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PART II: FIELD EXCURSION

1. DEEP RIVER BASIN, NORTH CAROLINA

GEOLOGY OF THE DEEP RIVER BASIN
(by P.J.W. Gore, J.P. Smoot, and P.E. Olsen)

Introduction

The Deep River basin is the southernmost of the exposed rift basins of the Newark Supergroup (Figure I.1). The basin ranges from 9 to 25 km wide and is 240 km long. The Deep River basin is situated near the eastern edge of the North Carolina Piedmont, where it is nearly surrounded by Late Precambrian and Cambrian metasedimentary and metavolcanic rocks of the Carolina slate belt. It is bordered on the northeast by gneiss, schist, and intrusive rocks of the Raleigh belt and is overlapped locally on the southeast by Cretaceous and younger sediments of the Atlantic Coastal Plain (Figure 1.1). The basin is bounded on the east and southeast by the Jonesboro fault system (a steeply-dipping normal fault zone), and on the northwest by a series of minor faults and unconformities (Figure 1.1). The overall structure of the basin is a half-graben in which rocks dip southeastward toward the Jonesboro fault system.

The Deep River basin is comprised of three interconnected sub-basins: from north to south they are the Durham, Sanford, and Wadesboro sub-basins (Figure 1.1). The Durham and Sanford sub-basins are separated by a constriction and basement high called the Colon cross-structure, named for the town of Colon. The Sanford and Wadesboro sub-basins are separated by the Pekin cross-structure and by Coastal Plain overlap.

Sedimentary rocks of the Deep River basin have been correlated with the European section using spores and pollen. The basal Pekin Formation of the Colon cross-structure has produced the oldest palynomorph assemblages, which are dated as early Carnian (Olsen *et al.*, 1982; Traverse, 1986, 1987). The rest of the Pekin Formation and overlying Cumnock Formation of the Sanford sub-basin produce assemblages of middle Carnian age. Younger rocks are probably present in the Sanford sub-basin because more than 1000 m of undated Sanford Formation red beds overlie the uppermost dated beds, which are in the Cumnock Formation. So far, no samples from the Sanford Formation or from the Durham sub-basin have produced spores or pollen. However, microflorules from lacustrine rocks of the Wadesboro basin and fish assemblages from the Durham basin suggest a late Carnian age (Olsen *et al.*, 1982; Cornet, 1977a). An upper age limit may be placed on the sedimentary rocks in the basin using lithostratigraphic inference. The sedimentary rocks of the basin are extensively intruded and metamorphosed by sheets and dikes of predominantly olivine-normative diabase of Jurassic age (see Part I). Many of the larger dikes that trend north and northwest can be traced across the basin and into slate belt rocks and beneath Coastal Plain strata by using aeromagnetic maps (Bond and Phillips, 1988). Basalt flows, however, are absent. In the northern and central basins of the Newark rift system, basalt flows are present just above the Triassic-Jurassic boundary, therefore suggesting that all Deep River basin strata are pre-Jurassic in age.

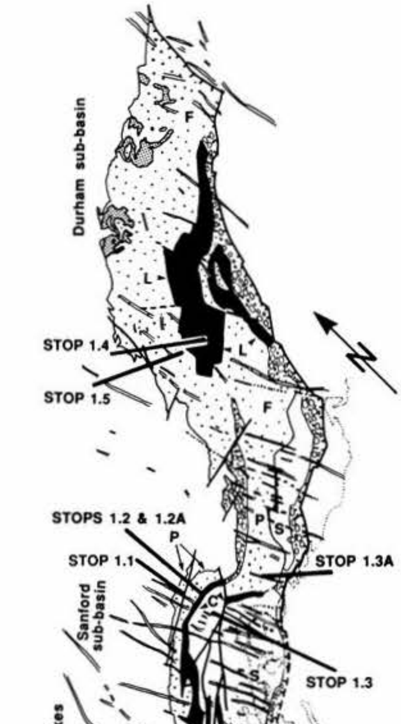

Figure 1.1: Geologic map of the Deep River basin, North Carolina and South Carolina. Thin, double lines represent dikes; regular stipples represent diabase intrusions; and black represents predominantly lacustrine deposits. Abbreviations are: F, fluvial deposits; L, lacustrine deposits; P, Pekin Formation; C, Cumnock Formation; S, Sanford Formation; U, undifferentiated deposits. After Bain and Harvey (1977) and Brown *et al.* (1985).

Table 1.1: Stratigraphy of the Deep River basin, South Carolina and North Carolina (after Emmons, 1856; Reinemund, 1955; Bain and Harvey, 1977; Brown et al., 1985; Gore, 1986a; Traverse, 1986; and Hoffman and Gallagher, 1988, in prep.).

	Units	*Thick-ness (m)*	*Age*	*Description*
Durham sub-basin	Lithofacies Association III	?	?Carnian	Reddish-brown, medium to very coarse fluvial and alluvial clastics
Durham sub-basin	Lithofacies Association II	?	Late Carnian	Pink to red, medium to coarse feldspathic sandstones and reddish-brown bioturbated siltstone and mudstone with nodular limestone zones; meandering stream, floodplain, and overbank deposits
Durham sub-basin	Lithofacies Association I	?	?Carnian	Gray feldspathic sandstone and reddish-brown bioturbated siltstone and mudstone; braided stream and floodplain deposits
Durham sub-basin	Western border conglomerate	?	?Carnian	Buff, coarse fluvial and alluvial clastics; quartz, granite, quartzite, aplite, and slate clasts
Durham sub-basin	Tan arkosic Ss	?	?Carnian	Tan, medium to coarse fluvial clastics
Durham sub-basin	Red Ss-mudstone	?	?Carnian	Red to brown, fine to coarse fluvial clastics with caliche horizons
Durham sub-basin	Chert-Ls-mudstone	?	?Carnian	Fine clastics, carbonates, and cherts deposited in a playa (?) lake
Durham sub-basin	Eastern border fanglomerate	?	?Carnian	Red, coarse alluvial fan clastics; clasts derived from Piedmont to the east of the Jonesboro border fault
Sanford sub-basin	Sanford Fm.	1240	?? Car.-Nor.	Mostly red to brown, coarse to fine fluvial and alluvial clastics; minor gray, fine to coarse fluvial-deltaic-lacustrine clastics
Sanford sub-basin	Cumnock Fm.	305	Middle Carnian	Mostly gray and black, fine to medium lacustrine and paludal clastics; thin coal seams near base
Sanford sub-basin	Pekin Fm.	1240	E.-M. Carnian	Red to brown, fine to coarse fluvial clastics; distinctive, quartz-rich, alluvial fan conglomerate ("millstone grit") near base
	Wadesboro sub-basin contains undifferentiated, Carnian-Norian, coarse to fine terrigenous clastics, including type section of the Pekin Formation (Campbell and Kimball, 1923). Middle lacustrine portion is Late Carnian (Cornet, 1977a).			

Lithostratigraphy

The sedimentary rocks of the Deep River basin, like those of the other Newark rift basins, are dominated by red to brown terrigenous clastics deposited in continental environments. The rocks of the Deep River basin are referred to collectively as the Chatham Group (Emmons, 1856; Olsen, 1978; Froelich and Olsen, 1984; Brown *et al.*, 1985), and the general stratigraphy has been recognized since the 1850's. Emmons (1856, p. 228) divided the rocks of the Sanford sub-basin into three formations: an upper unit and a lower unit of red terrigenous clastics, separated by a unit of gray to black shale, coal, and sandstone. These divisions were formally named by Campbell and Kimball (1923) (in ascending stratigraphic order) the Pekin, Cumnock and Sanford formations (Table 1.1). The distribution and character of these formations has been described in detail by Reinemund (1955) in the Sanford sub-basin, where they are known to vary laterally in lithology, texture and thickness, and to be somewhat intergradational.

The formations in the Sanford sub-basin can be traced northward into the Colon cross-structure, but the Cumnock is apparently replaced laterally by coarser-grained, red to brown or tan sandstones similar to the Pekin and Sanford formations (Reinemund,1955); gray to black siltstones have not been traced northward into the central part of the Durham sub-basin or southward into the Wadesboro basin. The Cumnock is absent throughout most of the Colon cross-structure, and the Pekin and Sanford formations are in direct contact.

Formal stratigraphic subdivision is confined to the Sanford sub-basin. To the north and south, in the Durham and Wadesboro sub-basins, the Triassic age sedimentary rocks are assigned to the Chatham Group, undivided, and consist of conglomerate, arkosic sandstone, siltstone, claystone, and mudstone. In the Durham sub-basin, four lithofacies are designated on the state geologic map (Table 1.1; Brown *et al.*, 1985;), whereas the rocks of the Wadesboro sub-basin are essentially undifferentiated, although the Pekin Formation was named for exposures in the Wadesboro sub-basin (Figure 1.1) (Campbell and Kimball, 1923). The relationships of the type Pekin Formation to the unit bearing its name in the Sanford sub-basin are uncertain, but they are lithologically and biostratigraphically distinct from each other (Olsen *et al.*, 1982) (Table 1.1). Recent mapping of two quadrangles which span an east-west transect across the Durham sub-basin has resulted in a more detailed understanding of the sedimentology (Hoffman and Gallagher, 1988, this volume) and an informal stratigraphic classification has been introduced (Table 1.1).

Depositional History

The Pekin Formation of the Sanford sub-basin is mostly composed of fluvial sandstone, conglomerate, and siltstone. Sandstones are commonly trough cross-bedded, forming fining-upward sequences of pebbly sandstone grading up into bioturbated siltstones. In many places the basal part of the Pekin is a distinctive gray, quartz-rich conglomerate called the "millstone grit" because it was quarried for millstones in the 1800's. The gravel-sized clasts in the millstone grit are 90-95% quartz and 5-10% rock fragments derived from the Carolina Slate Belt (Staggs, 1984) with silicified wood fragments present locally (Reinemund, 1955). Gray and purple flaggy siltstone and shale are locally important in the lower Pekin, particularly in the Colon cross-structure (Bain and Harvey, 1977; Bain and Brown, 1980) and in the middle Pekin in area of Gulf (Stop 1.1).

The Pekin Formation sandstones are interpreted as primarily braided stream deposits because they appear to lack obvious lateral accretion surfaces. However, the abundance of bioturbated siltstone surrounding these sandstones suggest relatively low gradient rivers as in anastomosing streams. Textoris *et al.* (1986) interpreted the "millstone grit" as the deposits of humid alluvial fans due to the maturity of the clasts. Alternatively, the "millstone grit" could have been deposited by higher-gradient streams during the initial stages of basin filling. Individual beds of gray and purple siltstones and shales cannot be traced laterally over a distance of more than about 100 m and may be the deposits of small ponds and shallow lakes on the river flood plains. Intense bioturbation by roots and burrows (mostly *Scoyenia*) and an abundance of *in situ* and transported plant material suggest that the Pekin Formation was deposited in at least a relatively humid climate. Paleocurrent measurements from a limited area by Patterson (1969) suggest the Pekin drainage in the Sanford sub-basin was southwestward from the Durham sub-basin. On the other hand, sparse paleocurrent data and provenance studies reported by Reinemund (1955) from more southern outcrops suggest southeastward flow for the basal Pekin and northwest for the upper Pekin.

Sandstone mineralogy and the character of pollen and spores in the lower Pekin indicate a relatively humid climate during the early history of the basin, and the abundant plant fossils indicate lush vegetation. Streams entered the Sanford sub-basin from the northwest and east (as shown by paleocurrent indicators in the lower Pekin), and alluvial fans were deposited along the faulted northwestern border of both the Sanford and Durham sub-basins. Streams flowing across the basin deposited red and brown terrigenous clastics. Finer sediments were deposited on floodplains and probably in shallow lakes. At this time (early to middle Carnian), the Colon cross-structure was topographically low and the site of shallow lacustrine deposition.

The Cumnock Formation is more or less restricted to the Sanford sub-basin. The lower part of the Cumnock is dominated by gray siltstone and fine-grained sandstone with minor shale and claystone which appear to interfinger with red beds of the Pekin Formation (Reinemund, 1955). Approximately 60-80 m above the base of the Cumnock, two major coal seams and several thinner coal beds are present. The lower Gulf coal seam ranges from a few centimeters to nearly 1 m thick, and the upper Cumnock coal seam consists of three beds which range from 1 to 3 m thick (Robbins and Textoris, 1986). The Cumnock Formation coals are primarily high volatile B bituminous ranging to anthracite; the coals are altered to natural coke near diabase intrusions (Reinemund, 1955). Both seams are underlain by shale, siltstone, and ferruginous shale containing limonite-, siderite-, ammonium- and phosphate-rich nodules. These dark, brittle layers are known as "blackband" (Reinemund, 1955; Krohn *et al.*, 1988). Fish and reptile bones and coprolites are very abundant in the "blackband", perhaps accounting for the high levels of ammonium and phosphate in bulk analyses.

The coal-bearing interval is overlain by about 150-160 m of locally calcareous and organic carbon-rich gray and black shale with minor claystone, siltstone, and sandstone. The upper part of the Cumnock is dominated by gray siltstone and fine sandstone, grading upward into red and brown terrigenous clastics of the Sanford Formation. Some of this fluvial input was from rivers draining southward through the Durham sub-basin (Gore, 1986a).

The Cumnock Formation is interpreted to have been deposited in a lacustrine and swamp environment surrounded by swamps and fed by rivers flowing primarily from the north and northwest (Gore, 1986a). The Cumnock lake was probably hydrologically open because most cores and outcrops do not seem to show well-developed Van Houten cycles characteristic of the more northern Newark rift lakes. This suggests that the lake was not maintained by a delicate balance of inflow and evaporation during most of its history (Langbein, 1961; Richardson, 1967; Smoot, 1985; Gore, in press). In support of this open drainage argument is the absence of evaporite minerals (Gore, in press). The "blackband" siderite deposits probably require at least interstitially anoxic, low-sulfate waters (Berner, 1981). If the siderite is primary, as suggested by its strata-bound occurrence, then the lake must have had low-sulfate and probably low-salinity water. Although there are many cores of the Cumnock and much material still accessible in old mine dumps, the Cumnock completely lacks the microlaminated facies so typical of most other Newark lacustrine sequences. This also suggests a low sill to the lake and open hydrology, even during high stands. Nonetheless, some exposures of the Cumnock do show repetitive alternations of shallower and deeper-water sediments (Olsen, 1980c) suggesting some sort of cyclically changing lake depth or shoreline aggradational sequences. These may reflect the climatic fluctuations responsible for the Van Houten cycles in the more northern basins.

The Sanford Formation of the Sanford sub-basin consists mostly of fluvial deposits nearly indistinguishable from the Pekin Formation. The transition from the Cumnock into the Sanford Formation is gradational and is marked by an increasing frequency of red and gray sandstones and a decreasing frequency of black and gray claystones. Exposures of the lower Sanford Formation still show some lacustrine influence (Stop 1.3) (Gore, 1986a), but stratigraphically-higher exposures consist only of fluvial deposits. Within the Sanford Formation, there are few distinctive beds and no consistently mappable subdivisions (Reinemund, 1955). Lenticular beds of gray, coarse-grained or conglomeratic, arkosic sandstone (probably fluvial channel-fill) are present in the lower 425-490 m of the formation, decreasing toward the southwest (Reinemund, 1955). Red to brown, coarse-grained arkosic sandstone and conglomerate with associated claystone, siltstone, and fine-grained sandstone dominate the upper 300 m of the formation (Reinemund, 1955). Grain size is coarser to the southeast (up section), and poorly-sorted conglomerates are present along the southeastern edge of the basin adjacent to the Jonesboro fault system (Reinemund, 1955). The poorly-sorted, matrix-supported conglomerates are suggestive of debris flows. They were clearly derived from rocks adjacent to the Jonesboro fault system to the southeast. Therefore, they probably represent alluvial fan deposits. It appears that these alluvial fan deposits interfinger with fluvial deposits exhibiting more axial flow orientation. In either case, the final episode of deposition in the Sanford sub-basin was fluvial, supporting the open drainage system model (Smoot, 1985).

A black shale facies similar to the Cumnock Formation has not been found in the central Durham or Wadesboro sub-basins; instead, the latter sub-basins are dominated by sandstones and siltstones with fluvial characteristics. In both basins , however, there are at least some lacustrine deposits sandwiched between the dominantly fluvial intervals.

In the Durham sub-basin the basal part of the section consists of conglomerates and conglomeratic sandstones with clasts reflecting drainage from the west or northwest. Spencer (1985) and Hoffman and Gallagher (1988) have found that litharenites to subarkoses dominate in the lower parts of the section whereas the upper parts of the basin section are dominated by arkoses with pink feldspars, except near the eastern border fault system, where clasts of eastern provenance occur. Three fluvial styles occur in the northern basin: a) lenticular sandstones with well-defined trough cross bedding and overlying tabular sets all of which are surrounded by bioturbated siltstones and sandstones; b) sandstones forming rhythmic fining upward sequences of trough cross beds to ripple cross laminated siltstones; and c) poorly sorted conglomerate to pebbly sandstones with no cross bedding or irregular tabular sets. The changes in provenance and fluvial styles are coincident; the litharenite to arkose transition appears stratigraphically controlled and the arkose to poorly-sorted conglomerate transition appears geographically controlled.

Thin red and green to gray, platy-bedded siltstone and claystone beds are present in the south-central part of the Durham sub-basin. They appear to be lateral equivalents of the arkosic sandstones as suggested by the provenance of the associated sands and their depositional character. They appear to be perennial lacustrine sequences cyclically alternating with meandering stream sequences in the central portion of the Durham sub-basin sequence (Stop 1.4). Wheeler and Textoris (1978) observed limestone, chert, and caliche in some of these lacustrine sequences which they interpreted as indicating playa lakes in a closed basin which responded to alternations from wet to dry climates, as suggested by Textoris and Holden (1986). However, the chert replaces carbonates (Wheeler and Textoris, 1978) and appears not to be parallel to bedding (Hoffman and Gallagher, 1988). No lacustrine fossils occur in the chert or associated carbonates, and because of the extremely irregular and nodular shape of the chert and limestone bodies, these may be silicified caliches as are common elsewhere in this facies (see Stop 1.4). Critically, the caliche nodules, as limestones or chert, have never been found as clasts in sandstones. Therefore, we have no direct evidence that the nodules were synsedimentary. Their distribution and internal fabric is consistent with pedogenic carbonates; however, they appear to not have been available as a source of clasts in the depositional environment. If the nodules were synsedimentary features, they must have been soft or crumbly, which is consistent with our observation of burrows which cross-cut caliche boundaries. We propose that this type of carbonate formation suggest that they formed in perennially-moist soils, not in soils subject to the intense drying characteristic of classic areas of caliche formation (Gile *et al.*, 1966; Reeves,1976). Bioturbation by roots and burrows are extremely abundant in the same horizons. Therefore, we argue that the evidence for playa lakes in an arid setting is weak and possibly only an expression of post-depositional silicification of relatively humid types of caliche.

The stratigraphy of the Wadesboro sub-basin is much more poorly known than either of the other sub-basins. Fluvial sequences clearly dominate the lower, upper, and marginal portions of the section, but a predominantly cyclical gray and red mudstone sequence is at least locally present near the center of the basin. These lacustrine sequences comprise the type Pekin Formation of Campbell and Kimball (1923); they lack black shales and are lithologically more similar to the lacustrine deposits of the central Durham sub-basin than to the Cumnock Formation.

Thus, all three sub-basins, show a tripartite division of stratigraphy, at least superficially. In each basin there are lower and upper mostly fluvial intervals separated by units with at least some lacustrine sequences (Table 1.1). The lacustrine sequences, however, do not appear to be of the same age based on fish and palynomorph assemblages (Cornet, 1977a; Olsen *et al.*, 1982) in each basin. The oldest lacustrine sequence is the Cumnock Formation of Middle Carnian age (Cornet, 1977a; Cornet and Olsen, 1985), whereas the lacustrine units in the Durham and Wadesboro sub-basins appear to be late Carnian in age (Cornet, 1977a; Olsen *et al.*, 1982). This tripartite division in each sub-basin can be explained by the basin filling model (Schlische and Olsen, in review; this volume), with the additional hypothesis that the transition to lacustrine deposition in the Wadesboro and Durham sub-basins began only after the end of most Cumnock deposition in the Sanford sub-basin.

mileage	
0	Leave hotel on Airport Blvd., turning right toward I-40. We are in the Deep River basin (Durham sub-basin).
0.3	Get onto US 40 East, heading toward Raleigh.
2.0	Note outcrops of red Triassic clastic strata on left. We are approaching the Jonesboro fault system which bounds the basin on the east and southeast. The strata are coarser grained near the fault.
2.4	Cross Jonesboro fault system and leave the basin. The rocks southeast of the fault belong to the Appalachian Piedmont province and are Late Precambrian to early Paleozoic in age. In this area, the Piedmont rocks consist of (1) metasedimentary and metavolcanic rocks (phyllite, metaconglomerate, metafelsite, epidote-actinolite greenstone, *etc.*) of the Cary sequence, in a belt 1.5-3 km wide east of the Jonesboro fault system; (2) mica and hornblende gneiss and schist, in part conglomeratic (diamictite?), in a belt 1.5-3 km wide, immediately east of the Cary sequence; (3) felsic gneiss and schist in a belt about 6.5 km wide; (4) mica and hornblende gneisses and schists that have been injected by numerous sills and dikes of granite, pegmatite, and aplite, in a belt 3-6.5 km wide; and (5) the granitic (adamellite) Rolesville batholith, approximately 24 km wide (Parker, 1977). Additional Piedmont lithologies include thick veins of quartz and lenses of amphibolite. In the next few miles, we will cross all of these except the Rolesville batholith. Fresh outcrops are rare, as most of the crystalline rocks are weathered to a very thick saprolite.
8.5	Intersect US 1 south (to I-64), and turn right toward Sanford and Wake Forest. Follow signs to Sanford.
8.9	Turn right at fork, south toward Sanford on US 1 South, and US 64 West.
12.6	US 64 turns off. Stay on US 1.
14.2	Cross Jonesboro fault system and re-enter Deep River basin (Durham sub-basin). (Approximate position of fault.)
15.7	Pass NC 55 overpass and continue southwest on US 1.
23.7	Harris Lake is on the left.
29.2	Cross the Haw River. Leaving the Durham sub-basin and entering the Colon cross-structure, named for the town of Colon, NC.
29.3	Poor exposures on right are of the basal unconformity; gray-blue conglomerates of Pekin Formation rest on Precambrian or Cambrian coarse-grained turbiditic slate belt metasediments. Palynoflorules from shales associated with these Pekin conglomerates indicate an

early Carnian age (Cornet, pers. comm., 1989; Traverse, 1986).

31.3 Cross the Deep River, for which the Deep River basin is named.

38.7 Leaving the Colon cross-structure and entering the Sanford sub-basin.

41.7 Turn right onto exit ramp to US 421, near Sanford.

42.0 End of ramp. Turn left (northwest) onto US 421.

45.4 Outcrops on left are red sandstone and siltstone of the Sanford Formation, the uppermost of the three formations in the Sanford sub-basin.

45.9 Egypt Coal Mine historical marker on right.

46.7 Cross Deep River into Chatham County.

47.8 Clay pit on right is in the Sanford Formation.

49.8 Turn right onto Creosote Road and make an immediate sharp right onto gravel road.

50.2 Park along dirt road adjacent to quarry.

STOP 1.1: BOREN CLAY PRODUCTS QUARRY, GULF, NC (by P.J.W. Gore)

Highlights: Fluvial sequences of Pekin Formation, plant fossils, trace fossils, organic-rich sandstone, diabase dikes.

The Boren pit, about 1.5 km east of the western border of the Sanford sub-basin, exposes strata from the middle Pekin Formation, the lowermost of the three formations in the sub-basin. These rocks are stratigraphically the lowest units that we will examine in the Deep River basin. The rocks in the Boren pit are dug for clay to make bricks. The rocks in the quarry are primarily red, reddish-brown, and gray cross-stratified, rooted, and burrow-mottled sandstone and siltstone. Traverse will begin at southwest end of pit, proceed to the north and then to the northeast corner of the exposures.

The southwest half of the Boren pit exposes approximately 10 m of red beds, overlain by approximately 4-6 m of gray siltstone and sandstone with associated intraformational conglomerate and shale, overlain by approximately 10 m of red beds (Gore, 1986a). The gray siltstone is the source of most of the well-preserved plant material and all of the invertebrates from the Boren pit (see below); unfortunately the section had just been buried at the time of writing.

Exposed grayish-red beds slightly to the north of and ?overlying the plant-bearing gray siltstones consist of a coarsening-upward sequence of wavy-bedded sandstones with mudstone partings. The thickness of the sandstones increase from a few centimeters in the lowest exposed beds to 30-40 cm through a stratigraphic distance of about 2 m. The sandstone at top consists of high-angle climbing ripple cross lamination. Claystone-replaced plant compressions occur in the sandstones and on the mudstone partings. Reptile footprints (Figure 1.5) occur sporadically between ripple-cross laminated beds, and root and burrow (*Scoyenia*) structures are abundant throughout, although not as densely as in the overlying red mudstones and sandstones. The sandstone layers appear to define larger-scale cross strata or low-angle inclined truncation surfaces.

Follow the dirt road which leads west through the center of the pit. Halfway across the pit the road turns to run along an *en echelon* series of mostly thin diabase dikes. Note the color differences between the weathered diabase (yellowish-orange) and the grayish-red to reddish-brown strata that dominate the pit. At the northeastern termination of the dirt road, walk to the north where a sequence of gray to white sandstones is well exposed. The sandstone consists of a single fining-upward sequence erosionally overlying red bioturbated siltstone and fine-grained sandstone. Relief on the erosion surface is at least 2 m. The basal part of the sandstone forms trough cross beds 40-50 cm thick and contains abundant mud intraclasts as much as 10 cm in diameter, marcasite nodules, wood fragments, and abundant plant hash. Some of the cross beds are defined by highly carbonaceous black laminae composed of macerated plant fragments alternating with white quartzose, organic carbon-poor laminae. Cross beds decrease in size to 10-15 cm in the upper sandstone beds. All cross beds appear to indicate northerly flow directions. The top of the sandstone grades upward into bioturbated red and grayish-red fine sandstone and siltstone.

Outcrops on the southeast side of the quarry show the diabase intrusive relationships especially well (Figure 1.2). The dikes are olivine-normative, vertical to subvertical, and the largest shows a distinctive vertical sheeted pattern made up of aphanitic chilled diabase at the edges of the dike surrounding an internal breccia of metamorphosed sediment clasts and diabase matrix. The intruded sedimentary rocks at this spot consist of a coarsening-upward sequence of sandstone beds with deceleration of flow, climbing-ripple cross lamination and mudstone partings. Sandstone beds thicken upward with more low-angle climbing ripples. Bioturbation decreases upward. Long exposure on northeast wall of the quarry consists of highly-bioturbated siltstones and fine-grained sandstones. Some sandstone lenses appear to define meter-scale fining-upward and coarsening-upward sequences.

The coarsening-upward sequences probably represent small crevasse deltas (showing a wide variety of orientations) that possibly entered small ponds or lakes. The grayish-red coarsening-upward sequence could represent the distal deposit of a large crevasse delta into a swampy lowland. The channel sandstone is a fining-upward sequence with no evidence of epsilon-cross beds (*i.e.*, point bars). This would presumably indicate a braided river environment. However, along with the very large amount of fine-grained sediment present, the absence of complex mid-channel bars (tabular sets or several large cross bed sequences perpendicular to small cross bed sequences), suggests that the sandstone represents an isolated channel

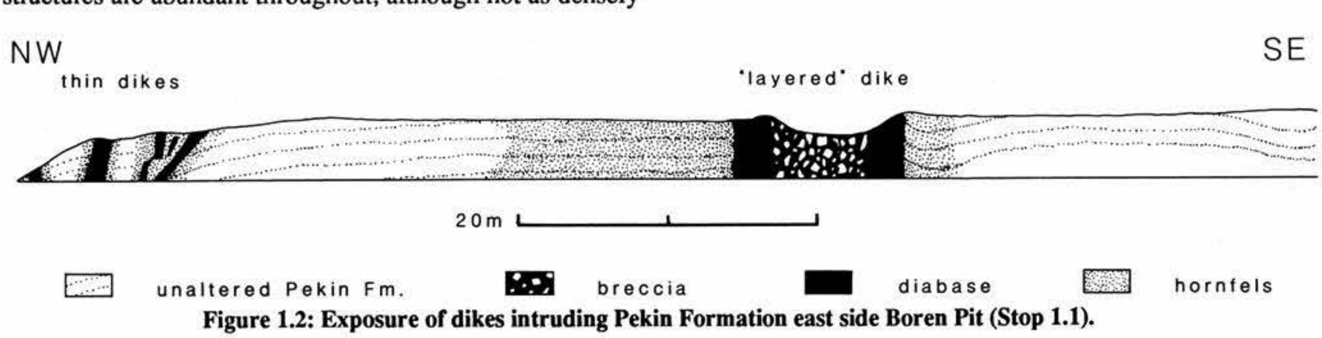

Figure 1.2: Exposure of dikes intruding Pekin Formation east side Boren Pit (Stop 1.1).

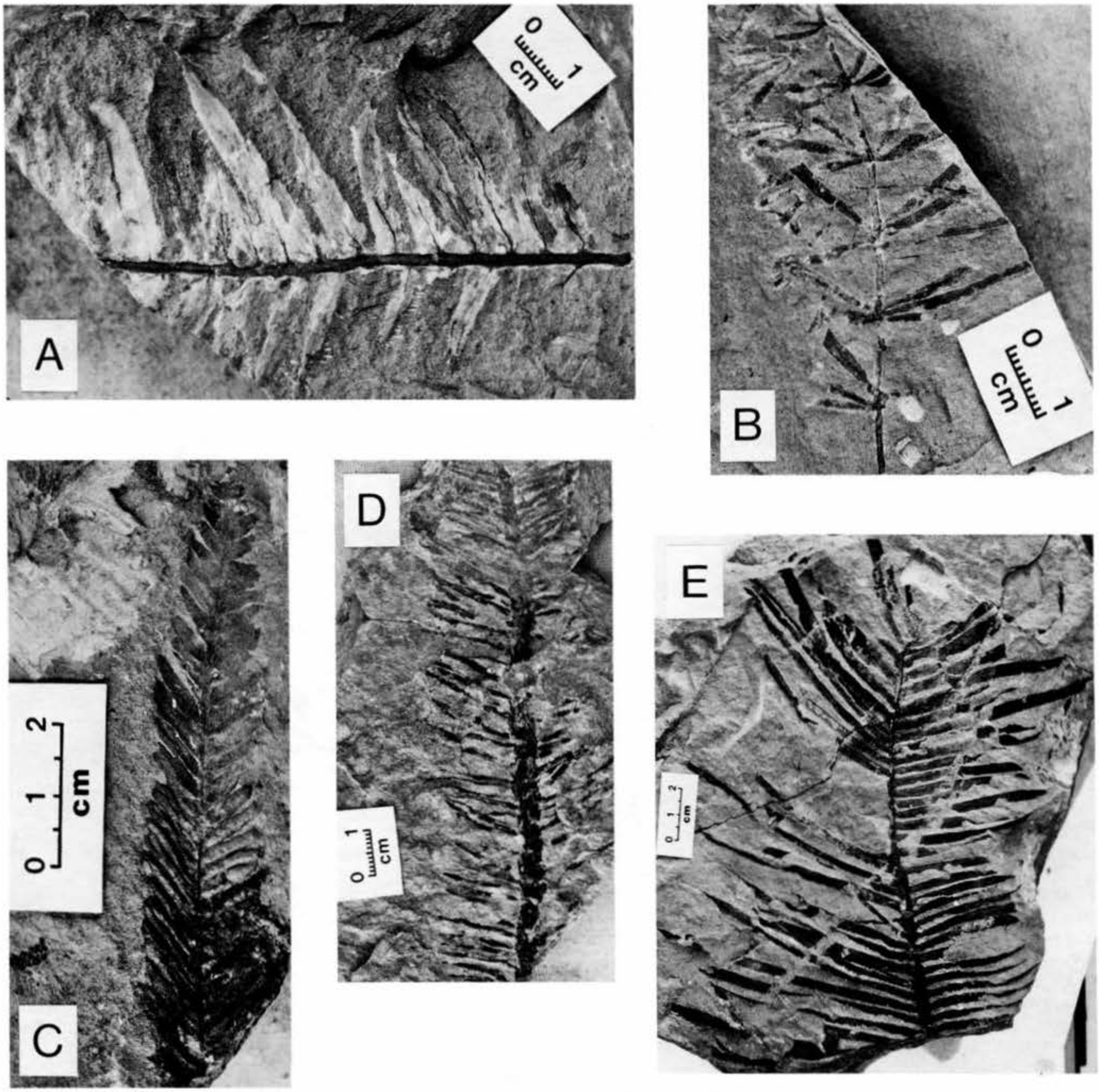

Figure 1.3: Remains of representative plants from the middle Pekin Formation of the Boren Pit (Stop 1.1): A) Portion of leaf of the fern *Pekinopteris auriculata*; B) Part of stem and whorled leaves of the horsetail *Neocalamites* sp.; C) Leaf tentatively assigned to the cycadeoid *Pterophyllum* sp.; D) Unidentified foliage similar to the enigmatic gymnosperm *Dinophyton*. E) Leaf of the common cycadeoid *Zamites*. Photographs courtesy of Patricia Gensel, adapted from Gensel (1986).

fill sequence incised into a wet, swampy, muddy area. It resembles a distributary channel, but it is not related to a large lake. Anastamosing river channels fill these constraints.

Carbonate nodules suggestive of caliche are notably absent at this locality and in adjacent exposures. Instead, small (<2 cm) hematitic nodules are abundant. In the adjacent Pomona pit, immediately on the southwest, wood replaced by hematite is also present. There is nothing in these exposures of the middle Pekin Formation to suggest an arid or even seasonally dry climatic setting.

The Boren pit is well known for the diverse assemblage of plant fossils. These plant fossils include ferns and their relatives (pteridophytes), horsetails, and gymnosperms, including conifers, cycads, and cycadeoids (Figure 1.3, Table 1.2). Stems, roots, leaves, cones, and seeds are preserved as compressions (plant material altered to a carbonaceous residue) and impressions or external molds. Some of the compressions contain well-preserved cuticles (the outer waxy covering of plant parts which retards water loss) and reproductive structures (Delevoryas and Hope, 1973; Gensel, 1986). Cuticle preservation ranges from excellent (*e.g.*, the cycad *Leptocycas*) (Delevoryas and Hope, 1971), to non-existent (most of the ferns)

(Delevoryas and Hope, 1973). In Mesozoic plants, features of the cuticle are also used to distinguish between cycads and cycadeoids, which can be difficult to identify from foliage alone (Gensel, 1986). The megafossil plants from the Boren pit constitute one of the better-known and more recently-studied Upper Triassic floras in eastern North America. This assemblage is placed in the *Eoginkgoites* megafossil floral zone by Ash (1980) , also recognized in the lower Chinle Formation of Arizona (Ash, 1980; Gensel, 1986).

Plant fossils are most abundant and best preserved in olive-gray to yellowish-brown siltstone and very fine-grained sandstone in the southwestern corner of the quarry (Gore, 1986a), not exposed at the time of this writing. Both black and white plant compressions are present. Leaf and stem impressions can be found on some bedding planes of grayish-red to moderate brown siltstone throughout the quarry. The most abundant plant fossils at this locality are leaves of cycads and cycadeoids including the genera *Otozamites*, *Pterophyllum*, and *Leptocycas* or *Pseudoctenis* (Delevoryas and Hope, 1973). Also abundant are leaves of the cycadeoid *Zamites*, and stems and leaves of the horsetail or sphenophyte, *Neocalamites*, as well as ferns (*Cladophlebis*, *Cynepteris* (=*Lonchpteris*), and *Phlebopteris*) and the fern-like plant *Pekinopteris* (Hope and Patterson, 1970; Delevoryas and Hope, 1971; Gensel, 1986). Among the conifer remains are cones belonging to the genera *Voltzia* and *Compsostrobus* (Delevoryas and Hope, 1973, 1975, 1981).

The dominant palynomorphs are fern spores, such as *Neoraistrickia americana* Schultz and Hope, *Triletes klausii*, *Convolutispora* sp., *Cyclogranisporites* sp., and *Cyclotriletes oligogranifer* Mädler (Traverse, 1986). Some conifer pollen is present, such as *Ovalipollis ovali* Krutzsch (Traverse, 1986). Also present is a very odd tetrad which Koob (1961) referred to as "*Placopollis raymondii*", but this palynomorph does not as yet have a validly published name (Traverse, 1986). The palynoflorules are Julian (middle Carnian) in age (Traverse, 1986). The dominance of fern spores suggests moist conditions (although some xerophytic ferns are known) (Traverse, 1986), which is certainly in line with the sedimentological interpretation.

Invertebrates from the gray siltstones of the Boren pit include conchostracans and clams (Table 1.2), and extremely abundant, large backfilled burrows (to 1.0 cm wide and at least 50 cm long) of *Scoyenia* (Gore, 1986a) found in beds of almost all lithologies in this pit (see also Stop 1.4). Vertebrates found in the Boren pit are thus far restricted to small three-toed footprints possibly dinosaurian. The nearby Pomona pit produced a rich vertebrate assemblage including bones of the large dicynodont mammal-like reptile cf. *Placerias*, phytosaurs, and fish, as well as abundant reptile footprints and clams (Table 1.2; Figures 1.4, 1.5). The footprint assemblage is the oldest from the Newark Supergroup and only one known from Newark Middle Carnian age strata; it is distinctly different than any younger assemblages (Olsen, 1988b).

50.6 Return to Creosote Road and turn left (southeast) onto US 421.

51.3 Turn left onto Alton King Road and immediately turn right into gravel driveway to Bethany Church.

51.5 Park in Bethany Church parking lot.

Table 1.2: Fossils from the Boren and Pomona pits (plants adapted from Gensel, 1986). Key as follows: †, ichnofossil; (B), found in Boren pit; (P), found in Pomona pit.

- PLANTS
  - Sphenophytes
    - Equisetales (horsetails)
      - *Neocalamites* (B,P)
  - Pteridophytes
    - Filicales (ferns and fern-like organisms)
      - *Cladophlebis (B)*
      - *Cynepteris* (B)
      - *Danaeopsis* (B)
      - *Phlebopteris* (B)
      - *Clathopteris* (B
      - *Wingatea* (B)
      - *Pekinopteris*
  - Cycadophytes
    - Cycadales (cycads):
      - *Leptocycas* (stems, leaves, cones) (B)
      - *Pseudoctenis* (leaves)(B)
    - Bennettitales (cycadeoids)
      - *Otozamites* (foliage) (B)
      - *Zamites* (foliage) (B,P)
      - *Pterophyllum* (foliage) (B)
      - *Eoginkgoites* (foliage) (B)
      - *Williamsonia* (sterile bracts) (B)
      - *Ischnophyton* (stem) (B)
  - Coniferophytes
    - Coniferales (conifers)
      - *Compsostrobus* (B) (male and female cones and foliage)
      - *Voltzia* (female cones) (B)
      - *Matridiostrobus* (female cones) (B)
  - ?Gnetophytes
    - *Pelourdea* (leaves) (B)
  - Uncertain affinity
    - *Phoenicopsis* (leaves) (B)
- ANIMALS
  - Mollusks
    - Pelecypoda
      - Unionidae
        - undetermined clams (B,P)
  - Arthropoda
    - Crustacea
      - Diplostraca (clam shrimp and water fleas)
        - *Cyzicus* sp. (B)
      - ?Decapoda
        - †*Scoyenia* (B,P)
    - Insecta
      - †undetermined trails (P)
  - Pisces (fish)
    - Actinopterygii (bony fishes)
      - Palaeonisciformes
        - undetermined redfieldiid scales and bones (P)
  - Reptilia
    - Synapsida (mammal-like reptiles)
      - Kannemeyeriidae
        - *Placerias* sp. (P)
    - Archosauria
      - Aetosauridae (armoured herbivorous archosaurs)
        - cf. *Typothorax* (P)
      - Rauisuchidae (carnivorous, usually quadrupedal archosaurs)
        - undetermined teeth (P)
        - †*Brachychrotherium* spp. (P)
        - †*Brachychrotherium* (*Rigalites*) sp. (P)
      - Phytosauridae (crocodile like archosaurs)
        - *Rutiodon* sp. (P)
        - †*Apatopus lineatus* (P)
      - ?Saurischia (lizard-hipped dinosaurs)
        - †(?)*Coelurosaurichnus* spp. (B,P)

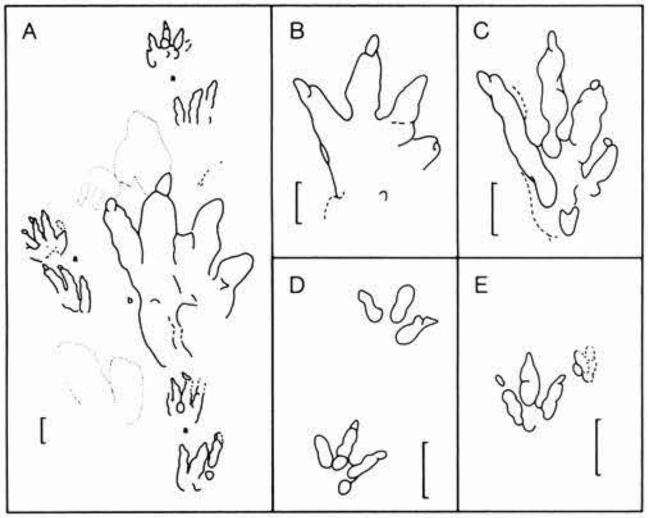

Figure 1.4: Footprints from the middle Pekin Formation of the Pomona Pit, adjacent to the Boren Pit (Stop 1.1) (from Olsen, 1988b): A) Natural cast of right pes impression of very large *Brachychirotherium* sp. with *Apatopus* trackway. B-C) Left pes impressions of *Brachychirotherium* sp. D) Natural casts of successive dinosaurian pes impressions of indeterminate genus; E) Natural cast of ?right pes impression and possible manus impression, possibly dinosaurian. Scale bars are all 10 cm.

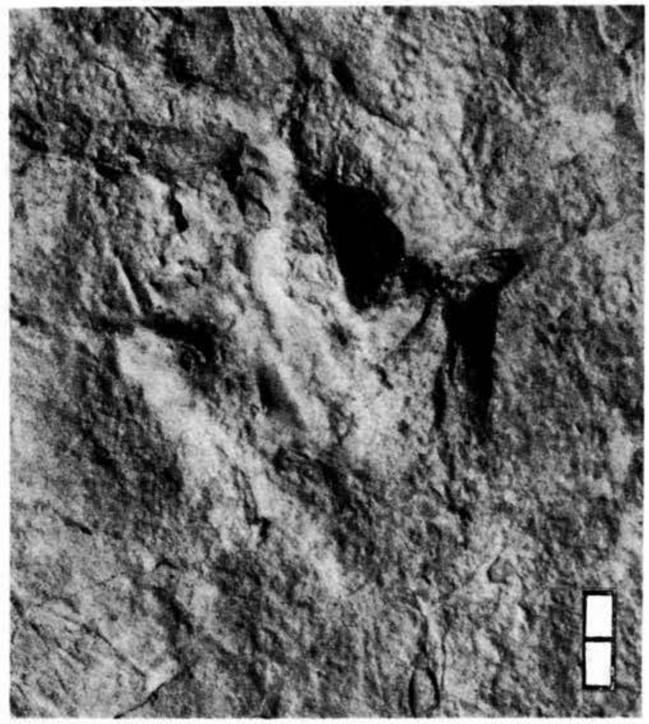

Figure 1.5: Natural cast of dinosaurian right pes impression (genus indeterminate) from the middle Pekin Formation of the Boren Pit, Stop 1.1. Scale bar is 2 cm.

STOP 1.2: CUMNOCK FORMATION AT BETHANY CHURCH, GULF, NC (by P.J.W. Gore)

Highlights: Fossiliferous black shale, coal, siderite nodules.

Proceed down embankment to railroad tracks. Look for small outcrops of the Cumnock Formation coal and black shale near the bridge (Figure 1.6). The shale and shaley coal are extremely fossiliferous, containing a non-marine invertebrate fauna consisting of conchostracans (*Cyzicus* sp.) and several species of smooth-shelled ostracodes in the genus *Darwinula*. Shiny, black, rhombic fish scales, coprolites, reptile bones and teeth, and plant fragments are also present (Table 1.3). The Cumnock coals, unlike the coals of the Richmond basin, are consistently interbedded with shales containing a rich lacustrine fauna. The Cumnock coals themselves apparently contain a large proportion of conifer material rather than cycadeoid material common in the Richmond basin coals.

Walk to the left (northeast) along the railroad tracks for about 100 m and enter the brushy clearing on the right (southeast) side of the tracks. Outcrops of red to brown sandstone, siltstone, and mudstone of the Pekin Formation are present here. These rocks are similar to those seen at the last stop in the Boren pit. According to a paced section presented by Bain and Harvey (1977), approximately 77 m of the Pekin are exposed here. These rocks are massive to poorly bedded, with abundant bioturbation, and local cross-stratification and they are generally non-calcareous. Gray reduction spots are present locally, particularly around root marks and scattered plant remains. There are thin, olive-gray silty to shaley interbeds locally, but thick gray horizons with plant fragments or coarse, organic carbon-rich sandstones are not exposed here. *Scoyenia* burrows with the typical external striations and internal backfilled structure are common but smaller here, with most ranging from 3 to 7 mm in diameter. Carbonate nodules (caliche?) 1-2 cm in diameter are abundant in some layers. This is a pronounced difference from the Boren pit exposures.

Table 1.3: Fossils from the Cumnock Formation at Stop 1.2.

PLANTS
- Sphenophytes -
  - Equisetales (horsetails)
    - *Neocalamites* sp.

ANIMALS
- Arthropods
  - Crustacea
    - Diplostraca (clam shrimp and water fleas)
      - *Cyzicus* sp.
      - ?*Paleolimnadia* sp.
    - Ostracoda
      - *Darwinula* spp.
      - undetermined forms
  - Insecta
    - Coleoptera (beetles)
      - undetermined fragments
- Pisces (fish)
  - Actinopterygii (bony fishes)
    - Palaeonisciformes
      - *Synorichthys* sp
      - *Cionichthys* sp.
  - Sarcopterygii (lobe finned fish)
    - Coelacanthini
      - cf. *Pariostegus* (*Diplurus*) sp.
- Reptilia
  - Archosauria
    - Phytosauridae (crocodile like archosaurs)
      - *Rutiodon* sp.

Proceed downhill to the south in the direction of dip, roughly toward the highway, until reaching a small (nearly dry) stream. Follow the stream downhill to outcrops of bituminous coal and black shale. The coal and black shale belong to the Cumnock Formation and are part of the same unit exposed along the railroad tracks. These beds are in fault contact with the Pekin redbeds, but the fault zone is covered here. The Cumnock Coal exposed here is known to lie about 60-80 m above the base of the Cumnock Formation, but in this area it is only a few meters from the Pekin red beds. A minimum of 50 m of section has been removed by faulting. The strike and dip of the Pekin and Cumnock differ considerably, although both units generally dip southward. For the Pekin, strike and dip are about N79°E, 42°SE (with some variation: locally dips are as shallow as 10°-20°). Strike and dip of the Cumnock are about N46°W, 40°SW (inconsistent due to faulting in the Cumnock). Bedding and possibly stratigraphic order are somewhat obscured by intense small-scale faulting in the Cumnock. A partial measured section in the Cumnock at this locality (Gore, 1986a) is given in Figure 1.6.

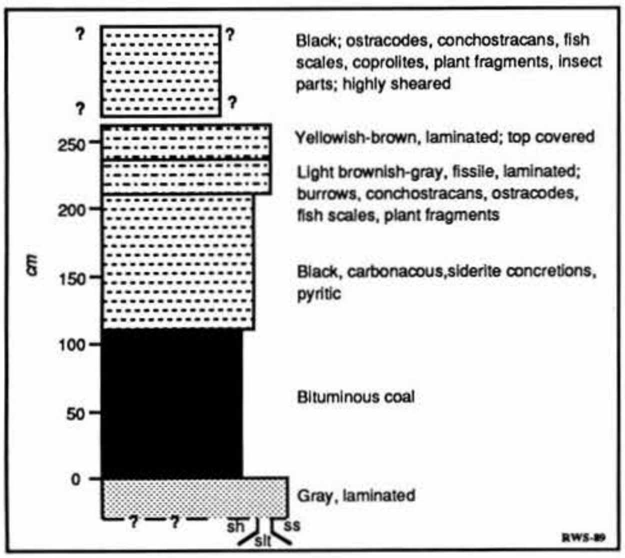

Figure 1.6: Measured section of Cumnock Formation coal (Stop 1.2), exposed south of Bethany Church, Gulf, NC. After Gore (1986).

Pollen and spores extracted from the coal and black shale at this locality are late middle Carnian in age and may indicate considerable drying in the source regions for the palynomorphs (as shown by a substantial decrease in fern spores) since the deposition of the gray Pekin beds at Stop 1.1 (Traverse, 1986). Of course, it is also possible that the advance of the lacustrine environment destroyed the fern-dominated habitats, or perhaps the swamp which produced the coals was dominated by conifers which were Cyprus-like in their adaptations to growing in submerged soils. The most prevalent palynomorphs in the coal include *Patinasporites*-complex (monosaccate conifer pollen), *Pretricolpipollenites ovalis* Danzé-Corsin and Laveine (a sulcate gymnosperm pollen grain), *Camerosporites pseudoverrucatus* Scheuring (a primitive circumpolloid), and *Pseudenzonalasporites summus* Scheuring (Traverse, 1986). Lesser amounts of trilete fern spores and *Cycadopites* spp. (a monosulcate pollen grain more or less identical to modern cycad pollen) are also present (Traverse, 1986). The black shale also contains some specimens of "*Placopollis*" and several types of bisaccate conifer pollen, including *Alisporites* sp. and *Colpectopollis* sp. (Traverse, 1986).

The non-marine fauna and fine-grained sediments indicate deposition in a lake with relatively quiet or deep water. The organic content of the Cumnock black shales is relatively high; total organic carbon (T.O.C.) averages about 1% but locally as much as 5-35% (Ziegler, 1983; Olsen, 1985a; Robbins and Textoris, 1986). The presence of abundant complete ostracodes and complete absence of microlamination indicate that the bottom waters of the lake were frequently oxygenated, however. Hence, the preservation of organics was probably due to high sedimentation rate. The presence of possibly primary siderite nodules in the Cumnock may indicate low sulfate content in the lake waters, at least some of the time (Gore, in press).

51.7 Return to Alton King Road. Turn left, then left again onto US 421 towards STOP 1.3.
OR, to reach Optional Stop 1.2a, continue straight across US 421 to the west, staying on Alton King Road, instead of turning left. Follow Alton King Road approximately 1 mile to strip mine on the left side of the road.

OPTIONAL STOP 1.2A: CHATHAM COAL COMPANY STRIP MINE, GULF, NC (by P.J.W. Gore)

Highlights: Black shales and coal of Cumnock Formation.

Over 2 million tons of coal have been mined in the Deep River basin, and it is calculated that the Sanford sub-basin has about 140,000,000 tons of remaining coal resources (Textoris, 1985). Coal has been mined in the basin since at least 1775, the time of the Revolutionary War (Reinemund, 1955). By 1850, many prospects and small mines had been opened along the coal outcrop belt. The first high production commercial mine was started in 1852, when the main shaft of the Egypt Mine was sunk; the main coal bed (Cumnock Coal) was encountered at a depth of 131 m (Reinemund, 1955). During the Civil War, the Confederate Army took over the mine, using the coal to supply the ships of blockade runners based in Wilmington, NC. Several other mines also operated in this area during the Civil War, including the Black Diamond Mine and the Carolina Mine. An iron furnace was built nearby along the Deep River to forge cannon balls and shot for the Confederate Army (Hetzer, 1987).

Other mines have been operated intermittently and unsuccessfully in the area because of geologic problems (faults and diabase intrusives), transportation problems, gas explosions (which killed over 200 miners), and flooding. The largest single mine disaster in the basin occurred in the Carolina Mine (also called the Farmville or Coal Glen Mine), which opened in 1922; in May of 1925, 53 miners were killed (Reinemund, 1955; Heltzer, 1987). The mine closed four years later due to flooding by the Deep River. The mine was reopened from 1947 to 1951, producing up to 100 tons/day, but failed to turn a profit and was allowed to flood again. Commercial mining in the basin ended in 1953 (Textoris, 1985), but a test pit (approximately 70 m by 30 m) was opened at this site in late 1987 by the Chatham Coal Company as a prelude to strip mining. This is the first attempt at strip mining in the basin, which at the time of this writing has not yet encountered unweathered rock.

The strip mine is near the old Gulf Mine, started during the Civil War and extended during the 1920's, and the old Deep River Mine, which was first opened in 1932 and closed in 1936. In addition, several small surface pits are present nearby. The Deep River lies less than half a mile south of this site. Between the strip mine and the river, about 30 m south of the road, is a large diabase sill. The coal adjacent to the diabase has been metamorphosed to anthracite. The rocks are highly faulted in this area. The Cumnock Coal Bed is repeated here three times by faulting [O. F. Patterson (mine geologist), pers. comm.]. Along the west side of the exploration pit, near a small stream, the coal is exposed at the surface in three places, marked by old hand-dug pits. On the far side of this stream, the coal is displaced to the south by a fault (O. F. Patterson, pers. comm.).

Two facies of shale in the Cumnock Formation similar to what is exposed at Stop 1.2 are present here: (1) black, organic carbon-rich, weathered non-calcareous shale crowded with external molds of ostracode valves, associated with fish scales and abundant powdery brown coprolites, and (2) medium dark gray clay shale with abundant, relatively large conchostracans (whole and fragmented) and plant fragments surrounded by tan oxidation zones, associated with a few ostracodes, fish scales, and coprolites.

From Alton King Road, turn southeast on US 421 (toward Sanford).

52.3 Turn right onto Route 1007 (S. Plank Road).

52.4 Cross the Deep River into Lee County.

55.6 Turn left (east) from Route 1007 onto NC 42 (Carbonton Road).

57.0 Roadcut on left (north) side of NC 42. Park along roadside.

STOP 1.3: SANFORD FORMATION NEAR SANFORD, NC (by P.J.W. Gore)

Highlights: Thin lake bed with conchostracans; cross-bedded red clastics (fluvial); Scoyenia *in laminated strata.*

This road cut (Figure 1.7) exposes 9.5 m of red to brown sandstone, siltstone, mudstone and shale of the lower Sanford Formation, the upper of three formations in the Sanford sub-basin (Gore, 1986a). Bedding in this outcrop tends to be more tabular than in obvious fluvial deposits in the Pekin and Sanford formations, but most of the beds change thickness laterally. The more resistant ledge-forming units are red to brown, non-calcareous, cross-stratified sandstone and massive siltstone. The less resistant beds are massive to poorly-laminated mudstone and shale. Two fining-upward sequences are present, consisting of an abrupt contact (scour surface) overlain by cross-stratified sandstone, grading up into bioturbated siltstone and mudstone (Gore, 1986a).

A convex-upward sandstone lens with rip-up clasts and climbing-ripple cross lamination in the upper part occurs along the left (western) end of the road cut. The morphology, texture, and sedimentary structures of this unit suggest that it may be a crevasse-splay deposit. Approximately 5.5 m above the base of the section is a thin (21 cm) gray bed. The gray bed occurs at the top of a 1.4-m-thick fining-upward sequence (Gore, 1985). The gray bed may be subdivided into three parts: (1) a lower unit, 5 cm thick, of light gray, massive to poorly-laminated, non-calcareous, plant-fragment-bearing siltstone, fining upward into (2) a middle unit, 8 cm thick, of light gray, fissile, non-calcareous clay shale containing closely-packed conchostracans on some bedding planes overlain by (3) an upper unit, 8 cm thick, of laminated, wavy-laminated, and cross-laminated, noncalcareous siltstone with asymmetrical ripple marks (Gore, 1986a). The mineralogy of the gray bed consists of quartz, illite, chlorite, plagioclase, siderite, and possibly ankerite (x-ray diffraction data from Andy Thomas, Texaco). The uppermost beds of the outcrop consist of tabular fine sandstone and interbedded mudstone beds with unidirectional cross beds at the base and abundant possible oscillatory ripples higher up. *Scoyenia* and roots are very abundant and have obscured the ripple cross lamination characteristics of the tabular thin-bedded sandstones.

There is debate about the depositional environments represented by this outcrop with two opposing hypotheses: 1) all of the deposits are related to a fluvial environment with the interbedded lacustrine strata being the deposits of shallow ponds and small lakes on a low relief flood plain; 2) the sequence represents alternating basin-wide shallow lake deposits and fluvial low-stand deposits.

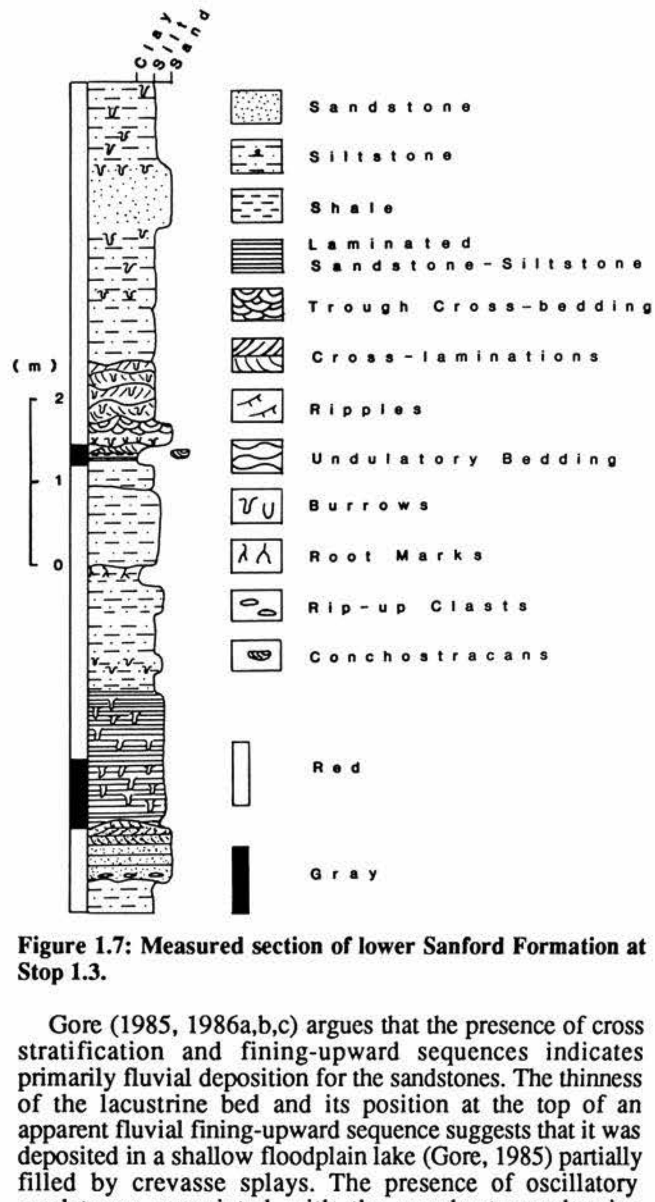

Figure 1.7: Measured section of lower Sanford Formation at Stop 1.3.

Gore (1985, 1986a,b,c) argues that the presence of cross stratification and fining-upward sequences indicates primarily fluvial deposition for the sandstones. The thinness of the lacustrine bed and its position at the top of an apparent fluvial fining-upward sequence suggests that it was deposited in a shallow floodplain lake (Gore, 1985) partially filled by crevasse splays. The presence of oscillatory sandstones associated with the conchostracan-bearing siltstones is not in conflict with this interpretation.

Olsen argues that the conchostracan-bearing siltstone represents substantial lake conditions, and that the associated tabular sandstones are wave-formed beds and associated distributary channels and bars. The associated fluvial beds were deposited during low-stands of the lake and dissection of the lake margin deposits by streams.

According to Olsen, alternations between fluvial and lacustrine deposition would thus be controlled by basin-wide changes in lake level, not lateral migration of channels and floodplains. The sequence appears intermediate in facies between the marginal facies of the Cumnock Formation as exposed near Carthage (Olsen, 1986) and the fully fluvial upper Sanford Formation.

This argument will come up several times during the course of the field trip. Resolution of the arguments rests on determining the regional distribution of beds, which is difficult due to poor exposure.

57.0 Continue east on NC 42 toward Sanford. Small outcrops of the Sanford Formation are present along both sides of the road.
62.6 Intersection with US 1-15-501. Head north on US 1-15-501.
74.6 Cross the Deep River.
90.0 Exit to NC 55, Apex/Fuquay Varina.
90.2 Turn left onto NC 55, heading north toward Apex. Pass through the town of Apex.
93.2 Intersection of NC 55 with US 64.
93.4 Continue north on NC 55.
101.3 Triangle Brick Quarry office. (Stop and ask for permission to enter the quarry).
101.4 Turn left toward quarry.
101.6 Stop sign at Kit Creek Road. Go straight onto quarry entrance.
101.8 Park where directed by quarry personnel. Stay out of the way of the large dump trucks. Descend into the pit beside the white shed.

STOP 1.4: TRIANGLE BRICK QUARRY, DURHAM, NC (by P.E. Olsen, J.P. Smoot, and P.J.W. Gore)

Highlights: Very fossiliferous thin lake bed, fluvial deposits with reptile bones and paleosols.

The Triangle Brick Quarry is on strike with the mudstone facies of Lithofacies Association II of Hoffman and Gallagher (1988). The dominant lithologies in the 60-m-thick exposed section are red-purple to red-brown massive siltstone (Figure 1.8) and gray to brown sandstone. There are subordinate amounts of green and red clay shale and calcareous siltstone to limestone. On the largest scale, the sequence consists of alternating fluvial and apparently lacustrine units (Figures 1.8, 1.9).

Three well-defined channel-fill deposits occur within the quarry. A thick, relatively poorly-exposed gray (weathering yellow) sandstone occurs below the upper lacustrine clay shale (Figure 1.8) and contains large (>20 cm) decimeter-scale trough cross beds fining upward into bioturbated sandy siltstone. Below this are a series of lenticular sandstone beds defining large-scale, low-angle cross strata. In places these strata consist of intensely bioturbated, red-brown, sandy mudstone grading down-dip into ripple cross-laminated fine sandstone and finally into coarser sandstone with trough cross bedding and abundant intraclasts. The sandstone lenses are separated by red-brown mudstones that thin towards the large trough cross-bedded bases of the sandstone lenses. These sequences define lateral accretion beds of a high-suspended load meandering stream (Figure 1.10) (Smoot, 1985) similar to the Barwon River of south Australia (see references in Smoot, 1985).

The lowest channel-fill sequence consists of a single lenticular body with trough cross bedding at the base grading into climbing ripple cross lamination. This sandstone is incised into a tabular sandstone body that

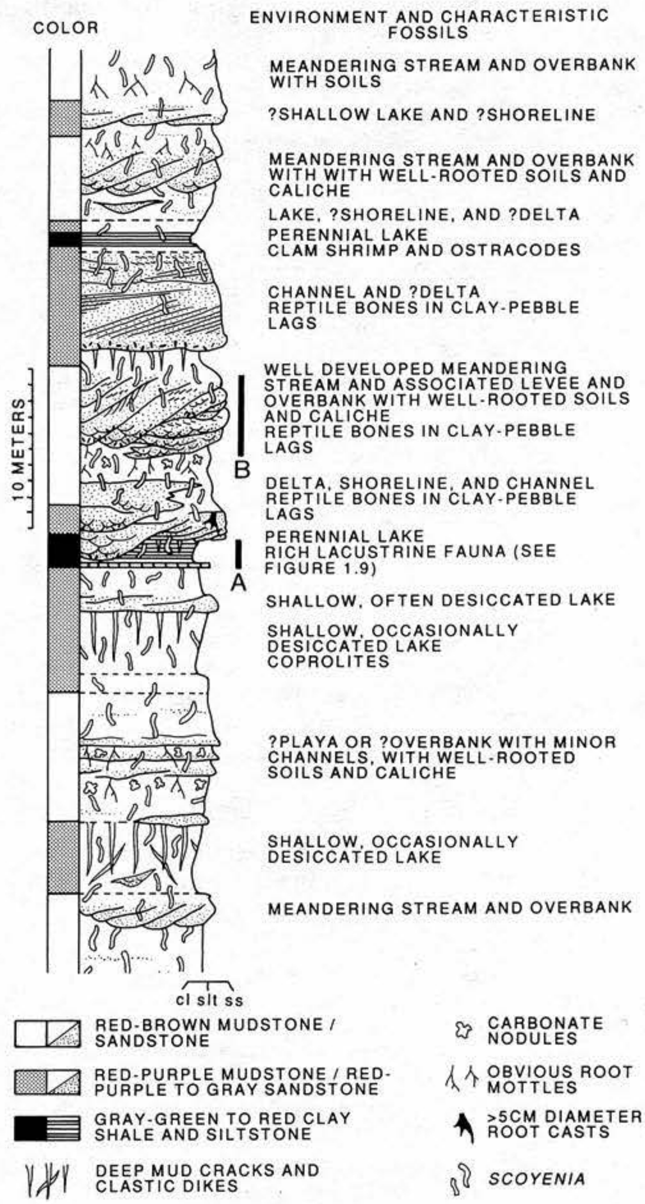

Figure 1.8: Measured section at Triangle Brick Quarry, measured January, 1989. A) Interval of highly fossiliferous clay shale shown in detail in Figure 1.9; B) interval of lateral accretion surfaces shown in detail in Figure 1.10.

gradationally overlies the lower and fossil-rich lacustrine clay shale. The tabular sandstone at the upflow (north) end of the exposure is dominated by planar to wavy lamination, whereas the tabular sandstone at the downflow (south) end of the outcrop contains climbing ripple cross lamination or tabular forsets. In both cases the tabular sandstone grades upward from the clay shales through a thickly laminated siltstone. This association suggests that the tabular sandstone was built out over the shaley sequence as a lobate sheet while the channel sand was cut into it as a crevasse delta or distributary mouth bar.

Most other sandstone bodies are thin and broadly lenticular. They are heavily bioturbated, particularly by *Scoyenia* and roots, and internal bedding and bed boundaries are indistinct. Most of the deposits around the sandstones are reddish brown mudstone or muddy siltstone similarly bioturbated with several horizons bearing irregular spongy appearing carbonate nodules that in places define portions of root-tubules. As described in the introduction to this section, these nodules do not appear to have been available for transport in the channel deposits and were probably not solid at the type of formation. This implies wetter conditions than usually assumed for caliche formation.

There are four distinctive mudstone beds that are traceable as tabular beds across the outcrops and represent lacustrine or possible lacustrine deposits. Most spectacular is the lower laminated clay shale which contains abundant fossils and underlies the tabular sandstone unit (Table 1.4; Figures 1.11); the distinctive distribution of the various types of fossils remains consistent across the quarry. The base of the fossiliferous part of the sequence is a calcareous ostracodal siltstone or limestone with abundant fish fragments and coprolites (see Figure 1.9). This is abruptly overlain by a finely-laminated (but not microlaminated) claystone with abundant small conchostracans (cf. *Palaeolimnadia*) and partially associated fish remains. The better than usual (for the Deep River basin) fish preservation and the preserved laminations suggest deposition in perennially poorly-oxygenated water. This is followed successively upward by clay shale showing a progressive decrease in lamination and an increase in the diversity of body fossils of infauna (Figure 1.9). Several thin (< 5 cm) green siltstone beds near the top of the clay shale are traceable across the quarry except where truncated by channels.

The lateral continuity of thin beds in the clay shale interval and the consistency of the faunal zonation suggest

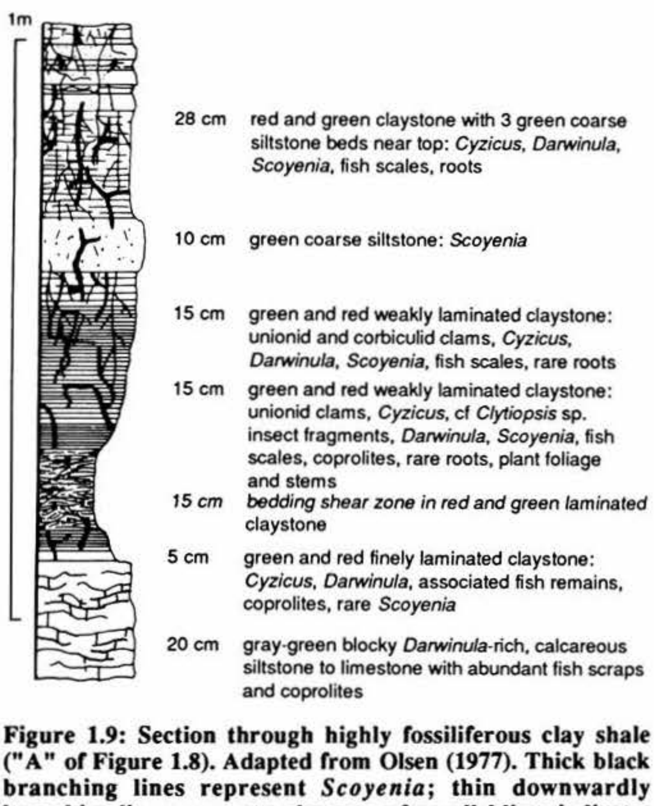

Figure 1.9: Section through highly fossiliferous clay shale ("A" of Figure 1.8). Adapted from Olsen (1977). Thick black branching lines represent *Scoyenia*; thin downwardly branching lines are roots; closeness of parallel lines indicates degree of lamination.

that the lake was considerably larger than the size of the quarry. The lake also had to have negligible bottom relief over the area of the quarry. The succession of fossils is similar to sequences seen in division 2 of Van Houten cycles in the Cow Branch Formation of the Dan River-Danville basin (Stop 2.2) and the lower Lockatong of the Newark basin (Stops 6.6-6.8), and at least the latter units demonstrably have great lateral extent.

The uppermost lacustrine clay shale is similar to the lower but is much thinner, lacks a basal calcareous bed, is less well laminated, and is less fossiliferous. Two other mudstone units contain almost no fossils (a few small coprolites have been found) and are not bedded. They are distinguished from the more typical mudstones by their color (purple-red) and in containing large (23 cm) and deep (>1 m) sandstone and siltstone-filled mudcrack polygons

Table 1.4: Fossils from the Triangle Brick Quarry, Stop 1.4. All fossils from middle lake bed except as noted. † Indicates an ichnotaxon.

- PLANTS
  - Sphenophytes -
    - Equisetales (horsetails)
      - *Neocalamites* sp.
      - *Equisetales* sp.
  - Pteridophytes
    - Filicales (ferns and fern-like organisms)
      - *Cladophlebis sp.*
  - Coniferophytes
    - Coniferales (conifers)
      - *Pagiophyllum cf. simpsoni*
- ANIMALS
  - Mollusks
    - Pelecypoda
      - Unionidae
        - undetermined aragonitic clams
      - ?Corbiculidae
        - undetermined calcitic clams
  - Arthropods
    - Crustacea
      - Diplostraca (clam shrimp and water fleas)
        - *Cyzicus* sp.
        - ?*Paleolimnadia* sp.
      - Ostracoda
        - *Darwinula* spp.
      - ?Decapoda
        - cf. *Clytiopsis* sp
        - †*Scoyenia*
    - Insecta
      - Coleoptera (beetles)
        - undetermined fragments
    - undetermined large arthropod fragments
  - Pisces (fish)
    - Actinopterygii (bony fishes)
      - Palaeonisciformes
        - *Turseodus* spp.
        - *Cionichthys* sp.
      - Semionotidae
        - *Semionotus* sp.
    - Sarcopterygii (lobe finned fish)
      - Coelacanthini
        - cf. *Pariostegus* sp.
        - *Osteopleurus* sp.
  - Reptilia
    - Archosauria
      - Phytosauridae (crocodile like archosaurs)
        - *Rutiodon* sp. (sandstone channel lags)
      - Aetosauridae (armoured herbivorous archosaurs)
        - *Stegomus* sp. (sandstone matrix, bed unknown)

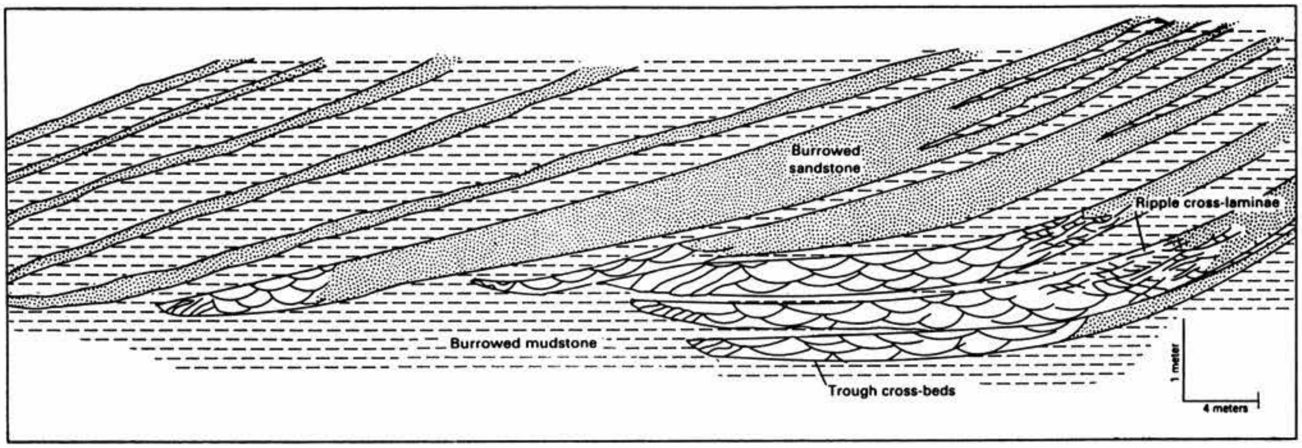

Figure 1.10: Simplified sketch of sedimentary features in the bed marked "B" in Figure 1.8 (from Smoot, 1985). Trough cross-bedded areas are coarse-grained sandstone with mud intraclasts, and the ripple cross-laminated areas are medium- to fine-grained sandstone. The stippled areas represent internally massive, burrowed, muddy sandstones, and the dashed areas represent internally massive, burrowed mudstones. Vertical exaggeration (X 4) has increased the apparent dip of bedding, which is actually ~ 5°. Paleocurrent direction, as indicated by the trough cross beds, is out of the page and to the right.

that become asymmetrically wider and more abundant upward. The association suggests that these mudstones were deposited in slightly more water-logged conditions than the other mudstones and that they may have accumulated in shallow lakes.

As in the Pekin and Sanford formations, *Scoyenia*-type burrows are exceedingly common, often obliterating any other textures. *Scoyenia* are burrows with external, longitudinal striations and a meniscate or tangential internal backfilling. They range here from approximately 0.5-1.0 cm in diameter. In general, the smaller burrows are sub-horizontal, and the larger burrows are sub-vertical, locally cutting or intersecting the smaller burrows. Knot-like and club-shaped terminations occur, as does branching. The branching indicates that the burrows remained open for some before being backfilled.*Scoyenia* puncture beds with the crayfish-like *Clytiopsis* in the lacustrine shale and have been interpreted as the burrows of crayfish or crayfish-like decapods (Olsen, 1977; *contra* Frey *et al.*, 1984). *Scoyenia* has been interpreted by Frey *et al.* (1984) as an indicator of moist or wet non-marine substrates, either shallow aquatic deposits which are periodically exposed, or low-lying subaerial deposits which are occasionally flooded. The fine sculptural details of *Scoyenia* are best preserved in clay shale, although *Scoyenia* are also preserved in siltstone and sandstone.

The overall environmental context and cause of the fluvial and lacustrine alternations are as unclear here as they were in the Sanford Formation at Stop 1.3. Gore (1985, 1986a) sees the alternations as due to the lateral migration of rivers and shallow flood plain lakes, whereas Olsen sees the alternations as reflections of cyclically-changing climate affecting lake depth in a closed basin with a low outlet or just a restricted outlet. Once again, observations of the lateral continuity of the putatively deeper water units are critical to testing these hypotheses. If the basin was open all during deposition, then the lake deposits should be of limited areal extent and the fluvial deposits could stretch across the entire basin. On the other hand, if the basin was hydrologically closed, the lacustrine intervals should be present over the center of the basin and the fluvial intervals should somewhere pass laterally into lacustrine strata in the deepest part of the basin (Smoot, 1985).

Whatever the cause, a vague 20 m alternation of red-purple and red-brown mudstone intervals seems apparent. If the cause of the apparent cyclicity is climate acting on lake level in a closed or semi-closed basin, the 20 m cycles could be due to the cycle of the precession of the equinoxes, although the number of cycles at this outcrop is certainly too small to obtain the full Milankovitch-type spectrum of small and larger-scale cycles even if they are present.

102.0 Leave quarry. Turn left onto Kit Creek Road as you exit the gate.
102.2 Turn left (north) on NC 55.
104.4 Intersection with NC 54. Turn left (west) toward Chapel Hill.
106.3 I-40 overpass over NC 54.
106.6 Turn left onto Fayetteville Road (NC 1118).
108.1 Bridge over abandoned railroad cut. Park.

STOP 1.5: RAILROAD CUT, DURHAM, NC

(by W. Hoffman and P. Gallagher)
Highlights: Fluvial sequences, diabase dike.

A 200-m-long by approximately 10-m-high cut along an abandoned section of the Norfolk and Southern Railroad exposes a large sequence of interbedded sandstone and mudstone of Lithofacies Association I (Hoffman and Gallagher, 1988, in prep.). This section has been subdivided into four units which are described below. The southeastern end of the exposure is terminated by a diabase dike; a normal fault is exposed near the southeastern end of the outcrop (Figure 1.12).

Unit 1 is a muddy sandstone with resistant lenses of coarse feldspathic sandstone. The unit is graded with coarser sandstone at the base and finer sandstone towards the top. The resistant lenses near the base of unit 1 are internally cross-stratified and the boundaries are gradational into the muddy sandstone which has similar grain sizes. The muddy sandstone underlying those lower resistant lenses in places consists of pebble-sized mud clasts in a coarse sand matrix. All layering is indistinct, possibly due to bioturbation. In the upper part of unit 1 burrows and root structures are evident and carbonate nodules are present.

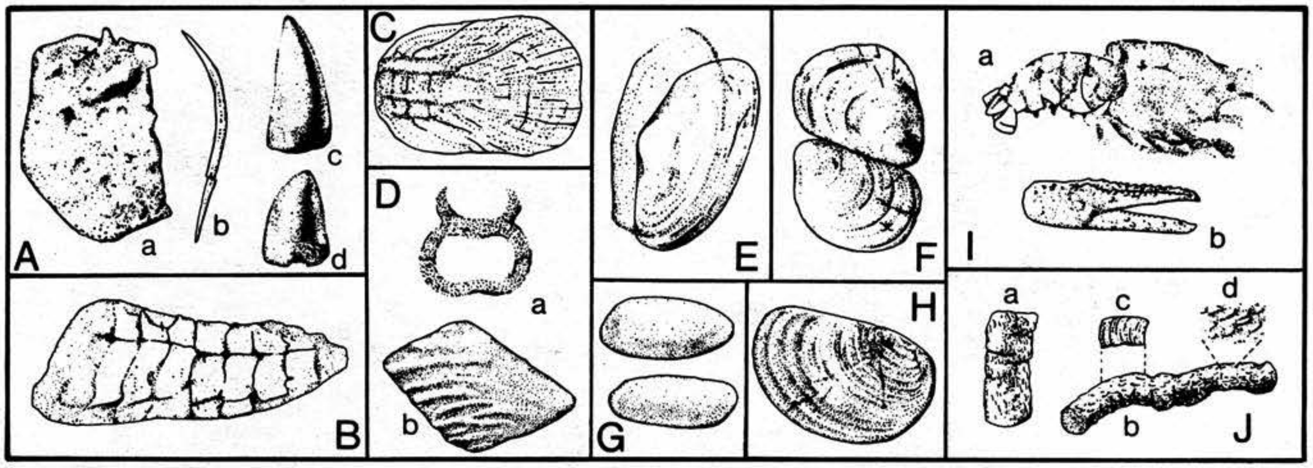

Figure 1.11: Vertebrate and invertebrate fossils from the Triangle Brick Quarry. A) Bones and teeth of the phtyosaur *Rutiodon* sp.: a, dorsal scute (X 0.13); b, gastralia element (X 0.19); c and d, posterior teeth (X 1.0). B) Ventral view of fragment of tail cuirass of armored archosaur *Stegomus* sp. (X 0.25). C) Scale of coelacanth *Osteopleurus* (*Diplurus*) sp.(X 3). D) Centrum and scale of palaeoniscoid fish *Turseodus* sp. (X 3). E) Undetermined unionid clam (X 2.5). F) Undetermined ?corbiculid clam (X 3). G) Ostracode *Darwinula* sp. (X 20). H) Clam shrimp *Cyzicus* sp. (X 5). I) Crayfish-like decapod crustacean cf. *Clytiopsis* sp.: a, specimen missing front claws (X 1.5); b, isolated front claws (X 1.6). J) *Scoyenia* burrows: a, segment pf large vertical burrow (X 0.5); b, segment of horizontal burrow (X 0.5); c, longitudinal section showing meniscus-type infilling; d, enlargement of "prod" marks on burrow exterior (X 2). From Olsen (1977).

Unit 2 is a silty mudstone with carbonate nodules, root structures, and abundant *Scoyenia* burrows. The lower contact of this bed is gradational with unit 1, and the upper contact with unit 3 is a scour surface.

Unit 3 consists of medium- to coarse-grained, trough cross-bedded feldspathic sandstone overlain by medium to coarse-grained, planar-tabular cross-bedded feldspathic sandstone. Large mud clasts occur along the bases of the lower, large-scale trough cross beds which grade upward into smaller-scale trough cross beds which lack mud clasts. Within the planar-tabular cross-bedded portion of the unit, large tabular sets grade vertically and laterally into small tabular sets. Paleoflow, determined from the troughs, is S50°W-S60°W. The planar-tabular cross beds yield a S70°W paleoflow direction. This unit is cut by a normal fault.

Unit 4 is a burrowed and rooted silty mudstone in fault contact with Unit 3. It closely resembles unit 2.

The rocks at this outcrop are interpreted as sandy braided stream system deposits within a muddy floodplain. The sequence of structures in unit 3 is similar to the sandy braid stream deposits described by Cant and Walker (1976, 1978). As in this type of braid stream, large-scale (>20 cm) trough cross beds form in the deepest part of the channel while smaller scale trough cross beds form in shallow water as the channel fills. Tabular forsets of a variety of thicknesses are produced by barfront accretion. These are oriented at considerably different angles than the trough cross beds which they typically overlie. On the other hand, the thick sequences of mudstone surrounding the channel fill sandstone (units 2 and 4) are not like the braided river model of Cant and Walker. This suggests that the river was incised into a low gradient muddy plain, more like anastamosing rivers of Smith and Smith (1980). The swampy wet conditions envisioned for this model are consistent with the abundant root and burrow structures. Unit 1 is a problem because it is unclear what effects bioturbation and/or modern weathering have had on the present appearance. The sequences of grain sizes and structures in unit 1 are consistent with a channel-fill sequence similar to unit 3 but thinner and without tabular sets. This may represent a shallow side branch of the braid river that was covered by vegetation during periods between high flood stages. We see no need to call upon climatic fluctuations (as in Textoris and Holden, 1985). As in the previous stop, the carbonate nodules are conspicuously absent from the sandstones. The random interbedding of channel fill sandstones with braid river characteristics and bioturbated mudstones is characteristic of the stratigraphically-lower outcrops of the northern Durham sub-basin. This is in contrast to the rhythmic fining-upward sequences in channel sandstones, similar to the previous stop, that characterize the overlying middle belt. This fluvial style suggests a possible change from anastomosing to meandering rivers as the basin developed. This change is accompanied by a change in provenance, this stop being very close to the boundary. There is no evidence to suggest the change is related to climate, although stream gradients may have been reduced by lake transgressions. Another possibility is that the source drainage areas changed in response to tectonic activity also changing the character of the rivers.

108.3 Turn around and return north on Fayetteville Road to NC 54.
109.8 Turn left (west) onto NC 54 toward Chapel Hill.
114.9 Chapel Hill city limits.
115.6 Turn right onto US 15-501 north toward Durham.
119.3 Durham city limits—"City of Medicine".
121.0 Turn right onto US 15-501 Bypass.
125.4 Intersect I-85. Roads merge.
128.0 Exit on US 501 North to Roxboro, NC. Leave Durham sub-basin of Deep River basin. Enter an area underlain by felsic volcanic rock (metamorphosed dacitic to rhyolitic flows and tuffs) interbedded with mafic and intermediate metavolcanic rock, and metasediments of

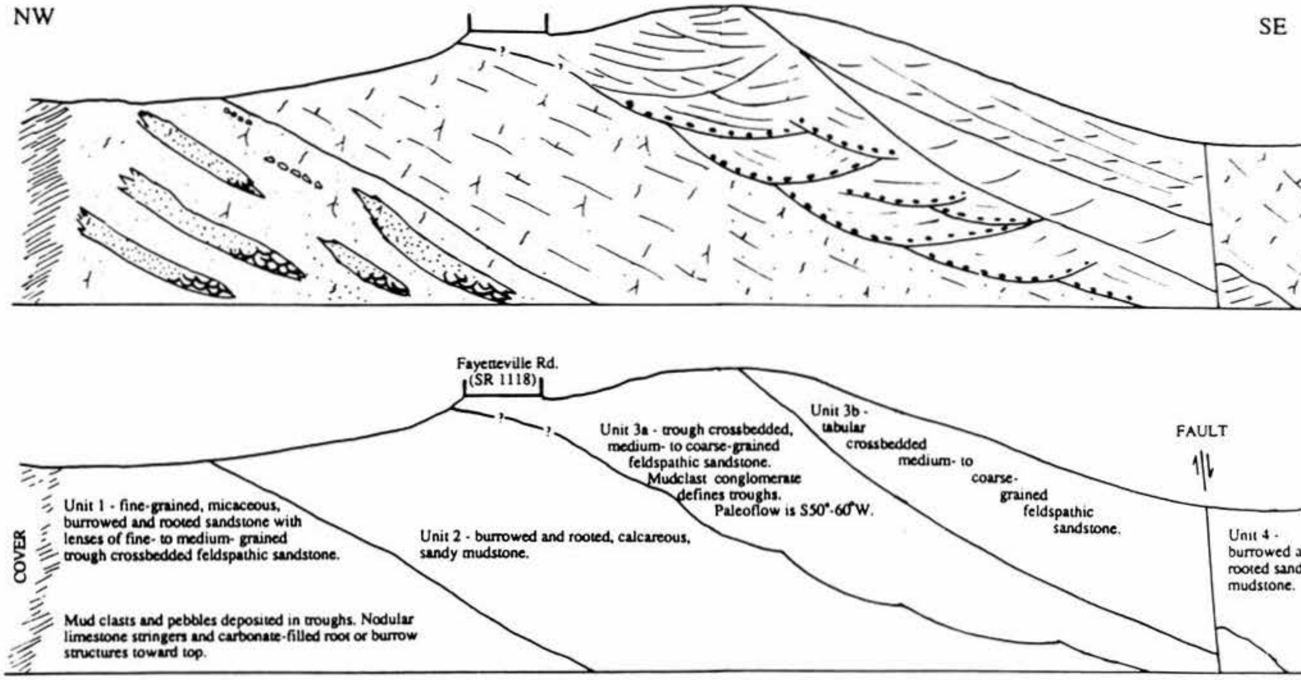

Figure 1.12: Generalized sketch of section exposed along abandoned railroad grade at Stop 1.5. Vertical exaggeration is about X 15; length of section is about 150 m.

the Carolina Slate belt (Late Precambrian to lower Paleozoic).

153.8 Roxboro city limits.

155.1 Turn left onto North 57-South 49-West 158.

155.5 Turn right onto Route 57 North.

161.0 Boulder-like outcrops of Late Proterozoic to Late Cambrian metamorphosed granite in and near Roxboro.

167.5 Intersection with NC 119. Continue north on NC 57. This area is underlain by Late Precambrian and Lower Paleozoic biotite gneiss and schist, and felsic mica gneiss.

172.5 Intersection with NC 62 at Milton, NC. Continue north on NC 57.

172.6 Cross the Dan River.

172.9 Virginia state line.

176.8 Turn left on US 58 West to Danville, VA.

183.7 Turn left onto Business Route 29 (N. Main Street).

183.8 Cross Dan River, home of Dan River Fabrics.

184.6 Last Confederate capital building.

184.8 Fork right onto West Main Street (South Business 29).

184.9 Turn right onto Route 86 North-Bypass 29.

185.2 Cross Dan River.

186.1 Exit right at Riverside Drive (US 58 west) going west.

187.3 Arrive at stop for evening.