. All of the deposits appear to be lacustrine in origin with few fluvial channels.

The Cow Branch Formation is strikingly cyclical at a number of levels. These cycles can be analysed quantitatively by Olsen's (1986) depth rank classification and Fourier methods. The fine-grained lithologies can be broken down into a number of sub-categories which can be ordered by their interpreted depositional environment and used in quantitative analysis of cycle periodicities as shown by Olsen (1986) for the Lockatong Formation of the Newark basin (see Stop 5.7). These categories are called depth ranks because they are ranked by the time-averaged depth of water in which they were presumably deposited. In the Solite Quarry, as in the Lockatong Formation, the depth-rank categories described in Table 2.2 can be recognized. Chemical data correlate well with depth rank (Figure 2.4), and the correlation is especially strong between total organic carbon (T.O.C.) and depth rank (Figure 2.5). Depth ranks are based on several bedding and layering characteristics and are probably a more sensitive indicator of lake depth than any single chemical parameter.

The power spectrum of the Solite Quarry section (Figure 2.6) shows a number of significant peaks, the most prominent of which are at 8.9 m, 12.0 m, 41.0 m, 68.3 m, and 208.8 m. There are also significant peaks at 5 m to 6.6 m and a less significant peak at 22.8 m. Visual examination of the actual section shows that the 8.9 and 12 m cycles correspond to the types of cycles described by Van Houten

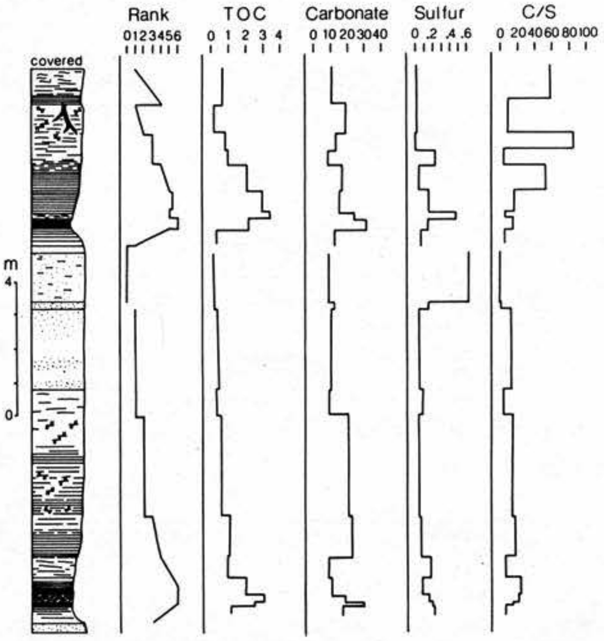

Figure 2.4: Depth ranks and chemical data from the upper two cycles (A in Figure 2.3) of the Cow Branch Formation exposed in the Solite Quarry. Note particularly the positive correlation between depth ranks and total organic carbon (T.O.C.). From Olsen (1984a).

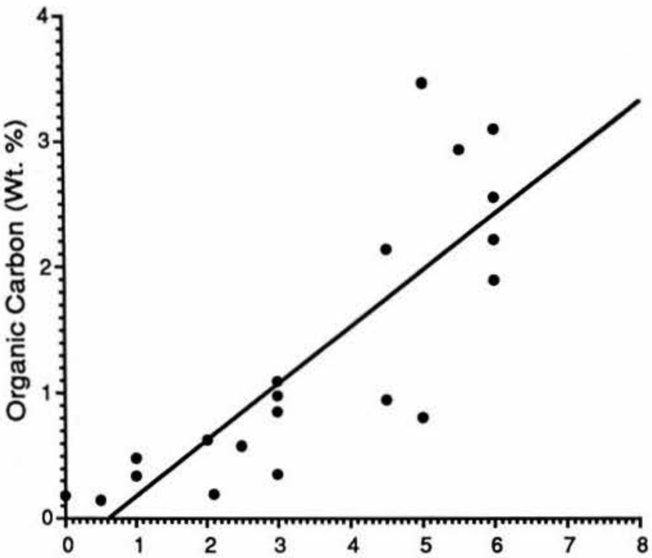

Figure 2.5: Correlation of depth rank and organic carbon content from the two cycles shown in Figure 2.4. $R^2 = 0.7$. Data from Olsen (1984a).

(1964) from the Lockatong Formation of the Newark basin (see Stop 5.7). These sorts of cycles are common in most Newark Supergroup basins.

In the Solite Quarry, the closest match between the ratios of the modern orbital periods and the periods in thickness are seen if the 8.9 and 12.0 m peaks are hypothesized to represent the precession cycles of 19,000 and 23,000 years, respectively (Table 2.3). If we set the average of these two periods in thickness to 21,000 years, corresponding to a sedimentation rate of 0.304 mm/yr, the durations in years of the main periods seen in the Solite section are shown in Figure 2.6. These periods are in rather close agreement with both the predictions of the orbital theory and the periods seen in the Lockatong and Passaic formations of the Newark basin.

Paleontology and Environments

The fossils follow a predictable sequence tracking the lithological changes seen through Van Houten cycles (Olsen *et al.*, 1978). Articulated fish and reptiles and complete insects occur only in the finest laminated (depth rank 6), organic carbon-rich (T.O.C. 2%) portions of division 2. Plant foliage compressions occur in these units and in surrounding slightly less well-laminated but still organic carbon-rich units. Root structures, burrows and casts of *in situ* plant stems occur in poorly-laminated units (depth rank 3-0) as do carbonized scraps of mostly conifer wood and foliage. Reptile footprints and plant fragments are present on surfaces of low depth rank (2-1) mudstones and sandstones that have polygonal cracks on thin bedding planes. Isolated bones and teeth of phytosaurs can occur in all lithologies. Besides producing extremely large numbers of articulated skeletons of the little reptile *Tanytrachelos* (Figure 2.7), the Solite Quarry has yielded some of the very oldest true flies and the oldest true water bugs (Figure 2.8). A faunal and floral list is given in Table 2.4.

The taphonomic pattern seen in division 2 of Van Houten cycles fits a chemically-stratified lake model (Bradley, 1929, 1963; Ludlam, 1969; Boyer, 1981), in which bioturbation is perennially absent from the deeper parts of the lake bottom because the bottom waters lack

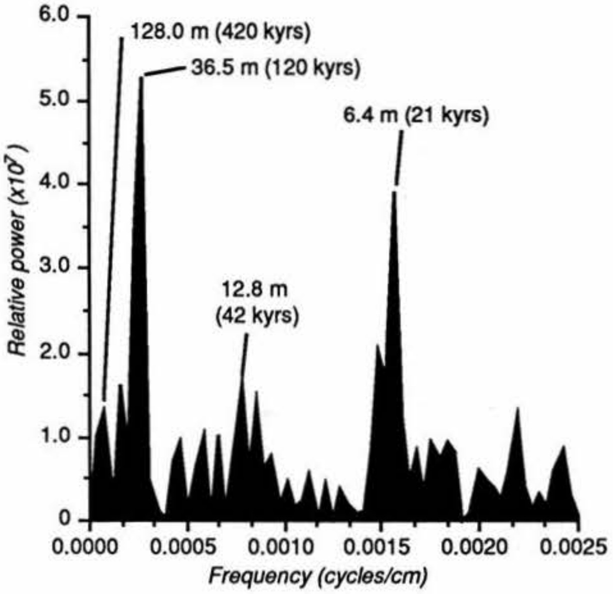

Figure 2.6: Power spectrum of depth rank curve (Figure 2.3) at the Solite Quarry, illustrating prominent periodic thicknesses. The sedimentation rate is .304 mm/yr.

Table 2.2: Description of depth ranks for fine-grained lacustrine sediments (from Olsen, 1986).

Depth Rank	*Description*	
0	Massively bedded calcareous claystone and siltstone with root, tube, crumb, and vesicular fabric; faint remnant parent fabric present; abundant clay cutans; intensely desiccated fabric	Shallow Oxygenated High-Energy Lake
1	Intensely brecciated and cracked calcareous claystone and siltstone; burrows can be common but obvious remnant parent fabric present; mud curls and cracks with vesicular fabric sometimes present	↑
2	Thin-bedded calcareous claystone and siltstone with desiccation cracks; large patches of uncracked matrix preserved; reptile footprints and burrows often present; infrequent desiccation cracks	
3	Thin-bedded calcareous claystone and rare siltstone with very small scale burrows; rare to absent desiccation cracks; pinch and swell lamination often present	*Time-Averaged Conditions*
4	Evenly laminated calcareous claystone with some small-scale burrows; abundant discontinuous laminations; no desiccation cracks	↓
5	Evenly and finely laminated calcareous claystone or limestone; abundant discontinuous laminations; no desiccation cracks	Deep Anoxic Low-Energy Lake
6	Microlaminated calcarous siltstone with only rare disruptions; no desiccation cracks	

Table 2.3: Ratios of periodicities in thickness compared with the ratios for the modern orbital periods. P is precession; O is obliquity; E1-3 are first three terms of eccentricity

	P	O	E1	E2	E3
Modern Periods	1.0	1.9	4.4	5.8	19.0
Lockatong Formation Average	1.0	1.8	4.3	5.5	16.3
Cow Branch Formation	1.0	2.0	—	5.7	20.0

oxygen, necessary for almost all macroscopic benthic organisms. Chemical stratification, often called meromixis, can arise by a number of mechanisms, but the main physical principle involved is the exclusion of turbulence from the lower reaches of a water column. This tremendously decreases the rate at which oxygen diffuses down from the surface waters and retards the upward movement of other substances. The main source of water turbulence is wind-driven wave mixing. This turbulence usually extends down about one-half the wavelength of surface wind waves, which depends on the fetch of the lake, wind speed, and wind duration. If the lake is deeper than the depth of the turbulent zone, the lake becomes stratified with a lower non-turbulent zone and an upper, turbulently-mixed zone. The thickness of the upper mixed zone is also dependent on density differences between the upper waters (epilimnion) and lower waters (hypolimnion) which can be set up by salinity differences (saline meromixis) or by temperature differences as in many temperate lakes. In the absence of saline or temperature stratification, chemical stratification can still arise in a deep lake with relatively high levels of organic productivity. Because oxygen is supplied slowly by diffusion, consumption by bacteria of abundant organic matter sinking into the hypolimnion plus oxidation of bacterial by-products eliminates oxygen from the hypolimnion. Lakes Tanganyika and Malawi in East Africa are excellent examples of very deep lakes in which there is very little temperature or density difference between the epilimnion and hypolimnion, but still chemical stratification occurs with the exclusion of oxygen below 200 m. Such a pattern is common in deep tropical lakes. The preservation of microlaminations and fossils in Cow Branch cycles may have been a function of great water depth relative to a small surface area of the lake.

An alternative explanation is that the Cow Branch lakes exhibited saline meromixis, in which a low-density, relatively dilute epilimnion floated on a highly-saline, high-density hypolimnion. Although probably not stable over long periods of time, a shallow body of water could be chemically stratified in this way, possibly decoupling inferred "depth ranks" from depths (*e.g.*, Bradley and Eugster, 1969). Berner (1979) and Berner and Raiswell (1983) have documented a relationship between salinity and pyrite sulfur content (water sulfate content related to salinity) and this should allow us to tell whether or not the bottom waters of the Cow Branch lakes were saline. Dissolved sulfate is limiting to the growth of sulfate-reducing bacteria until roughly 14 ppt (1100 mg/l sulfate) is reached, and at higher salinities, the amount of metabolizable organic matter is limiting. Thus, under low sulfate concentrations, as in most non-saline lakes, there is no correlation between T.O.C. and pyrite sulfur. Carbon and sulfur data (Figure 2.9) from the two Van Houten cycles shown in Figure 2.4 show essentially no correlation and fall in the fresh water field of Berner *et al.* (1979) and Berner and Raiswell (1983). It is, of course, possible that the sulfates have been removed diagenetically or that the bottom waters could have been saline without being enriched in sulfate, but the compositions of the rocks surrounding the Dan River-Danville basin would appear to

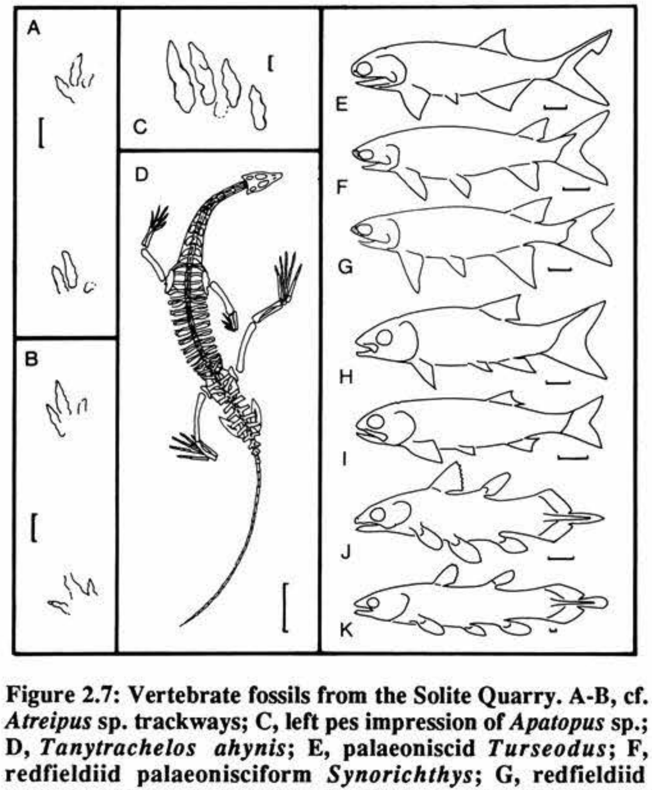

Figure 2.7: Vertebrate fossils from the Solite Quarry. A-B, cf. *Atreipus* sp. trackways; C, left pes impression of *Apatopus* sp.; D, *Tanytrachelos ahynis*; E, palaeoniscid *Turseodus*; F, redfieldiid palaeonisciform *Synorichthys*; G, redfieldiid palaeonisciform *Cionichthys*; H, holostean of the *Semionotus brauni* group; I, undetermined holostean; J, coelecanth *Osteopleurus newarki*; and K, coelecanth *Pariostegus*. Scales are all 1 cm. Modified from Olsen (1988b).

Table 2.4A: Plants from the Solite Quarry, Stop 2.2.

- PLANTS
  - Lycopodiales (lycopods)
    - cf. Grammaephoios sp.
  - Sphenophytes -
    - Equisetales (horsetails)
      - *Neocalamites* sp.
  - Pteridophytes
    - Filicales (ferns and fern-like organisms)
      - *Lonchopteris virginiensis*
      - cf. *Acrostichites linnaeafolius*
      - *Dictyophyllum* sp.
    - Caytoniales (Mesozoic seed ferns)
      - cf. *Sagenopteris* sp.
  - Coniferophytes
    - Coniferales (conifers)
      - *Pagiophyllum* spp.
      - *Glyptolepis* cf. *G. platysperma*
      - cf. *Compsostrobus neotericus*
      - cf. *Dechellyia* sp.
      - *Podozamites* sp.
  - Cycadophytes
    - Cycadales (cycads):
      - *cf. Zamiostrobus lissocardus*
      - *Glandulozamites* sp.
      - large androsporophylls
    - Bennettitales (cycadeoids)
      - *Zamites powelli*
      - *Pterophyllum* cf. *Ctenophyllum giganteum*

be capable of producing high-sulfate brines (Robbins, 1982). Thus, the bottom waters of the Cow Branch lakes were probably not saline, and chemical stratification probably developed as a consequence of great water depth and stratification of turbulence (Olsen, 1984a).

Van Houten cycles with a microlaminated division 2 thus reflect the alternation of shallow, ephemeral lakes or subaerial flats and deep perennial lakes with an anoxic hypolimnion set up by turbulent stratification under conditions of relatively high primary productivity and low organic consumption (*e.g.*, low ecoystem efficiency). The low organic content of divisions 1 and 3 of the cycles probably reflects higher ecosystem efficiency caused by shallow water depths rather than lower total organic productivity.

Table 2.4B: Animals from the Solite Quarry, Stop 2.2. † indicates an ichnotaxon.

- ANIMALS
  - Arthropods
    - Crustacea
      - Diplostraca (clam shrimp and water fleas)
        - *Cyzicus* sp.
        - ?*Paleolimnadia* sp.
      - Ostracoda
        - *Darwinula* spp.
      - Decapoda
        - cf. *Clytiopsis* sp.
    - Insecta
      - Blattaria (roaches)
        - several genera
      - Heteroptera (true bugs)
        - cf. Hydrocorisiae (water bugs)
          - new genus
      - Coleoptera (beetles)
        - cf. Nitidulidae (sap beetles)
          - several genera
        - cf. Buprestidae (metallic wood-boring beetles)
          - several genera
      - Psocoptera
        - new genus
      - Diptera (true flies)
        - Tipulidae (crane flies)
          - several genera
        - Bibionidae (March flies)
          - several genera
        - cf. Glosselytrodae
          - undetermined genus
  - Pisces
    - Actinopterygii (bony fishes)
      - Palaeonisciformes
        - *Turseodus* spp.
        - *Cionichthys* sp.
        - *Synorichthys* sp.
      - Semionotidae
        - *Semionotus* sp.
      - ??Pholidophoridiformes
        - new genus
    - Sarcopterygii (lobe finned fish)
      - Coelacanthini
        - cf. *Pariostegus* sp.
        - *Osteopleurus* sp.
  - Reptilia
    - Lepidosauromorpha
      - Tanystropheidae
        - *Tanytrachelos ahynis*
    - Archosauria
      - Phytosauridae (crocodile like archosaurs)
        - *Rutiodon* sp.
        - †*Apatopus* sp.
      - ?Ornithischia
        - †*Atreipus* cf. *A. milfordensis*
      - Saurischia
        - †?*Grallator* sp.

A large (*ca.* 10 m^2) excavation in cycle CB1-2 (Figure 2.10) produced over 150 skeletons of *Tanytrachelos*, dozens of fish, and over 300 insects, as well as abundant conchostracans and plant foliage. The microstratigraphy of this excavation reveals details of the lake transgression and regression. Many details of the pattern seen in the microstratigraphy and taphonomy of cycle CB1-2 are seen not only in other Cow Branch Van Houten cycles but in many other places where Van Houten cycles are recognized in the Newark Supergroup (see Stops 5.7, 6.2, 6.6-6.8). Normally, however, the occurrence of articulated reptiles is not symmetrical but rather limited to the lower few centimeters of division 2. The reasons for this common asymmetry are not clear but might involve increasing salinity as the lake evaporated.

"Syneresis Cracks"

Well-laminated, organic carbon-poor portions of Van Houten cycles in the Newark Supergroup often show small (<1 cm) to large (>10 cm) structures on bedding planes which have variously been referred to as subaqueous shrinkage cracks or syneresis cracks. These are especially well developed in the Solite Quarry section (Figure 2.11).

In plan view, these structures appear as elongate, lozenge-shaped impressions. Some appear to have a preferred orientation. Recent examination, at this section and also in the Jurassic Portland Formation of the Hartford basin, reveals that these structures are mechanically similar to the half-graben structures described by Shelton (1984) and Barnett *et al.* (1987). As seen in cross section and plan view, the structures are bounded on one side by a low-angle normal fault in which the net slip appears to be maximized at the center and dies out in all directions through just a few millimeters in the vertical direction and larger amounts in the horizontal direction (Figures 2.11, 2.12). The hanging wall adjacent to the fault is depressed in proportion to the relative amount of slip on the fault, producing a micro-half-graben. The footwall adjacent to the fault is similarly uplifted. Thus, the structures appear similar regardless of whether they are right-side up or up-side down. There is no evidence for filling of the micro-half-graben during deformation; instead adjacent material seems to have flowed. Therefore, the formation of these micro-half-graben seems to have been a process occurring below the sediment-water interface, within the sediment layers.

The net effect of many of these micro-half-graben is that bedding is thinned. In tectonics, such thinning and faulting is usually thought of as a consequence of stretching. However, the beds which appear to show a random orientation of these structures show that, because stretching cannot take place in all directions at once, the bed itself must have shrunk in volume. These micro-half-graben are thus evidence of a volume change within the bed. Compaction compensates for shrinkage in the vertical direction. Because the structures formed within the bed, there is no reason to suspect that the shrinkage occurred subaqueously. All we can infer is that shrinkage occurred, perhaps by water loss and/or clay mineralogy change, and there are no compelling reasons why such structures should be characteristic of any specific environment.

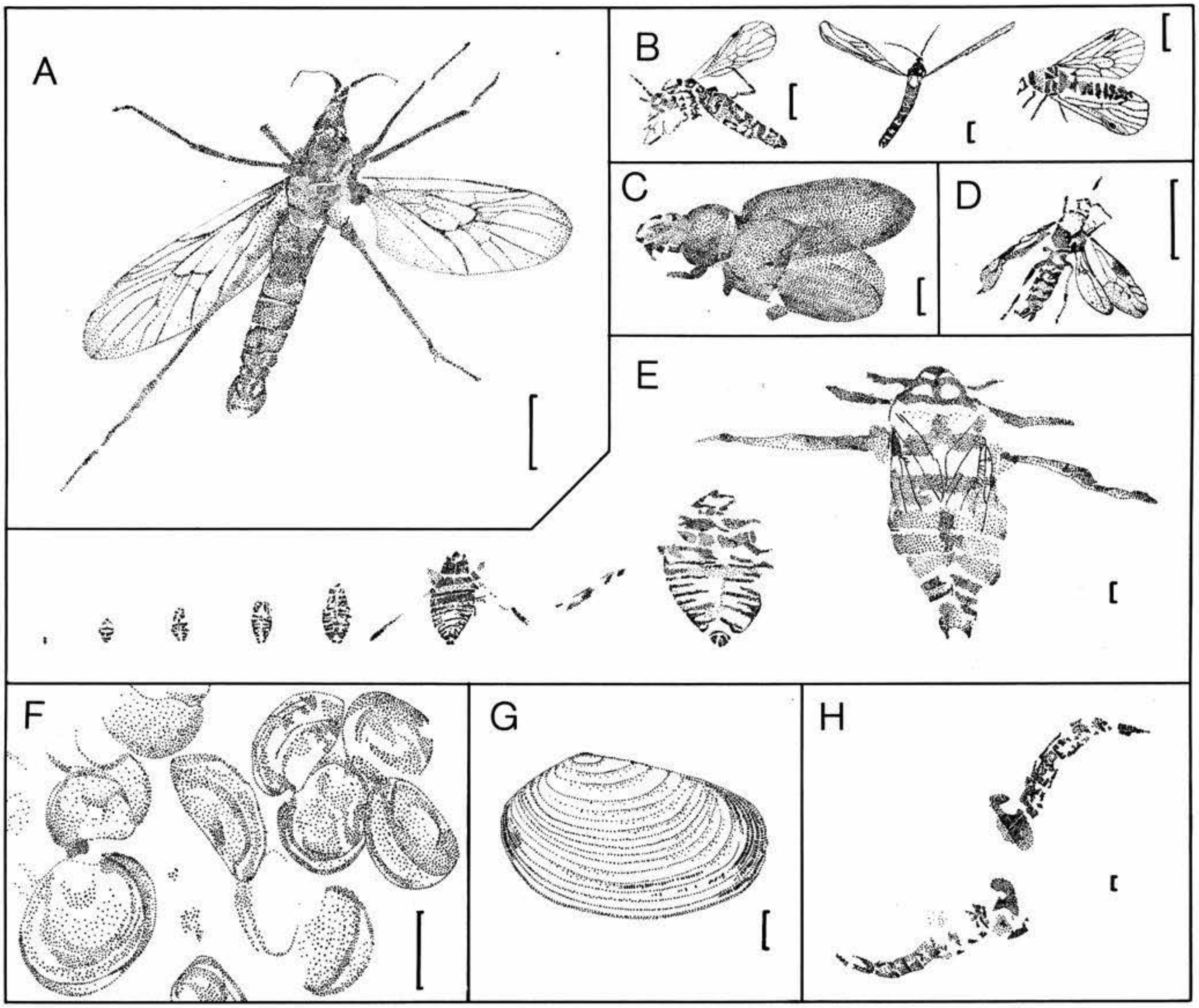

Figure 2.8: Insect fossils from the Solite Quarry. A and B, true flies (Diptera, ?Tipulidae); C, beetle; D, psocopteran; E, partial growth series of ?hydrocoricid water bugs. Scales are all 1 mm. From Olsen (1988b).

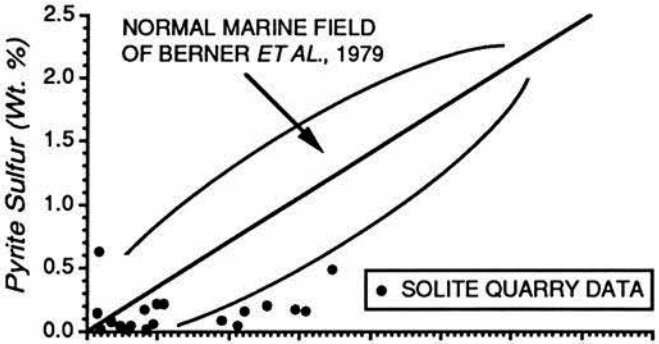

Figure 2.9: Correlation of weight percent organic carbon and weight percent pyrite sulfur from the Solite Quarry in relation to the marine fields. Note that there is no correlation between the variables which is characteristic of continental environments. From Olsen (1984a).

Deformation

Two partially gradational styles of deformation are evident in the Solite Quarry section which are also characteristic of the Newark Supergroup in general. Brittle deformation is concentrated in bedding plane shear zones and occasional high-angle faults, and ductile deformation is especially noticeable in the beds adjacent to the bedding plane shear zones. The bedding plane shear zones most often invade division 2 of Van Houten cycles, usually within more clastic portions and often in the best-laminated intervals (Figure 2.13). Slip can be concentrated along single bedding planes or sets of bedding planes with the development of slickensides, polished surfaces, and well-organized duplexes. Folds are often present both within and outside the duplexes. Sometimes there are voids, filled with evidently liquefied sediments, and clastic dikes, which probably formed quite early in the burial history. On the other hand, slip can involve decimeters of section, with the development of complex zones of polished and slickensided flakes and plates, almost totally decalcified. Duplexes consisting of coherent phacoids, themselves made up of

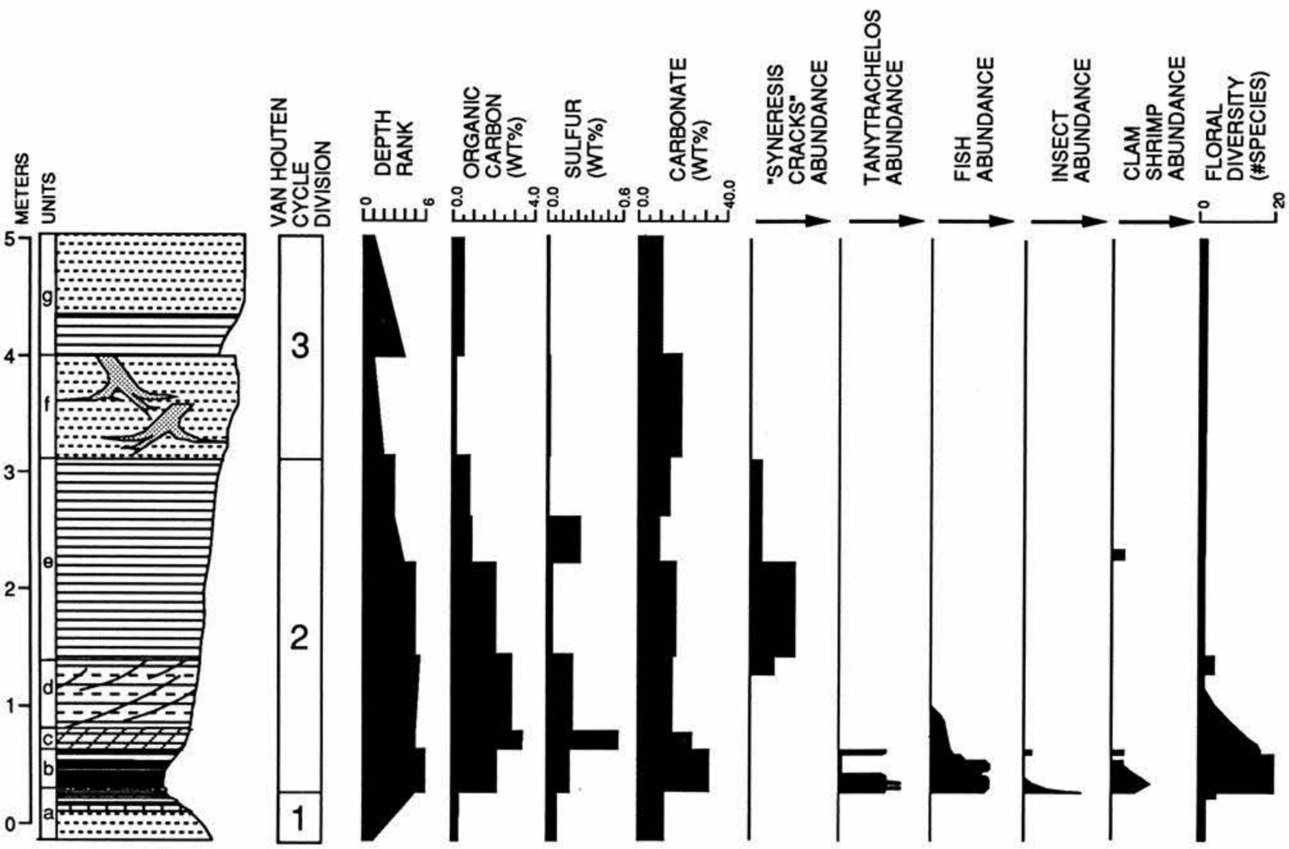

Figure 2.10: Microstratigraphy of the uppermost cycle of the Solite Quarry section. Modified from Olsen (1984a).

Figure 2.11: Oriented "syneresis cracks" surrounding a root cast from the Solite Quarry. Photo by P.E. Olsen.

slickensided flakes and plates, are often present, as are mineralized voids and gouge. The absence of liquefied sediment and the presence of mineralized zones suggest that these features formed later in the burial history of the sequence.

Many bedding planes in division 2 also show bedding plane-parallel ductile deformation which is especially obvious in deformed fossils, such as skeletons of reptiles (*Tanytrachelos*—Figure 2.13) and as a lineation caused by numerous deformed fossils, such as conchostracans. Small-scale folds are also present, commonly associated both with bedding-parallel shortening and the development of duplexes. Polygonal cracks within divisions 1 and 3 of Van Houten cycles do not show evidence of this kind of ductile deformation, as is seen in the Jacksonwald syncline of the Newark basin (see Stop 5.1).

We can imagine a sequential development of deformation styles in bedding shear zones from ductile deformation in water-rich sediments at shallow burial depths to brittle deformation in the same strata with additional shear under greater burial depths. There have been no systematic studies of bedding plane shear zones in the Newark Supergroup, and thus this scenario of progressive deformation remains untested. At least in part, these shear zones are related to the mechanism of accommodation within half-graben sediments, necessary because of rotation and thinning of strata.

42.7	Leave quarry, turn right (west) onto NC 770/VA 863.
43.7	Welcome to Eden, NC.
47.0	Turn right onto NC 14-87-770.
47.3	Cow Branch Formation with *Diplurus* fish fossils is exposed on left in ditch.

47.9	Turn around and go back to NC 770-700.
48.1	Exit right onto ramp at and go east on NC 700-770. (Just past Cow Branch outcrop).
52.6	Railroad tracks and Solite Quarry entrance.
53.0	Left into old Webster Brick Quarry (now abandoned).

STOP 2.3: WEBSTER BRICK COMPANY QUARRY, EDEN, NC (by P.J.W. Gore and P.E. Olsen)

Highlights: Black shale, tan cross-bedded sandstone, and red beds of Pine Hall Formation.

The Pine Hall Formation is thickest in this part of the basin and exceeds 2100 m. It is much thinner in the southern part of the outcrop belt, being only about 75 m (Thayer, 1970). The formation coarsens southeastward toward the basin margin, and a conglomeratic lithofacies unconformably overlies pre-Triassic basement rocks in a narrow belt along the southeastern edge of the basin about 3.5 km from here (Thayer, 1970).

Maroon claystones and shales were quarried here from the uppermost part of the siltstone facies of the Pine Hall Formation for the manufacture of brick (Thayer *et al.*, 1970). Most of the rocks exposed here are red, but cross-bedded tan sandstone and black, laminated shale are also exposed. This exposure is in the siltstone facies of the Pine Hall Formation, which is composed of reddish-brown siltstone, claystone, and shale that form planar, thin-bedded

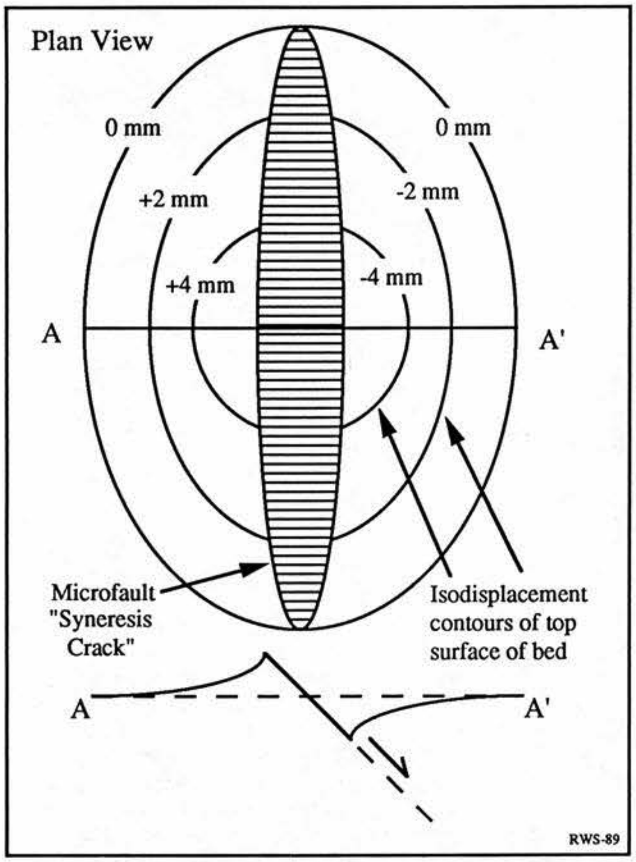

Figure 2.12: Conceptual diagram of a "syneresis crack" based on models of faults of finite length (Shelton, 1984; Barnett *et al.*, 1987). Note that the "cracks" are miniature half-graben.

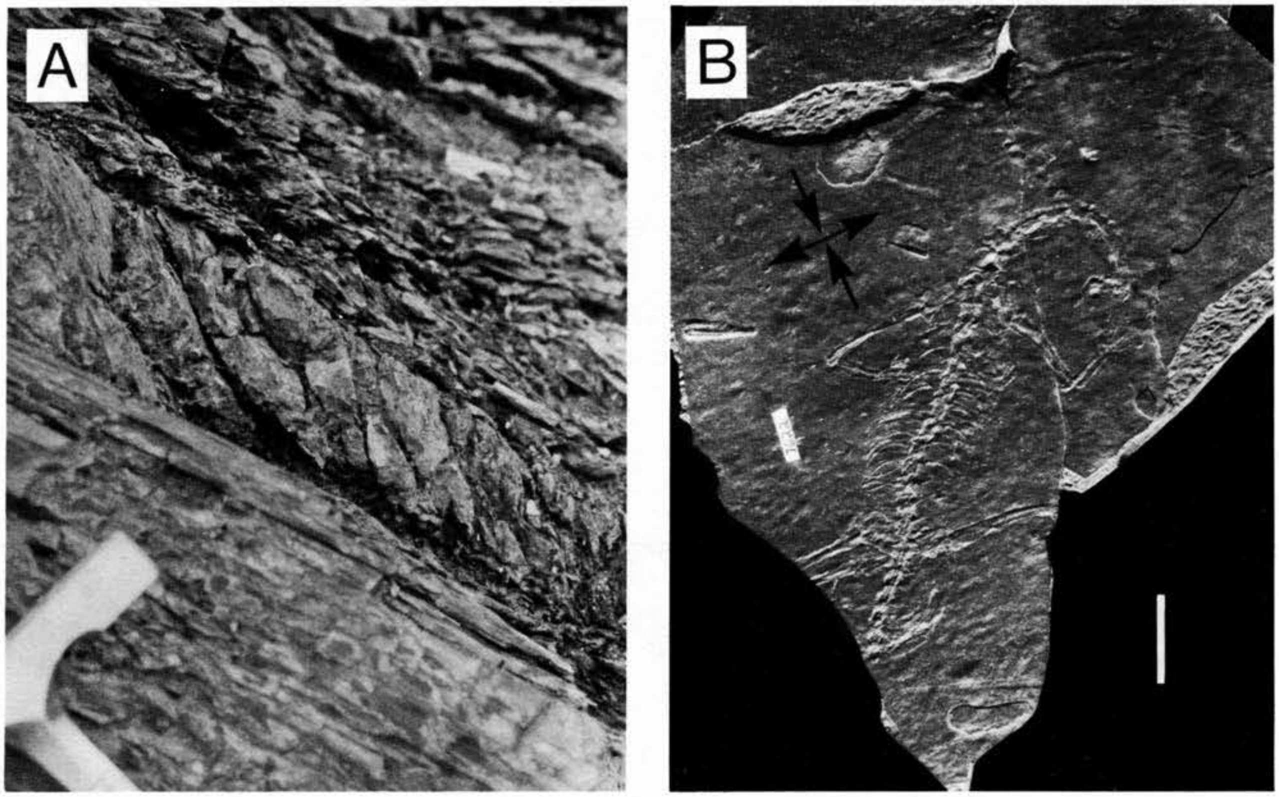

Figure 2.13: A) Bedding plane-subparallel shear zone and fault-bound slivers of rock (phacoids) forming what appears to be a duplex within laminated siltstone of the Solite Quarry. Sense of shear is top to the left. B) Deformed *Tanytrachelos* associated with shear zone similar to that shown in (A); scale bar is 2 cm. Photos by P.E. Olsen.

to thick-bedded (decimeter) units and less common grayish-orange, poorly sorted arkosic sandstone that also forms thin to thick beds (Thayer, 1970). The strata are characterized by mottled and disturbed bedding, calcareous concretions, cut-and-fill structures, current lineation, graded bedding and *Scoyenia*-type burrows (Thayer, 1970).

The upper contact of this formation is gradational into the Cow Branch Formation, the base of which is placed at the lowest persistent dark colored shale (Thayer, 1970). The black shale present in this quarry is not microlaminated, as is typical of the transition between the Pine Hall and Cow Branch formations. Fossils from the black shale include the fish ***Turseodus***, ***Synorichthys***, and ***Diplurus***, as well as phytosaur teeth, coprolites, conchostracans, and extremely abundant darwinulid ostracodes. Large inclined sandstone and siltstone beds that were formerly exposed above the black shale may have been delta foresets.

53.4 Leave Webster Brick Quarry. Turn left (east) onto NC 770.
55.6 Virginia state line.
61.1 Oak Ridge Estate on right
63.1 Turn right onto US 58 East.
68.4 Cross US 29 and continue east on US 58.
71.6 Intersection of Main Street and US 58.
78.6 Intersection of US 58 and the road to Milton, N.C.
101.3 Turn left onto US 360 East toward Richmond (at flashing yellow light).
117.1 Cross Staunton/Roanoke River.
127.6 Lookout tower.
134.9 Exit onto Business US 360-US 15 to Keysville, VA.
138.7 Exit onto US15 North to Farmville, VA.
150.8 Cross Briery Creek. We are now in the Briery Creek basin.

The Briery Creek basin is one of the smallest basins of the Newark rift system, a maximum of 2 km wide and 7 km long (Figure I.1). Several other small basins lie a few kilometers to the south in this area, including the Roanoke Creek, Randolph, and Scottsburg basins. The Farmville basin, which is somewhat larger, lies a few kilometers to the north. The Briery Creek basin is a graben in which the rocks dip toward the western faulted margin (Wilkes, 1987) which occurs in an epidote-rich, Paleozoic mylonite zone up to 91 m wide, adjacent to feldspar-rich amphibolite gneiss. The eastern margin of the basin is in fault contact with garnetiferous schist (Wilkes, 1986, 1987). The sedimentary rocks in the basin have been dated as Carnian based on palynomorphs and megafossils (E.I. Robbins, personal communication, ***in*** Wilkes, 1987).

The rocks in the Briery Creek basin include breccia, conglomerate, sandstone, siltstone, mudstone shale, coal, and diabase (Wilkes, 1986, 1987). Coal was discovered in the southern part of the basin in 1833, and a coal seam about 60 cm thick was mined during the middle 1800's (Wilkes, 1987).

150.9 Pass sign to Chesapeake Nature Trail.
153.4 Pass VA 133

The Farmville basin is the largest and northernmost of a line of several small basins clustered in the south-central Virginia Piedmont, southwest of Richmond (Figure I.1). The basin is approximately 37 km long, and about 7 km wide, elongated in a northeast-southwest direction, similar to the other basins of the Newark rift system. The western border of the basin is a high-angle normal fault associated with a Paleozoic? mylonite zone, and the rocks in the basin dip westward toward the fault at 30°-35°. The eastern border of the basin is also faulted. Diabase dikes cut across the basin and its border faults. Although the dikes are only a few feet wide, many are mappable for kilometers (Wilkes, 1986). The present basin is probably a small erosional remnant of a formerly much larger basin. In all probability, the Farmville basin and the cluster of smaller basins to the south were originally part of one larger basin. Exposures in all of these basins are poor, and we will not visit them on this trip.

156.3 Arrive at stop for evening.