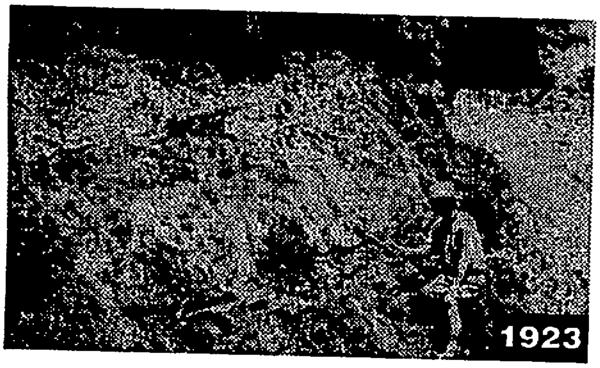
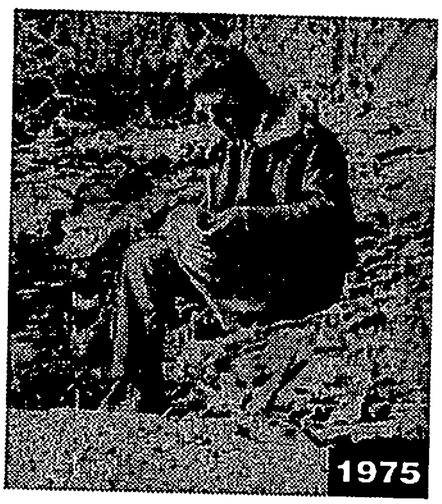




TRIBI: Triassic Basin Initiative

1997

Abstracts with Programs and Field Trip Guidebook

edited by
Timothy W. Clark

March 21-23, 1997
Duke University
Durham, North Carolina

On the Cover:

1923 - "Outcrop of the Cumnock coal bed near Gulf. This outcrop, in a recent cut made by the Norfolk Southern Railroad, shows about 4 feet of badly weathered coal." *from* Campbell, M.R. and Kimball, K.W., 1923, The Deep River coal field of North Carolina: North Carolina Geoloical Survey Bulletin 33, 95 p.

1955 - "Diabase dike in Sanford Formation about 1 mile south of Sanford. Contact of diabase (light) with siltstone (dark) is indicated by hammer. Dike is about 30 feet wide, trends perpendicular to plane of photograph. Exposure on county road 1,300 feet west of Buffalo Church." *from* Reinemund, J.A., 1955, Geology of the Deep River coal field, North Carolina: United States Geological Survey Professional Paper 246. 159 p.

1975 - Paul Olsen of Columbia University looking for fossils at the Lockville Dam exposure along the Deep River, southern Durham sub-basin. Photo courtesy of Paul Olsen.

1986 - "Field assistant, Patricia Renwick, is pointing to gray, fossiliferous lacustrine shale below sandstone. Gray shale is present about 5.5 m above base of section, at top of a 1.4 m fining upward sequence." *from* Gore, P.J.W., ed., 1986, Depositional framework of a Triassic rift basin: The Durham and Sanford sub-basins of the Deep River Basin, North Carolina, *in* Textoris, D.A., ed., Society of Economic Paleontologists and Mineralogists Field Guidebook - Southeastern United States third annual midyear meeting, Raleigh, North Carolina, p. 53-115.

1992 - North Carolina Geological Survey geologist Rick Wooten alongside a trench exposing a diabase dike at the proposed low-level radioactive waste site, near Merry Oaks, NC. Photo courtesy of the NCGS.

TRIBI: TRIASSIC BASIN INITIATIVE

Workshop and field trip in the Deep River Triassic basin, North Carolina

Abstracts with Programs

and

Field Trip Guidebook

edited by Timothy W. Clark

TRIBI

Duke University
Durham, North Carolina

March 21-23, 1997

ACKNOWLEDGEMENTS

The editor gratefully acknowledges the assistance of the following persons.
Without their help this workshop would not have existed.

Debbie Gooch, Frances Harrison, and Mary Anne Perez
Duke University Division of Earth Sciences

Cindy White, Office of Public Affairs
North Carolina Department of Environment, Health and Natural Resources

The staff of the North Carolina Geological Survey

The editor especially wishes to thank Karen and Sarah,
a very patient wife and daughter.

ALPHABETICAL LISTING OF FIELD TRIP LEADERS AND CONTRIBUTORS

David E. Blake, Department of Earth Sciences, University of North Carolina-Wilmington, Wilmington, NC 28403-3297 (blaked@uncwil.edu)

Timothy W. Clark, North Carolina Geological Survey, P.O. Box 27687, Raleigh, NC 27611-7687 (jeff_reid@mail.ehnr.state.nc.us)

Kathleen M. Farrell, North Carolina Geological Survey, P.O. Box 27687, Raleigh, NC 27611-7687 (jeff_reid@mail.ehnr.state.nc.us)

William S. Grimes, Department of MEAS, North Carolina State University 27695-8208 (wsgrimes@eos.ncsu.edu)

Matthew J. Heller, Department of MEAS, North Carolina State University 27695-8208 (MHeller@mro.ehnr.state.nc.us)

Phillip Huber, Department of Education, University of Bridgeport, Bridgeport, CT 06601

Peter E. Malin, Division of Earth Sciences, Duke University, P.O. Box 90227, Durham, NC 27708-0227, (pem@vaino.geo.duke.edu)

Paul E. Olsen, Lamont-Doherty Earth Observatory of Columbia University (LDEO), Rt. 9 W, Palisades, NY 10964 (polsen@ldeo.columbia.edu)

Edward F. Stoddard, Department of MEAS, North Carolina State University 27695-8208 (skip_stoddard@ncsu.edu)

Richard M. Wooten, North Carolina Geological Survey, P.O. Box 27687, Raleigh, NC 27611-7687 (jeff_reid@mail.ehnr.state.nc.us)

TABLE OF CONTENTS

FIELD TRIP STOPS

WORKSHOP AND FIELD TRIP PROGRAM

Friday, March 21, 1997

7:00 - 9:00 pm **Registration - Welcoming Party**
Regal Class Lounge
Regal University Hotel

Saturday, March 22
Workshop 8:00 am - 5:00 pm
Old Chemistry Building, Duke University

8:00 - 8:30 am Registration - Coffee

8:30 - 8:40 am Opening remarks

Oral Presentations

8:40 - 9:05 am **Timothy W. Clark**: A brief history of geologic research in the Deep River Triassic basin, North Carolina

9:05 - 9:30 am **Paul E. Olsen**: Advances in correlation of the southern Newark Supergroup basin sections

9:30 - 9:55 am **Kathleen M. Farrell**, Richard M. Wooten, and Timothy W. Clark: Facies architecture of Triassic-age, flood basin /distal fan deposits at well-exposed localities in the Deep River basin, North Carolina

9:55 - 10:20 am **Richard M. Wooten**, Timothy W. Clark, Timothy L. Davis, and Peter E. Malin: Transtensional faulting, and related folding and fracturing in the Deep River Triassic basin, North Carolina

10:20 - 10:50 am coffee break

10:50 - 11:15 am **George L. Bain**: Triassic water budget

11:15 - 11:40 am **Robert H. Carpenter** and S. W. Felix Fong: Investigation of radionuclides in groundwater, Deep River basin, using iron-manganese oxide boulder coatings

11:40 - 12:05 am **Paul E. Olsen:** The oldest Late Triassic footprint assemblage from North America (Pekin Formation, Deep River basin, North Carolina, USA)

12:05 - 12:30 pm **Matthew J. Heller**, Edward F. Stoddard, William S. Grimes, and David E. Blake: Post-paleozoic brittle deformation in basin-bounding crystalline rocks east of the Jonesboro fault

12:30 - 1:30 pm **Lunch**

Poster Session **1:30 - 3:00 pm**

John W. S. Davis Jr.: Seismic observations of the geometry, structure and sedimentologic evolution of the Upper Triassic Deep River basin, North Carolina

Paul C. Ragland, Stephen A. Kish, and William C. Parker: Compositional patterns for lower Mesozoic diabase dikes in the Deep River basin, North Carolina

Jeffrey C. Reid and Charles W. Hoffman: Organic geochemistry and source rock potential, Deep River and Dan River Triassic basins, North Carolina

Angela Sanderson: Construction problems associated with soil types common to the Durham Triassic basin

3:00 - 5:00 pm Planning discussion / Future research opportunities

5:00 - 7:00 pm Break

7:00 - 9:00 pm Banquet
Regal Class Lounge
Regal University Hotel

Sunday, March 23, 1997

8:00 am Field trip departs Regal University Hotel

12:00 noon Lunch

4:00 pm (approx.) Field trip returns to Regal University Hotel

ABSTRACTS

TRIASSIC WATER BUDGET

BAIN, George L., BC GeoLogic, LLC, 3966 Bachelor Creek Rd., Asheboro, NC 27203

The North Carolina Triassic terrane has, by far, the lowest baseflow discharge to streams of any other rock type in the state. Most precipitation falling on Triassic rock either runs off or is evaporated. Most recharge (±3 in/yr) reaching the water table is transpired by plants. Consequently, groundwater flushing of rock aquifers may be extremely poor, and because neither evaporation nor transpiration removes mineral matter, salts may tend to be concentrated in the shallow groundwater, in the soil, and possibly in vegetative matter. High chlorides in the shallow Triassic rocks may not be an indicator of slow groundwater movement in fractures, per se, but to a very slow flushing of the total volume of stored groundwater.

INVESTIGATION OF RADIONUCLIDES IN GROUNDWATER, DEEP RIVER BASIN, USING IRON-MANGANESE OXIDE BOULDER COATINGS

CARPENTER, Robert H., North Carolina Geological Survey, P.O. Box 27687, Raleigh, NC 27611-7687 (ncs1274@interpath.com)
FONG, S. W. Felix, Division of Radiation Protection, 3825 Barrett Dr., Raleigh, NC 27609-7221

Based on results of the NURE (National Uranium Resources Evaluation) Program of the late 1970's, groundwater analyzed from domestic wells in the Deep River Basin (DRB) locally contain very high concentrations of dissolved uranium. Of 58 statewide samples which exceed the 99th percentile (>3.6 ppb uranium), 22 samples are from wells located in the DRB. Uraniferous groundwater in the DRB typically contains high concentrations of dissolved solids which include sodium, chloride, potassium, magnesium, sulfate, and other ions. If the DRB is considered to be a water-rock system that approaches equilibrium, high concentrations of radon in groundwater (as well as soil gas and other media) can be expected in portions of the basin. Identifying areas in which groundwater is enriched in radon would be an important step in mitigating health effects of radon exposure in households utilizing groundwater.

In an experimental project, boulder coatings from streams were utilized as a medium for evaluating the radon-potential of groundwater. The coatings consist of a black precipitate of Fe-Mn oxide, as well as other elements, which are derived from shallow groundwater percolating into stream beds. Coated boulders were collected at 77 sites throughout the basin and analyzed for Fe, Mn, U, and Ra-226, as well as a suite of trace metals. Since Radium-226 is the immediate parent of Radon-222 in the U-238 decay series, high concentrations in boulder coatings should be indicative of areas where groundwater is enriched in radon. In the present study, Ra-226 is normalized as Ra-226/Mn; uranium is normalized as U/Fe.

Areas with highest levels of U/Fe in boulder coatings correspond with those areas where, according to the NURE survey, groundwater is enriched in uranium. Consequently, analyses of boulder coatings can be used to identify areas of uraniferous groundwater.

High levels of Ra-226/Mn occur in the Wadesboro, Sanford, and Durham sub-basins. These preliminary findings suggest a possible spatial association of high Ra-226 in boulder coatings with major faults (Jonesboro, Bonsal-Morrisville, and Deep River faults) along the eastern margin and within the basin. If follow-up surveys of radon in groundwater confirm these results, boulder coating surveys would provide a means of locating and mapping faults as well as the radon-potential of groundwater and associated health risks.

A BRIEF HISTORY OF GEOLOGIC RESEARCH IN THE DEEP RIVER BASIN, NORTH CAROLINA.

CLARK, Timothy W., North Carolina Geological Survey, P.O. Box 27687, Raleigh, NC 27611-7687 (jeff_reid@mail.ehnr.state.nc.us) *and* Division of Earth Sciences, Duke University, P.O. Box 90227, Durham, NC 27708-0227 (tclark@geo.duke.edu)

The Deep River Triassic basin of North Carolina has been the subject of geologic research for almost 180 years. Since the first published report in 1820 by Dennison Olmstead, the majority of research has been economically focused, predominately on coal, and to a lesser extent, brownstone (dimension stone). The geologic literature is divided into two main subjects: 1) coal and brownstone investigations (1820-1955) and 2) modern geologic investigations (1955-present).

The coal and brownstone investigations can be subdivided into four distinct time periods, each affected greatly by major socio-economic events such as depression, war and post-war growth. The four subdivisions described are the Olmstead Geological Survey, the Emmons Geological Survey, the Industrial Era coal and brownstone mining, and the World War II era coal mining.

The modern geologic investigations are subdivided by geologic subject into six categories: 1) stratigraphy/paleontology/palynology; 2) structure; 3) geophysics; 4) petroleum exploration; 5) igneous intrusions; and 6) geologic mapping. Significant advancement in our understanding of the Deep River basin has been made in each of the first five subject areas over the last 40 years. Detailed geologic mapping has, however, lagged far behind. Published 7.5-minute detailed geologic maps exist for only about 5 percent of the basin. Although time-consuming, detailed geologic mapping provides the basic framework to support almost all other types of investigations. Future geologic mapping that combines all of the above geologic elements is needed to advance our understanding of the Deep River basin.

SEISMIC OBSERVATIONS OF THE GEOMETRY, STRUCTURE AND SEDIMENTOLOGIC EVOLUTION OF THE UPPER TRIASSIC DEEP RIVER BASIN, NORTH CAROLINA

DAVIS, John W. S., Jr., Environmental Investigations, Inc., 720 Moorefield Park Dr., Suite 140, Richmond, VA 23236 (richie@erols.com)

A grid of multichannel seismic reflection data collected in the northern half of the Sanford and southern portion of the Durham sub-basins of the Deep River basin of North Carolina has been analyzed to obtain the basin geometry and structure development. The basin architecture is defined by a strong reflector that dips gently to the east to form the half graben asymmetric basin. Three wells located along one dip line have penetrated metamorphic basement at the level of this strong reflector. This basal reflecting surface, which correlates with metamorphic basement, is relatively undeformed except near the eastern border of the basin where sedimentary strata are thickest (9200 feet, 2800 m). Here, high angle normal faults have isolated several basement blocks in a stairstep pattern. Another reflecting surface, on the eastern border of the basin dips to the west at an average of 18 degrees and extends beneath the sedimentary basin before soling out into the subhorizontal reflectors deep in the metamorphic basement. The same surface extends updip to outcrop at or near the Jonesboro fault system. It is proposed that the eastern border of the basin is formed by a low angle detachment fault.

A zone of intrabasinal faults in the western half of the basin coincides with the Deep River fault of Reinemund (1955). Isopach thicknesses of the alluvial Pekin Formation are similar throughout the faulted zone. The overlying lacustrine Cumnock Formation is thicker on the down thrown block indicating post Pekin and syndepositional Cumnock fault activation. This faulting caused a basement graben block to be displaced some 2300 feet (700 m). The thickest accumulations of the Cumnock Formation overlie this structure implying impounding and a temporary shift of the basin depocenters to the west. Depocenters of the uppermost Sanford Formation indicate a return of the depocenters to the vicinity of the depocenters of the Pekin Formation.

FACIES ARCHITECTURE OF TRIASSIC-AGE, FLOOD BASIN/DISTAL FAN DEPOSITS AT WELL-EXPOSED LOCALITIES IN THE DEEP RIVER BASIN, NORTH CAROLINA

FARRELL, Kathleen M.
WOOTEN, Richard M.
CLARK, Timothy W.
all with:
North Carolina Geological Survey, P.O. Box 27687, Raleigh, NC 27611-7687
(jeff_reid@mail.ehnr.state.nc.us)

East-dipping, faulted, Triassic sedimentary rocks are exposed at a spillway and borrow pit about 6 km west of the eastern border fault (Jonesboro Fault) of the Deep River basin. Here, a relatively fine-grained, heterogeneous siliciclastic sequence of siltstones, mudstones, sandstones, and conglomerates is interpreted as flood basin and distal fan deposits.

Flood basin deposits include well-sorted, burrowed siltstones and very fine- to fine-grained silty sandstones that are interpreted as backswamp deposits. Sandier intervals may be distal levee and crevasse splay sands. Distinct, root-mottled, purple mudstones that locally include carbonate nodules are interpreted as paleosols. Gray mudstones with laminated intervals and plant debris are commonly associated with the paleosols. These are lake or pond deposits. Well-sorted, clast-supported sandstones with sharp bases and lens-shaped cross-sections are small-scale channel deposits. Thin (<0.4 m) tabular sheets of clast-supported sandstones are associated with the channel sand and may be proximal levee or splay deposits. Large-scale channel sandstones were not observed.

Distal fan deposits are interstratified with the flood basin facies described above and include several additional facies indicative of deposition from a fan source. Sharp-based amalgamated beds of clast- to matrix-supported, muddy, sandy conglomerate and conglomeratic sandstone are interpreted as sediment gravity flow deposits (possibly hyperconcentrated flows). Thick (m), very poorly-sorted, silty to muddy sandstones with coarse sand or conglomerate-sized grains as 'floaters' that are pervasively burrowed are interpreted as either: 1) single event, cohesive debris flows that were pervasively burrowed from the top downward; or 2) incremental burrowing of coarse-grained, normally graded rhythmites from multiple sheet wash events. The second explanation is probably correct. Mudstones with floating gravel-sized grains probably do represent cohesive debris flow deposits.

With the exception of the shoe-string channel sandstone at the spillway, the exposed units appear sheet-shaped in distribution. This suggests that facies units were deposited on a succession of relatively flat landscapes. Changes in dip along a profile through the south borrow pit may indicate that unconformities or bedding plane faults separate supra-adjacent packages of sediment. Through-going faults, depending on the amount of offset, potentially demarcate blocks of rock with unique stratigraphic signatures.

In this general area, both flood basin and fan facies are commonly arranged as a series of fining upward sequences with thin (<1 m) clast-supported sandstones or conglomerates marking the bases of sequences. This is not always the case. Coarsening-upward sequences of facies indicate basinward progradation of clastic wedges as possibly lacustrine deltas. Some sequences lack coarse-grained units but include stacked fine-grained units separated by distinct bedding planes. These bedding planes may correlate laterally with unconformities or represent periods of non-deposition. In the absence of coarse-grained deposits, extensively root-mottled mudstones, interpreted as paleosols, are probably important markers that separate periods of renewed basin flooding.

Future work in the basin should focus on understanding the complex relationships between basin evolution, tectonism, unconformities, and sequence emplacement.

POST-PALEOZOIC BRITTLE DEFORMATION IN BASIN-BOUNDING CRYSTALLINE ROCKS EAST OF THE JONESBORO FAULT

HELLER, Matthew J., Department of MEAS, North Carolina State University 27695-8208 (MHeller@mro.ehnr.state.nc.us)
STODDARD, Edward F., Department of MEAS, North Carolina State University 27695-8208 (skip_stoddard@ncsu.edu)
GRIMES, William S., Department of MEAS, North Carolina State University 27695-8208 (wsgrimes@eos.ncsu.edu)
BLAKE, David E., Department of Earth Sciences, University of North Carolina-Wilmington, Wilmington, NC 28403-3297 (blaked@uncwil.edu)

Recent 1:24,000-scale mapping of Paleozoic to Neoproterozoic metamorphic and igneous rocks exposed to the west of the Rolesville Batholith and east of the Jonesboro fault provides new information about overprinting brittle deformation adjacent to the Durham sub-basin. Thirteen map-scale brittle faults have been identified in southern Wake County. Two additional map-scale faults have been identified approximately 30 km to the north, in southern Vance County. The Wake County faults have consistent trends of either N80E to N80W or N20E to N30E; Vance County faults trend N-S and N30E to N45E. Apparent lateral offsets of up to 200 m have been identified across fault zones in Wake County, but slickenline data suggest that movement along faults may be largely dip-slip in nature. Mapping indicates that outcrop-scale extensional fractures and joints, common features in crystalline rocks in this region, become more closely spaced adjacent to map-scale brittle faults; the orientations of these structures are similar to those of adjacent faults, suggesting that all of these structures developed in response to the same regional stresses. Map-scale faults are typically exposed as discontinuous siliceous microbreccia and breccia zones that tend to form linear topographic highs. Clasts within breccia zones commonly do not appear to correlate with wall rocks present at the current level of exposure; the apparent lower grade nature of some of these clasts suggests that they may have been derived from structurally higher material.

ADVANCES IN CORRELATION OF THE SOUTHERN NEWARK SUPERGROUP BASIN SECTIONS

OLSEN, Paul E., Lamont-Doherty Earth Observatory of Columbia University (LDEO), Rt. 9 W, Palisades, NY 10964 (polsen@ldeo.columbia.edu)
KENT, Dennis V., Lamont-Doherty Earth Observatory of Columbia University (LDEO), Rt. 9 W, Palisades, NY 10964 (dvk@ldeo.columbia.edu)
LETOURNEAU, Peter, Lamont-Doherty Earth Observatory of Columbia University (LDEO), Rt. 9 W, Palisades, NY 10964 (letour@ldeo.columbia.edu)
HUBER, Phillip, Department of Education, University of Bridgeport, Bridgeport, CT 06601

Recent years have seen a great improvement in understanding the correlation and ages of strata in the southern basins of the Newark Supergroup, comprising the Taylorsville, Richmond, Culpeper, Dan River-Danville, and Deep River basins. Five critical areas which have been instrumental in this major improvement are: 1) the coring of virtually the complete Newark basin section, which for the first time provides a Milankovitch cycle-calibrated, magnetostratigraphic time scale for the Late Triassic and earliest Jurassic (Olsen et al., 1996; Kent et al., 1995; Olsen and Kent, 1996); 2) the development of polarity and cyclo-stratigraphies for other basins, particularly the Dan River, Culpeper, and Taylorsville basins; 3) the discovery of much richer vertebrate assemblages coupled with improved systematic and biostratigraphic techniques; 4) the study of high quality and now available regional seismic sections tied to deep drill holes; and 5) the recognition that there are unconformities that segment the sections into regionally correlative tectonostratigraphic sequences (Olsen, 1997).

Here we will focus on four highlights of the new correlations. First, detailed magnetostratigraphic correlation of the Dan River-Danville basin (Kent and Olsen, 1997) clearly demonstrates that there are two major gray and black shale and mudstone sequences in the Dan River basin, not one that was fault repeated as previously thought (Olsen et al., 1989; Olsen et al., 1991; Weems and Martin, 1988). The upper one of these is correlative with the Lockatong Formation of the Newark basin, while the lower, coal-bearing one correlates with the upper Stockton Formation (Raven Rock Member). The existence of two such units agrees with Olsen et al. (1978) and Robbins and Traverse (1980). Fine scale correlation between the upper lacustrine sequence and the Lockatong Formation demonstrates that the Dan River basin lakes were strongly effected by a 10 ky double precession cycle, rather than the more typical 20 ky cycle seen in the Newark basin. The 10 ky cyclicity turns out to be generally more typical of the older parts of the southern basin sections. These new correlations show that the stratigraphy of the Dan River-Danville basin is in need of considerable nomenclatural revision.

Second, cores collected by the USGS in the Culpeper basin have allowed detailed correlation of the older part of the Bull Run Formation (Balls Bluff Siltstone) with the Passaic Formation using polarity and cyclostratigraphy. These correlations show that the lower Bull Run Formation is the same age as the middle Passaic Formation. This is strong substantiation of the palynostratigraphic correlations of Cornet (1977) and Litwin and Skog (1991) and the facies-based correlation of Smoot (1991). Comparison of the details of the sedimentary fill of the correlative portions of the two basins show an exact cyclostratigraphic match over a distance of more than 500 km.

Third, over 6000 m of core from the Taylorsville basin show basically the same lithostratigraphy as Cornet and Olsen (1990) outlined for the Richmond basin (LeTourneau, et al., 1996). A regional unconformity separates an older lacustrine and fluvio-deltaic sequence from a younger lacustrine and fluvio-deltaic sequence. In the Taylorsville basin the older sequence is the Stagg Creek and Falling Creek members of the Doswell Formation of Weems (1980). These correlate to the "barren beds", "productive coal measures" and Vinita Formation of the Richmond basin. Above the unconformity in the Taylorsville basin there is a thick unnamed lacustrine sequence that correlates with the Turkey Branch Formation (Cornet and Olsen, 1990) of the

Richmond basin. In both basins, the lower lacustrine sequence is characterized by sedimentary cycles exhibiting the 10 ky cyclicity, but with few or no signs of exposure. In contrast, the upper lacustrine sequence has cycles with abundant indications of desiccation and emergence, although the 10 ky cyclicity is still evident. Surprisingly, the upper lacustrine sequence in both the Richmond and Taylorsville basins correlates to the lower and part of the upper lacustrine sequences in the Dan River basin, all of which are late Tuvalian of the Late Carnian in age. The older lacustrine sequence is the oldest recognized in the Newark Supergroup and has no counterpart in the Dan River basin.

Fourth, a reconsideration of the vertebrates from the Deep River basin has revealed some surprises. First the middle Pekin reptile assemblage listed by Baird and Patterson (1968) indicates an early Tuvalian (early Late Carnian) age and thus correlates with the Vinita Formation of the Richmond basin and Falling Creek Member of the Taylorsville basin (Huber et al., 1993). The Cumnock Formation, on the other hand, is of late Tuvalian (late Late Carnian) age and correlates with the Turkey Branch Formation of the Richmond basin and upper lacustrine sequence of the Taylorsville basin. Inasmuch as the older and younger sequences of the Taylorsville basin are separated by an unconformity, the question arises, "are the Pekin and Cumnock Formations separated by an unconformity as well?" This is testable and is being investigated. The tetrapod assemblage from Lithofacies Association II of the Durham basin is Early to Middle Norian in age. Lithofacies Association I of the Durham basin appears identical to the Pekin Formation and appears connected in map view. There is apparently, however, no equivalent of the Cumnock Formation in most of the Durham basin. Is there is an unconformity between Lithofacies Association I and II? If so, it would occupy all of the Late Carnian.

The larger implication of these interpretations is that rift basin subsidence and sedimentation was dominated by regional pulses of extension of variable magnitude that generated fluvial-lacustrine-fluvial sequences, separated by quiescent periods during which regional unconformities were occasionally produced by erosion of hanging wall strata and subsequent onlap of strata of the next tectonostratigraphic sequence. Quantification of these extensional pulses should allow new insights into the mechanism of rifting in general.

REFERENCES

Baird, D. and Patterson, O. F., 3d, 1968, Dicynodont-archosaur fauna in the Pekin Formation (Upper Triassic) of North Carolina [abs.]: Geol. Soc. America Spec. Paper 115, p. 11.

Cornet, B., and Olsen, P. E., 1990, Early to Middle Carnian (Triassic) flora and Fauna of the Richmond and Taylorsville basins, Virginia and Maryland, U.S.A.: Virginia Museum of Natural History, Guidebook, no. 1, 83 p.

Huber, P., Lucas, S. G., and Hunt, A. P., Revised age and correlation of the Upper Triassic Chatham Group (Deep River Basin, Newark Supergroup), North Carolina: Southeastern Geology, v.33, n.4, p.171-193.

Kent, D. V. and Olsen, P. E., 1997, Magnetostratigraphy and paleopoles from the Late Triassic Dan River-Danville basin: interbasin correlation of continental sediments and a test of the tectonic coherence of Newark rift basins in eastern North America: Geological Society of America Bulletin, in press.

Kent, D. V., Olsen, P. E., and Witte, W. K., 1995, Late Triassic-Early Jurassic geomagnetic polarity and paleolatitudes from drill cores in the Newark rift basin (Eastern North America): Journal of Geophysical Research, v. 100 (B8), p. 14,965-14,998.

LeTourneau, P. M., Olsen, P. E., and Kent, D. V., 1996, The stratigraphy and structure of the buried Late Triassic Taylorsville basin, Virginia and Maryland: results of recent subsurface investigations *in* LeTourneau, P. M. and Olsen, P. E. (eds.), Aspects of Triassic-Jurassic Rift Basin Geoscience: Abstracts: Connecticut Geological and Natural History Survey Miscellaneous Reports 1, 57 pp.

Litwin, R. J. and Skog, J. E., 1991, Morphology and palynostratigraphy of the genus *Camerosporites* Leschik 1956: Palynology, v.15, p.5-28.

Olsen, P. E., 1997, Stratigraphic record of the early Mesozoic breakup of Pangea in the Laurasia-Gondwana rift system: Annual Reviews of Earth and Planetary Science v. 25, p. 337-401.

Olsen, P. E., Kent, D V., Cornet, B., Witte, W. K., and Schlische, R. W., 1996, High-resolution stratigraphy of the Newark rift basin (Early Mesozoic, Eastern North America): Geological Society of America, v. 108, 40-77.

Olsen, P. E. and Kent, D. V., 1996, Milankovitch climate forcing in the tropics of Pangea during the Late Triassic: Palaeogeography, Palaeoclimatology, and Palaeoecology, v. 122, p. 1-26.

Olsen, P. E., Remington, C. L., Cornet, B., and Thomson, K. S., 1978, Cyclic change in Late Triassic lacustrine communities: Science, v. 201, p. 729-733.

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, 174 p.

Olsen, P. E., Froelich, A .J., Daniels, D. L., Smoot, J. P., and Gore, P. J. W., 1991, Rift basins of early Mesozoic age, *in* Horton, W., ed., Geology of the Carolinas: University of Tennessee Press, Knoxville, p. 142-170.

Robbins, E. I. and Traverse, A., 1980, Degraded palynomorphs from the Dan River (North Carolina) - Danville (Virginia) basin: Carolina Geological Society Field Trip Guidebook, p. BX1-11.

Smoot, J. P., 1991, Sedimentary facies and depositional environments of early Mesozoic Newark Supergroup basins, eastern North America: Palaeogeography, Palaeoclimatology, Palaeoecology, v.84, n.1-4, p.369-423.

Weems, R. E., 1980, Geology of the Taylorsville Basin, Hanover County, Virginia: Virginia Division of Mineral Resources Publication, n.27, p.23-38.

Weems, R. E. and Martin, J. H., 1988, Structural vs. stratigraphic parsimony; an example from the Triassic Danville Basin of Va.-N.C. Abstracts of papers presented at Sixty-sixth annual meeting, Virginia Academy of Science, Virginia Journal of Science, v.39, n.2, p.155.

THE OLDEST LATE TRIASSIC FOOTPRINT ASSEMBLAGE FROM NORTH AMERICA (PEKIN FORMATION, DEEP RIVER BASIN, NORTH CAROLINA, USA)

OLSEN, Paul E., Lamont-Doherty Earth Observatory of Columbia University (LDEO), Rt. 9 W, Palisades, NY 10964 (polsen@ldeo.columbia.edu)
HUBER, Phillip, Department of Education, University of Bridgeport, Bridgeport, CT 06601

An assemblage of reptile footprints from the abandoned Pomona Pipe quarry in the Middle Pekin Formation of the Sanford sub-basin of the Deep River basin is the oldest track faunule recognized to date in strata of Late Triassic in Eastern North America. The most common taxon is a possibly new pentadactyl ichnite similar to but distinct from *Brachychirotherium*. It differs from the latter in lacking manus impressions, having a strong tendency to be functionally tridactyl, and having an extremely reduced digit IV impression. The size range of this form is large ranging from about 10 cm to over 30 cm. The second most common taxon is a small (<15 cm) bipedal tridactyl form with widely splayed digits. Although distinct from all of the named Newark dinosaurian taxa, a new name for this ichnotaxon is not yet warranted because none of the specimens have distinct pads. A single trackway represents *Apatopus*, an ichnotaxon shared with younger Newark assemblages. This trackway consists of 3 successive manus-pes impressions and indicates a sprawling gait as predicted by Baird from less complete material of Norian age from the Newark basin (Baird, 1957). Other ichnites recovered are poorly preserved, but do not fit easily into named forms.

The footprint assemblages is directly overlain (ca 5-10 m) by strata that have produced an important, although fragmentary tetrapod assemblage (Baird and Patterson, 1968). Most distinctive is the rotund dicynodont synapsid *Placerias* cf. *hesteurnis* and aetosaur scutes assignable to *Longosuchus meadi*. Based on a correlation web with the Chinle group and the European section, these indicate an early Tuvalian (early Late Carnian) age (Huber et al., 1993). Also present are indeterminate phytosaur material and apparent rauisuchian teeth.

A palynoflorule from the basal Pekin Formation of the Sanford basin (Cornet, 1977) and the well known Boron Clay pit (adjacent geographically and stratigraphically to the Pomona locality) that has produced an extensive floral assemblage (Hope and Patterson, 1969; Delevoryas and Hope, 1975; Olsen et al., 1989; Axsmith et al., 1995) suggest correlation of the lower to middle Pekin Formation with Tectonostratigraphic sequence II (TS II, Olsen, 1997) of the Richmond and Taylorsville basins. The vertebrate assemblage also suggests a correlation with TS II of the Fundy basin of the Canadian Maritimes and the Argana Basin of Morocco. The Argana basin has also produced an as yet unstudied assemblage of footprints, which at first glance appears very similar to that from the Pomona pit.

The middle Pekin footprint assemblage is thus distinctly different and older than all other Newark Supergroup footprint assemblages, which are late Tuvalian (late Late Carnian) or younger and are in TS III and IV. The assemblage is important because it represents a transitional stage between the well known Middle Triassic assemblages (Courel et al., 1968; Demathieu and Gand, 1972) and the more typically Newarkian Late Triassic assemblages (Baird, 1957; Olsen and Baird, 1986). The apparently dinosaurian ichnites from this horizon are therefore arguably among the oldest in the world.

REFERENCES

Axsmith, Brian J., Taylor, T. N., Delevoryas, T., and Hope, R. C., 1995, A new species of *Eoginkgoites* from the Upper Triassic of North Carolina, USA: Review of Palaeobotany and Palynology, v.85, n.3-4, p.189-198.

Baird, D., 1957, Triassic reptile footprint faunules from Milford, New Jersey: Harvard Coll. Mus. Comp. Zoology Bull. v. 117, no. 5, p. 449-520.

Baird, D. and Patterson, O. F., 3d, 1968, Dicynodont-archosaur fauna in the Pekin Formation (Upper Triassic) of North Carolina [abs.]: Geol. Soc. America Spec. Paper 115, p. 11.

Cornet B., 1977, The palynostratigraphy and age of the Newark Supergroup: Ph.D. thesis, The Pennsylvania State Univ., 504 p.

Courel, L., Demathieu, G., Buffard, R., 1968, Empreintes de pas de vertebres et stratigraphie du trias: Soc. Geol. Fr., Bull., Ser. 7, Vol. 10 (1968), No. 3, p. 275-281.

Delevoryas, T. and Hope, R. C., 1975, *Voltzia andrewsii*, n. sp., an upper Triassic seed cone from North Carolina: U.S.A. Rev. Palaeobot. Palynol., v.20, n.1-2, p.67-74.

Demathieu, G. and Gand, G., 1972, Les Pistes dinosauroides du Trias moyen du plateau d'Antully et leur signification paleozoologique: Bulletin Trimestriel de la Societe d'Histoire Naturelle et des Amis du Museum d'Autun, v.62, p.4-18.

Hope, R. C. and Patterson, O. F., 3d, 1969, Triassic flora from the Deep River basin, North Carolina: North Carolina Div. Mineral Resources Spec. Pub. 2, 22 p.

Huber, P., Lucas, S. G., and Hunt, A. P., Revised age and correlation of the Upper Triassic Chatham Group (Deep River Basin, Newark Supergroup), North Carolina: Southeastern Geology, v.33, n.4, p.171-193.

Olsen, P. E. and Baird, D., 1986, The ichnogenus *Atreipus* and its significance for Triassic Biostratigraphy: *in* K. Padian (ed.), The Beginning of the Age of Dinosaurs, Faunal Change Across the Triassic-Jurassic Boundary: Cambridge University Press, New York, p. 61-87.

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, 174 p.

COMPOSITIONAL PATTERNS FOR LOWER MESOZOIC DIABASE DIKES IN THE DEEP RIVER BASIN, NORTH CAROLINA

RAGLAND, Paul C.
KISH, Stephen A.
PARKER, William C.
all with: Department of Geology, Florida State University, Tallahassee, FL 32306

Sixty-six screened analyses were chosen from a large number of chemical analyses for Lower Mesozoic diabase dikes in the Deep River basin, North Carolina. Samples that were altered, contained abundant cumulus phases, or had inferior analyses were not chosen, and only one or two representative samples were taken from transverse profiles across any dike. All samples are from the swarm of NW-striking dikes that extend from northern Virginia to Georgia within the Lower Mesozoic ENA mafic petrographic province; all the samples are olivine normative and modal. Two compositional groups exist: a main group (58 samples) and a high-Ti (also high Fe/Mg, Zr, Y, and Zn) group. At least part of the reason the smaller group is compositionally different is because of higher concentrations of Fe-Ti oxides. Trends on variation diagrams and least-squares mixing calculations for the main group indicate that the most differentiated sample can be derived from the least differentiated by low-pressure fractionation (35 percent) of about 2/3 olivine and 1/3 plagioclase. Textures range from fine-grained iso- and intergranular to medium-grained subophitic; the rocks are olivine-plagioclase phyric or aphyric. Little direct age information is known about these olivine-bearing diabases; indirect age evidence suggests that their age is about 200 Ma.

Chondrite-normalized REE and spider diagrams are generally flat, with slight LFSE enrichment; values average about 10 times chondritic abundance and no Eu anomalies exist. Patterns most closely compare with those for E-MORBs, except for positive Ba and negative Nb anomalies. Moreover, despite the fact that these dikes are rift-related continental mafic rocks, their compositions plot on the MORB field on several tectonic discrimination diagrams. However, whereas MORB compositions are in the $+\varepsilon^{Nd}$ - $-\varepsilon^{Sr}$ field on a Sr-Nd isotopic correlation diagram, those from the diabases are in the $-\varepsilon^{Nd}$ - $-\varepsilon^{Sr}$ field. On a $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ diagram, the diabase trend parallels the MORB trend, but at a higher $^{207}Pb/^{204}Pb$, more typical of subduction-related arc tholeiites or calcalkaline basalts. Thus despite some chemical similarities to MORBs, the isotopic evidence indicates that the diabases are from a different mantle source, which might include old lithospheric components, than MORB sources. The flat patterns and lack of Eu anomalies suggest that the most likely source for the normal group is an enriched spinel lherzolite. The origin of the high-Ti group is more problematic. Partial melting took place during the rifting stage of the Pangaean breakup, at moderately shallow levels in the upper asthenosphere, and magmas were emplaced through attenuated lithosphere.

Two multivariate numerical techniques, principal components analysis (PCA) and discriminant function analysis (DFA), were used to examine the data set. PCA indicates no compositional differences between dikes in three geographic areas of the basin, nor does it reveal any relationship between dike composition and strike. It does, however, confirm the two compositional groups mentioned above, and loadings are petrographically reasonable. Although DFA indicates no difference between strike and composition, it does suggest some very subtle distinctions between the central and northeast groups; the southwest group spans the entire compositional range. DF1, which accounts for about 91 percent of the discriminating power, is most strongly controlled by MgO (the next most important controls on DF1 are FeO* and SiO_2), thus these subtle compositional differences are probably a function of small differences in degree of crystal fractionation.

ORGANIC GEOCHEMISTRY AND HYDROCARBON SOURCE ROCK POTENTIAL, DEEP RIVER AND DAN RIVER TRIASSIC BASINS, NORTH CAROLINA

REID, Jeffrey C., North Carolina Geological Survey, P.O. Box 27687, Raleigh, NC 27611-7687, (jeff_reid@mail.ehnr.state.nc.us)
HOFFMAN, Charles W., North Carolina Geological Survey, 4100 Reedy Creek Road, Raleigh, NC 27607 (ncs0527@interpath.com)

This report presents and interprets previously unpublished organic geochemistry and hydrocarbon source rock potential data for Triassic sedimentary rocks of the Deep River and Dan River basins, North Carolina. The organic geochemical data is from the Sanford basin (Cumnock Formation) of the Deep River basin and the Dan River basin (Cow Branch Formation). Available organic geochemical data is biased because industry collected samples for analysis from available drill holes containing igneous intrusive rocks (diabase of Jurassic age) which metamorphosed the coals and black shales. The intrusive rocks heated the surrounding sediments and organic matter and masked the unaltered source rock potential.

The organic data show potential source rocks exist in the Sanford and Dan River basins and that the sediments are gas prone rather than oil prone. Total organic carbon (TOC) data are all greater than the conservative 1.4% TOC threshold for hydrocarbon expulsion. Both the Cow Branch Formation (Dan River basin) and the Cumnock Formation (Sanford basin) are potential source rocks for some oil, but more likely natural gas. The organic material was derived primarily from terrestrial Type III woody (coaly) material. Thermal alteration index (TAI) and vitrinite reflectance data (Ro%) indicate levels of thermal maturity for generation.

The genetic potential of Triassic basin sediments is moderate to high. Favorable source rock sections have at least moderate, and generally good source rock potential. Some Cumnock Formation data indicate considerably higher source rock potential with S1 + S2 data in the mid-20 mg HC/g sample range. Some oil and/or natural gas was generated. This implies that the genetic potential for these rocks was somewhat higher originally. However, porosity and permeability are low.

Diabase dikes, sills and sheets of Jurassic age generated overmature vitrinite reflectance (Ro%) profiles and metamorphosed the coals to semianthracite, anthracite, and coke. The maximum burial depth is unknown, and may have contributed to elevated maturation profiles.

Possible exploration plays include: (1) a fractured reservoir because of the enclosing sediments' low porosity and permeability, and (2) fault-controlled structural plays. Gravity and magnetic surveys to locate intrusives may identify a local thermal source which led to gas generation. Alternatively, awareness of the intrusives' distribution may direct exploration away from them to areas with thermal maturation below the limits of hydrocarbon destruction. The intrusives and their contact metamorphic aureoles may provide seals for gas concentration. Fracture zones in the thermal aureoles surrounding intrusives may serve as conduits to concentrate gas. Such intervals and the generally fractured nature of the Triassic sedimentary rocks might be suitable for testing by horizontal drilling. Basin faulting and cross-faulting may provide structural traps for small natural gas accumulations. Areas prospective for natural gas also contain large surficial clay resources (principally for brick). The gas could be used as fuel for local industries which produce clay products.

CONSTRUCTION PROBLEMS ASSOCIATED WITH SOIL TYPES COMMON TO THE DURHAM TRIASSIC BASIN

SANDERSON, Angela, North Carolina Department of Transportation, Geotechnical Unit, P.O. Box 25201, Raleigh, NC 27611

Heavy rainfall occurring during March 1994 contributed to a sliding block failure located at the interchange of NC 147 (Durham Freeway) and Hillandale Road and Fulton Street. NC 147 was partially closed after the failure during a focused subsurface investigation and subsequent rebuilding and repairing. The failure plane was identified at a contact with a residual clay and a hard residual silt with a dip/dip direction of 9°/234°. These types of failures are not uncommon in the Durham Triassic basin due to the soil types encountered. Triassic soils, especially the residual clay, when utilized for construction, can have detrimental effects as evidenced by the sliding block failure at this location.

TRANSTENSIONAL FAULTING, AND RELATED FOLDING AND FRACTURING IN THE DEEP RIVER TRIASSIC BASIN, NORTH CAROLINA

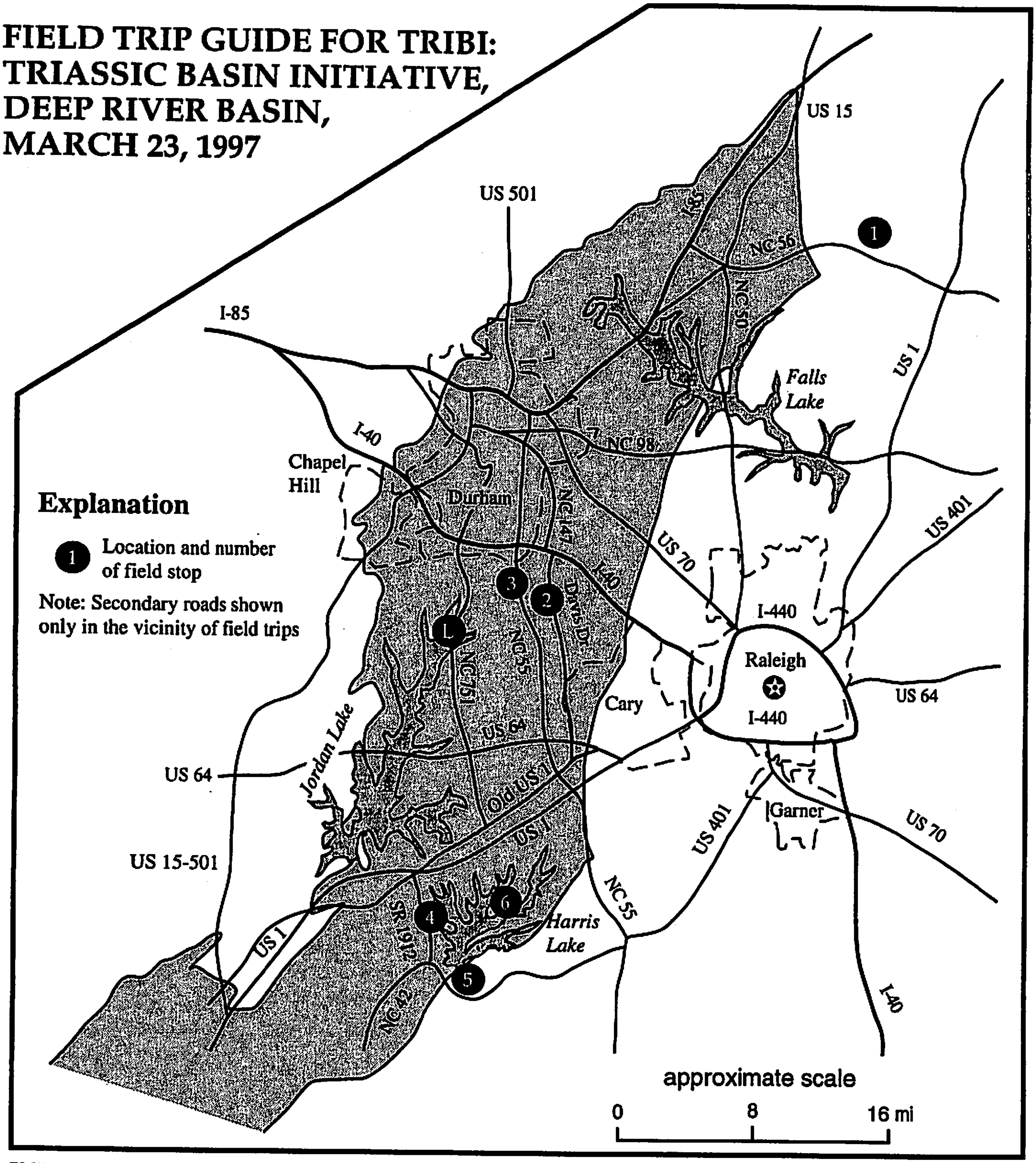
WOOTEN, Richard M., North Carolina Geological Survey, P.O. Box 27687, Raleigh, NC 27611-7687 (jeff_reid@mail.ehnr.state.nc.us)
CLARK, Timothy W., North Carolina Geological Survey, P.O. Box 27687, Raleigh, NC 27611-7687 (jeff_reid@mail.ehnr.state.nc.us)
DAVIS, Timothy L., Exxon Production Research Company, P.O. Box 2189, Houston TX 77252-2189
MALIN, Peter E., Division of Earth Sciences, Duke University, P.O. Box 90227, Durham, NC 27708-0227 (pem@vaino.geo.duke.edu)

Geologic mapping (1:12 to 1:3,750 scale), structural analyses and seismic reflection profiling has revealed transtensional faulting, and related folding and fracturing in the Cokesbury 7.5-minute quadrangle. The rocks studied are well-exposed in excavations made in the late-1970's for material to construct the auxiliary dam for the Shearon Harris nuclear power plant. The study area, informally referred to as the north and south borrow pits, exposes a heterogeneous siliciclastic sequence of rift basin deposits including conglomerate, sandstone, siltstone, and mudstone characteristic of the Deep River Triassic basin.

Geologic mapping and seismic reflection profiling reveal stratigraphic marker units, map- and outcrop-scale folding, and four previously unreported faults. Stratigraphic and seismic marker units can be traced along strike for several hundred feet. A major transtensional fault, informally referred to as the south borrow pit fault (SBPF), strikes generally N. 72° W. and dips 30° to 70° southwest, and can be traced for a minimum of 1,400 ft (430 m) across the south borrow pit. The total displacements along the SBPF and the other faults cannot be determined from the available data; however, the magnitude of normal displacement along the SBPF appears greater than dextral strike-slip movement. Two additional faults, exposed in the south borrow pit, and a fourth fault, exposed near the north borrow pit strike oblique to the SBPF. Two dominant fracture sets occur in the study area: 1) a set striking generally parallel to the SBPF, and 2) a set striking generally north at a high angle to the SBPF.

Kinematic relations between the faults, folds, and fractures suggest two stages of displacement: stage 1 normal faulting, and stage 2 normal and dextral strike-slip faulting. The map pattern and seismic reflection structure are consistent with the development of fault-related folding along the SBPF during Stage 2 as follows: a map-scale, hanging wall anticline related to normal displacement; and an outcrop-scale, hanging wall syncline related to dextral strike-slip displacement.

FIELD TRIP GUIDE FOR TRIBI: TRIASSIC BASIN INITIATIVE, DEEP RIVER BASIN, MARCH 23, 1997



INTRODUCTION:

This one day field trip consists of 6 formal stops and 1 informal lunch stop. The objectives of this field trip are to show a variety of rock sequences throughout the Durham sub-basin and surrounding areas in order to increase our understanding of the evolution of the Deep River basin. All stop locations are shown on the regional index map above. Individual stop locations are shown on repoductions of 7.5-minute quadrangle maps with no change in scale. North is toward the top in all figures. The field trip leaders appreciate the cooperation of representatives of Triangle Brick Company, the Low-Level Radioactive Waste Management Authority, Carolina Power and Light Company, and all of the private landowners who graciously permitted us on their property.

STOP 1: QUARTZ BRECCIA, FALLS LAKE MELANGE

LEADERS: Skip Stoddard, Matt Heller, Will Grimes, Dave Blake, and Tyler Clark

In southeastern Granville County, the basin-bounding fault abruptly bends from N50°E to N15°W (Figure 1-2). Mapping in the crystalline rocks east and southeast of the basin shows that the N50°E-trending segment continues out of the basin and into the older rocks. It constitutes perhaps the most obvious map-scale brittle structure in pre-Mesozoic rocks in the eastern Piedmont. Looking northwest from Stop 1, the topographic expression of the northern terminus of the Durham sub-basin is evident. Prominent ridges of the Carolina slate belt are visible beyond.

This area was originally studied by Carpenter (1970), who mapped a "siliceous zone" along the ridge here at Stop 1 for a distance of approximately eight km. This zone extends northeastward to the Tar River, at the edge of his map area. (1:24,000-scale topo maps were not available for this region during Carpenter's mapping. His map area corresponds approximately to the southern three-fourths of the Wilton 7.5-minute quad plus the northern one-third of the Grissom 7.5-minute quad.) Carpenter also mapped a short siliceous zone along the N15°W basin-bounding fault just north of the abrupt fault bend.

More recent mapping to the northeast in the Kittrell quad (Grimes, in progress) shows that the brittle fault extends for at least two km to another northeast-trending ridge, locally referred to as "Little Egypt Mountain." Just beyond that point, the fault approaches the N10°E-trending Nutbush Creek fault, a ductile shear zone of Late Paleozoic ("Alleghanian") age (see Figure 1-2). Mapping is still in progress, but at present no obvious fault-related features have been observed east of the Nutbush Creek zone in the Kittrell quad. However, in south-central Wake County, similar faults do offset ductilely sheared crystalline rocks (Heller, 1996).

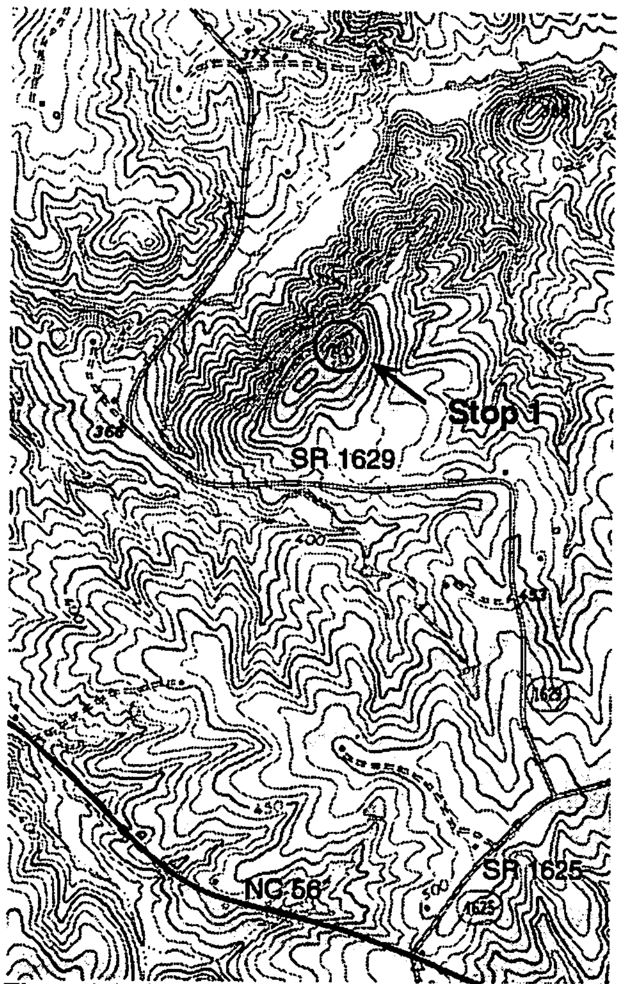


Figure 1-1. Location of Stop 1 on the Wilton quad.

Mesozoic brittle faults are more widespread in the Piedmont than the impression conveyed by published geologic maps. Garihan and his co-workers (e.g., Garihan and others, 1993) have documented an impressive family of faults in the western Piedmont of South Carolina and North Carolina. Recently, Heller (1996) has mapped a network of brittle faults in the Lake Wheeler quad south of Raleigh. The most extensive of these faults trends about N70°W and has been mapped eastward through the Lake Wheeler quad and into the Garner quad for approximately 12 km (Heller, 1996; Stoddard, 1995).

Reconnaissance mapping by McDaniel (1980) in the northern portion of the eastern Piedmont shows numerous occurrences of "quartz breccia" and other presumably brittle features, suggesting the presence of more faults in that area. In many places, these brittle faults

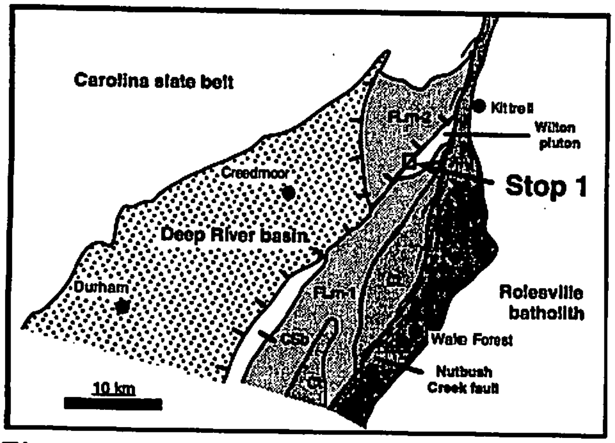


Figure 1-2. Geologic sketch map of the region around the northern terminus of the Deep River basin, showing the location of Stop 1, and the general relationships among crystalline rocks and map-scale structures. Modified from NCGS (1985) and Horton and others (1994). Abbreviations as follows: CSb = Carolina slate belt; Rgn = Raleigh gneiss; Ct = Crabtree terrane; FLm-1 = Falls Lake melange, high grade; FLm-2 = Falls Lake melange, low grade.

are expressed topographically by relatively sharp but discontinuous ridges. Silicified breccia and microbreccia are common along such faults, but usually the only evidence is rugged outcrops of milky quartz, or linear arrays of locally vuggy quartz float. Breccia in the Lake Wheeler area contains clasts of country rock interpreted to be derived from a level above the present erosion surface (Heller, 1996). Slickenlines and fibers have been observed in places; however, to our knowledge, no kinematic analysis of brittle faults has been attempted in the eastern Piedmont.

Fracture orientations at Stop 1 appear to fall into two main clusters, averaging about N23°E and N15°W, and a minor group running nearly east-west. The N15°W orientation is roughly parallel to the northern segment of the basin-bounding fault, and also similar to trends of diabase dikes in the area.

In the Wilton and Kittrell quads, the brittle fault observed at Stop 1 constitutes a geologic contact of significance in understanding the pre-Mesozoic history of the region (see Figure 1-2). Carpenter (1970) observed that the zone occurs along the western margin of the Wilton pluton, a Pennsylvanian ("Alleghanian") granite. He observed brecciated granite in at least one locality. In older models of the Piedmont, this fault would mark the boundary between the Raleigh belt and the Carolina Slate belt. More recent work along the western flank of the Raleigh metamorphic belt (Blake, 1986; Stoddard and Blake, 1994) shows the Falls Lake melange on both sides of the fault. We believe that the fault juxtaposes two different crustal levels of an accretionary complex, though detailed mapping and further study are still needed.

STOP 2: KIT CREEK FAULT ZONE

LEADER: Tyler Clark

NCGS summer intern James Gilmer found this excellent exposure of faulted Triassic sandstones during geologic reconnaissance mapping along a small tributary to Kit Creek (Figure 2-1). The two main rock units at this location include: 1) medium-grained, moderately sorted, lithic arkoses containing 10-15% lithic grains and pebbles which consist of schists, gneisses, slates, phyllites, and metavolcanocis (in order of abundance) with index minerals such as garnet, magnetite, myrmekitic feldspar, and epidote; and 2) reddish-brown, poorly to moderately-sorted, matrix supported, muddy sandstone. These rocks are provisionally correlated with the Trcs map unit of Lithofacies Association III, interpreted to be distal alluvial fan deposits in which sandstone units were deposited in broad shallow channels incised into muddy flats (Hoffman and Gallagher, 1989; Hoffman, 1994). The average strike and dip of these units is N30°W 10-15°NE.

The small creek has undercut the steep hillside, creating a 5 m high by 20 m wide outcrop. Blocks of rock have recently fallen from the hillside, exposing a left-lateral, oblique-slip (?) fault and numerous small-scale, strike-slip faults in both the footwall and hanging wall of the main fault.

The main fault has an orientation of N48°E, 76°W and is defined by a 5 cm wide foliated breccia. Foliated clayey components of

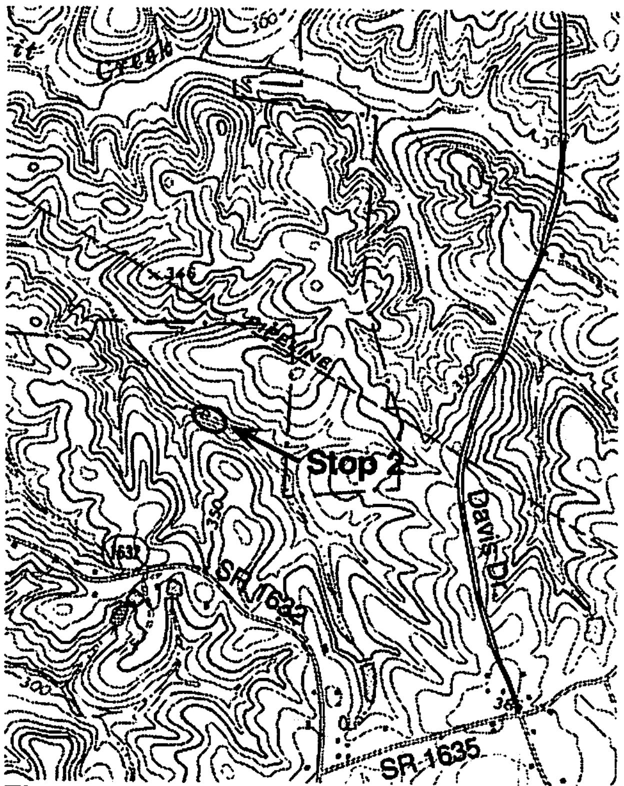


Figure 2-1. Location of Stop 2 on the Cary quad.

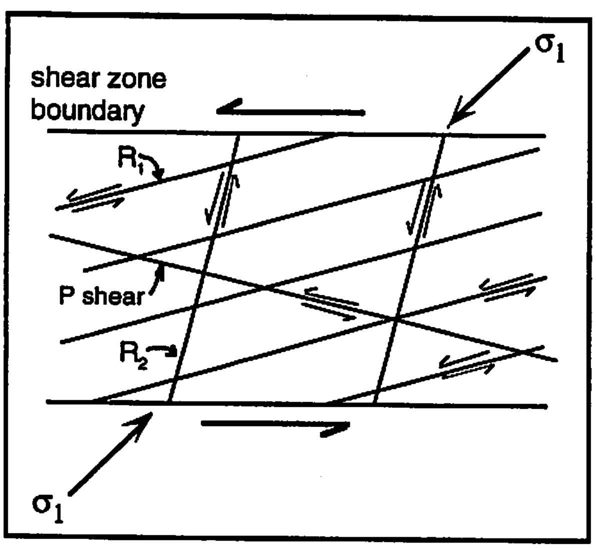


Figure 2-2. Orientations of common fault-related features in a left-lateral Riedel shear system. The main fault at Stop 2 is represented by the large black arrows. The small-scale slickensided faults are represented by R_1 (synthetic Riedel shears). P shears and R_2 (antithetic Riedel shears) were not observed at this location.

the breccia have wrapped around more resistant, rounded sandstone clasts.

Numerous small-scale, strike-slip faults occur in both the footwall and hanging wall of the main fault. These faults are characterized by very undulatory and corrugated slickensided surfaces. Kinematic indicators along these surfaces include lunate fractures and "step faulting". Slickenlines plunge to the northeast with rakes between 15° and 24°. Both left- and right-lateral sense of movement are observed on these faults. Most of the faults strike N02°E to N30°E and dip 75-90° to both the northwest and southeast.

Compositional layering (clay drapes and gravel layers) in the sandstones serve as excellent marker horizons for measuring small offsets along faults. Most of the faults have little to no dip-slip component of offset, but a few show dip-slip offset of a much as 0.5 m. In relationship to the main fault, the orientations of these small-scale faults suggest they might be synthetic Riedel shears (Figure 2-2) in a left-lateral shear zone.

The location of the outcrop is directly along the projected N40°E strike of the Bonsal-Morrisville fault of Bain and Harvey (1977.) They interpreted the Bonsal-Morrisville fault to be a basin longitudinal normal fault with approximately 600-1200 m of vertical offset. It is certainly not unreasonable to suggest that the fault at Stop 2 is probably a related structure.

STOP 3: TRIANGLE BRICK QUARRY

LEADERS: Paul Olsen and Phillip Huber

Introduction

Extensive exposures of Durham sub-basin sedimentary rock in the Triangle Brick Co. Quarry comprise a world-class locality for late Triassic continental vertebrates and invertebrates, as well as an excellent view of Durham sub-basin fluvio-lacustrine strata. The purpose of this stop is to examine the stratigraphy, depositional environments, and overall context of rich fossil assemblages.

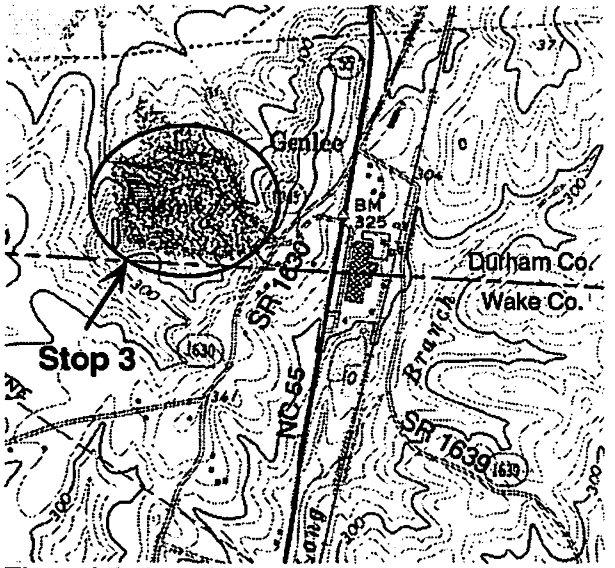


Figure 3-0. Location of Stop 3 on the Green Level quad.

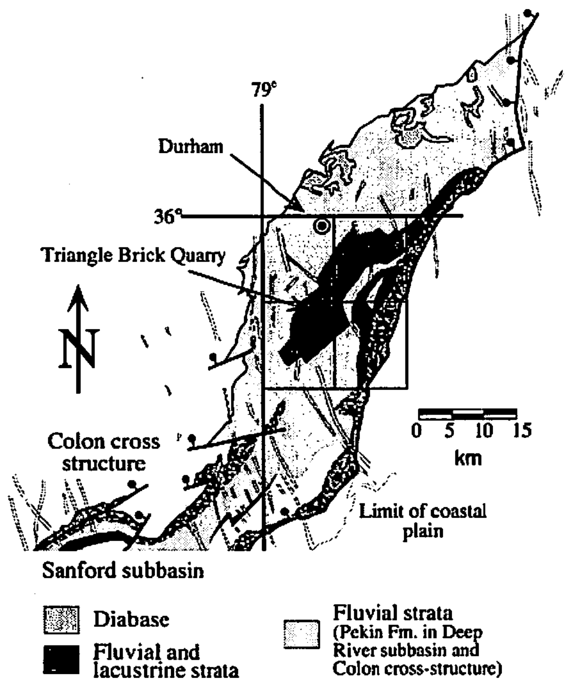


Figure 3-1. Map of the Durham sub-basin of the Deep River basin showing the position of the Triangle Brick Company quarry. The four 7.5-minute quads, from upper left clockwise: Durham Southwest, Durham Southeast, Cary, and Green Level. Map is modified from Bain and Harvey (1977) and Olsen et al. (1991).

Location

The quarry is located in the northeast corner of the Green Level 7.5' quadrangle at 35°52'09" latitude and 78°53' 67" longitude in the village of Genlee, Durham County, North Carolina (Figures 3-0, 3-1). It is situated in the south central part of the Durham sub-basin, on a weakly defined ridge that trends NE-SW, parallel with the regional strike. The soft red and purple mudstones exposed in the quarry are used mostly for making brick. Permission must be sought from the main office prior to visiting.

Stratigraphic Position

Exposures in the main quarry are located in the mudstone facies of Lithofacies Association II of Hoffman and Gallagher (1989) (Figure 3-2). The low strike ridge containing the quarry runs for at least 8 km to the north and nearly identical strata (including the lacustrine sequence) have been found on Ellis Road in Durham indicating considerable lateral continuity for this interval. The relationship of these strata to the better known sequence in the Sanford sub-basin is still poorly resolved (see below).

Lithological Sequence

The main quarry exposes about 60 m of red, purple, and gray fissile to bioturbated massive mudstones interbedded with gray, brown, and red arkosic sandstones (Figure 3-3). The upper half of the sequence consists of fissile red to gray-green fissile mudstones interbedded with bioturbated massive mudstone and arkosic sandstones arranged in a pattern reminiscent of cyclical lacustrine sequences in other Newark Supergroup basins (Olsen, 1986; 1997). At the scale of the outcrop, at least, each fissile mudstone bed is laterally persistent with little lithological change (Olsen, et al., 1989). The lowest fissile mudstone is particularly fine-grained and well laminated and contains a rich invertebrate assemblage (Figures 3-3, 3-4). The lower half of the exposed sequence consists of red to purple bioturbated massive mudstone with lenticular arkosic sandstones and several caliche-bearing horizons (Coffee and Textoris, 1997) with occasional articulated to fragmentary reptile skeletons.

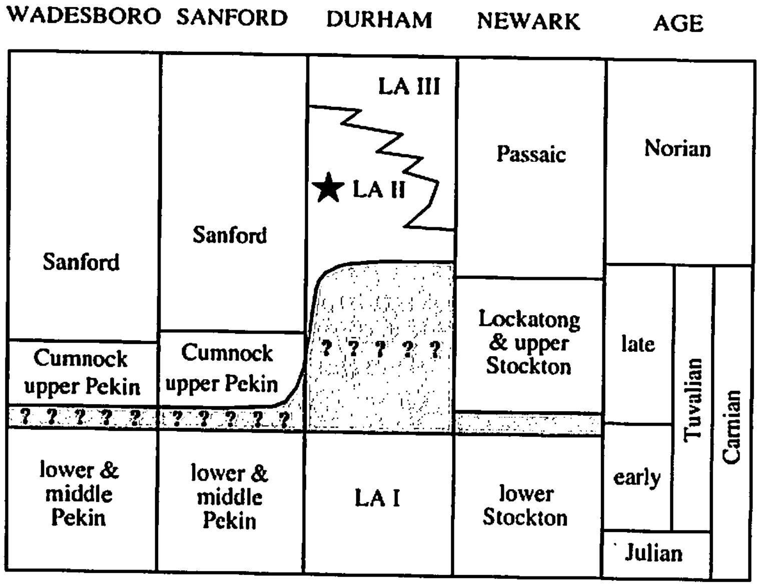


Figure 3-2. Correlation of units within the Deep River basin with the Newark basin section (NY, NJ, PA) and the European standard ages. The gray area represents a hiatus caused by a syn-rift unconformity between tectonostratigraphic sequence II and III, seen in the Newark, Richmond, Taylorsville, and Fundy basins of the Newark Supergroup and the Argana basin of Morocco (Olsen, 1997) and hypothesized in the Deep River basin largely based on vertebrate biostraigraphy. Star shows the position of the Triangle brick Company quarry.

Biota, Depositional Environments and Paleoecology

The Triangle Brick Quarry is a world-class locality for both continental invertebrates and vertebrates, particularly reptiles (Renwick, 1988; Gore and Renwick, 1987; Olsen et al., 1989, Olsen, 1977; Good and Huber, 1995) (Figure 3-4). At least three fossil assemblages can be recognized in three distinctive facies: 1) fissile clay-rich mudstones, 2) channel and shoreline lags, and 3) bank and overbank deposits with reptile skeletons (Table 3-1).

Fissile clay-rich mudstones

The fissile, laterally persistent mudstones in the upper part of the section contain abundant ostracodes and clam shrimp. The lowest fissile mudstone also produces rare fragmentary plants, unionid and myalinid clams (Good and Huber, 1995), articulated crayfish, abundant fragmentary to articulated fish, occasional reptile (phytosaur) teeth, and abundant coprolites. The enigmatic burrow *Scoyenia*, occurs throughout the fissile mudstone.

Particularly unusual is the occurrence of cambarid crayfish (Figure 3-4). When these were first found (Olsen, 1977), they were thought to be clytiopsid decapods. However, Hasiotis (personal communication) has determined that they are true crayfish and members of the extant family, the Cambaridae. The crayfish occur mostly as articulated, reddish, compressions, often poorly preserved. Some, however, are well preserved and show considerable surface detail (Figure 3-4). The occurrence of these crayfish in association with the burrow *Scoyenia,* as well as the morphology of the burrow itself suggested to Olsen (1977) and Olsen et al. (1989) that *Scoyenia* was the product of crayfish. Hasiotis and Dubiel (1993), however, have shown that crayfish from the Chinle Formation produce a burrow type very unlike that of *Scoyenia*, and suggests instead that the latter was produced by a burrowing beetle. The argument is of some significance, because *Scoyenia* is the most abundant ichnofossil in the Newark Supergroup and the burrower must have been of considerable ecological importance. The preservation of *Scoyenia* in the crayfish-bearing fissile mudstone is exceptionally fine (Figure 3-4) and should allow for a exceptionally detailed description of its morphology.

The sequence of specific lithologies and fossils within this interval (Figure 3-3) is distinctive and maintained throughout the quarry, however, the upper part of the sequence is variably cut out by overlying sandstones, and the lower part is cut by bedding parallel faults that frequently disturb the most fossiliferous units. Overall, the

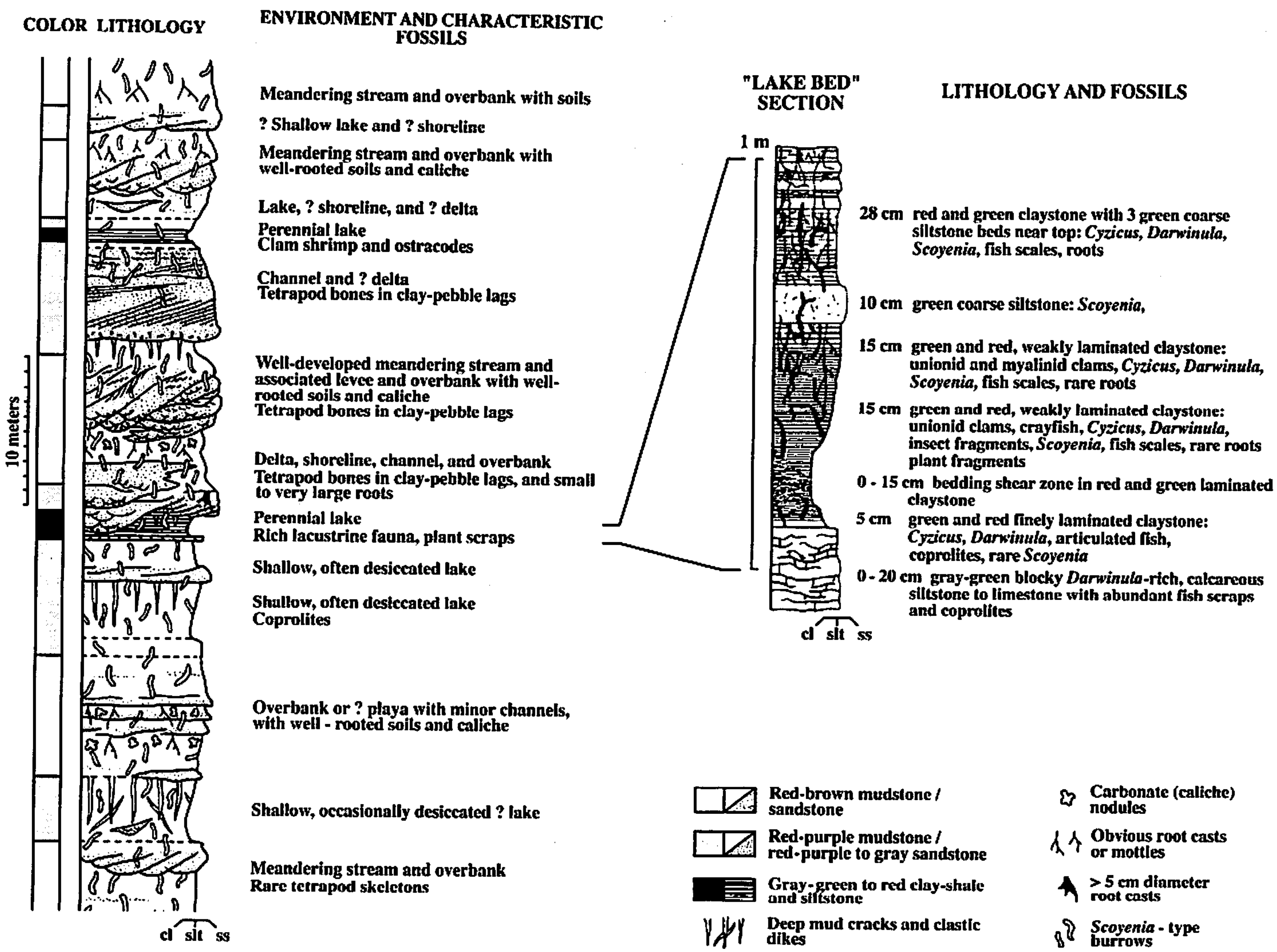


Figure 3. Section exposed at the Triangle Brick Co. Quarry. Modified from Olsen (1977) and Olsen et al. (1989, 1991).

sequence is reminiscent of that seen within individual Van Houten cycles of other parts of the Newark Supergroup (Olsen, 1986; Olsen et al., 1989). Specifically, this mudstone sequence has an abrupt transition upward from what appears to be a wave-winnowed lag (see below) into finely laminated fine mudstone with occasional partly articulated fish suggestive of a low oxygen environment. This gives way upward to a progressively less well-laminated mudstone, with a biota indicating higher degrees of oxygenation (e.g., mollusks) and eventual emergence (i.e., roots). This kind of sequence in contemporaneous deposits in other parts of the Newark has been interpreted as a lake level cycle responding to climate changes. Gore and Renwick (1987) and Renwick (1988) interpret this sequence as a small flood plain lake that filled with mud. However, at the scale of the outcrop, there is so little lateral change in this sequence that the lake must have been at least several times the area of the quarry. In addition, the discovery of a very similar unit in the same stratigraphic position with a nearly identical assemblage some 8 km away suggests the lake may have been quite large indeed.

Channel and shoreline lags

The base of the most fossiliferous fissile shale at the quarry (Fig. 3-3) has an ostracode-rich calcareous mudstone and limestone bed. This unit lies upon massive mudstones and suggests a transgressive shoreline lag deposit.

The sandstones interbedded with more massive bioturbated mudstones in the upper half of the quarry section often contain beds of intraformational conglomerate (channel lags) with isolated bones and teeth, mostly of phytosaurs. A single metoposaurid intercentrum was found in one of these intervals. One associated, very fragmentary phytosaur skeleton has been found in a moved block of yellow-weathering gray sandstone. It seems likely that the partial articulated skeleton of the armored aetosaur *Aetosaurus* (=*Stegomus*; Fig. 3-4N) described by Parker (1966) and Lucas et al. (1997) comes from these sandstones as well, although it is possible that the specimen came from a bank deposit (see below). The sandstones have also produced one particularly large tap root, plausibly of a cycadeoid (Fig. 3-4A). These massive mudstones and interbedded sandstones appear to be fluvial in origin and likely were produced by anastamosing streams, with extensive muddy banks.

Bank and overbank deposits

Reptile material has also been recovered from one lenses of muddy sandstone low in the quarry sequence. The unit was directly laterally adjacent to a red-to-cream-colored lenticular sandstone. Although extensive bioturbation and subsequent excavation precludes a detailed analysis of small-scale sedimentary structures, the overall arrangements suggests a levee or crevasse splay sequence next to a channel. The massive mudstones themselves adjacent to and interbedded with the coarser deposits are intensively burrowed by *Scoyenia* and locally contain abundant roots.

Coffey and Textoris (1997) have described moderately developed calcite horizons in presumed overbank deposits about

Figure 3-4. (facing page) Representative fossils from the Triangle Brick Co. Quarry, all but A and N from the main "lake bed" fissile mudstone (see Figure 3-3). A) large tap root plausibly of a cycadeoid from a channel sandstone; B) a unionid clam cast (above) and an isolated valve of the clam shrimp *Cyzicus* (below) along with numerous much smaller darwinulid ostracodes; C) the two calcitic valves of what is apparently a myalinid clam and darwinulid ostracodes; D) numerous clam shrimp (*Cyzicus* spp.); E) scanning electron photomicrograph of single valve of the clam shrimp *Cyzicus* sp.; F) detail of ornamentation between growth lines seen in E showing superb preservation; G) beautifully preserved ostracode valve (*Darwinula* sp.); H) nearly complete cambarid crayfish (note claws in upper part of photo) and clam shrimp (upper left); I) cambarid crayfish carapace missing claws, tail is to left; J) scanning electron photomicrograph of single cambarid crayfish claw showing sculpture; K) Scoyenia burrow, removed from matrix (note branching burrows, one with a rounded termination); L) isolated beetle elytron (wing cover); M) dissociated scales of the palaeoniscoid fish *Turseodus*; N) partial tail of *Aetosaurus* (=*Stegomus*) sp. with the characteristic amour plates - possibly from a channel sandstone.

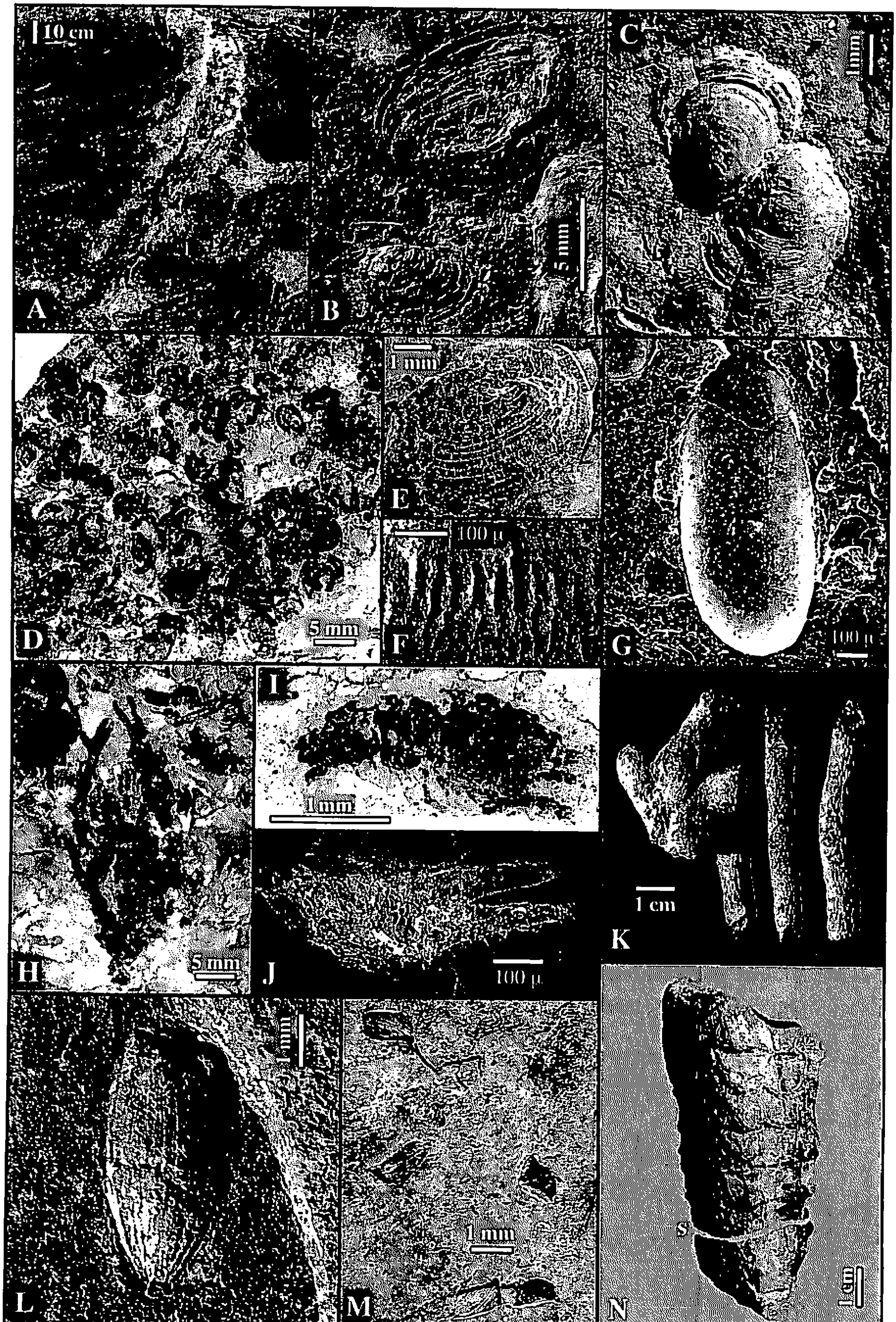

10 cm
A
B
5 mm
C
1mm
D
5 mm
E
1 mm
F
100 µ
G
100 µ
H
5 mm
I
1 mm
J
100 µ
K
1 cm
L
1 mm
M
1 mm
N
S
1 cm

TABLE 3-1: Fossils from the Triangle Brick Company quarry (modified from Olsen et al., 1989).

- PLANTS
  - Sphenophytes
    - Equisetales (horsetails)
      - *Neocalamites* sp.
      - *Equisetales* sp.
  - Pteridophytes
    - Filicales (ferns and fern-like organisms)
      - *Cladophlebis* sp.
  - Coniferophytes
    - Coniferales (conifers)
      - *Pagiophyllum* sp.
- ANIMALS
  - Mollusks
    - Pelecypoda
      - Unionidae
        - undetermined aragonitic clams
      - Myalinidae
        - undetermined calcitic clams
  - Arthropods
    - Crustacea
      - Diplostraca (clam shrimp and water fleas)
        - *Cyzicus* sp.
        - ?*Palaeolimnadia* sp.
      - Ostracoda
        - *Darwinula* spp.
      - Decapoda
        - Cambarid crayfish
        - ?*Scoyenia* sp.
      - 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.
  - Reptilia
    - Archosauria
      - Crurotarsi
        - Phytosauria (crocodile-like archosaurs)
          - intederminate sp.
        - Suchia (crocodiles and relatives)
          - Aetosauridae (armored herbivorous archosaurs)
            - *Aetosaurus* cf. *arcuatus*
          - three undetermined species belonging to three groups of Suchia

10 m above the skeletons (Fig. 3-3). According to them, the fibrous radial caliche seen in some nodules may be due to the replacement of original aragonite by calcite implying an arid environment with seasonal wet periods.

Age

Olsen (1977), Olsen et al. (1982), and Olsen et al. (1989) argued that the presence of the fish *Turseodus* in the Triangle Brick Quarry (Table 4-1) indicated correlation with the Lockatong Formation of the Newark basins and the "upper member" of the Cow Branch Formation of the Dan River basin, and was hence late Carnian in age. The Triangle Brick assemblage would therefore be younger than the Cumnock Formation of the adjacent Sanford sub-basin of the Deep River basin. However, Huber et al. (1993) pointed out that *Turseodus* ranges throughout the entire Chinle group of Carnian and Norian age and was therefore of very limited time-stratigraphic value. Huber et al. (1993) also suggested that the presence of *Stegomus* in the Triangle Brick assemblage indicated correlation with the lower to middle Passaic Formation of the Newark basin and was therefore of early to ?middle Norian in age. Thus, it would be in the Neshanician land vertebrate faunachron of Huber et al. (1993). Most recently Lucas et al. (1997) show that *Stegomus* is a junior synonym of *Aetosaurus*, the latter well known from Norian age continental strata in the Germanic basin and Greenland and from marine strata in the middle Norian columbianus zone of the Italian Alps. This strongly supports a Norian age for the Triangle Brick assemblage. A Norian age is also consistent with a preliminary assessment of the new skeletal material. If indeed the Triangle Brick assemblage is Norian in age as the new interpretations suggest, it is indeed significantly younger than the Cumnock Formation of late Carnian age (Fig. 3-2).

STOP 4a: AUXILIARY LAKE SPILLWAY

LEADERS: Kathleen Farrell and Tyler Clark

Spillway Field Stop

The purpose of this stop is to show the architecture of sedimentary facies and their bounding surfaces at a locality about 6 km west of the eastern border fault (Jonesboro Fault) of the Deep River Basin. Here, a relatively fine-grained, heterogeneous assemblage of siliciclastic rocks is interpreted as flood basin and distal fan deposits. The field stop is located on the west bank of a north-east trending spillway channel (Figure 4-1). Approximately 8 m of section are exposed in the spillway banks.

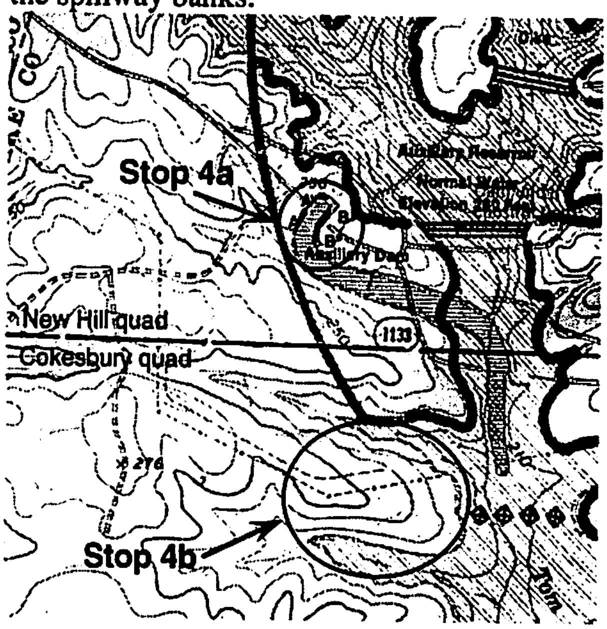


Figure 4-1. Location of Stops 4a and 4b on the New Hill and Cokesbury quadrangles.

Facies distribution and interpretation

Figure 4-2 shows two cross sections (A-A' and B-B'-B") sketched from photomosaics of the east and west banks of the spillway and field checked for lithology. Five distinct facies are defined and interpreted in the cross sections.

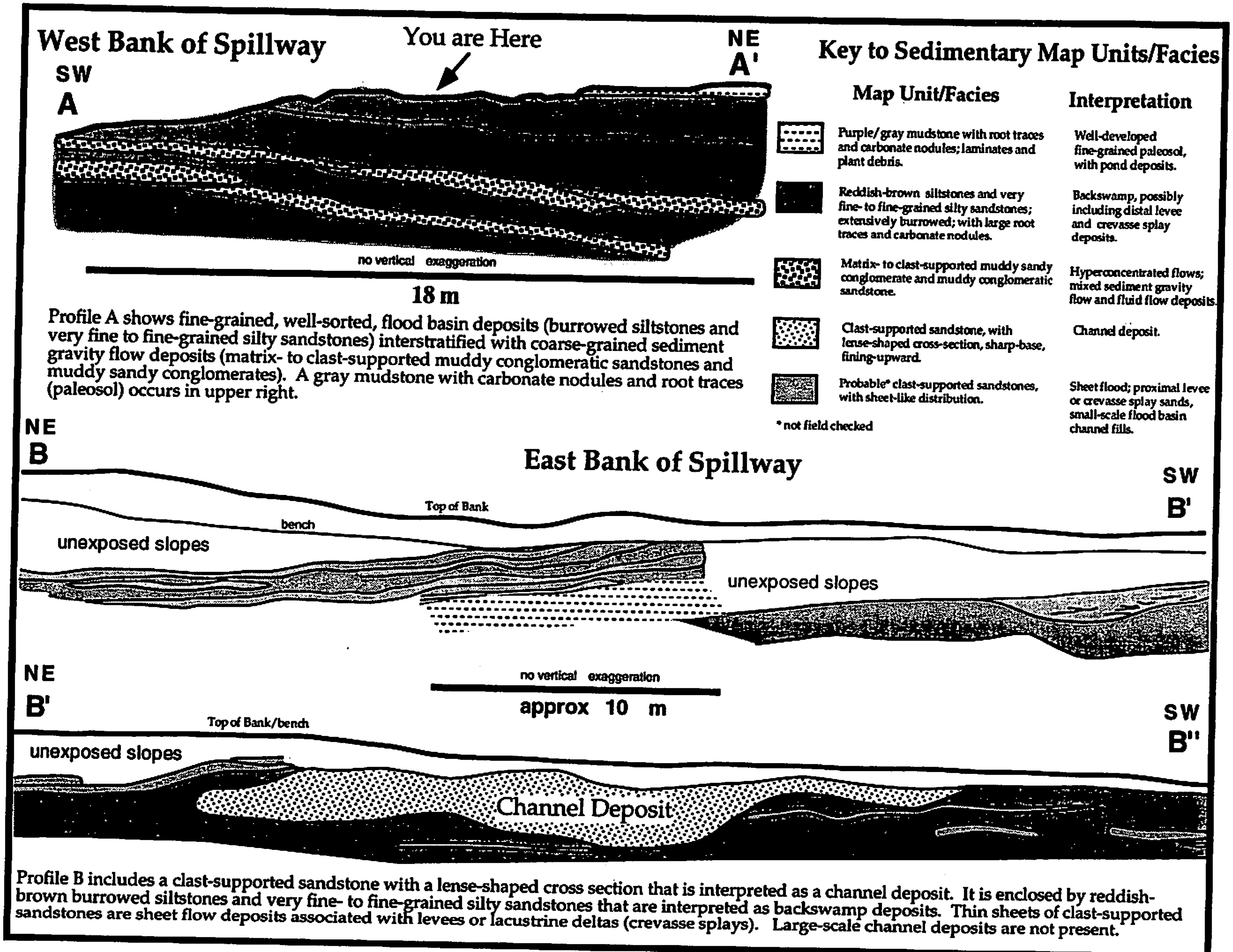


Figure 4-2. Cross sections from the east and west banks of the spillway. Locations are shown in Figure 4-1.

The west and east bank sections (A-A' and B-B'-B", respectively) are dominated by reddish-brown, massive-appearing, well-sorted, burrowed siltstones and very fine- to fine-grained silty sandstones that are interpreted as backswamp deposits. These fine-grained sediments were deposited via settling from silty to sandy flood waters that periodically entered the flood basin. After deposition, each newly deposited layer was bioturbated to form a massive deposit. A *Scoyenia* ichnofacies assemblage dominates. Sandier intervals were deposited closer to the source of the flood waters and may be distal levee or crevasse splay deposits. Large root traces and drab root halos penetrate the section and commonly have carbonate nodules associated with them.

On the west bank (A-A'), the top right of the section is marked by a distinct, root-mottled, purple to gray mudstone with abundant carbonate nodules and is interpreted as a well-developed paleosol (Figure 4-2). Carbonate nodules commonly form as casts of backfilled burrows in reduction zones associated with root traces. Laminated intervals with plant debris, interpreted as pond deposits, are commonly associated with this paleosol. The east bank of the spillway also includes gray mudstone (B-B'-B").

The west bank of the spillway (A-A') includes thin (<0.6 m), coarse-grained beds of mostly conglomerate and sandstone. Above a sharp, erosional base, each bed consists of amalgamated lobes of clast- and/or matrix-supported muddy conglomeratic sandstone and muddy sandy conglomerate. The poorly-sorted, matrix-supported beds are interpreted as sediment gravity flow deposits. Better sorted, clast-supported beds lacking mud are interpreted as fluid flow deposits. Beds that change internally from a clast- to matrix-supported fabric may indicate hyperconcentrated flows with evolving flow conditions. These thin, coarse-grained intervals probably were deposited during periodic major floods that transported coarse clastics from a fan distally into the flood basin. The result is a sheet-like deposit of coarse-grained material sandwiched within an otherwise fine-grained, well-sorted deposit. Root traces extend through these coarse-grained units.

The east bank of the spillway (B-B'-B") includes two types of coarse-grained units. A lens-shaped, sharp-based, clast-supported sandstone represents a cross-section through a small-scale channel deposit. The channel was less than 2 m deep and only about 25 meters wide. Thin (<0.3 m) sheets of sharp-based, clast-supported sandstones are also present. Locally these sheets are discontinuous or fine into siltstone. Where these sandstones thicken and infill paleo-topographic lows they are interpreted as very small-scale channels in backswamps. These sheets are closely stacked and interstratified with siltstones at the northeast end of section B-B'-B". Here, these sandstones may represent proximal levee, or lacustrine delta or crevasse splay sands.

With the exception of the channel sandstone exposed on the east bank of the spillway, the units observed appear tabular to sheet-shaped in distribution. This suggests that facies units were deposited on a succession of relatively flat landscapes over broad areas. Both flood basin and distal fan environments include extensive flat areas.

The type of fluvial system at this locality is interpreted as an anastomozed channel network with bar sands infilling entrenched channels. Large-scale channel deposits with cross-stratification and lateral accretion surfaces have not been observed in the immediate vicinity. The channel sand in Profile B may represent a single channel in a complex anastomozed channel network. Such channel networks are entrenched into fine-grained flood basin deposits, and do not freely meander to generate lateral accretion sets.

STOP 4b: SOUTH BORROW PIT FAULT

LEADERS: Rick Wooten, Tyler Clark, and Peter Malin

The south borrow pit is located adjacent to Harris Lake, in the Cokesbury 7.5' quadrangle, Wake County (Figure 4-1). Access to the south borrow pit is through the proposed Wake/Chatham low-level radioactive waste

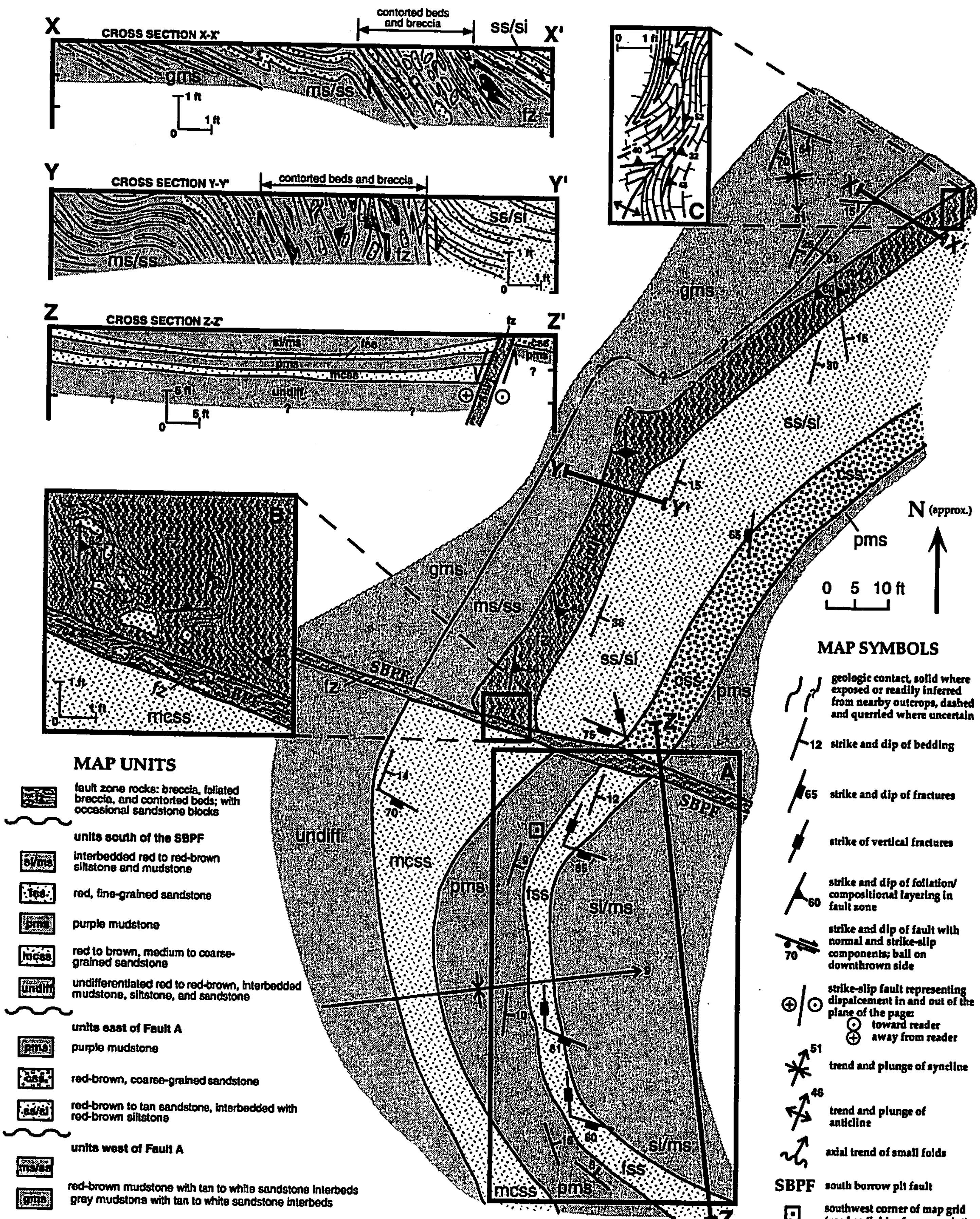


Figure 4-3. Geologic map (1:240 scale) and cross sections showing structural relationships at location 4 (plate 2) where fault A terminates against the south borrow pit fault (SBPF). Inset A - fracture trace map area for figure 7. Inset B - detail of the fault fabric where fault A terminates against the SBPF. Inset C - schematic detail of deformation patterns within fault A.

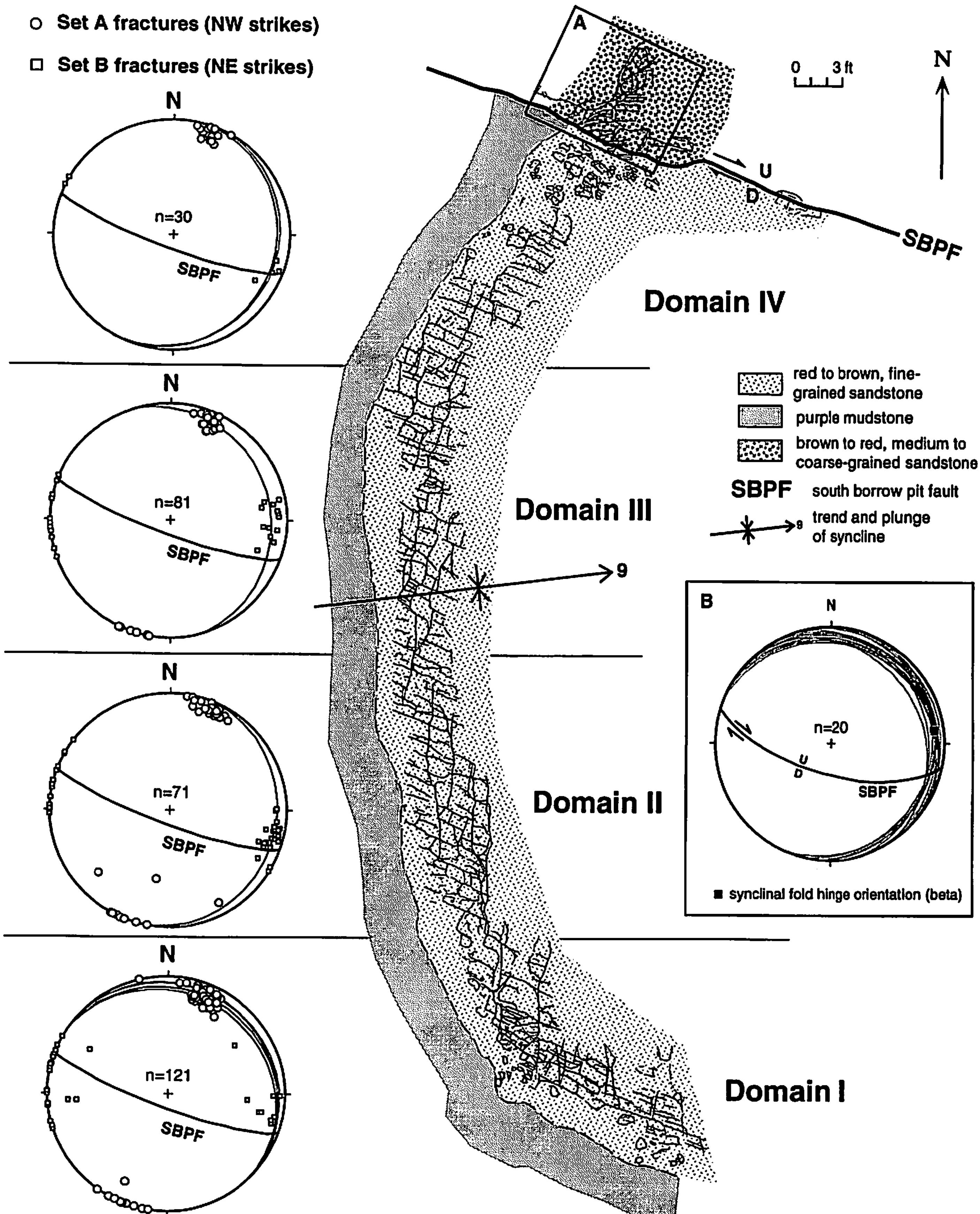


Figure 4-4. Fracture trace map (1:96 scale) and lower hemisphere equal-area projections of the south borrow pit fault (SBPF), bedding, and fracture data from location 4 (plate 2). Map area is divided into domains I, II, III, and IV based on changes in bedding strike. Projections include: fault and bedding orientations (great circles) and fractures (poles to planes); Set A fractures (filled circles); and Set B fractures (filled squares). Data for projections are listed in Appendix B. Inset A - map area for figure 12. Inset B - lower hemisphere equal area projection of bedding and fault orientations (great circles) and synclinal fold hinge orientation (beta) from the detailed fracture trace map area.

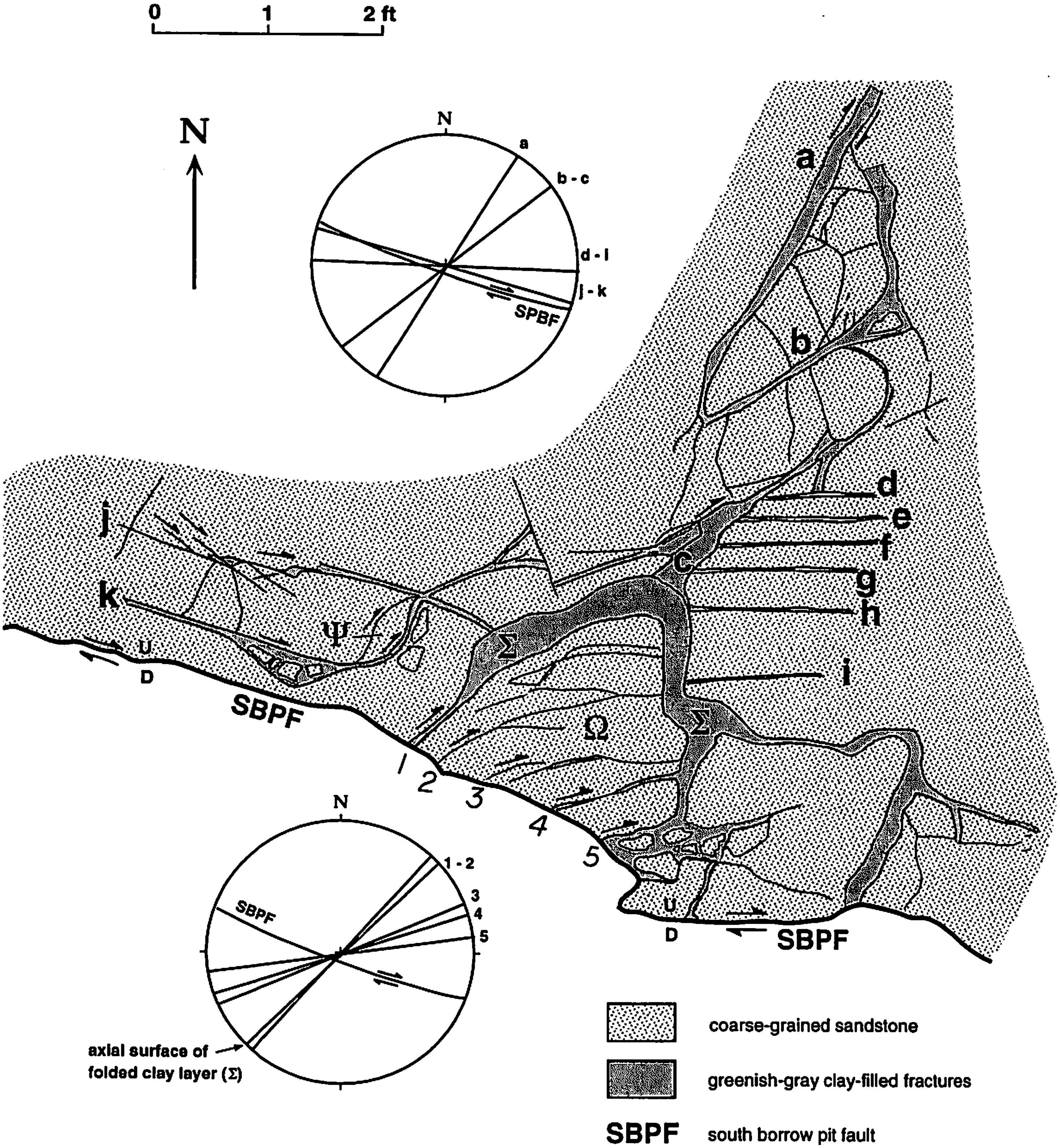


Figure 4-5. Detailed geologic map (1:15 scale) and lower hemisphere equal area projections of structures in the footwall of the south borrow pit fault at location 4 (plate 2).

disposal site. Sign in at the site administrative compound on SR 1912 is required for access.

Introduction

Stop 4b is located approximately 6 km northwest of the Jonesboro fault in faulted, folded, and fractured siliciclastic rift basin deposits of the Deep River Triassic basin. Plate 1 (in back) illustrates the geologic relationships in the vicinity of stop 4b that are exposed in the north and south borrow pits near the Shearon Harris Reservoir. Figure 4-3 illustrates outcrop-scale structural relationships at this locality where the northeast-striking Fault A terminates against the west-northwest-striking SBPF. Fault related fabrics, outcrop-scale folding, and fracture patterns in the hanging wall and footwall of the SBPF are well-exposed here. Analysis and interpretation of this outcrop is based on 1:240 scale geologic mapping (Figure 4-3) and 1:12 scale fracture trace mapping (Figures 4-4 and 4-5). More detailed information on this and other outcrops in the south and north borrow pits can be found in Wooten, Clark, and Davis (1996).

Fracture Trace Mapping

Fracture trace mapping was conducted adjacent the SBPF in the hanging wall and in the footwall. The fracture trace map shown in Figure 4-4 contains three distinct rock units; two rock units in the hanging wall and one rock unit in the footwall. Hanging wall rock units include a purple mudstone overlain by a fine-grained, red to brown sandstone. Fracture trace mapping and fracture descriptions were restricted to the fine-grained sandstone unit (< 1 ft. thick) in the hanging wall of the SBPF. The footwall rock unit is a brown to red, medium- to coarse-grained sandstone. Structures in the footwall rock unit are shown in detail in Figure 4-5.

Hanging Wall Structures

The change in bedding strike from northwest to northeast as one approaches the SBPF from the south defines an outcrop-scale syncline within the hanging wall of the SBPF. The beta diagram constructed from bedding data defines a fold axis of N. 83° E. 9° (inset B, Figure 4-4). The hanging wall portion of the fracture trace map has been divided into four domains (I, II, III, and IV) based on the change in bedding strike across the map area.

Two primary fracture sets occur in the hanging wall of the SBPF at the fracture trace map location. These include a set striking nearly parallel to the strike of the SBPF (Set A) and a set at a high angle to the SBPF (Set B). Both fracture sets have steep dips, generally greater than 80°. Set A maintains a constant strike sub-parallel to the strike of the SBPF. The strike of Set B, however, changes across the fracture trace map area. The fracture map and corresponding equal-area stereonet projections (Figure 4-4) show a change in orientation of Set B from north-northwest in domains I and II to north-northeast in domains III and IV. This change to a more northeast strike of Set B, when approaching the SBPF from the south, mimics the change in strike of the bedding units previously discussed.

Fracture crosscutting and fracture termination relationships in the hanging wall suggest Set A fractures, which parallel the SBPF, are generally younger than Set B fractures. This conclusion is based on several observations: 1) Set A terminates against Set B in many cases; 2) Set A fractures locally offset Set B fractures; and, 3) the strike of Set B fractures changes orientation near the SBPF similar to the stratigraphic units defining the outcrop-scale syncline. In contrast, the strike of Set A fractures maintains a constant orientation across the fracture trace map area. These facts indicate Set B fractures were deformed during folding of the outcrop-scale syncline, whereas Set A fractures were unaffected by this folding.

The geometry of the outcrop-scale syncline in the hanging wall of the SBPF as shown in Figures 4-3 and 4-4 suggests it formed by drag related to dextral strike-slip faulting. This fold geometry, however, could also be explained by drag during normal faulting. The orientation of the fold hinge (N83°E 9°) for this structure, however, appears to more consistent with the shortening direction expected in a dextral strike-slip system. The orientation of pinnate structures on several east-striking, Set A fractures are consistent with fracture formation during dextral strike-slip faulting. In addition, some north-striking, Set B fractures are offset in a dextral sense by Set

A fractures. The change in orientation of north-striking fractures in the outcrop-scale syncline is also consistent with the concept of dextral strike-slip displacement.

Footwall Structures

Detailed mapping in the footwall portion of the fracture trace map area was limited to an 8 foot by 8 foot area immediately north of the SBPF in a medium- to coarse-grained sandstone. The footwall structures contrast with those in the hanging wall portion of the map (Figures 4-4, 4-5). For example, the pervasive, rectilinear hanging wall fracture Sets A and B were not observed in this portion of the footwall. Footwall structures and their orientations are shown in a 1:15-scale map (Figure 4-5) and the attributes of several of these features are briefly discussed below.

Structural features observed in the footwall of the SBPF also suggest dextral strike-slip displacement along the SBPF (Figure 4-5). Fractures at location j, and structures Ψ, Ω, Σ are particularly illustrative. The fractures at location j in Figure 4-5 are interpreted as pinnate fractures or conjugate shear fractures and their geometry and sense of displacement are consistent with dextral shearing. Likewise, the asymmetry (S-shape) of the sigmoidal clay-filled fractures associated with structure Ψ also suggest dextral shearing. Structure Ψ is interpreted as a fault bounded block (e.g., horse block). The S-shape asymmetry of this block also supports dextral strike-slip shearing.

Structure Ω is interpreted as a contractional strike-slip duplex similar to those described by Woodcock and Fischer (1986) and also indicates a dextral sense of displacement. The duplex comprises fractures 1-5 on Figure 4-5, interpreted as faults, that sole into the SBPF. The angle between each fault and the SBPF increases from fault 5 to fault 1. This change in angle is interpreted to reflect the steepening of earlier faults (e.g., 1) because of emplacement of later faults (2-5) during a forward-breaking sequence similar to that observed in foreland thrust systems.

The formation and geometry of the folded clayey layer (Σ on Figure 4-5) is likely to be related to the duplex structure Ω, similar to fault related folds developed in foreland thrust systems. The geometry of the folded clayey layer Σ, including its vertically plunging fold hinge, the axial surface orientation (N45°E 90°), and the sense of asymmetry or vergence suggests dextral strike-slip displacement.

Discussion and Kinematic Model

Initial movement along fault A is interpreted as extensional (longitudinal) displacement, which predates transtensional faulting along the SBPF. Reactivation of fault A during movement along the SBPF may have produced some of the complicated internal fabric observed within fault A (inset C, Figure 4-3). The map-scale anticline in the hanging wall of the SBPF shown in Plate 1 (in back) and in the seismic reflection data is interpreted to have formed during normal displacement along the SBPF. The outcrop-scale syncline in the hanging wall of the SBPF is interpreted to have formed during dextral strike-slip movement along the SBPF.

We interpret the relative magnitude of normal displacement along the SBPF to be greater than the magnitude of strike-slip movement along the SBPF, given the hanging wall anticline (inferred as the result of normal displacement) is a map-scale feature in contrast to the smaller, outcrop-scale syncline related to strike-slip movement.

STOP 5: HARRIS LAKE SPILLWAY: BUCKHORN GRANODIORITE

LEADER: Tyler Clark

Extreme caution should be taken when visiting this outcrop! This stop involves crossing an active railroad bridge, descending a steep slope, and viewing the exposure from a narrow, 2-4' wide concrete ledge. Permission should be obtained from Carolina Power and Light's senior land manager for the Shearon Harris nuclear power plant prior to visiting this outcrop.

The purpose of this stop is to view both brittle and ductile deformation in crystalline rocks affected by Mesozoic extension. The location of this outcrop is approximately 3000' southeast of the Jonesboro fault. Construction of the main spillway of Harris lake in the early 1980's required blasting through a ridge of the Buckhorn granodiorite. This work created a benched cut over 200 m long and 40 m high. Excellent outcrop exists on both the east and west sides of the spillway.

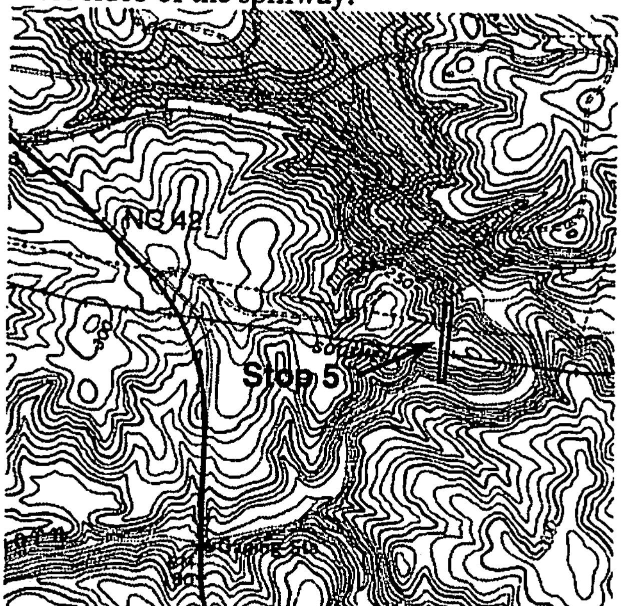


Figure 5-1. Location of Stop 5 on the Cokesbury quad.

Preliminary studies indicate the outcrop contains a wide variety of rock types and structural features, including both brittle and ductile deformation. Rock types range from coarse-grained, undeformed, leucocratic granite to fine-grained, well-developed mylonite. Shear zones range from 2-20 cm in thickness and have S-C fabrics suggesting normal or "tops down" movement. Most of these shear zones strike sub-parallel to the Jonesboro fault and have similar dips to the northwest.

Most of the ductile deformation is overprinted by a later brittle deformation characterized by extremely well-preserved slickensided fault surfaces, some with up to 1 cm thick vuggy quartz mineralization. Brittle deformation clearly offsets ductile deformation at the location. The best-developed slickensided fault surfaces occur along the boundaries of the ductile shear zones mentioned above and also strike sub-parallel to the Jonesboro fault with similar dips to the northwest. This suggests that brittle faulting was concentrated on the preexisting ductile fault planes. Kinematic indicators such as step-faulting and lunate fractures suggest normal or "tops down" movement. Rare reverse faults are also present.

The main topic for discussion at this stop is the relative age of both the ductile and brittle deformation. While it is obvious that the brittle deformation post-dates the ductile deformation, the age span between the two deformations is unclear. One hypothesis is that the ductile deformation at this location may not represent Paleozoic compressional deformation, but perhaps ductile, Mesozoic extensional deformation exhumed to the surface due to crustal thinning and uplift.

STOP 6: HOLLEMAN'S CROSSROADS CONGLOMERATE

LEADER: Tyler Clark

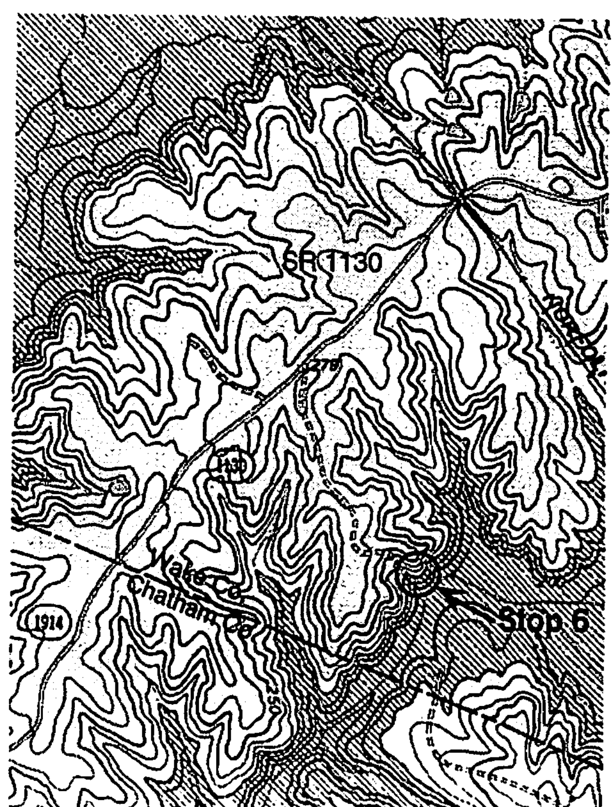


Figure 6-1. Location of Stop 6 on the Cokesbury quad.

The purpose of this stop is to view some of the best-preserved, boulder conglomerates in the Durham sub-basin. This stop was visited almost 20 years ago (prior to the lake's existence) by the Carolina Geological Society field trip of Bain and Harvey (1977). The stop description was written by V.V. Cavaroc of North Carolina State University.

This abandoned quarry is located approximately 1 km northwest of the Jonesboro fault. The high ridge along the lakeshore to the southeast marks the approximate location of the Jonesboro fault. The orientation of the units here is N15°E 17°SE (Bain and Harvey, 1977). Cavaroc interpreted these rocks as part of an alluvial fan, with moderately high gradient, braided stream development. The rocks at this location consist of fining-upward sequences of matrix- and clast-supported, sandstones and conglomerates. The clast sizes range from 5-53 cm. Such large clast size suggests a relatively high gradient and short transport distance.

Clast composition is highly variable. The most predominate clasts are foliated to non-foliated, black to green, schists and phyllitic rocks of the Carolina Slate belt. Some of the larger, more rounded clasts are boulders of the Buckhorn granodiorite. Minor amounts of angular to rounded quartz are also present. Unpublished geologic mapping in the Cokesbury quadrangle by the late Robert Butler (UNC-Chapel Hill), and recent reconnaissance by Tyler Clark (NC Geological Survey), suggest the large clast size is a local phenomena restricted to the Harris Lake area, and that Buckhorn granodiorite clasts in relation to their source area suggest a transport direction to the north.

END OF THE FIELD TRIP

REFERENCES CITED

Bain, G.L., and Harvey, B.W., eds., 1977, Field guide to the geology of the Durham Triassic basin: Carolina Geological Society Fortieth Annual Meeting, 7-9 October 1977: North Carolina Department of Natural Resources and Community Development, Division of Earth Resources, Geology and Mineral Resources Section, 83 p.

Blake, D. E., 1986, The geology of the Grissom area, Franklin, Granville, and Wake Counties, North Carolina: A structural and metamorphic analysis: M.S. thesis, N. C. State University, 300 p.

Carpenter, P. A., III, 1970, Geology of the Wilton area, Granville County, North Carolina: M.S. thesis, North Carolina State University, 106 p.

Coffey, B. P. and Textoris, D. A., 1997, Paleosols and paleoclimate evolution, Durham sub-basin, North Carolina. In Aspects of Triassic-Jurassic Rift Basin Geoscience, LeTourneau, P. M. and Olsen, P. E. (eds.), in press.

Garihan, J. M., Preddy, M. S., and Ranson, W. A., 1993, Summary of Mid-Mesozoic brittle faulting in the Inner Piedmont and nearby Charlotte belt of the Carolinas: in, Hatcher, R. D., Jr., and Davis, T. L. (eds.), Studies of Inner Piedmont Geology with a focus on the Columbus Promontory: Carolina Geological Society Guidebook for 1993 Annual Meeting, p. 55-65.

Good, S. C. and Huber, P, 1995, Taxonomic position of small bivalves from the Newark Supergroup; a unionid dwarf and a nonmarine myalinid. Geological Society of America, Abstracts with Programs v.27, n.1, p.49

Gore, P. J. W. and Renwick, P. L., 1987, Paleoecology of floodplain lakes in the Durham sub-basin of the Deep River basin (Late Triassic), North Carolina. Geological Society of America, Abstracts with Programs - v.19, n.2, p.86

Grimes, W. S., in progress, Geology of the northwestern Kittrell 7.5-minute quadrangle, Vance County, NC: M.S. thesis, North Carolina State University.

Hasiotis, S. T. and Dubiel, R. F., 1993, Crayfish burrows and their paleohydrological significance; Upper Triassic Chinle Formation, Fort Wingate, New Mexico. in Lucas, S. G. and Morales, M. (eds.), The Nonmarine Triassic, Bulletin of the New Mexico Museum of Natural History and Science, v.3, p.G24-G26.

Heller, M. J., 1996, Lithostratigraphy and structure of the Lake Wheeler area, Wake County, North Carolina: M.S. thesis, North Carolina State University, 135 p.

Hoffman, C. W., 1994, Triassic sedimentary rocks of the central Durham basin, North Carolina: *in* Stoddard, E. F., and Blake, D. E., (eds.), Geology and Field Trip Guide, Western Flank of the Raleigh Metamorphic Belt, North Carolina: Carolina Geological Society Guidebook for 1994 Annual Meeting, p. 63-68.

Hoffman, C. W. and Gallagher, P. E., 1989, Geology of the Southeast Durham and Southwest Durham 7.5-minute quadrangles, North Carolina. North Carolina Department of Natural Resources and Community Development, Geological Survey Section, Raleigh, NC, Report 92.

Horton, J. W., Jr., Blake, D. E., Wylie, A. S., Jr., and Stoddard, E. F., 1994, Geologic map of the Falls Lake-Wake Forest area, north-central North Carolina--A synopsis: in Stoddard, E. F., and Blake, D. E., (eds.), Geology and Field Trip Guide, Western Flank of the Raleigh Metamorphic Belt, North Carolina: Carolina Geological Society Guidebook for 1994 Annual Meeting, p. 1-11.

Huber, P., Lucas, S. G., and Hunt, A. P., 1993, Revised age and correlation of the upper Triassic Chatham Group (Deep River Basin, Newark Supergroup), North Carolina. Southeastern Geology, v. 33, no. 4, p. 171-193.

Huber, P., Lucas, S., Hunt, A., 1993, Vertebrate biochronology of the Newark Supergroup Triassic, eastern North America. in Lucas, S. G. and Morales, M. (eds.), The Nonmarine Triassic, Bulletin of the New Mexico Museum of Natural History and Science, v.3, p.179-186.

Lucas, S. G., Heckert, A. B., and Huber, P., 1997, *Aetosaurus* (Archosauromorpha) from the Upper Triassic of the Newark Supergroup eastern United States, and its biochronological significance. Paleontology, in review.

McDaniel, R. D., 1980, Geologic map of Region K (Person, Granville, Vance, Warren, and Franklin Counties): North Carolina Department of Natural Resources and Community Development, Geologic Survey Section, Open-File Map 80-2, scale 1:100,000.

North Carolina Geological Survey, 1985, Geological Map of North Carolina: scale 1:500,000.

Olsen, P. E., 1977, Stop 1 - Triangle Brick Quarry: In G. L. Bain and B. W. Harvey (eds.), Field Guide to the Geology of the Durham Triassic Basin, Raleigh: Carolina Geological Society. p. 59-60.

Olsen, P. E., 1986, A 40-million-year lake record of early Mesozoic climatic forcing. Science, v. 234, p. 842-848.

Olsen, P. E., 1997, Stratigraphic record of the early Mesozoic breakup of Pangea in the Laurasia-Gondwana rift system. Annual Reviews of Earth and Planetary Science v. 25, p. 337-401.

Olsen, P. E., Froelich, A .J., Daniels, D. L., Smoot, J. P., and Gore, P. J. W., 1991, Rift basins of early Mesozoic age, in Horton, W., ed., Geology of the Carolinas, University of Tennessee Press, Knoxville, p. 142-170.

Olsen, P. E., McCune, A. R. and Thomson, K. S., 1982, Correlation of the early Mesozoic Newark Supergroup by Vertebrates, principally fishes: American Journal of Science, v. 282, p. 1-44.

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, 174 p.

Parker, J. M., 3d, 1966, Triassic reptilian fossil from Wake County, North Carolina.[Elisha Mitchell Science Society Journal v. 82, no. 2, p. 92.

Renwick, P. L., 1988, Paleoecology of a floodplain lake in the Durham Sub-basin of the Deep River basin (Late Triassic), North Carolina. M.S. thesis, Emory University; Atlanta, 324 p.

Stoddard, E. F., 1995, Geology of the eastern Lake Wheeler and western Garner quadrangles: unpublished mapping on file with the North Carolina Geological Survey.

Stoddard, E. F., and Blake, D. E., (eds.), 1994, Geology and Field Trip Guide, Western Flank of the Raleigh Metamorphic Belt, North Carolina: Carolina Geological Society Guidebook for 1994 Annual Meeting, 110 p.

Woodcock, N.H., and Fischer, M., 1986, Strike-slip duplexes: Journal of Structural Geology, v. 8, p. 725-735.

Wooten, R. M., Clark T. W., and Davis, T. L., 1996, Bedrock geologic maps, and fracture and fault data for portions of the Cokesbury and New Hill 7.5-minute quadrangles, Deep River Triassic Basin, Wake County, North Carolina, North Carolina Geological Survey Open-File Report 96-3, 46 p.