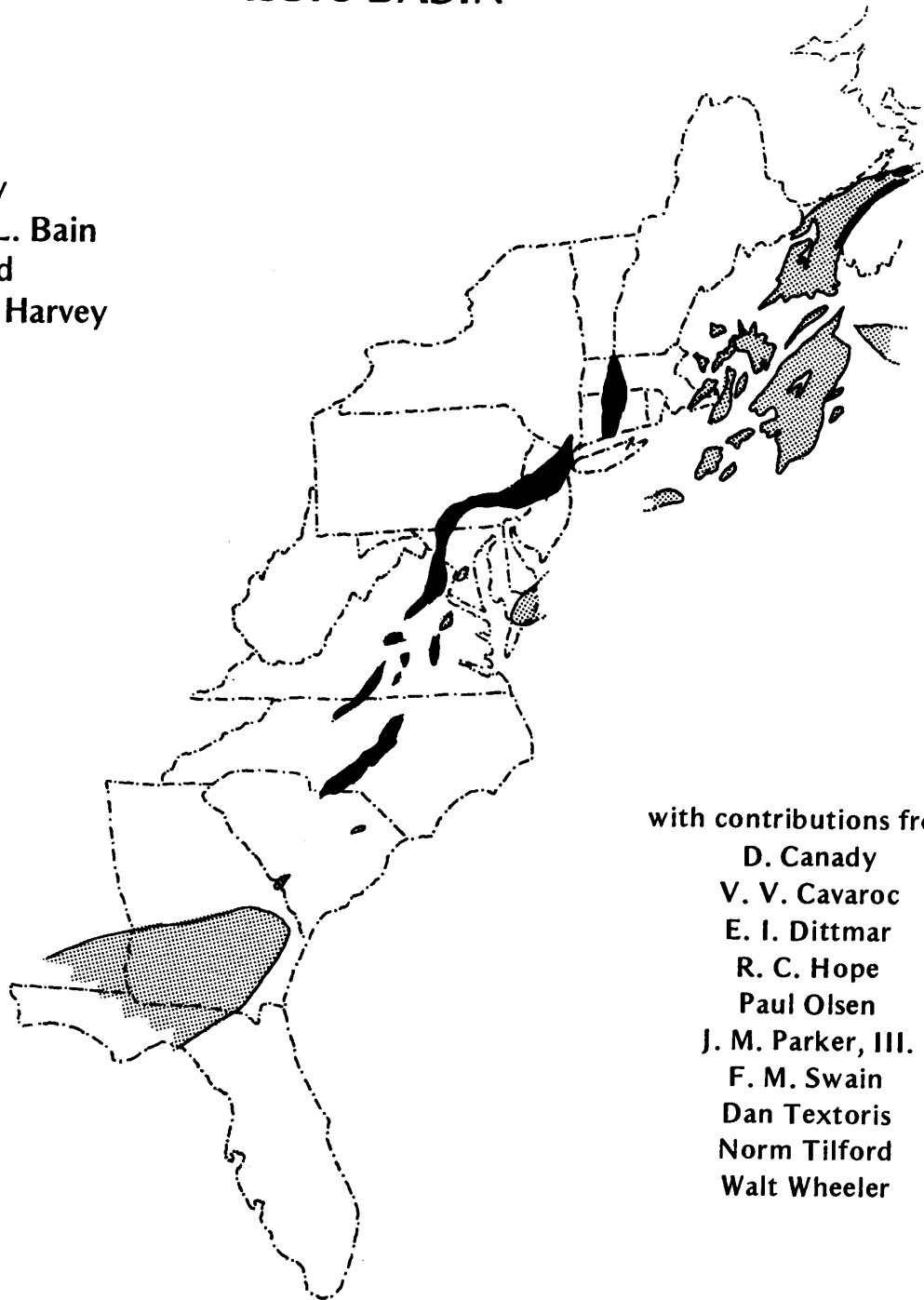


FIELD GUIDE TO THE GEOLOGY OF THE DURHAM TRIASSIC BASIN

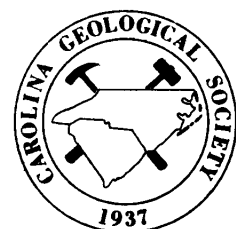
By
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Carolina Geological Society
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COVER PHOTO: DISTRIBUTION OF EAST COAST TRIASSIC BASINS



EXPOSED TRIASSIC BASINS



BURIED TRIASSIC BASINS

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DURHAM TRIASSIC BASIN**

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INTRODUCTION

The existence and general distribution of the continental Triassic basins of the Eastern United States have been known since the early 1800's. They are in the backyard of practically every major Eastern university where they have served professor and student alike as a classic example of continental sedimentation. There are more than 2000 Triassic papers in the geologic literature. It is important to note what is obvious from that literature. Geologists still disagree about the exact structural origin, climate, and past and present-day geometry of the basins. The diversity of ideas and the related controversy result from the general scarcity of reliable subsurface data and erroneous structural and sedimentological conceptual models.

The data deficit is caused partly by the very nature of the Triassic rocks. Being continental, there are rapid vertical and horizontal facies changes; thus, there are few mappable temporal marker horizons. Apparently having no vast store of valuable mineral resources, there are few deep wells for subsurface control. Being more easily eroded in contrast to the surrounding crystallines, they are in a lower, topographically less favorable position for good surface exposures, particularly in the south where there are no inter-bedded basalt flows.

Conceptual ideas of the tectonic origin of the Triassic basins range from gentle geosynclinal downwarps through extensional faulting of the Appalachian orogen to aborted proto-Atlantic rifts in Late Triassic time. The former extent of the Triassic deposits has been envisioned as: (1) a continuous deposit covering an area largely represented by the pattern of exposed Triassic basins shown by the inset of Figure 1 which were later broken up by a regional anticlinal warp;

(2) a distribution pattern and basin size little changed from today; or (3) a distribution pattern similar to that of today but with basin size somewhat larger. The continuing discovery of new basins beneath the Coastal Plain sediments at least as far east as the outer edge of the continental shelf demonstrates their widespread nature and the probable physical continuity of a continental facies with its European counterpart.

Obviously, this discovery also obviated the creation of oppositely dipping half grabens dropped symmetrically and keystone-like along a NE-SW Piedmont anticlinorium at the collapse of the Appalachian orogen as proposed by Longwell (1922).

Recent work by Klein (1962) in the maritime provinces, Wessel (1969) in the Connecticut basin, Glaeser (1966) and Abdel-Monen and Kulp (1968) in the Newark-Gettysburg basin, and many others demonstrates the local nature of the basins' sediment source and effectively kills the "Broad Terrane Hypothesis" as envisioned by Russell (1880) and revived by Sanders (1960).

The structures of the individual basins are variously described as half graben, full graben, and faulted remnants of synclinal warps. The attitude of the bedding is described as: (1) homoclinal toward a master boundary fault; (2) homoclinal toward a master fault but interrupted by normal, post-depositional, down-to-the-boundary faults; and (3) intrabasin horsts and grabens rotated uniformly toward a master fault. Some works show all rocks at the surface dipping uniformly toward one margin; others show local reversals; and a few, more-detailed maps show large intra-basin areas wherein the dips are fairly uniform but different from adjacent areas.

The geophysical work done in this basin by the U.S. Geological Survey, that done by Sumner (1977) in the Newark-Gettysburg basin, and the drill hole reported by Cloos

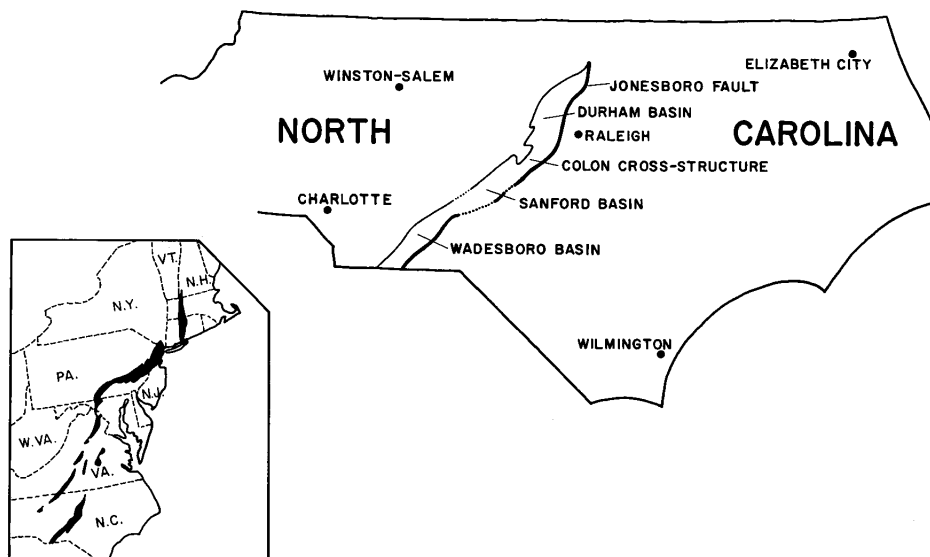


Figure 1. Location map of Durham-Wadesboro Triassic basin.

and Pettijohn (1973) clearly demonstrate that the East Coast basins are not deepest at the master fault. Indeed the half-graben boundary fault in this and probably the other basins is a fault zone several kilometers wide that steps down basinward giving a cross-basin profile that is asymmetrically pseudo-synclinal. Recent investigations of dike displacements along the eastern border of the Durham and Sanford basins by EBASCO Services show that latest movement on the Jonesboro fault is at least post-dyabase-intrusion.

The depositional contemporaneity of the East Coast Triassic basins espoused by Fontaine (1883), Redfield (1856), and Ward (1899) and documented by their excellent early paleontological and paleobotanical work has recently been refined. The palynology of Cornet (1977) and Cornet and Traverse (1975) demonstrates that sedimentation began first in the southern basins and gets progressively younger to the northeast where it is occurred as late as Early Jurassic. Paleomagnetic work by de Boer (1967) and geochemistry studies by Weigand and Ragland (1970) on the tholeiitic dikes also gives evidence for a progressive southwest to northeast decrease in age and change in composition.

Of all controversies, however, the climatic environment existing at the time the continental redbed facies were deposited is perhaps the point about which there is the least unanimity. To some, the presence of coal necessitates humid tropical rain forest. To others, the red hematitic sandstones and shales containing gypsum, analcime, anhydrite, and occasionally salt crystals necessitates either a hot, arid climate or arid with seasonal rainfall (savannah) climate.

This fieldtrip into the Durham and northern part of the Sanford basins will not solve the redbed facies controversy nor address the concept of early Atlantic rift origin of the Triassic basins. However, the fieldtrip is designed to visit

outcrops selected to show the structural model that has evolved from the recent geophysical work, the interrelationships of the different facies present in the basins, and the refined stratigraphic concepts derived from them. The scarcity of outcrops and subsurface data has been alleviated by using a variety of remote sensing and geophysical techniques. These techniques which are described below include aeromagnetic mapping, sidelooking airborne radar (SLAR), Landsat photo-lineament interpretation, seismic profiling, electrical sounding, and gravity mapping.

GEOLOGY OF THE DURHAM-WADESBORO BASIN

General Relationships

Triassic basins are distributed along the Atlantic Seaboard from Nova Scotia to the subsurface of Florida (fig. 1). They extend eastward beneath the Cenozoic cover onto the Continental Shelf where they continue to be discovered by exploratory drilling and geophysical work. The Durham-Wadesboro basin extends almost across North Carolina, was filled with continental clastics in Late Triassic, and is the southernmost exposed of this series formed from Late Triassic to Early Jurassic in tectonically negative areas.

The East Coast Triassic basins are mostly half grabens and/or tilted full grabens. In North Carolina, the Durham-Wadesboro basin is bounded on the east and southeast by high angle normal faults traditionally known as the Jonesboro fault. The basin trends southwestward from near the North Carolina-Virginia line to a point a short distance across the North Carolina-South Carolina line. It is about 226 km long and averages about 16 km in width. The Durham-Wadesboro basin is traditionally divided into four

substructures which from north to south are: Durham basin, Colon cross-structure, Sanford (or Deep River) basin, and Wadesboro basin. Most of the present study has concentrated on the Durham sub-structure. The Durham-Wadesboro basin is surrounded and presumed underlain by the crystalline Piedmont complex composed of acid igneous intrusives, metavolcanics, metasediments, and high-rank metamorphic rocks. Continental sediments preserved in the Durham-Wadesboro basin include maroon to grey fanglomerate, conglomerate, feldspathic sandstone, graywacke, argillite, siltstone, mudstone, black shale, and minor amounts of chert and coal.

The Triassic sedimentary mass was intruded by diabase dikes and sills in Late Triassic and Early Jurassic time. Individual dikes are spaced about one km apart and range from 0.3 to 20 m in width and up to 16 km in length. Dikes trend north, northwest, northeast, and east, but are predominantly north and northwest.

The basin is further faulted longitudinally and transversely creating individual horsts and grabens that are as small as 1 km by 3 km. Most are tilted to the east and southeast; a few are tilted to the north. Vertical displacement along the largest known intra-basin fault is at least 300 m and perhaps as much as 600 m. All known faults are high angle and normal. Diabase dikes crossing the eastern border are right-laterally offset. More extensive strike slip is suspected but has not been demonstrated.

Sedimentation and stratigraphy

The sedimentary pile preserved in the Durham-Wadesboro basin contains rock types whose lithologic variety, mineralogy, and inherent depositional structures reveal much about its tectonic origin and evolution, paleotopography, climate, and sediment dispersal patterns.

The alluvial fans, the angularity of the sand, the poor sorting of the fines, the size of the boulders in the fanglomerates, and the freshness of the feldspar in the Durham basin all point to short transport distance from an elevated source area to a nearby valley floor or graben of low relief. The depositional environment was not unlike modern deposition in the intermontane basins of the Basin and Range Province or of the Salton Trough of Southern California.

Typically in this environment alluvial fans formed as a direct result of a sharp break in slope and a corresponding decrease in stream competency. The decrease in stream competency was further aggravated by loss of water through the permeable alluvium by "sieving". The resulting high ratio of rock detritus to water at the fan surface created shallow braided streams that slowly (?) prograded the coarse proximal fan deposits over the finer distal ones. Individual facies within the fan are quite localized and were caused by intermittent faulting and attendant increased relief, by meandering bifurcating channels, and by variability of stream

discharge.

Braided streams on the fan surface created longitudinal and transverse bars which migrated downstream. Sedimentary features of both the upper and lower flow regime are characteristic- i.e., parallel laminae, thin lenticular shales, many interclasts, cut-and-fill structures, and planar and trough cross-stratification (Smith, 1970). There is a general down-the-fan slope increase in ratio of planar cross-stratification over horizontal due to the decreased flow. Longitudinal bars of coarse poorly sorted debris dominate in the upper reaches of the braided stream. Transverse bars containing finer, better sorted material dominate at the distal end of the fan.

The finer grained sediment at the distal end of the fan was carried onto the basin floor into a playa, bolson, or lake or was further distributed in the floodplain of through-flowing longitudinal streams.

Springs and seep lines developed on the valley floor near the boundary fault(s) of these fault-controlled intermontane valleys or grabens and supported local swamps and peat bogs. Swamps also formed in shallow water in the low lying sites remote from active deposition which existed parallel to the natural levees of through-flowing streams of low gradient and along the edge of ponds and lakes. Organic matter accumulated on the lake or bog floor to form peat where conditions were sufficiently reducing to prevent its biologic destruction.

Preservation of the organic rich mud produced a black or brown shale, the laminations of which record periodic, seasonal (?) changes in sediment or vegetative supply. Preservation and compaction of peat from a more sediment-free environment produced coal, the type and quality of which is determined by the ratio of organic matter to sediment, the type of organic matter (rooted or floating, spore and pollen, or algae), and whether formed in place or disarticulated and transported.

In those situations where evaporation exceeded precipitation because of either seasonal or perennial aridity, such as existed in the playa environment, dissolved salts were concentrated in starved lakes and

large expanses of salt flat developed. Various chemical deposits accumulated on the lake floor including normal carbonate, chert, anhydrite and gypsum, glauberite, and salt either in discrete beds or in fine dispersal in the bottom muds. Chert precipitated where there was a seasonal fluctuation in alkalinity and an abundance of detrital silica. Silica taken into solution at pH 9 and above was precipitated when the pH was rapidly reduced by the rotting vegetation killed as the lake periodically dried (Peterson and Borch, 1965). Analcime was sometimes formed in the bottom muds of those lacustrine environments marked by seasonal aridity and soda-rich sediment (Van Houten, 1977).

Thus, the fanglomerate-conglomerate association shown in figure 2 marks the locations of greatest relief and least

transportation. They are associated with the border faults and are principally developed on the east side in the Durham basin and on the west side in the Wadesboro basin. The fanglomerates represent scree and mud-flow deposits from the steep terrain along the bounding fault scarps. Fanglomerates and conglomerates also mark the points where major intermittent (?) streams entering the basin dropped their bedload. The presence of conglomerates in thinner beds near the middle of the Durham basin record the locations of major braided stream channels and very possibly times of movement on the faults. There is no rigid evidence that longitudinal or transverse growth faults were active during sedimentation to produce mid-basin conglomerates.

The fanglomerate-conglomerate association on both sides of the basin contains clasts identical to the crystalline rocks immediately adjacent, attesting to local infill from both sides. Mixed with the clasts, especially along the western border in the argillite-graywacke-conglomerate facies (fig. 2), however, are rounded to subrounded quartz pebbles and cobbles which indicate greater transport distance and/or mixed supply.

The coarse tan arkosic fluvial facies (granite wash) best developed between Carpenter and Apex and north and east of Creedmoor represents the mid-fan braided stream deposits of one such alluvial fan. Paleo-stream direction data of Custer (1966) indicate that this particular deposit may have originated from the southeast side—perhaps south and west of Holly Springs. However, the macroscopic petrology indicates a plutonic source. Although there is a small granitic pluton south and west of Holly Springs, the volume and general lack of metamorphic clasts indicate a larger mostly granitic source such as the Rolesville pluton to the northeast. Tentative paleocurrent data of E.I. Dittmar do indicate that the prevalent paleostream direction in this facies is south and southwest both in the Carpenter-Apex area and in the Creedmoor-Oxford area. This particular facies is the uppermost unit penetrated in the Sears No. 1 test well and is approximately 610 m thick at that point. It grades laterally and vertically into the red and grey, finer, less sorted deposits.

This mid-fan facies is also represented (although possibly not the same rock stratigraphic unit) on the western side of the basin between Durham and Chapel Hill (fig. 2), on the western side of the Deep River (Sanford) basin in the subsurface, and throughout much of the Wadesboro basin. The general lack of red color is due to the absence of hematitic cement caused by the winnowing of the hematitic muds or its general absence from the source materials. Fluvial conditions along probable longitudinal streams are indicated by channel and point-bar sands and overbank muds. Coarse cut-and-fill channel sandstones record where distributary channels cut through fine deltaic muds. The poorly sorted overbank and distal fan deposits into which the above facies grade are represented by the mudstones, siltstones, and massive argillites in a down-fan direction and by the bimodal

coarser sandstones in an up-fan direction. They are best represented in the Durham basin (fig. 2) in the area south of Apex and west of Holly Springs toward Brickhaven, from the Raleigh-Durham Airport north to Oak Grove and southwest from that point toward Farrington. In the Sanford area, they are characteristic of both the Pekin and Sanford Formations indicating that this particular facies was being deposited somewhere in the basin throughout the Late Triassic. The red mudstones and argillites of this facies are utilized throughout the basin as a source of brick. Locally this facies is unquestionably lacustrine.

Triassic lakes are recorded by limy evaporitic (?) red mudstones, flaggy micaceous sandstones, red and black fossiliferous shale, and chert. Limy redbeds, nodular and thin limestones, and chert are generally confined to the interfan areas. Lacustrine conditions occurred in at least two places in the basin at different times. In the Pekin Formation in the Colon cross-structure (fig. 2) and southward at the base, flaggy sandstone and fossil-bearing argillite occur, followed by chert in the Colon cross-structure and apparently by limy shales, coal, and reported chert (Reinmund, 1955) in the Sanford area.

Farther north and somewhat later, lacustrine and paludal conditions are marked in the Oak Grove-Bethesda-Research Triangle-Morrisville area by thin-bedded micaceous sandstone overlain by two thin beds of red to black fossiliferous shale succeeded by a thick section of limy redbeds containing widespread chert beds. One additional fossiliferous zone is present in this facies, apparently high in the section, between the Olive Branch Church community and the Raleigh-Durham Airport.

The gray to bluff paludal shales and thin coal zones in the Pekin from west of Sanford to north of Moncure (Olive Chapel), the relatively thick coal and humic shale of the Cumnock Formation of the Sanford area and its thinner equivalent near Brickhaven, and the thin black shales centered around the Research Triangle Park occur in the same geographic area as the lacustrine facies and are interbedded with them. They are obviously products of the same tectonic environment within the basin—coal, shale, limy redbeds, or chert formed in swamp, lake, or playa in response to different combinations of climate, water depth, and sediment supply.

Stratigraphic Correlation

Lateral correlation of stratigraphic units in the Durham basin is complicated by the rapid facies changes described above and extensive faulting which has placed units of different ages into juxtaposition. Most workers have proposed a tripartite division of the sediments in the Durham-Wadesboro basin solely on the basis of a coal and black shale occurrence in the Sanford area near the middle of the section named the Cumnock Formation. The Cumnock is overlain

DURHAM TRIASSIC BASIN

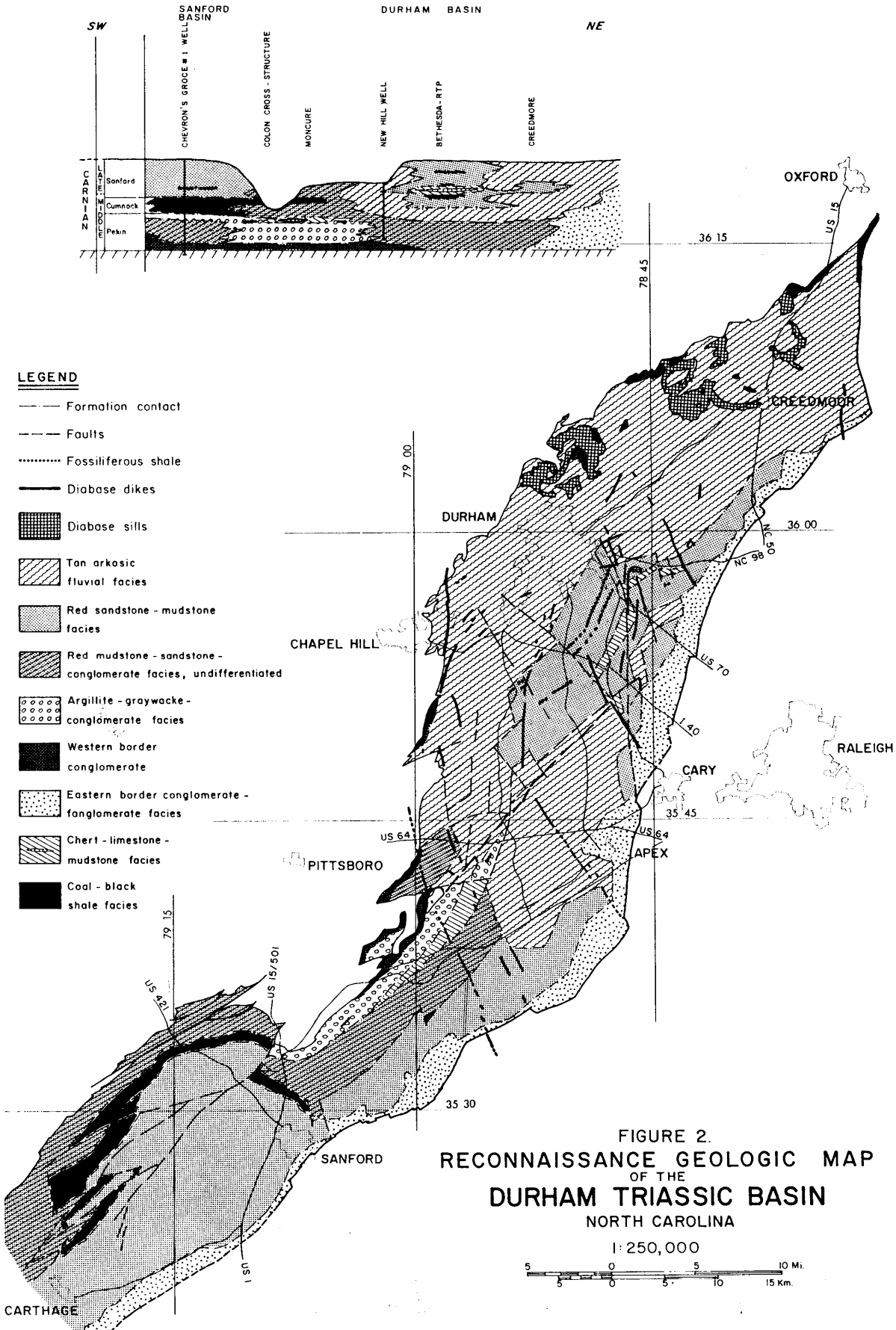


FIGURE 2.
 RECONNAISSANCE GEOLOGIC MAP
 OF THE
 DURHAM TRIASSIC BASIN
 NORTH CAROLINA

by the Sanford and underlain by the Pekin Formations. The facies correlation chart inset of figure 2 is an attempt to illustrate the probable vertical and lateral facies relationship existing between the Durham and Sanford basins based on our understanding of the latest structural models, paleocurrent directions, palynology, and surface geology.

The coal and the black shale of the Cumnock Formation near Sanford and its thinner equivalent near Brickhaven, the grey shales and thin coal zones of the Pekin Formation on the Colon cross-structure, the thin black shales of the Research Triangle Park-Bethesda area all contain plant remains and fresh water biota--Ostracoda, fish bones and scales, and Branchiopoda. Fossils from these rocks are adequately described in Emmons (1852), Jones (1862), Redfield (1856), Fontaine (1883), Ward (1899), Murray, Jr. (1938), Prouty (1931), Hope and Patterson (1969), Delevoryas and Hope (1971) and Swain and Brown (1972). They are further discussed by Swain, Hope, and Olsen in this guidebook. Many of the same fossils are represented in all the shales. Almost without exception they indicate a late Triassic age. Unfortunately, their age ranges are too long to be very diagnostic of specific horizons within the Durham basin.

Recent work by Cornet and Traverse (1975) and Cornet (1977) on the palynoflorules of the East Coast Triassic basins demonstrates that spores and seeds can be used not only to correlate between the basins, but also to establish temporal zones within the basins. As a direct result, coal from the Copper Creek prospect near Moncure formerly placed in the Cumnock is now found to be Pekin in age. The age change has greatly simplified the stratigraphic problems of the area. Chert in the Moncure area, which is an apparent down-strike equivalent of the Copper Creek prospect, cannot be traced laterally across the Bonsal-Morrisville fault zone into the chert of the Research Triangle Park. Chert and the associated black shales in the Research Triangle Park area are thought now to be slightly younger than the Cumnock Formation on the basis of the faunal (?) evidence. The other possibility--that the two chert beds were age equivalents--would have either required that the entire west and northwest part of the Durham basin be older than Pekin or the basal part of the Colon cross-structure be a Cumnock equivalent.

Cornet's correlations between the basins indicates sedimentation began first in the North Carolina and Virginia basins in the middle Carnian and became progressively younger northward. Reference to Cornet's correlations between the basins and to our facies correlation diagram (fig. 2) indicates that lacustrine and paludal conditions occurred in different basins at different times, probably in response to a proper combination of tectonic framework and climate. The traditional assumption that the lacustrine-paludal facies position near the middle of the basins also indicates middle position in the simple, monoclinial, half-graben model is erroneous (Bain, 1973 and Sumner, 1977).

This simple tripartate division based on coal does not

hold up even within the Durham-Wadesboro basin. The chert in the Moncure area was not penetrated in the Sears No. 1 test well at New Hill even though correlation of the basal 350 m of the Sears well within the basal section of the Groce No. 1 well west of Sanford shows that the Sears well was within 90 m of being through the Pekin. Although the lower section of the Sears well correlates with part of the lower section of the Groce No. 1 well, the Cumnock is very thin or absent in the Sears well. The upper section of both wells are in entirely different facies.

The position of the fanglomerate at the surface along the down-faulted side of the Durham and other basins is frequently cited as evidence for continued periodic movement along the downthrown side. Recent resistivity, gravity, and aeromagnetic evidence shows that the basin floor "steps up" near the border fault making at least some of the surface-exposed fanglomerates early and in a basal position. In fact, part of the eastern side of the Sanford basin now mapped as Sanford Formation is most probably Pekin in age. Thus, the evidence for or against continued movement through Durham deposition may be eroded away. The presence of the basal conglomerate does indicate strong initial relief and may indicate only the time of maximum local relief between Piedmont and basin floor.

Provenance

The Durham-Wadesboro basin is surrounded by crystalline rocks of the North Carolina Piedmont. The northern part of the basin lies between the Carolina slate belt to the west and the Raleigh plutonic-gneiss belt to the east. The southern half of the basin is entirely within the slate belt. The slate belt is a low-rank metamorphic complex (greenschist) of silicic land wastes and felsic to mafic pyroclastics which has an overall andesitic composition (McCauley, 1961). Individual rock types include: slate, (laminated argillite), graywacke, tuff breccia, crystal lithic tuffs, flows, and phyllite.

The Raleigh plutonic-gneiss belt has an acid plutonic core surrounded by gneisses, schists, phyllites, graywackes, and quartzites ranging up to the almandine-amphibolite metamorphic facies (Parker, 1968). The Raleigh side of the basin contains some pegmatite. Both provinces are intruded by many quartz veins.

Few studies have attempted to determine the specific source area or character of the Durham-Wadesboro basin parent material. Whitehead (1962) concluded from a study of the major rock types exposed at the surface in the Sanford basin that the grain composition indicated a metamorphosed Precambrian sediment source now largely eroded away. More specifically, he proposed that the source lithology consisted predominantly of moderate-rank metamorphic rocks

accompanied by low-rank metamorphic granite and interbedded volcanic rock. Klein (1969) found sedimentation from both sides of the basin based on K-Ar and paleocurrent measurements.

Liggon (1972), from examination of a 448-m core from near Gulf in the Sanford basin, concluded that the source area was comprised of rocks of the quartz-albite-muscovite-greenschist metamorphic facies.

Reinemund (1955) found that the conglomerate and sandstone at the base of the section in the Sanford basin contained clasts identical to metamorphic rock types outcropping in the Slate Belt west of the basin. Crossbedded arkosic sandstone and schist arenite channel deposits indicated to him that streams flowed from the west and northwest into the basin on the west side (base of section) and from the southeast in the middle and upper part of the section. He also noted an increase in coarseness in the Sanford Formation to the southeast, an increase in arkose toward a Carboniferous (?) granite pluton to the southeast, and an abundance of muscovite in the Triassic from rock types exposed on the east side of the basin.

Bell, and others (1974) reported that the Wadesboro basin shows no eastward coarsening of sediments toward the southeast, although an arkosic conglomerate clearly derived from a granite along the eastern border occurs near the western border. Randazzo, Swe, and Wheeler (1970) found that arkose (K feldspar) content increases to the east in the Wadesboro basin.

It is therefore obvious that there was coarse sediment contribution from both sides of the Durham-Wadesboro basin. The available paleocurrent data from Reinemund (1955), Patterson, (1969), Custer (1966), and the present work of Dittmar indicate that streams depositing the alluvial fans along the southeast border flowed into the basin more or less at right angles to the border as might be expected. Dittmar's work in the coarse tan arkosic facies shows a strong south-southwest direction. His data from the other facies are not sufficient at present to draw a tentative conclusion about their paleocurrent directions. Patterson's work also indicated a strong southwest direction across the Colon cross-structure. As stated above, Reinemund found a few indicators at the base pointing toward the southeast.

STRUCTURE

The conceptual structural model described below is heavily dependent on our interpretation of several geophysical techniques used in the Waste Disposal Evaluation project. Although conclusions are augmented by the reconnaissance geologic map and the stratigraphic correlations, the correctness of the structural model depends much on the accuracy of the geophysical interpretation.

Airborne Magnetometer Survey

The earth's total magnetic intensity in and surrounding the Durham Triassic basin has been mapped at 252 m (500 ft.) above ground level with an airborne magnetometer on flight lines spaced on 0.8 km (0.5 mile) apart. The aeromagnetic map was a cooperative project of the U.S. Geological Survey, the N.C. Division of Mineral Resources, and the Wake County Planning Commission. Figure 3 is a contour map of the measured data. In this illustration, the magnetic reference field has been removed and the rectified data contoured at a 60-gamma contour interval.

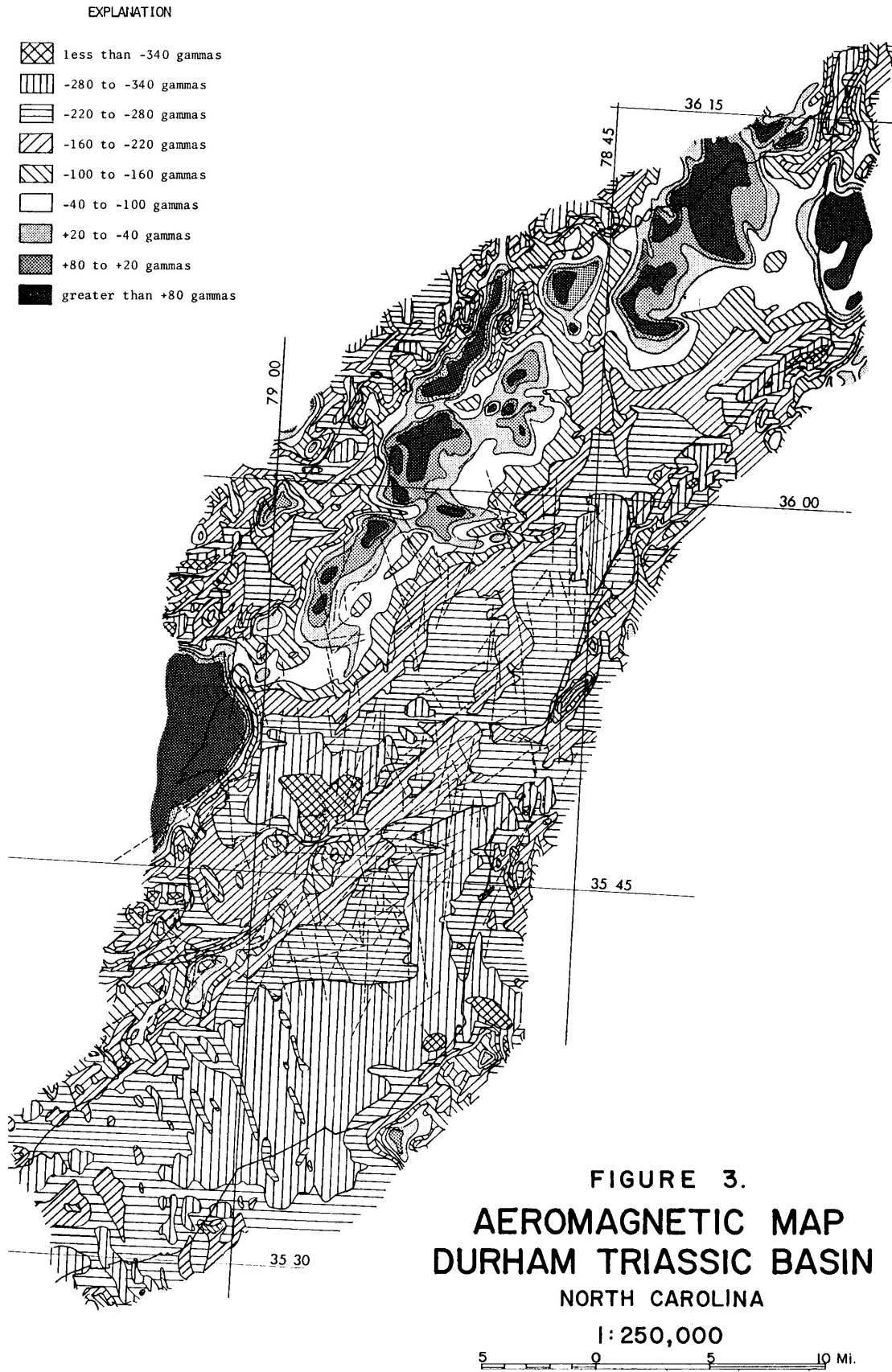
The map shows the northern half of the northeast-trending Triassic basin, whose sedimentary rocks have a comparatively low magnetic intensity, bounded on both sides by numerous high frequency, high amplitude anomalies. The area is intruded by northwest to north-northeast trending diabase dikes having a narrow linear magnetic anomaly signature 20 to 300 gammas above that of the surrounding rocks. A few dikes trend east-west.

The entire western side of the Durham basin from Chapel Hill northward is either underlain by Basement rock of high magnetic susceptibility or intruded by thick diabase "sills". The major magnetic feature within the basin is a northeast-trending intra-basin fault appearing as a well-defined positive anomaly that bisects the basin and dies out to the northeast. As on the Bouguer map (fig. 6), the positive magnetic anomaly over this fault is interpreted as a down-to-the-northwest fault effectively separating the areally smaller 100-milligal anomaly from the much larger one to the southeast. (See also section A-A' of fig. 7.) A basin is created on the northwest side similar to that west of the Jonesboro fault.

Side-Looking Radar Lineations

Side-Looking Radar (SLAR) imagery has been flown by the U.S. Geological Survey for the Triassic rocks from Wadesboro to Oxford, N.C. The lineations observed in the Durham area from both a NW and SE "look" have been transposed to a corrected base and are overlain on Figures 3 and 6. They are also combined on a cartesian plot (fig. 4) with east coast lineaments and diabase dike trends.

As is true of Landsat images, most of the lineations observed on the SLAR imagery can be identified in the field or from maps as diabase dikes, faults, lithologic contacts, streams, roads, power lines, pipe lines, and field-edge corner reflectors. Power lines, pipe lines, most field-edge reflectors, and roads can be eliminated by their extreme linearity or straightness. Abandoned roads, logging trails, slightly sinuous roads, and property lines that trend in one direction (usually due north and due east) give more trouble. Some observed linears cannot be identified on the ground. However, most such linears are parallel to known geologic elements and are therefore assumed to have some geologic significance.



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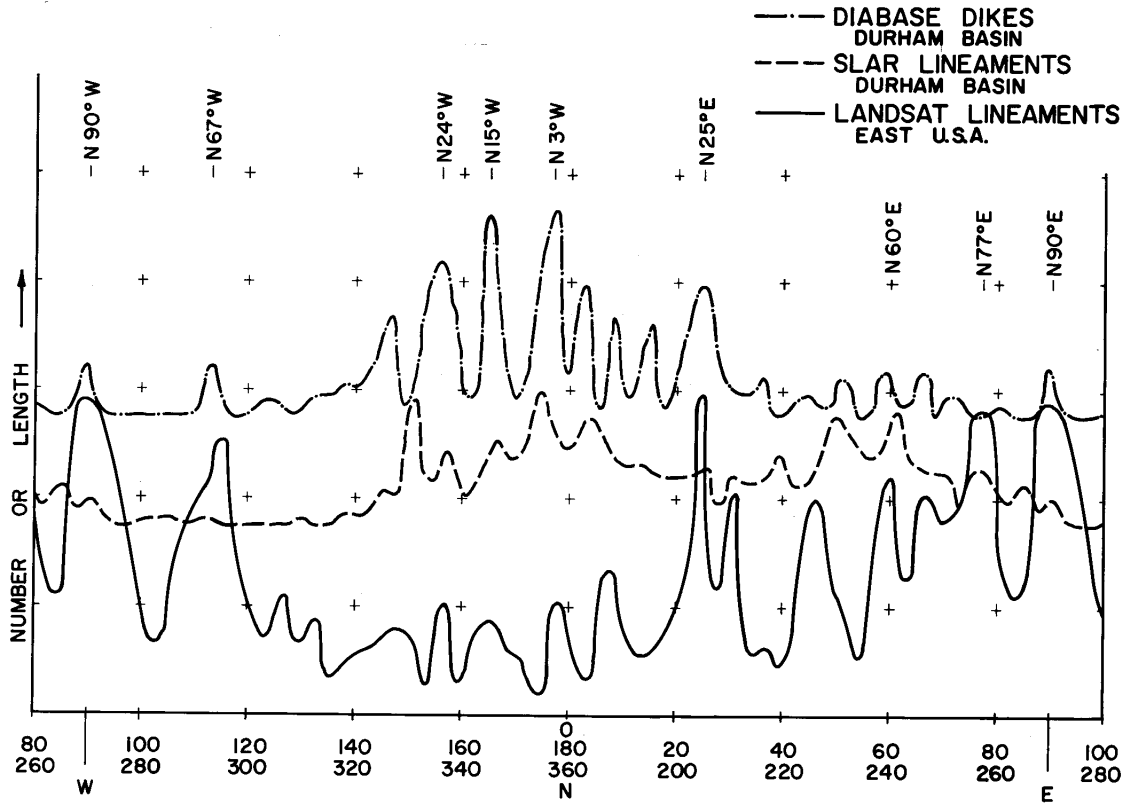


Figure 4. Cartesian plot of SLAR and Landsat lineaments and diabase dikes.

Although not differentiated on the above figures, diabase dikes give unique raised outlines and are readily mapped from the SLAR imagery where the length and thickness of the dikes permits their resolution. Faults and fractures appear as linear depression or *en echelon* offsets. Roads and streams appear as linear depressions, but the stream depression on radar imagery is generally broader in cross section.

The strike of observed radar lineaments cluster in narrow zones along N15° W to N 3° E, N 50° -62°E, and N 20° -30° W. Very few lineaments are observed in the east-west direction apparently because this was the approximate "look" direction perpendicular to the flight path.

The close agreement between radar lineaments and magnetic anomalies is exhibited by Figure 3. Major discontinuities in magnetic expression are bounded by many of the radar linears. Many of these have been identified on the ground as faults or dikes. Comparison of radar linears to the Bouguer gravity anomaly map shows the same general agreement. (See fig. 6.) From comparison of these radar lineaments with gravity and magnetic anomalies and with the basin margins, most of the linears are concluded to be geologic elements. They have proved a valuable tool to refine and extend the structural stratigraphic model produced from sparse outcrop data and were used to locate geologic contacts in preparation

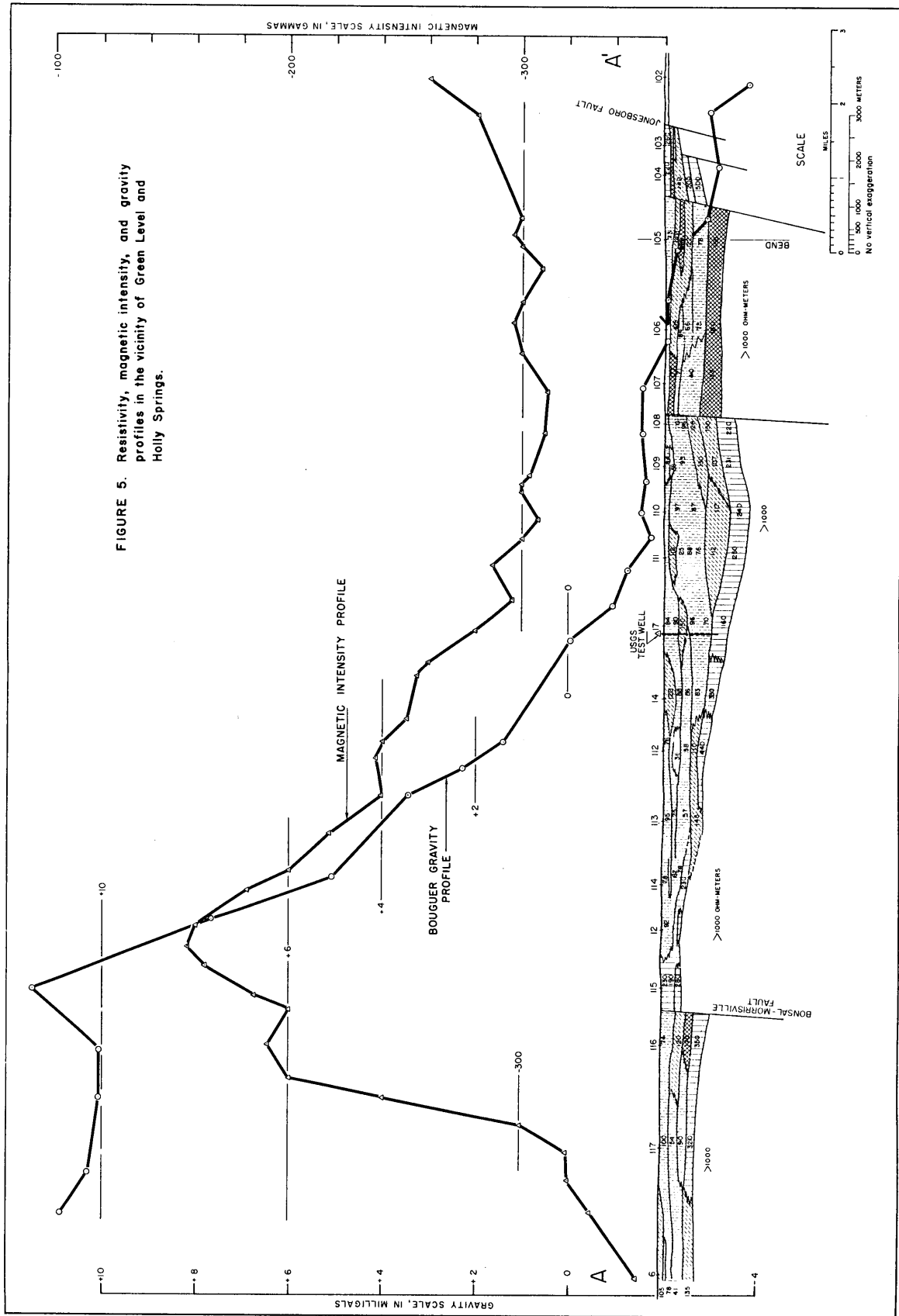
of Figure 2 where surface data were unavailable.

Resistivity Surveys

Subsurface exploration using the resistivity or electrical sounding method depends on the contrast in electrical conductivity of earth materials and their thicknesses relative to their depth. Best results are obtained where the geologic units are thick and their resistivity contrasts large. Precision decreases with decrease in thickness and resistivity contrast and increase in depth. Differences in porosity, clay content, and interstitial water chemistry are the primary causes of electrical contrast. The U.S. Geological Survey made 62 Schlumberger electrical soundings along roads in the Durham-Wadesboro basin in an effort to determine basin geometry, the depth of the sedimentary infill, and the spatial distribution of individual facies.

Field interpretations showed a range of 1000 to 7000 ohm meters for the Piedmont rocks. Subsequent measurements in the Triassic rocks indicated that they characteristically range from 30 to 350 ohm meters and that the underlying Basement rocks have resistivities of > 1000 ohm meters, similar to those rocks measured outside the basin. To better illustrate the vertical and lateral distribution of resistivity across the basin, cross sections or resistivity profiles were constructed from the individual soundings.

FIGURE 5. Resistivity, magnetic intensity, and gravity profiles in the vicinity of Green Level and Holly Springs.



Section A-A'

Figure 5 is a section trending north-northwest for 23 km from a point 7 km southwest of Holly Springs through New Hill to a point 6 km northwest of Green Level. The horst-and-graben character of the Basement floor is clearly displayed. The profile indicates movement on the Bonsal-Morrisville fault has caused vertical separation of the overlying Triassic rocks of up to 600 m. The southeastern edge of the basin is not defined here by a single master fault, but by a fault zone several km wide which causes the crystalline Basement floor to "step up" to the eastern boundary. As a result the geoelectrical section has a pseudosynclinal shape. Near Green Level the basin shallows to approximately 380 m at sounding 12. The deepest part of the basin along this profile is predicted at sounding 110 at 1800 m.

To construct this profile, vertically adjacent electrical units of similar resistivity were combined into larger units of more convenient ranges. The individual electrical units may or may not correspond to Triassic rock units. In general, rocks are formed of quartz, feldspar, and other silicates which are relatively poor conductors. The resistivity of such rocks is a function of two independent variables—the shape, size, and degree of interconnection of the pore spaces and the resistivity of their contained fluid (Guyod, 1944). Thus, the variations in salinity (conductivity) of the Triassic formation water may mask vertical and lateral changes in resistivity caused by facies changes.

If the resistivity assumptions and restrictions are correct, this resistivity section resembles the geologic section. This conclusion is supported by:

1. The interpretation of sounding 17 predicted a Basement depth of 1350 m and the USGS Sears #1 well drilled to a total depth of 1150 m did not encounter Basement.
2. The known location and sense of displacement of the Bonsal-Morrisville fault was correctly shown by the electrical section A-A'.
3. The eastern limit of the Triassic basin as shown on section A-A' agrees with known locations of the Jonesboro fault zone.
4. The depths on the electrical sections agree reasonably well with the estimates obtained from aeromagnetic, gravity, and seismic data.

Another resistivity profile (not shown) 13 km in length was run beginning at a point 10 km (6 mi.) due west of Sanford, N.C. and ending 7 km (4 mi.) due south of that city just east of the basin edge. This profile also exhibits the lateral discontinuities in resistivity seen in the above profile that are due either to faulting, facies changes, or differences in water quality.

The profile passes through the site of Chevron's Groce #1 well where the depth to Basement (1550 m--5080 feet) is known. Sounding 128 has an interpreted Basement depth that agreed within 4 percent of the drilled depth. Again, this profile shows that the Basement floor and the overlying Tri-

assic rock dip progressively eastward as conventionally thought. However, the eastern edge is quite different. There is no electrical evidence for a master Jonesboro fault with 1500 to 2200 m of throw. Rather, the Basement floor begins "stepping up" within 2-5 km of the eastern edge, and the cumulative throw is distributed among the fault slices.

Figure 5 also shows the Bouguer gravity and magnetic intensity profiles along section A-A'. Shallow Basement at the Bonsal-Morrisville fault zone and at the eastern boundary has the greatest visible effect on these profiles. Other discontinuities in the slope of these curves are caused by intra-basin faults of shorter throw and by contrasts in Basement rock types.

Gravity Measurements

The gravity data available for the Durham-Wadesboro basin at the project's inception are published in Mann and Zablocki, 1961. Over 1200 stations were measured in or near the Durham-Wadesboro basin by Zablocki (1959). Bouguer and residual anomaly maps and 8 gravity profiles were produced from the data. The deepest parts of the basin are inferred from the negative anomalies to occur through most of the central area of the Wadesboro basin, in the Sanford area of the Deep River basin, and between Moncure and Cary and in a long narrow area from Carpenter to Oxford in the Durham basin.

Additional gravity measurements were made in the Durham basin for this project to fill in large areal gaps in the Zablocki data net and to take advantage of the newer more densely spaced vertical control. The addition of over 600 stations reduced the spacing from 3 to 6 km to about 2 km.

The resulting more detailed Bouguer (fig. 6) and residual gravity maps support the general sub-basinal character of the Triassic outlines by Mann and Zablocki but also reveal the Durham basin to be more complex than previously thought. In particular, the maps show that the gravity low in the Apex area is separated from the northern part of the basin by the northeast trending fault or horst in the Basement previously discussed. This horst or fault zone extends northeasterly from the slate belt inlier 3.2 km north of Moncure to at least the vicinity of Morrisville. The trend and attitude of the above structure is also supported by the resistivity, aeromagnetics, surface geology, and lineament studies above. The detailed gravity map also supports the presence of an additional gravity low on the northwest side of this structure which is interpreted to be a downfaulted wedge of Triassic rocks. Too, and perhaps more importantly, the shape and gradient of the gravity anomalies along the eastern border of the basin indicate the possibility that there is much variation in depths to Basement along it.

The regional gravity gradient was removed graphically along several sections across the Bouguer map of this project to determine the thickness and general geometry of the Tri-

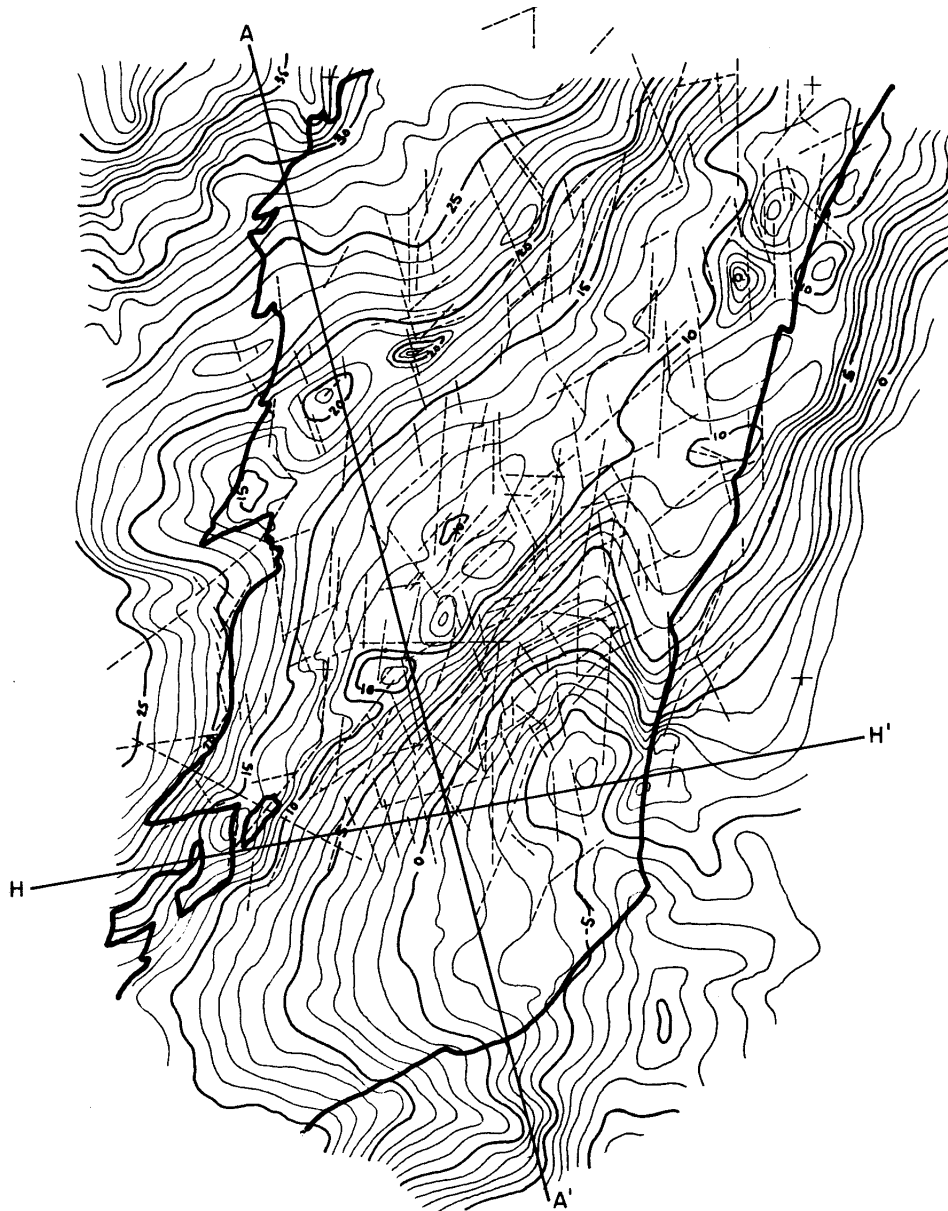


Figure 6. Bouguer gravity map of the Durham - Apex area.

assic sedimentary infill. The locations of these sections are shown on Figure 6.

Section H-H' (fig. 7b) is approximately east-west from a point 6.4 km (4 miles) north of Moncure on the western side to a point 3.2 km (2 miles) south of Apex on the eastern side. Use of a density contrast of 0.117 gm/cm^3 yields depth estimates consistent with electrical sounding depths along this profile. Depth to Basement at the New Hill well site is estimated from the residual profile anomaly at that point (6.8 mgal) to be 1390 m (4560 ft.) and at the deepest point along the profile to be 1695 m (5560 ft.). The average bulk density of the Durham Triassic rocks is 2.556 gm/cm^3 . The underlying rocks then have a density of slightly over 2.67 gm/cm^3

— a reasonable density for acid igneous and pyroclastic rocks. Use of the 0.117 gm/cm^3 gravity contrast in areas of the basin underlain by more basic rocks will result in depth estimates that are too deep.

Section A-A' of Figure 7a is a residual profile from the Chapel Hill area to a point in the border 9 km (5.6 miles) southwest of Holly Springs. It coincides with the resistivity profile A-A' except at the extreme SE end. Note that the residual profile shows the basin divided into 3 negative gravity anomalies that become larger and more negative to the southeast. Geologically they represent 3 down-to-the-southeast fault slices or half grabens. The Moncure-Morrisville fault zone discussed above is represented by the sharp posi-

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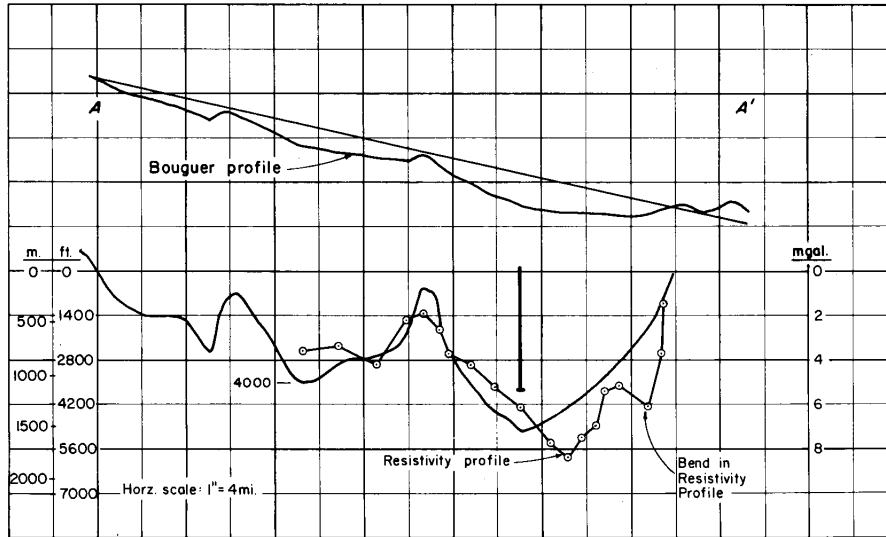


FIGURE 7A. Residual profile A-A' along Resistivity profile A-A'.

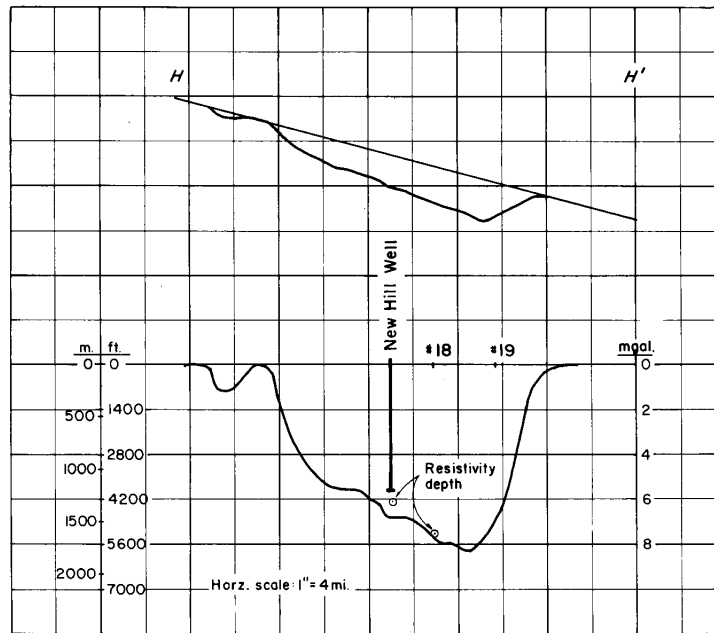


FIGURE 7B. Residual profile H-H'.

tive anomaly approximately in the center of the profile. Maximum depths along the profile are estimated from the gravity profile to be approximately 915 m (3000 ft.), 1224 m (4000 ft.), and 1677 m (5500 ft.) in each of the sub-basins.

The resistivity profile plotted at the same scale agrees in general shape with the residual gravity. The deepest part of the basin, however, is indicated farther to the southeast at about 1830 m (6000 ft.).

The SLAR lineaments have also been overlain on the Bouguer map (fig. 6) to show the fidelity of lineaments to gravity anomalies. The gravity low near Apex and the Bon-

sal-Morrisville fault zone are particularly well outlined by these lineaments.

Seismic Velocities in Triassic Basin Sediments

Reflection and refraction seismology was used in the Durham basin to help determine the sedimentary and structural geometry of the Triassic infill. Three traverses were shot in 1973-74 in cooperation with the Geology Department of the University of North Carolina at Chapel Hill. The longest is a 20-km reflection profile which crosses the Jonesboro fault zone at the basin's eastern edge. This profile also indi-

cates that Basement "steps up" toward the Jonesboro. The second and third are refraction profiles that were located near the basin's western edge.

The rocks of the Durham basin are typical of Triassic basins elsewhere--mostly sandstones and shales. The characteristic velocities of these rocks, however, are not typical of sandstone and shales from non-Triassic environments. Typical values for sandstones and shales elsewhere (Birch, 1942) range from 1800 to 3600 m/sec. The refraction data of two lines indicate seismic velocities ranging from 3400 to 4200 m/sec overlying Basement having a velocity ranging from 5600 to 6100 m/sec. There is apparent but not conclusive evidence of a directional velocity anisotropy within the Triassic rocks. Sonic-log velocities in a nearby 3750-ft. test well ranged from approximately 3600 to 5500 m/sec below 500 ft. Laboratory analysis by Terra Tek of core from the above test well under simulated overburden conditions indicated velocities ranging from 3300 to 5100 m/sec. Measurements made on 3 pieces of core along 3 directions at 120 spacings normal to the horizontal axes of the core indicated a maximum p-wave anisotropy of 4 percent. Sonic-log measurements taken by I.W. Marine in the Dunbarton basin, S.C. (personal commun., 1975) indicate velocities in excess of 5800 m/sec for Triassic rocks in that basin.

Diabase Intrusives

The Piedmont and New England provinces of Eastern United States were intruded by swarms of diabase dikes in Late Triassic (?) and Jurassic time (190 to 140 million years). Although some dikes are probably of latest Triassic age, and basalt of similar composition was extruded into the sedimentary pile in the northern basins in Late Triassic, the dikes are clearly not tectonically related to genesis of the Triassic basins. Diabase dikes cross the Triassic basins without change in trend and although widespread in the east, their westward occurrence ends abruptly as if confined to a specific crustal zone. They are much more difficult to distinguish from the rocks of the Piedmont, but the aeromagnetic maps indicate that they are just as numerous there. The diabase dikes change trend from NW in the southern Piedmont to nearly NE in New England. Most of the dikes in the Durham area occur between the due north and northwest direction (fig. 4 and fig. 8). Their outcrop pattern presumably represents a fossil tensional stress system(s) of Late Triassic (?) and Early Jurassic time.

The diabase dikes are deep crustal tholeites changing composition from predominantly olivine normative in the south to high and low titanium quartz normative in the north (Weigand and Ragland, 1970). The older diabase dikes appear to be in the south with a progressive change to younger age to the north.

The diabase dikes are vertical and are therefore post-basin rotation and sediment lithification. In the Durham

basin, they are offset right laterally along the basin's eastern boundary. The more detailed aeromagnetic map of the area from which Figure 3 was generalized indicates that *most* of the dikes within the basin are offset by faulting. If all of the dikes were emplaced at the same time in fractures produced by the same tectonic system, then regional changes in composition must be related to inherent compositional differences in the parent magma. This of course does not account for regional differences in adjacent dikes. If the dikes were emplaced at slightly different times, regional differences in composition could be explained by differentiation within the magma. If the progressive regional differences of dike orientation are due to that from changes in the principal stress direction which caused different sets of tensional fractures at different times in different places, then regional differences in the dikes may be related to dike swarm orientation. Because few dikes are found beyond the Brevard fault, it seems obvious that the tholeitic magma was available only from a deep source aligned in a NE-SW direction along the East Coast and that suitable fractures for intrusion were opened only in the East Coast block or blocks. This rules out tensional fractures produced by either right- or left-lateral trans-Appalachian shears and favors north-south shears. Movement along a north-south shear could not produce tension fractures in the northwest-southeast direction but does not account for dikes in the Durham area in the NNW, due north, and NNE directions unless they represent transition from one force to another or that diabase was also intruded into synthetic faults.

SUMMARY

The preceding geophysical data describe a fault graben more complex than previously thought. The fault that produced it probably was a deep crustal one expressed at the surface as a series of *en echelon* positive fault blocks which supplied sediment and negative ones which received that sediment. The irregular linear basin which resulted contains a spatial facies distribution controlled by the then existing combination of tectonic-climatic elements. The Colon cross-structure was negative during Pekin time, and the locus of a restricted lacustrine-playa facies. In Cumnock time the area west of Sanford was alternately a vast bog and lake wherein Cumnock coal and black shale accumulated. Still later, thin lacustrine shale, chert, and limy red beds accumulated in a lacustrine-playa environment in the Research Triangle Park area. All of these facies grade laterally into maroon, tan, arkosic, fluvial sandstone for which the tentative paleocurrent data indicates a major extra-basin source to the northeast for much of the Durham basin.

The basin was sliced and rotated along northeast-trending fracture zones and cross-faulted along a north-to-northwest fracture set resulting in an intrabasin horst-and-graben structural character. Individual horsts and grabens are trian-

DURHAM TRIASSIC BASIN

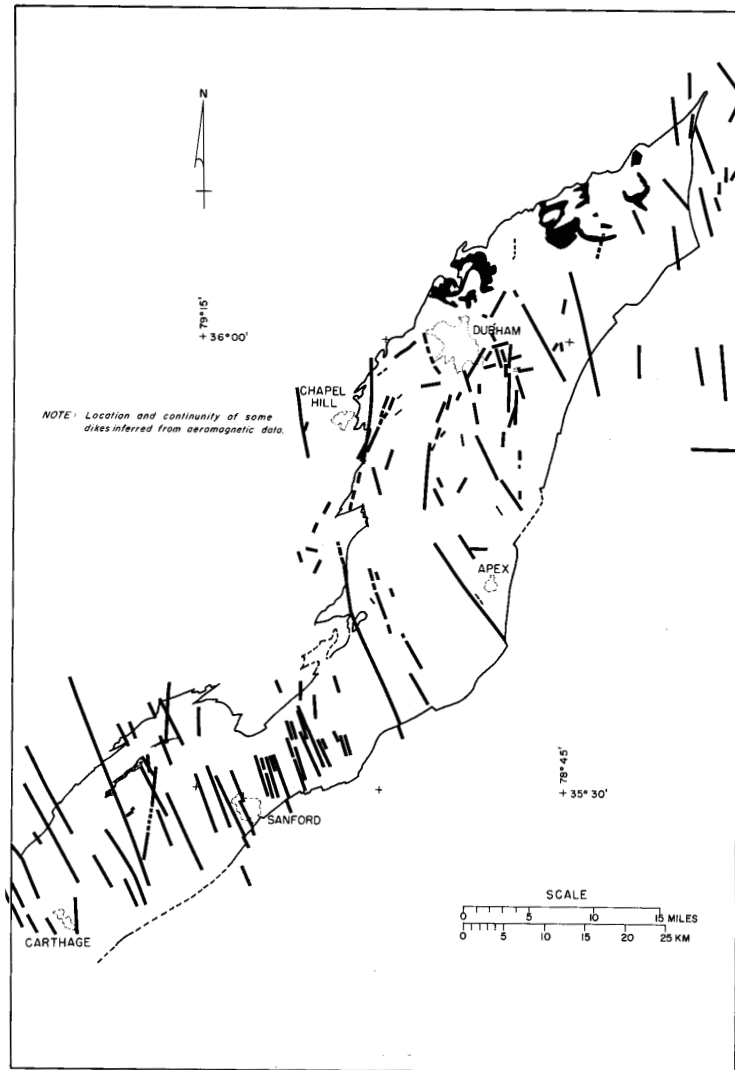


Figure 8. Diabase Intrusives Durham-Sanford Basin

gular to diamond shaped and pitch to the east and southeast. A few pitch north. Diabase dikes intruded the rotated sediment pile and were in turn faulted and offset by later tectonic adjustments in the Piedmont. The step-faulted border is probably a post-depositional phenomenon.

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FIELD TRIP LOG FOR FIRST DAY

October 8, 1977

The field trip will be by bus from the parking lot of the Ramada Inn at Apex, North Carolina. The trip will begin promptly at 8:00 a.m.

ElapsedInterval
MileageMileage

- | | | |
|-----|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0 | 0 | <i>RAMADA INN PARKING LOT.</i> Turn right on N.C. Highway 55 toward Holly Springs. |
| 0.5 | 0.5 | Road cut contains fanglomerate, conglomerate, and red mudstone. Road parallels Jonesboro fault zone located about 200 yards to your left. |
| 2.2 | 1.7 | Road crosses Jonesboro fault zone at this point into crystalline rocks of Piedmont. |
| 2.9 | 0.7 | Phyllitic rocks crop out in cut. |
| 3.0 | 0.1 | Road crosses back into fanglomerate of Triassic basin. Fault here has strike of about N30° W. |
| 3.9 | 0.9 | <i>HOLLY SPRINGS</i> town limit. The road has again crossed over Jonesboro fault into crystalline rocks. |
| 4.5 | 0.6 | <i>TURN RIGHT</i> on SR 1115 at DeWars Antiques and Interiors. Cross railroad track and bear left. |
| 6.2 | 1.7 | Bear right towards Holleman's Crossroads. |
| 6.8 | 0.6 | Approximate location of Jonesboro fault zone. Two electrical soundings on the next road to the southwest that descends into the basin indicate that basement "steps down" by a series of fault slices from 1000 ft., to 3300 ft., to its maximum local depth of 5000 ft. |
| 7.9 | 1.1 | Outcrop of red mudstone facies. |
| 9.9 | 2.0 | <i>HOLLEMAN'S CROSSROADS.</i> Continue straight ahead on gravel road SR 1130. Roads parallels southeastern border passing through |

interbedded red mudstone, muddy sandstone, and conglomerate. An electrical sounding made at this point indicates depth to Basement is about 5000 ft.

- | | | |
|------|-----|----------------------------------------------------------|
| 11.9 | 2.0 | Cross over railroad bridge. |
| 12.3 | 0.4 | <i>TURN LEFT.</i> (South) on dirt access road to quarry. |
| 12.6 | 0.3 | Park on left and walk 0.2 miles down hill to quarry. |

STOP1-Easternconglomerate-FanglomerateFacies.

V.V. Caravoc

This first stop is located about one km (0.62 mi) northwest of the Jonesboro boundary fault and provides an exceptionally good exposure of the "fanglomerate facies" of the eastern basin margin. Bedding attitude is N 15° E 17° SE. Figure 9, a sketch map of the outcrop face, shows the boundaries of major units. Fanglomerate boulders provide reasonably fresh samples.

The *depositional environment* is interpreted as an alluvial fan, probably representing moderately high gradient, braided stream deposition. The dominant lithologies are clast- to matrix-supported conglomerates and sandstones arranged in cycles of decreasing grain size upward. Each cycle base usually is marked by a pronounced scour which cuts up to two meters into the underlying cycle. Based on 251 randomly selected cobbles with long axes over 5 cm (2 in), 42 percent were 5-7 cm (2.0-2.75 in), 38 percent were 7-11 cm (2.75-4.33 in), and 20 percent were greater than 11 cm (4.33 in). The maximum clast size located was 53 cm (21 in). These grain sizes indicate that very competent, upper flow regime currents dominated the initial stage of the depositional cycles. The terminal stage of each cycle is removed by the later scour. However, the conglomerates do pass upward into poorly sorted sandstones which locally approach a pebbly, sandy mudstone. The common, matrix-supported clasts, the absence of pronounced crossbeds in the sandstone, and the "non-sorting" of the finer tail of the depositional cycle indicate abrupt decrease in current velocities with consequent "dumping" of suspended and saltation loads. Together with rapid changes within units (i.e. B,C), these features suggest a system of braided, sediment-choked channels with thalwegs continually shifting as sediment bars build up to deflect the current. If this interpretation is correct, then the major units (A to G) shown in Figure 9 may represent periodic (seasonal) fluctuations in overall discharge. However, given the scale of the outcrop (about 6.5 m or 20 ft.) relative to that of an alluvial fan (in kms.), unit breaks probably reflect simply

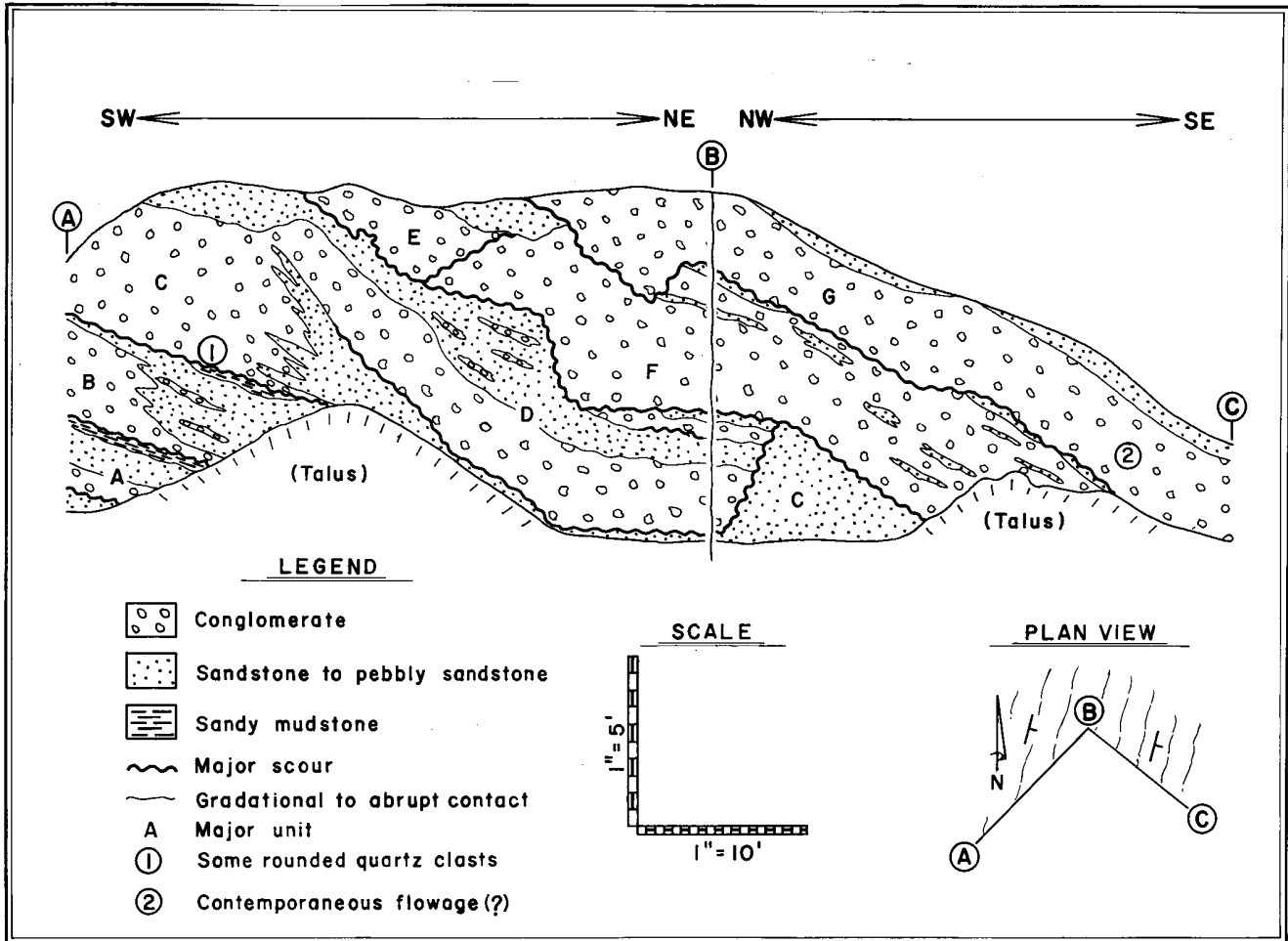


Figure 9. Field Stop 1.

shifting of sediment transport.

The *source* of this fanglomerate is interpreted to be the adjacent Jonesboro fault scarp. In J. C. Griffith's model of sediment dispersal with transport, the high degree of heterogeneity within units relative to between units would place these deposits near their erosional source. This is in contrast with the much better size-sorted sandstone, mudstone, and claystone of later stops within the basin.

Composition of individual clasts is quite variable. A rapid tabulation of 204 clasts greater than 5 cm (2 in) indicates:

43 percent	non-foliated, visibly crystalline, dominantly intermediate to mafic rocks, black to green
13 percent	non-foliated, visibly crystalline, dominantly felsic (quartz feldspar ± others), light color

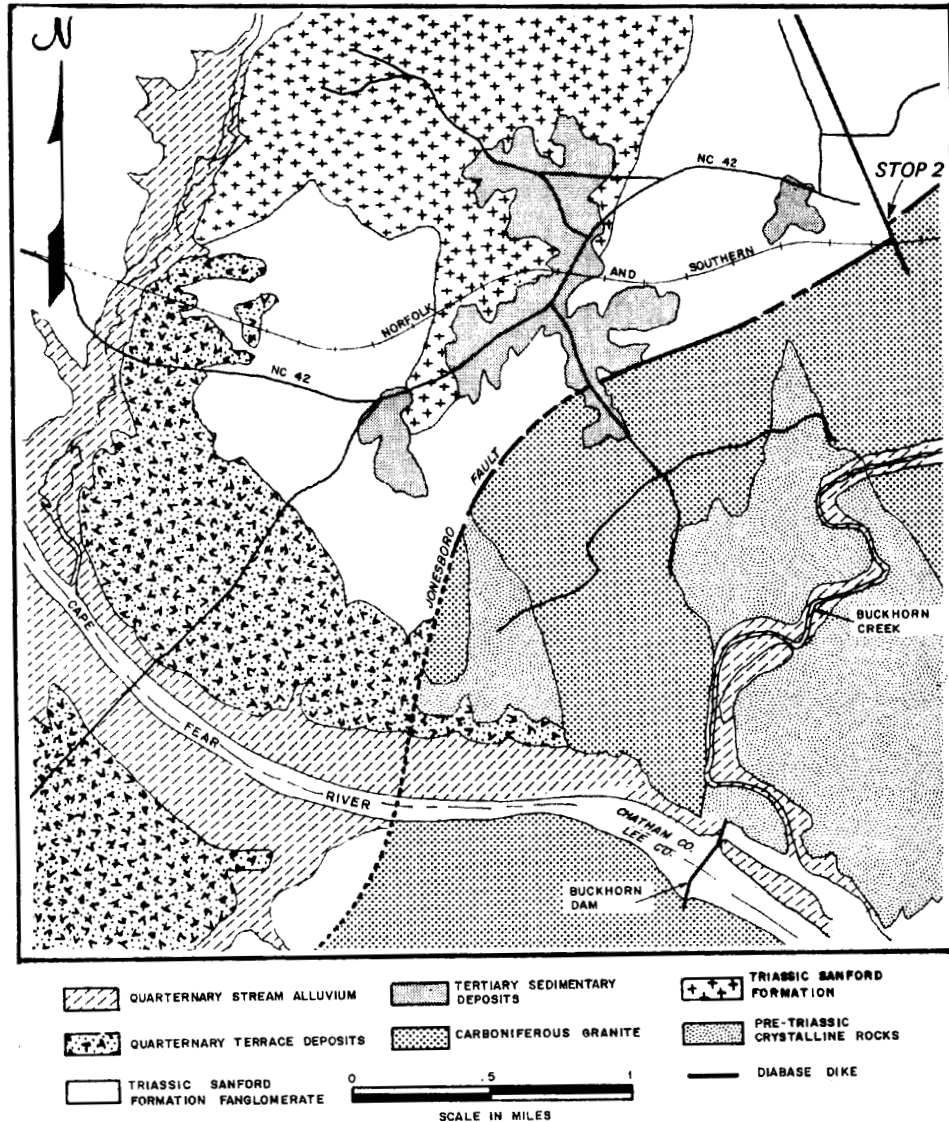
35 percent	markedly foliated, fine- to coarse-grained (schistose, phyllitic, slaty)
9 percent	miscellaneous others, including quartz

These clast types generally are compatible with the phyllites, meta-arkoses, greenstones, mica gneisses, and locally exposed igneous complexes mapped (Region J Map) in the adjacent upthrown side of the Jonesboro fault.

Makeup of the clasts also argues very strongly for short transport distance. Many of these clasts are "non-durable" rock types which would not survive the physical stresses of appreciable transport. Based on a visual estimate of 80 random clasts, 29 percent are rounded, 55 percent are subrounded, and 16 percent are angular to subangular. Interestingly, no statistical association of clast type and roundness could be detected (Chi-square, 4 d. f., n=80).

No traces of woody remains have been found in this

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Source: *Geologic Map of the Deep River Coal Field (Reinemund, 1955)*

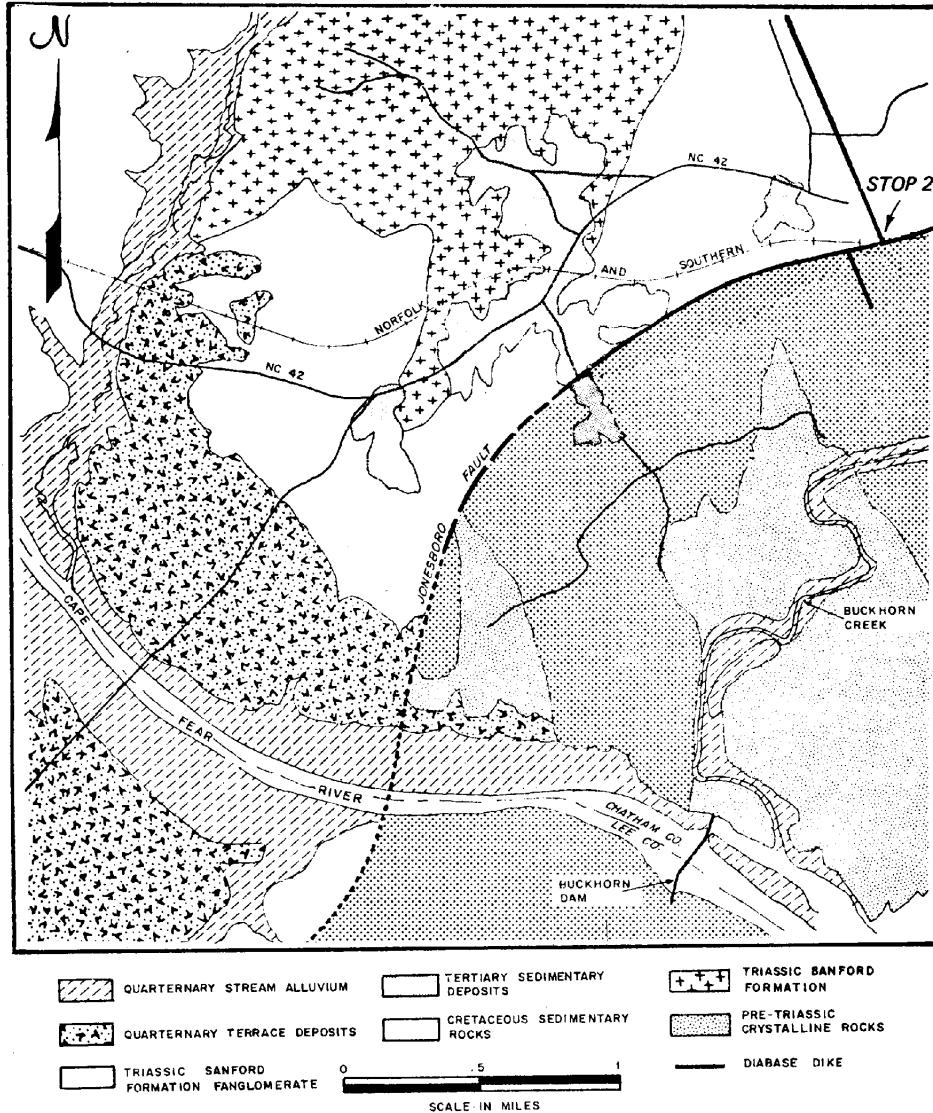
Figure 10A. Original interpretation (1975) of the Jonesboro Fault, Chatham and Lee Counties.

eastern conglomerate facies from here northwest to Interstate 40, despite their occurrence in some western-edge conglomerate. This suggests a somewhat higher depositional interface of these alluvial fans along the eastern margin of the Durham basin. Uncommon, well-rounded, sub-spherical, fine to medium quartz pebbles (both clear and milky) occur in the eastern conglomerate facies (i.e., base of C). Normally the transport abrasion required to round these quartz clasts should have completely destroyed the more common, but less durable clast types. The roundness of these quartz pebbles suggests a mixed source for the conglomerates— a mineralogically mature “highland” stream load (clay + quartz ± feld-

spar/mica), combined with mineralogically immature debris primarily derived from a steep fault scarp.

E.I. Dittmar reports that a tilt-corrected paleocurrent direction from 25 imbricated platy clasts (all 5 cm) measured on the face of the southeast end of the quarry have an average azimuth of 011.

- 12.9 0.3 Turn around and return to road. **TURN LEFT** on SR 1130 and continue southwest toward Corinth.
- 13.4 0.5 Chatham County-Wake County line. SR 1130 changes to SR 1914.
- 14.9 1.5 Road crosses over fair outcrop of fanglomerate-conglomerate-mudstone facies as is descends



Source: *Geologic Map of the Deep River Coal Field (Reinemund, 1955)*

Figure 10B. Revised interpretation (1975) of the Jonesboro Fault, Chatham and Lee Counties.

to White Oak Creek.

- 15.9 Road crosses north-trending diabase dike(s) marked by changes in soil color and a few pieces of float.
- 16.0 *TURN LEFT* onto SR 1912.
- 16.2 *TURN LEFT* onto N.C. Highway 42 toward Jonesboro fault zone which is about 100 feet beyond railroad track.
- 16.5 *JONESBORO FAULT ZONE.*
- 17.0 *TURN AROUND* at construction site and return to vicinity of Jonesboro fault zone. Park on right shoulder *CAREFULLY.*

STOP 2 - Diabase Dike — Right Laterally Offset

Tilford and Canady

Exposures at this stop illustrate reinterpretation of structural and age relationships between the Jonesboro fault and near vertical diabase dikes, based on portable magnetometer surveys conducted in 1975. As mapped and interpreted by Reinemund (1955), the dikes were thought to be continuous, following faults offsetting the Jonesboro fault at this locality (figure 10a) and others. As presently mapped (fig. 10b), the dike is shown to be offset right laterally approximately 750 feet by the Jonesboro fault.

Six magnetometer traverses were run at this locality (fig. 11). Traverses 1 and 2 were completed to confirm the location and record the magnetic “signature” of

DURHAM TRIASSIC BASIN

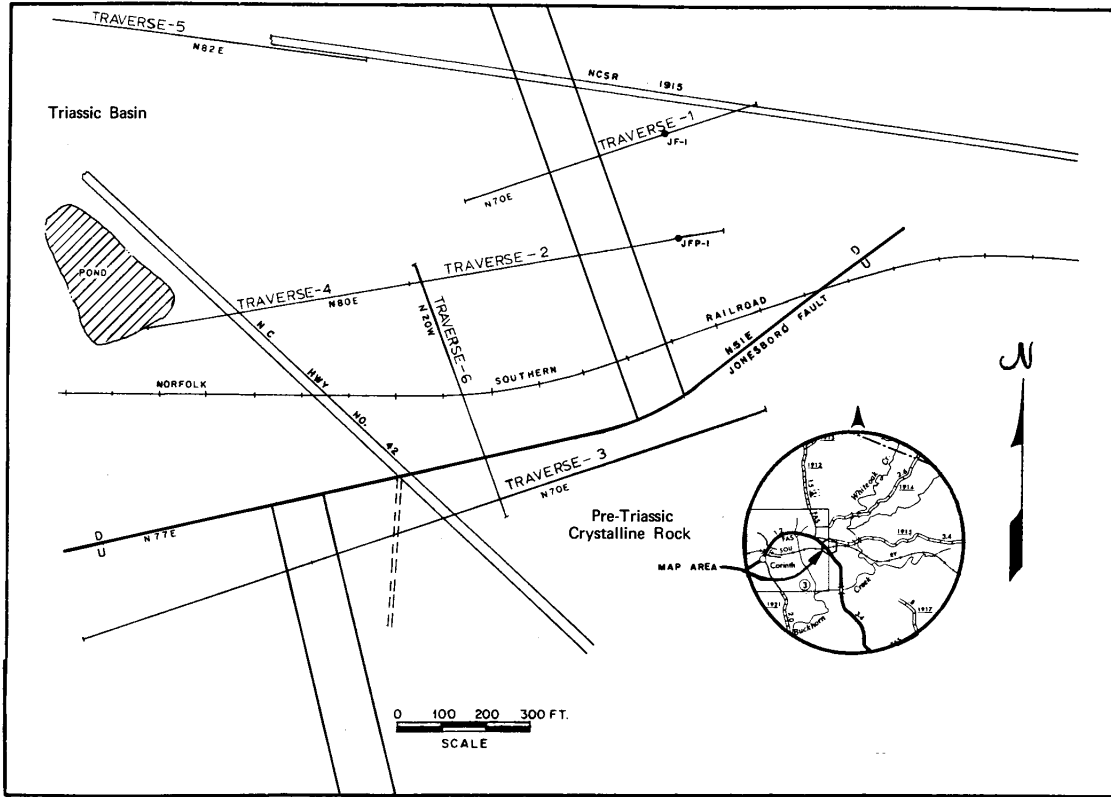


Figure 11. Magnetometer traverses of Jonesboro Fault / dike intersection (Stop 2).

the dike in the Triassic basin to the northwest of the Jonesboro fault. Traverse 3 was run in crystalline rock across a dike south of the Jonesboro fault. The magnetic signature of this dike was similar to that of the dike at the northwest of the fault. Traverses 4 and 5 were run to determine if the northerly dike extended into crystalline rock on the southern side of the fault; no evidence for this was found based on the magnetic survey. Traverse 6, run perpendicular to the fault, showed that no diabase material was emplaced along the fault.

The results of these investigations at this locality suggest both dikes truncate at the Jonesboro fault and that they are genetically related. Both dikes have the same strike and are similar in width, magnetic intensity and profile, and verticality. Therefore, it is concluded that the dikes are a single intrusive that has been offset by the Jonesboro fault.

The investigation into the structural relationship of the Jonesboro fault and diabase dikes to the north and south was expanded to four other localities, based on the results of the magnetic survey at this stop. While the Jonesboro fault was initially thought to be offset by several diabase-filled, cross-cutting faults (fig. 12), this expanded study at five locations shows that the

dikes were intruded prior to the last movement on the Jonesboro fault. As the dikes are Late Triassic (?) and Jurassic, this implies movement having some lateral component during Jurassic time. There is no evidence the dikes follow faults or other pre-established planes of weakness.

Continue west on N.C. Highway 42 toward Corinth after stop.

- 19.0 1.5 Corinth
- 19.8 0.8 *BEAR RIGHT* on SR 1916 toward Brickhaven.
- 21.3 1.5 Brickhaven Village. Site of Cherokee Brick Company. The Triassic rocks have progressively fined as we have moved westward across the Colon cross-structure. The fine-grained red mudstone and argillite are quarried here for brick.
- 22.6 1.3 Coal prospect in old roadcut on left. This is possibly the northern extremity of the coal swamp in Cumnock time,
- 22.8 0.2 Abandoned Cherokee Brick Quarry.
- 24.6 1.8 *BUSY RAILROAD TRACKS.*
- 24.8 0.2 *TURN LEFT* on SR 1011.

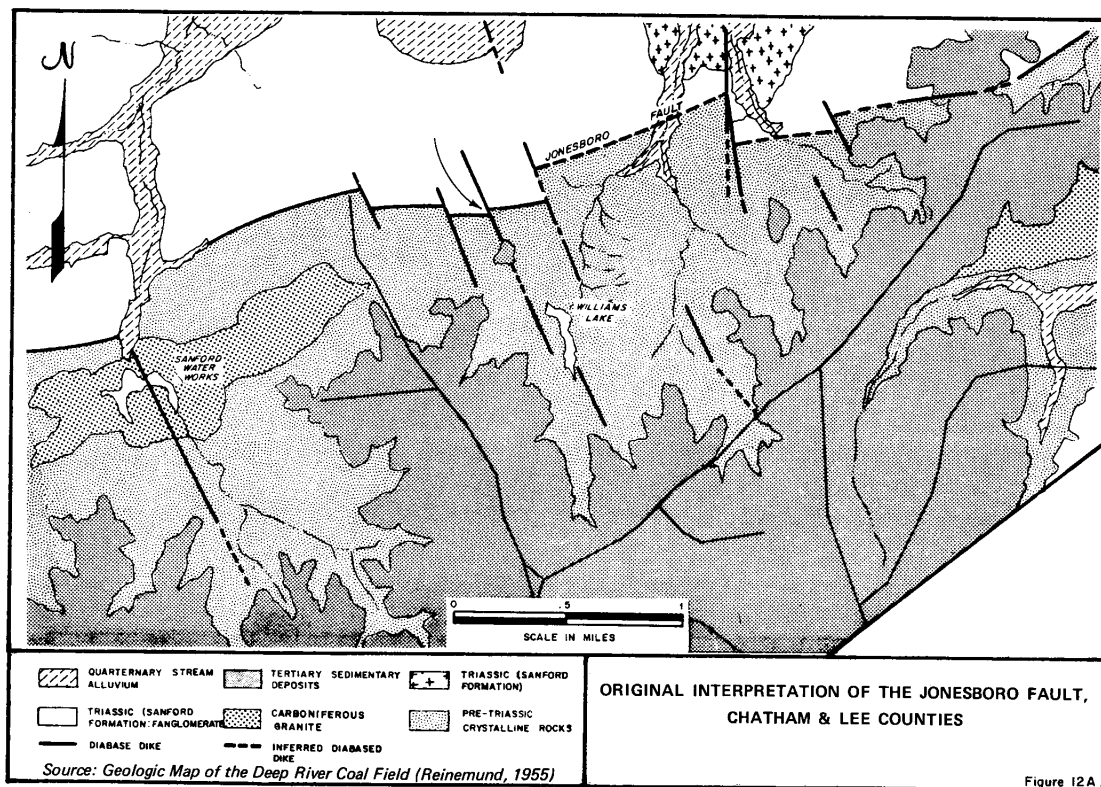


Figure 12A. Original interpretation of the Jonesboro Fault, Chatham and Lee Counties.

- 25.0 0.2 *TURN RIGHT* on SR 1700.
- 26.3 1.3 *TURN LEFT* on U.S. Highway 1 South toward Sanford.
- 30.0 2.7 Deep River and Lockport Canal at Moncure. New U.S. Highway 1 parallels the western border for several miles here. Flaggy argillites and sandstones of Pekin age crop out in the grassed-over cuts. The Copper Creek Coal prospect is approximately 2.4 miles from the Deep River bridge along this road. Red mudstone and sandstone increase in frequency toward Sanford.
- 38.3 8.3 Overpass over U.S. Highway 15-501. The Cumnock Formation crops out between here and the next overpass, being exposed along the service road on the south side of the highway just over the crest of the hill.
- 40.5 2.2 *EXIT RIGHT* (North) on U.S. Highway 421 ramp toward Siler City and Greensboro.
- 47.4 6.9 Village of Gulf.
- 48.6 1.2 *TURN RIGHT* into Pomona Pipe Products plant. Turn right immediately beyond entrance down gravel access road about 0.3 miles to quarry site.

48.9 0.3 STOP 3

STOP 3-Boren Clay Products Pit, Gulf, N.C.

Exposed is the Pekin Formation, oldest Triassic rocks of the Sanford basin. The rocks are unique in that they represent a reducing environment. This gives a buff to grey color rather than the usual red-bed pattern. Close observations show nodules of marcasite, in some instances replacing plant structures.

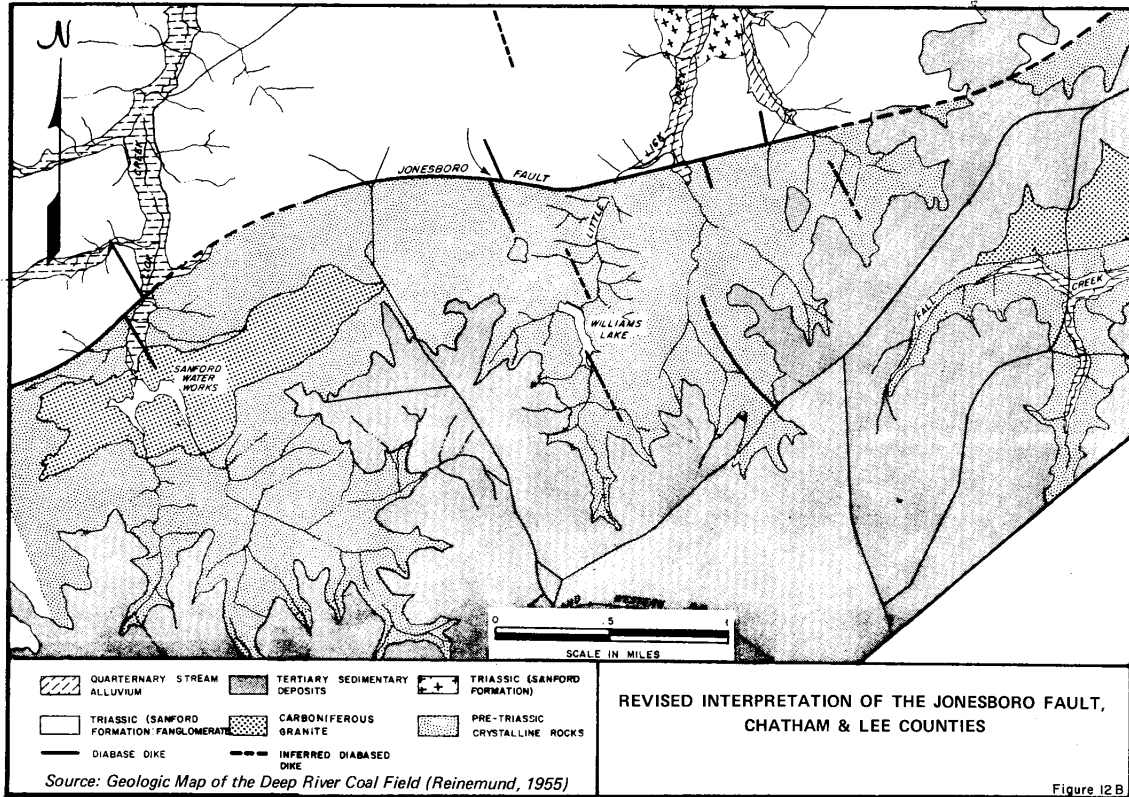
A flora of cycadophytes, conifers, sphenophytes, and peridophytes has been preserved as compressions. The preservations show reproductive structures associated with vegetative remains as well as cuticle showing epidermal patterns useful in morphological comparisons.

Sporpmorphs obtained at this locality support a Late Triassic age for the sedimentary rocks, probably equivalent to the Carnian and Norian.

The zone of disrupted sediment represents root zones, indicating that most of the plants were preserved where they grew, probably in a swamp and flood plain community. The presence of *Cyzicus*, a branchiopod characteristic of a sluggish fresh water environment, adds support to the flood plain environment.

Note the attitude of the rocks in which the strike and

DURHAM TRIASSIC BASIN



REVISED INTERPRETATION OF THE JONESBORO FAULT, CHATHAM & LEE COUNTIES

Figure 12.B

Figure 12B. Revised interpretation of the Jonesboro Fault, Chatham and Lee Counties.

dip change over a matter of a few feet. The rocks are siltstones that range from arenaceous to argillaceous.

- 49.2 0.3 *TURN LEFT* on U.S. Highway 421 toward Sanford after leaving Pomona plant.
- 49.8 0.6 *TURN LEFT* on gravel road and immediately *RIGHT* 0.2 miles to Bethany Baptist Church.
- 50.2 0.2 STOP 4

STOP 4- Faulted Outcrop of Cumnock Coal

The Cumnock coal crops out at the southeast abutment of the U.S. Highway 421 bridge over the railroad track at the south side of the Bethany Baptist Church (fig. 13). From that point, it trends southwestward across an old eroded coal pit in which approximately 350 feet of the Cumnock Formation is exposed.

The coal outcrop consists of possibly 10 feet of coal, bony coal, underclay (?), and carbonaceous shale which is sheared and badly deformed at this point. A nearby core hole, BDH 2 of Reinemund (1955) is reproduced in part as Appendix 1. Black fissile shale containing one the best (documented) fauna of the Durham Wadesboro basin is exposed below the coal (Appendix 1).

The coal exposed here is in fault contact with red and grey calcareous shales and siltstones which appear to be younger. That is, the south block has moved up relative to the northern one. However, an outcrop at the east side of the pit (fig. 14) contains several fault slices where there is obvious normal down-to-the-east gravity movement on one fault. Reinemund shows this pit to be about 1000 ft. north of his down-to-the-east Gulf fault and to be a wedge between two NNW-trending diabase dikes. Whatever the structural relationship, it is obvious that the trend of the coal is different from the trend of the strata on the north side of the pit and that the coal is badly sheared and deformed.

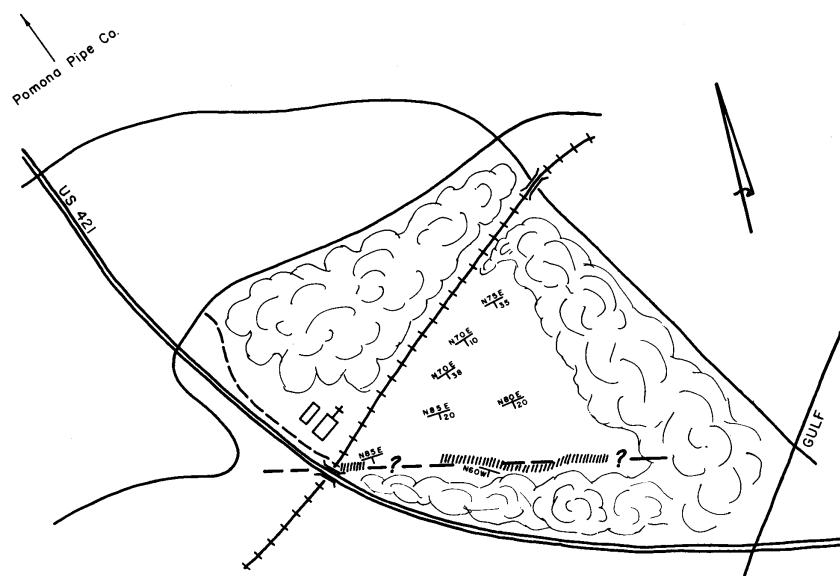


Figure 13. Field Stop 4. Plan view of coal pit.

Paced Section - STOP 4

		Approximate Vertical Thickness
1	Red sandstones up to 1 m thick interbedded with red silty hematitic shales up to 3 m in thickness dipping 10 -35 to the south (250 ft.)	108 ft.
2	Grey-green to red silty shales, flaggy sandstones, and thin rubbly limestones in calcareous shales. The thin siltstones show small scale crossbedding. Shales show numerous worm burrows (200 ft.)	85 ft.
3	Flaggy sandstones and siltstones	7 ft.
4	Same as in #2 above	23 ft.
5	Buff flaggy siltstone similar to basal Pekin type. This unit crops out in the cut bank at the SE end of the pit.	5 ft.
6	Same as in #2 above	25 ft.
7	Coal, bony coal, underclay, carbonaceous shale, all badly sheared	3-10 ft.
8	Black fissile carbonaceous shale containing abundant fresh water ostracoda and conchostreacons	86 ft.

- 50.2 0.2 *TURN LEFT* on U.S. Highway 421 after leaving Bethany Baptist Church and retrace route to Moncure.
- 57.8 7.6 *TURN NORTH* on U.S. Highway 1 toward Raleigh.
- 68.1 10.3 *EXIT RIGHT* off U.S. Highway 1 toward Moncure.
- 68.3 0.2 *TURN LEFT* on access ramp to U.S. Highway 1 North. Park on ramp shoulder and field to right.
- 68.4 0.1 STOP 5 and LUNCH

STOP 5 - Basal Western Conglomerate Facies

This outcrop of coarse, crossbedded, mostly Carolina slate belt debris represents a point near the apex of an alluvial fan. Clast sizes range up to greater than football size. Subrounded to angular clasts are predominantly tuffaceous and epiclastic rocks. Quartz pebbles make up to 10 percent of the deposit. Thin interbedded flaggy sandstone and indurated conglomerate are present along with cut-and-fill structures at the SW end of the ditch. The finer grained conglomerate and sandstone strike N 20° - 60° E and dip 5° - 20° to the SE. The NE end of the ditch is underlain predominantly by indurated conglomerate.

E.I. Dittmar reports that orientations of 25 imbricated, platy clasts give a paleocurrent azimuth of 320 and that the average of the 10 largest clasts is 12 in (30.3 cm). The slate belt contact is *immediately* across U.S. Highway 1 on the NW bank of the highway in the indicated direction of the paleocurrent. Consequently, two conclusions are immediately evident: (1) There

DURHAM TRIASSIC BASIN

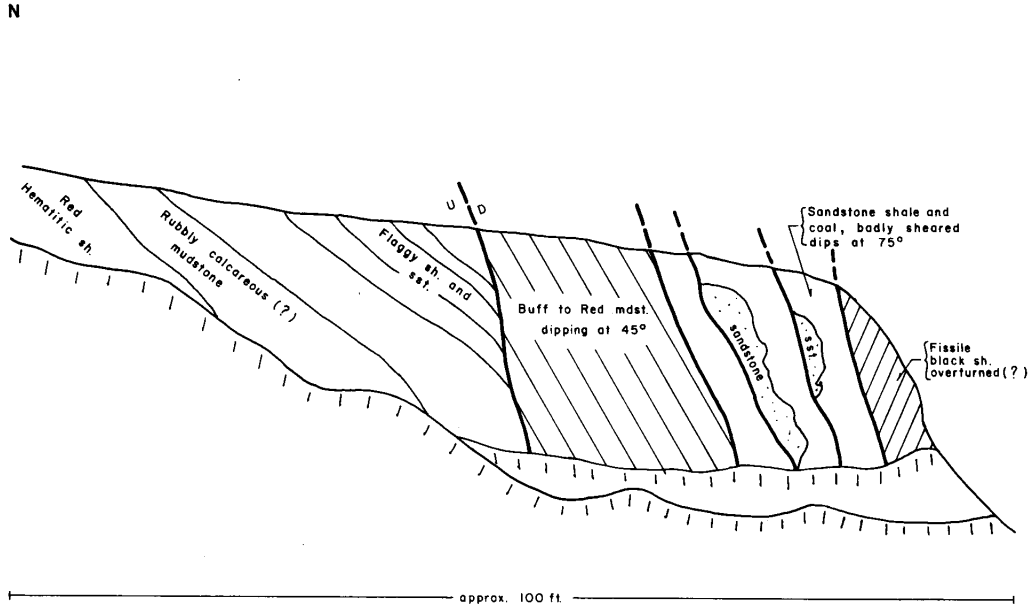


Figure 14. Field Stop 4. Profile of east wall of coal pit.

was a slate belt source not far to the SE and (2) The basin extended substantially farther to the northwest than it does today.

- 68.4 0 CONTINUE NORTH on U.S. Highway 1. Enter CAREFULLY please.
- 70.6 2.2 Haw River.
- 70.9 0.3 EXIT RIGHT off U.S. Highway 1 to Pea Ridge Road.
- 71.1 0.2 TURN LEFT (North) on Pea Ridge Road - SR 1700.
- 71.7 0.6 Pea Ridge Road parallels the western border for several miles. Low outcrops along the roadside are flaggy argillite and graywacke sandstone which weather to ochreous reds and yellows. An electrical sounding here indicates a depth to Basement of 1100 ft.
- 73.2 1.5 BEAR LEFT on SR 1700.
- 74.0 0.8 Slate Belt rocks underlie hills in left distance.
- 74.6 0.6 Site of STOP 6a, Continue north on SR 1700.
- 75.1 0.5 TURN around at intersection.
- 75.6 0.5 STOP 6. Park on right shoulder.

STOP 6 - Argillite-Graywacke-Conglomerate Facies of the Pekin Formation

STOP 6a — Outcrop of interbedded flaggy argillite, crossbedded sandstone, and conglomerate of the argillite-graywacke-conglomerate facies totaling about 25 ft. of the Pekin Formation. The three outcrops described here as STOPS 6a, 6b, and 6c are in a tight

post-depositional syncline between the slate belt on the west and a small slate belt inlier to the east. Cross-bedding is well developed in one very coarse bed and indicates a paleocurrent direction to the south (azimuth 192) according to measurements by Dittmar. Geothite (?) and/or limonite is present in thin beds near the top of the cut. Manganese oxide stains are present along joint faces and coats the pebbles in the conglomerates. Rounded quartz pebbles make up at least 20 percent of the conglomerates. Some thin argillaceous beds contain flattened clasts up to 2 cm in diameter which probably represent flattened clay balls.

- 75.8 0.2 Entrance to Corps of Engineers Recreation site.

STOP 6b — About 150 feet of the base of the Pekin Formation and its contact with the crystal tuff of the slate belt is exposed along 600 ft. of the access road into a Corps of Engineers recreation site. Plant fragments and probable branchiopod fossils are found in a buff argillite on the west side of the curve about 300 feet down the road from the Triassic-slate belt contact. The mudstones, argillites, sandstones, and conglomerates exposed here have dips ranging from 15° to 60° that tend to increase toward the basal contact. Strike is to the NE ranging from N 2° E to N 20° E. A measured section is presented below:

Measured Section - STOP 6b

		Approximate Vertical Thickness
1.	Red mudstone - N 20° E 40° SE	35 ft.
2	Crudely bedded argillite - N 15° E 10°SE	50 ft.
3.	Sandstone with interbeds of argillite and conglomerate- N 2°E 40°SE	50 ft.
4.	Argillite as in #2 above - N 20° E 26°SE	25 ft.
5.	Flaggy medium-grained sandstone	10 ft.
6.	Argillite as above but blocky	10 ft.
7.	Red and bleached (?) argillite interbedded with pebbly red mudstone. Iron oxide evident	35 ft.
8.	Medium-grained red-brown sandstone. Dips 40° SE	15 ft.
9.	Tan to pink argillite and siltstone dipping 60° SE	25 ft.
10	Red mudstone dipping 30°SE	20 ft.
11	Tan to buff argillite grading downward to sandstone and then again to argillite. Plant fossils near base. Dip ranges from 35° to 60° SE	20 ft.
12	Sandstone and quartz-pebble conglomerate	5 ft.
13	Buff argillite with plant remains and Branchiopoda (?)	5 ft.
14	Buff to red-brown sandstone and conglomerate to base (estimated thickness)	20 ft.
15	Slate belt - andesitic (?) crystal tuff	

76.2 0.4 *TURN LEFT* on gravel SR 1972.

76.5 0.3 Turn around. Park on shoulder.

STOP 6c— At this point, 20 ft. of coarse sandstone, quartz pebble conglomerate, and argillite similar to that of STOPS 6a and 6b are exposed 200 ft. up the hill beyond the gate. The white, coarse sandstone exposed in this cut now dips about 25° NW and strikes about N 60° E. The contact with the horst is also exposed about 450 ft. up the gravel road. Down

the hill, quartz-pebble conglomerate similar to the millstone grits at the base of the Pekin in Moore County (Conley, 1962) crop out in the east ditch of the gravel road. The best exposures of limonite-filled joints are found just beneath in the argillite.

76.7 0.2 *TURN LEFT* back towards U.S. Highway 1 on SR 1700.

77.4 0.7 *BEAR LEFT* on SR 1910.

78.3 0.9 Cross contact between argillite-graywacke unit and red mudstone-sandstone facies.

78.6 0.3 Park on edge of road— the shoulder is quite narrow. Road beyond bridge parallels large diabase dikes.

STOP 7 - Chert — Base of Red Mudstone-Sandstone-Conglomerate Facies, Undifferentiated

Chert crops out here at the base of a red mudstone unit overlying the argillite-graywacke-conglomerate facies of the Pekin Formation. Chert has been mapped at this end of the basin from this point south for approximately 6 miles. It occurs parallel to bedding in thin interbeds up to 4 inches in thickness. The bright red to maroon mudstone with which it is typically associated here is interbedded with sandstone and conglomerate having at least 30 percent rounded quartz pebbles. The remainder are predominantly Slate Belt lithologies. A diabase dike trending subparallel to the road cuts through the chert outcrop at this point. The bluish-purple shale and chert in the west ditch beneath the highway right-of-way sign at the north end of the roadcut marks the narrow hornfels zone. The chert crops out next about 0.3 miles north at the intersection just passed.

79.6 1.0 *TURN LEFT* on old U.S. Highway 1 toward New Hill.

80.1 0.5 Typical red mudstone of the mudstone-sandstone-conglomerate facies beneath overpass on right side of road.

81.9 1.8 *TURN LEFT* on SR 1963 at Bonsal. First typical fluvial sandstone of tan arkosic facies is exposed beneath railroad overpass. Electrical sounding data indicate a depth of 1900 ft. to Basement here.

82.1 0.2 Chatham County line. SR 1963 becomes SR 1008.

83.8 1.7 *TURN RIGHT* on SR 1903.

84.5 0.7 Diabase dike crosses road.

84.8 0.3 Cut showing fluvial sands and drag folds of down-to-the-west (?) faults. A nearby electrical sounding indicated the basin is quite shallow here. Dittmar found that seven crossbedded

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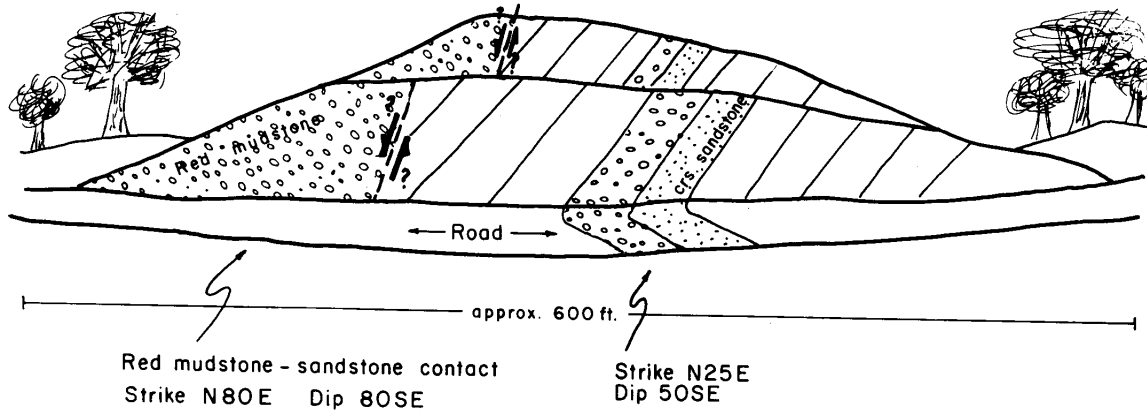


Figure 15. Field Stop 8.

- 85.5 0.7 Diabase dikes cross about 0.1 mile apart.
- 86.5 1.0 Wake County line. SR 1903 becomes SR 1142.
- 88.0 1.5 *TURN LEFT* on SR 1141. New Hill test well site is about 0.3 mile to right.
- 90.2 2.2 Village of Olive Chapel.
- 90.5 0.3 *BEAR LEFT* on SR 1101.
- 90.8 0.3 U.S. Highway 64 intersection. Cross highway *CAREFULLY* to N.C. Highway 751 toward Durham.
- 91.8 1.0 Park on right shoulder.

STOP 8 - Uptthrown Side, Bonsal-Morrisville Fault

This stop is near the projected trend of a basement high shown by the aeromagnetic and gravity maps to cross the basin obliquely from the vicinity of STOP 5 to the vicinity of Morrisville and the Raleigh-Durham Airport (figs. 3 and 6). Electrical sounding data indicate a depth to Basement at this point of 1300 ft. in contrast to 3300 ft. at a point 0.7 mile north on N.C. Highway 751 (See fig. 5.). This 600-foot-long cut, interpreted to be on the shallower upthrown side, is predominantly steeply dipping mudstone at the south end. There, a fault (?) contact having an attitude of N 80 E 80 SE separates the red mudstone from a sequence of interbedded coarse sandstone, conglomerate, and green to buff siltstone that comprise the remaining northerly two-thirds of the exposure. A coarse sand and quartz conglomerate bed near the north end is traceable up the cut and has an approximate attitude of N 25° E 50° SE, fig. 15.

Continue on N.C. Highway 751.

- 92.6 0.8 *TURN RIGHT* on SR 1743.

- 92.7 0.1 Quartz pebble conglomerate crops out along road here. Our interpretation is that it is a basal conglomerate faulted into its present shallow position.
- 93.4 0.7 *TURN RIGHT* on SR 1742.
- 93.6 0.2 Wake County line. SR 1742 becomes SR 1605.
- 94.6 1.0 *TURN LEFT* on SR 1606.
- 95.4 0.8 Railroad track. Park on right side of road. Walk about 500 ft. south on tracks.

STOP 9 - Crossbedded Arkosic Sandstone - Tan Arkosic Fluvial Facies

This outcrop of tan to buff, medium- to coarse-grained arkosic sandstone overlies massive argillite that ranges from gray-green to red. It represents a profile of anastomosing, braided, south-flowing streams which have channeled into the underlying fine-grained overbank and levee deposits along a major longitudinal stream or at the distal end of a large alluvial fan.

Dittmar reports that along much of the railroad cut, "basal", red-and-green mottled, silty to fine-sandy shales (average horizontal attitude) are cut by feldspathic, micaceous, fine- to very coarse-grained sand channels. Gravel stringers and lenses, sequences of typical fluvial fining upward, and evidence of cut-and-fill processes are common. Both planar and simple medium-scale cross-bedding are abundant in the sand units. It is evident that some of the previously feldspathic sands are now clayey sands due to weathering of the feldspars. Twenty measured crossbed units (mostly simple and planar, medium scale crossbeds) give a strong resultant paleocurrent direction (azimuth 168) (S 12 E, current south). Seventeen of the 20 crossbedded units indicated "south" current direction. The long-axis orientation of a silicified log or limb in one of the clayey sand units is N 60° E. The

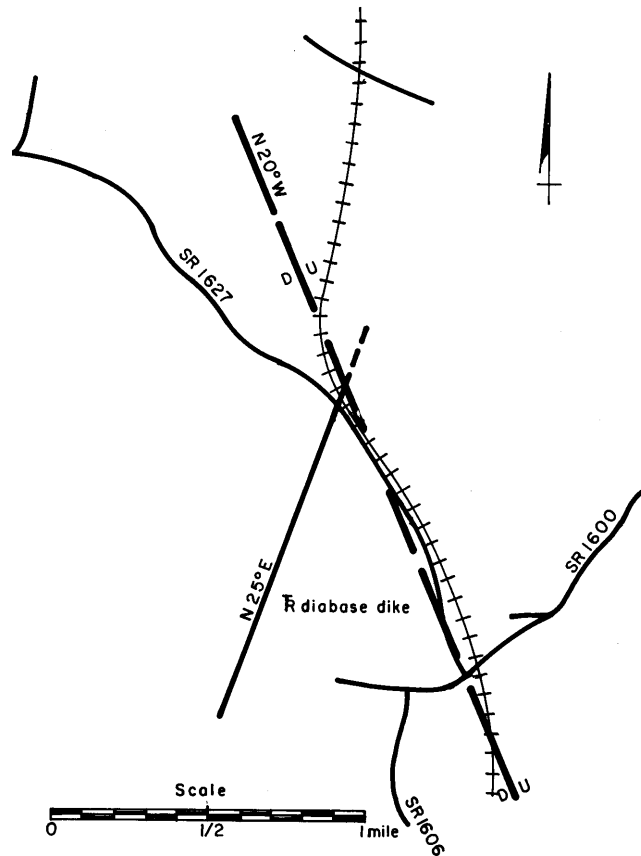


Figure 16. Plan view of Stop 10.

log is about 3 in (8 cm) in diameter and > 3.25 ft. (1 m) in length (not completely excavated). The average maximum clast size of quartz pebbles (mostly subangular to subrounded) is 4.3 in (10.9 cm).

This outcrop is located in and typical of the arkosic sandstone unit which crops out in a 50-square-mile, triangular-shaped area between Carpenter, Apex, and Bonsal. It is also very typical of the upper 2000 ft. penetrated in the New Hill test well.

The gamma ray and resistivity logs of that well show that the New Hill well facies consists of a series of fining-upward sequences. Cycle frequency is about one per 18 ft. The cycles are initiated at the base with a highly resistive conglomerate which fines progressively upward into massive red or grey-green argillite.

Continue straight ahead on SR 1606.

- 96.0 0.6 *TURN RIGHT* on SR 1600.
- 96.2 0.2 *TURN LEFT* on SR 1627.
- 96.3 0.1 Red mudstone in fault contact with coarse arkosic sandstone.
- 96.8 0.5 Chatham County line.
- 97.0 0.2 Turn around.

STOP 10 - Railroad Cut through Faulted Diabase Dike and Crossbedded Channel Sandstone

Here, fluvial sandstone of the arkosic sandstone facies and a northeast-trending diabase dike are cut by a series of down-to-the west-southwest antithetic faults, trending N 10° - 20° W. Both the aeromagnetic and Bouguer gravity maps indicate that a triangular-shaped block lying west and southwest of this stop is deeply depressed with Basement being possibly as deep as 6000 ft.

The thin, badly weathered diabase dike trending N 25° E has been offset slightly by the northwest slices. The southeast-dipping dike is earlier than the fault as evidenced by the hornfels zone created by the dike which abuts against normal red mudstone across the fault. To the left (northwest) of the dike, a slickensided fault surface trending about N 15° W dips 75° W. The striations dip 25° NW along the fault plane. The opposite bank (west side) also shows the diabase dike to be offset by small faults.

Another part of the fault zone (fig. 16) having the same attitude and character is exposed about 300 ft. south of the dike along the east side of the track. The fault is also exposed 850 ft. to the north on either side

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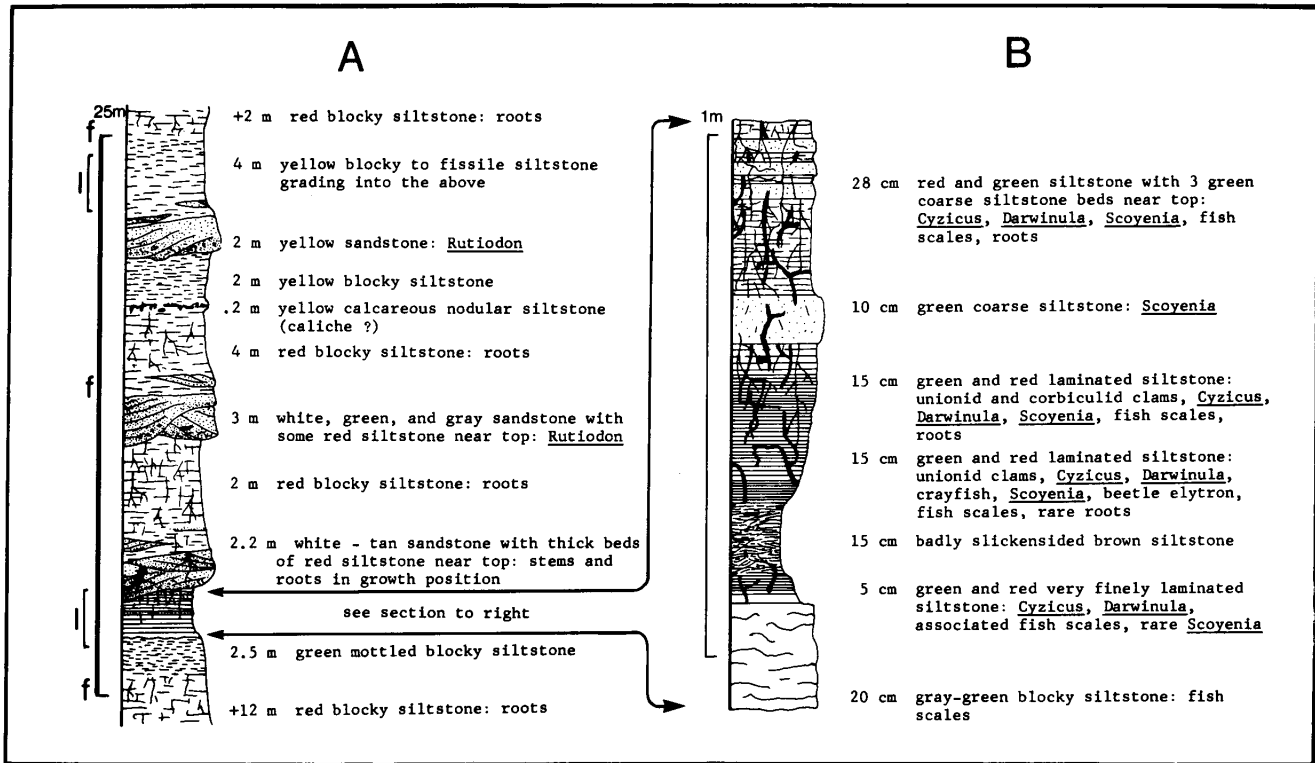


Figure 17. Measured section at the main quarry of the Triangle Brick Co., Genlee, N.C.: A, entire section. The 1 indicates lacustrine facies, while the f indicates fluvial facies: B, detail of the lacustrine beds which produced the fauna in Figure 18. (section and description by P. E. Olsen)

of the track. There, normal faults striking about N 30° W slice across the fluvial sands and mudstones. All of the faults observed appear to have small displacements--perhaps 10 ft. If the fault slices are an average 20 ft. apart, a throw of even 1000 ft. would necessitate a fault zone 2000 ft. wide.

Dittmar suggests that the massive fluvial units are a probable flood plain facies. Corrected measurements of simple, medium, and large scale crossbeds by Dittmar in four different sandy units indicate paleocurrent azimuth of 255 (to the southwest). The average maximum size of 10 quartz pebbles is 2.8 in (7.2 cm).

- 97.8 0.8 *TURN LEFT* on SR 1600.
- 99.0 1.2 *TURN LEFT* on SR 1625.
- 99.7 0.7 Nearly flat-lying interbedded red mudstone and channel sands.
- 100.3 0.6 Intersection of SR 1625 and SR 1624. Channel sands are well-developed to right toward Carpenter. *CONTINUE STRAIGHT AHEAD.*
- 100.5 0.2 Sand and mudstone units in next 0.3 mile dip to north. Our interpretation is that these rocks are on the downthrown side of the Bonsal-Morrisville fault.

- 101.8 1.3 *TURN RIGHT* on SR 1725.
- 101.9 0.1 *TURN LEFT* on SR 1630 (Blacktop).
- 103.8 1.9 Durham County line and Triangle Brick Quarry. *TURN LEFT* into quarry and park.

STOP 11 - Triangle Brick Quarry

The main quarry of the Triangle Brick Co. at Genlee, N.C. exposes 40 m+ of lacustrine and fluvial clastics of the Chatham Group (Newark Supergroup) of Cornet (1977).

This is one of the best exposures of the central basin facies of the Durham basin. The section (fig. 17) consists of two main sediment assemblages. The fluvial facies is made up of massive red siltstones with root casts and drab crossbedded sandstones containing arthropod burrows (*Scoyenia*) and root and stem casts in growth positions. The lacustrine facies is composed of very well-bedded, mottled red-green siltstones with a characteristic fauna (fig. 18). Reptile bones and teeth are found in association with intra-formational conglomerate and allochthonous wood fragments in the fluvial sandstones, although isolated elements and small bone assemblages of phytosaurs are the only common reptile remains. Parker (1966) has described the occurrence of a partial skeleton of the armored

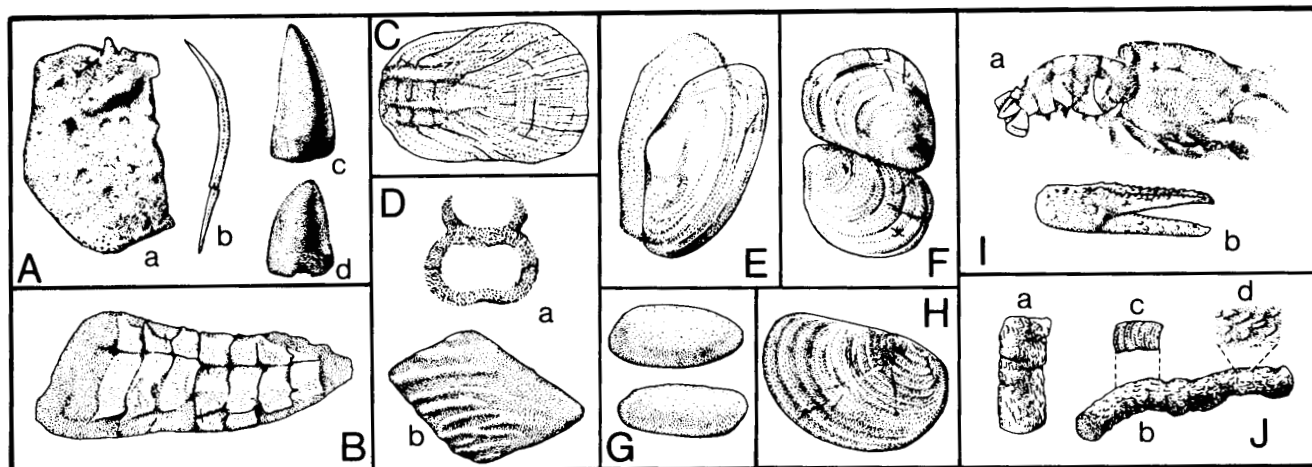


Figure 18. Fossils from the Triangle Brick Co. quarry, Genlee, N.C.: A, bones and teeth of the phytosaur ?*Rutiodon*, (a) dorsal scute, .13 X, (b) gastral element, .19 X, (c, d) posterior teeth, 1 X; B, ?*Stegomus* sp., ventral view of fragment of tail cuirass, .25 X; C, scale of *Diplurus newarki*, 3 X; D, centrum (a) and scale (b) of *Turseodus* sp., 3 X; E, unionid clam, 2.5 X; F, corbiculid clam, 3 X; G, *Darwinula* spp., 20 X; H, *Cyzicus* sp., 5 X; I, crayfish, (a) specimen missing front claws, 1.5 X, (b) isolated front claw, 1.6 X; J, *Scoyenia* type burrows presumably made by crayfish, (a) large vertical burrow, .5 X, (b) horizontal burrow, .5 X, (c) transverse section showing meniscus infilling, (d) enlargement of sculpture on burrow exterior, 2 X. (fossil collection and description by P. E. Olsen)

thecondont ?*Stegomus* sp. from this locality (fig. 18). The lacustrine siltstones exposed here contain a benthic assemblage made up of ostracods (*Darwinula* spp. and *D.*? spp. from here described by Swain and Brown, 1972), clams (unionids and ?corbiculids), crayfish (?*Clytiopsis* sp.), and presumed crayfish burrows (*Scoyenia*) and a pelagic assemblage composed of conchostracans (*Cyzicus* spp. [= *Howellisaura*] and fragmentary fish. The fish genera found so far include the palaeoniscid *Turseodus*, the subholostean ?*Cionichthys*, the holostean *Semionotus*, and the coelacanth *Diplurus*. The upper lacustrine beds are riddled with fine root casts, and common allochthonous plant fragments (conifers, cycadophytes, and ferns) occur throughout. A single beetle elytron has also been found.

The sequence of bed forms and sedimentary structures in the lacustrine deposits (fig. 17) exposed here are nearly identical to those of sedimentary cycles of the Lockatong Formation of the Newark basin; only the color of the beds differ (red and green here, black and grey in the Lockatong),

The fish and reptiles from these beds indicate a Late Triassic age correlative with the Lockatong Formation of the Newark basin, the middle New Oxford Formation of the Gettysburg basin, and the upper member of the Cow Branch Formation of the Dan River Group of Thayer, 1970. Studies of pollen and spores from the Lockatong and New Oxford Formations show them to be Late Carnian (Cornet, 1977). Thus, these lacustrine and fluvial beds of the Durham basin are also Late

Carnian and slightly younger than the middle Carnian Cumnock Formation (Cornet, 1977) of the Sanford basin to the south, suggesting correlation with part of the overlying Sanford Formation.

This quarry is located near the southwestern end of the traceable lacustrine horizon. The red-bed facies with which these fossiliferous beds are associated are terminated to the southeast by the Bonsal-Morrisville fault zone and to the southwest by a large 6-mile-long north-trending diabase dike. Stewart and others (1973) estimated seismic depth to Basement at this quarry to be 5600 to 6600 ft. An electrical sounding made 2 miles to the south did not "see" Basement at 6500 ft.

- 104.2 0.4 *TURN LEFT* on SR 1945 as you leave the quarry.
 104.4 0.2 *TURN RIGHT* on N.C. Highway 55 and return to Apex and Ramada Inn.
 115.5 11.1 Ramada Inn.

FIELD TRIP FOR SECOND DAY

October 9, 1977

Sunday's field trip will assemble again in the Ramada Inn parking lot in Apex and will leave at 8:00 a.m. The buses are scheduled to return to the motel between 12 noon and 1 p.m.

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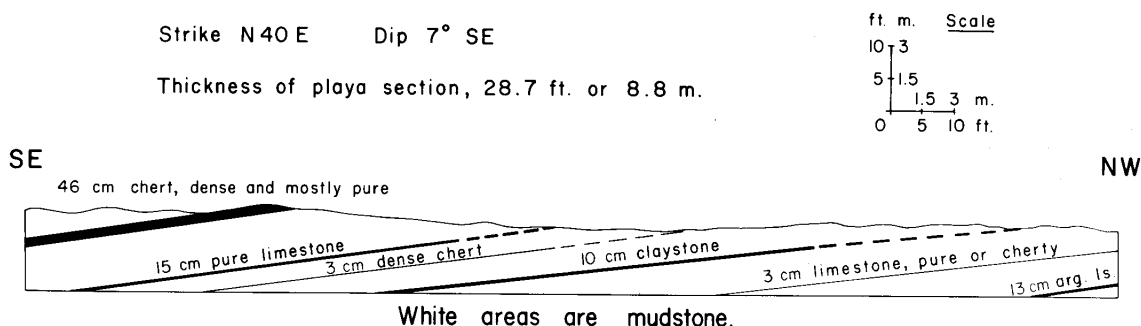


Figure 19. Limestone and chert locality, Durham Triassic Basin, North Carolina. Diagram of measured section corner of N.C. Highway 54 and SR 1999, 10 km south of Durham.

STOP 12 - *Limestone Tufa and Chert*

ElapsedInterval
MileageMileage

0.0	0	Ramada Inn Parking Lot. <i>TURN LEFT</i> on N.C. Highway 55 (North) toward Apex.
1.4	1.4	Old U.S. Highway 1 intersection. <i>CONTINUE STRAIGHT AHEAD</i> on N.C. Highway 55.
1.6	0.2	Good outcrop of weathered conglomerate in roadcut on right. N.C. Highway 55 traverses coarse arkosic fluvial facies from this point to beyond Carpenter. Paleocurrent data being gathered by Dittmar of UNC, Chapel Hill indicates that this unit was deposited by streams flowing in a general southwestward direction which is consistent with a granitic source area.
3.3	1.7	Intersection with U.S. Highway 64. <i>CONTINUE STRAIGHT AHEAD</i> .
4.8	1.5	Due east diabase dike. This is one of the rare dikes aligned in this direction. It is a composite of two different episodes or has locally split. It includes a sandstone slab converted to sanidine hornfels (J.M. Parker, III, personal commun., 1977).
6.1	1.3	Good outcrops of the arkosic sandstone unit.
8.4	2.3	Village of Carpenter.
9.8	1.4	Approximate contact of arkosic sandstone facies with red mudstone facies.
10.9	1.1	Triangle Brick plant on right.
11.2	0.3	<i>BEAR RIGHT</i> on SR 1945 (paved).
12.1	0.9	<i>TURN RIGHT</i> on T. W. Alexander Road - SR 2028.
13.4	1.3	<i>TURN RIGHT</i> on N.C. Highway 54.
14.5	1.1	<i>TURN LEFT</i> at Interstate 40 and Raleigh-Durham Airport signs onto Davis Road.
14.9	0.4	Park on right shoulder. <i>DO NOT BLOCK EXITS</i> .

Wheeler and Textoris

This is one of the best localities for studying the character of the limestone and chert and its relation to the other lacustrine units of this facies of the Durham sub-basin. The remainder of the stops except the last will be in this lacustrine facies. The presence of limestone in the Durham basin is first mentioned by Kerr (1875). Grannell (1960), Custer (1966), Wheeler and Textoris (1971) and Parker (1977) have further described its distribution. The following description of STOP 12 and the geologic section (fig. 19) is abstracted from a paper by Wheeler and Textoris recently submitted to the *Journal of Sedimentary Petrology*.

At this stop and prior to "improvement", an 8.8 m section was measured. The section is of typical red-brown mudstone and sandstone containing continuous but wavy bedded layers of impure limestone from 1 to 20 cm thick. A few beds of chert up to 60 cm are associated with the limestone.

Several dozen rock samples of the chert, limestone and caliche (with which it is also associated elsewhere) were thin-sectioned and studied petrographically. Five samples of limestone were studied by X-ray diffraction, and all limestone samples were stained with Alizarine-red S in order to identify dolomite. No dolomite was found petrographically, even with the aid of the stain, but three of the five samples which were X-rayed showed possible traces of the mineral. Two limestone samples were tested for the presence of non-calcareous algal filaments following the procedure of Meijer (1969), but none was recovered. All chert samples were studied in order to identify length-slow chalcedony (Folk and Pittman, 1971), but none was found.

The limestone beds are somewhat impure, containing varying amounts of the surrounding mudstone as impure zones and clasts. For the most part the lime-

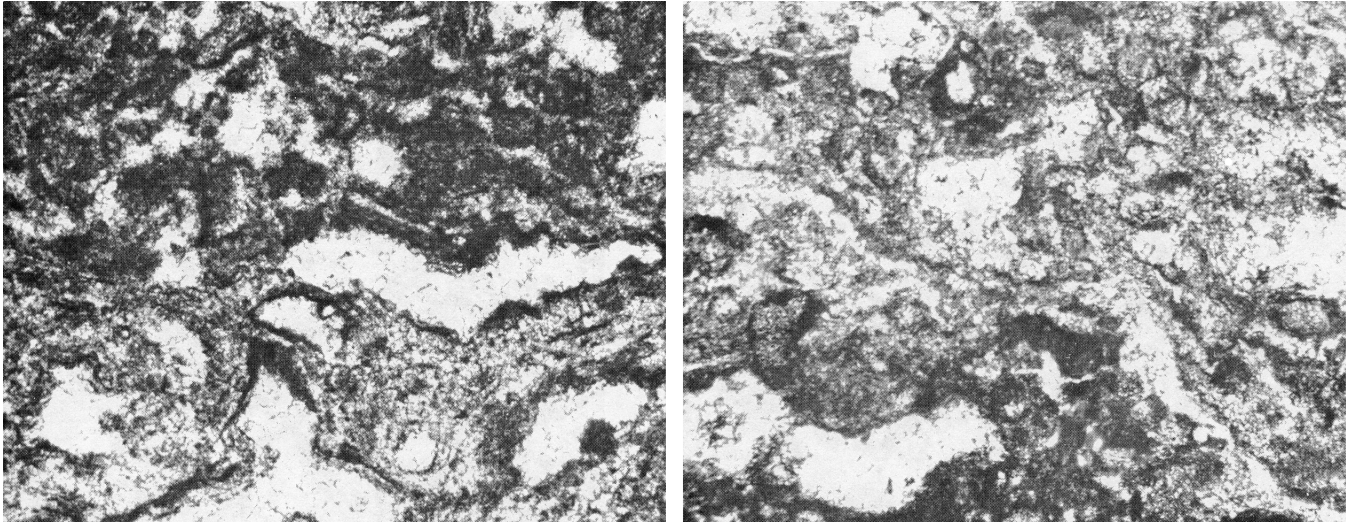


Figure 20. A (left) Limestone tufa consisting of irregular laminae of brown micrite and pelletoidal micrite, and equant calcite spar which fills original voids. Void geometry was probably controlled by plants which grew in the water and were encrusted by the inorganically precipitated micrite and pelletoidal micrite. Plane-polarized light. B. (right) Limestone tufa nearly identical with the sample shown in A, except that chalcedony fills the void in the upper right corner rather than calcite spar. Plane-polarized light.

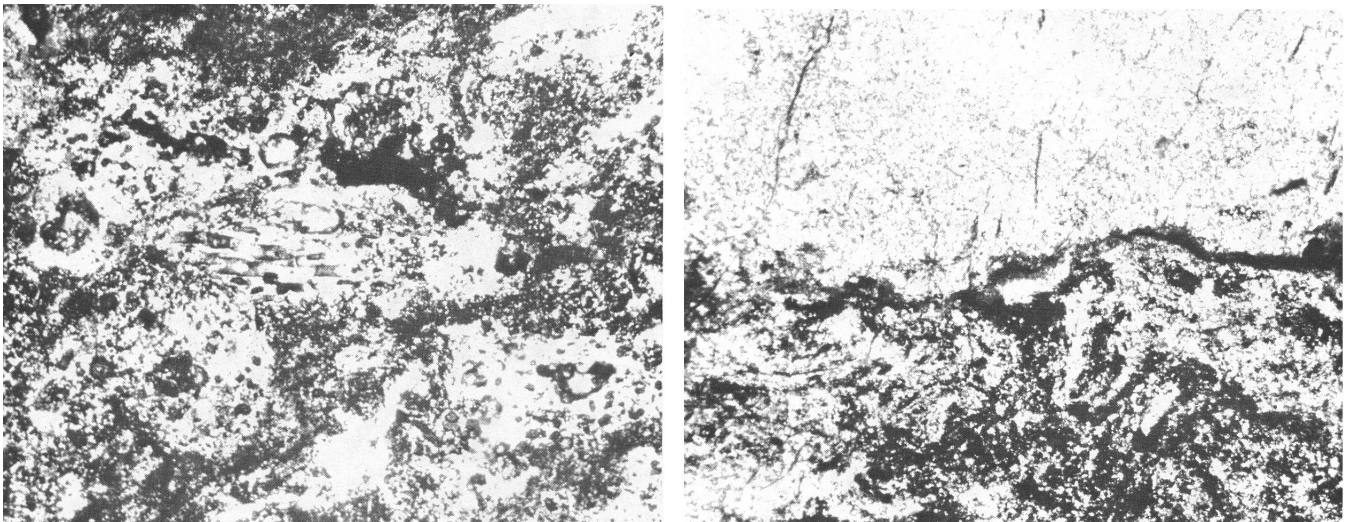


Figure 21. A (left) Completely chertified porous limestone tufa, with bubbles of organic nature in center. Plane-polarized light. B. (right) Bottom half is chertified porous limestone tufa. Top half is pure, primary, inorganic chert. Crossed-polarized light.

stone is laminated, micritic, nonporous, and pelletoidal. Void-filling, medium-crystalline calcite spar has eliminated most of the original pore spaces (fig. 20a).

We interpret this limestone to represent an original inorganic calcareous tufa which was deposited in a playa lake. Chertified tufa tends to be found both with the limestone tufa and with the pure chert. It is light brown, porous, and the preserved texture indicates that the chert has filled in and replaced portions of the tufa (fig. 20b). Generally, calcite spar precipitation in the voids preceded the filling by chalcedony. As the

tufa samples became more chertified, both chalcedony and crystalline microquartz fill voids, and chert replaces the micritic textures. The early nature of chertification and the accompanying spar filling is shown by occasional organic tubes, which were replaced before they rotted. (Fig. 21a).

A pure chert, occurring in beds up to 2 ft. (60 cm) thick, is dense, dark grey, and consists of medium chalcedony with very finely crystalline quartz. (Figs. 21b and 22a). It does not contain ghost textures of the limestone tufa and is nearly pure quartz. A number of

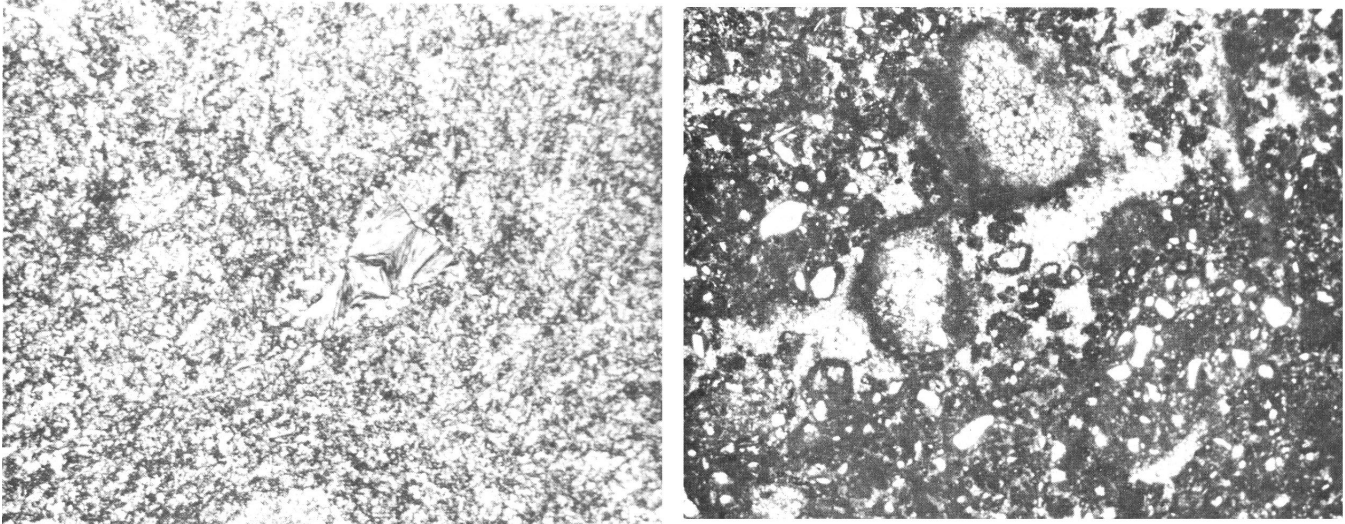


Figure 22. A (left) Pure, primary, inorganic chert with larger chalcedonic zone in center. Crossed-polarized light. B (right) Calcareous nodule, caliche, consisting of micritic and equant calcite spar cements, scattered silicate grains (many of which are coated with spar), peloids, and two juvenile pisolites in the near center. The core of the lower one is silicate minerals. Plane-polarized light.

samples of both types of chert were tested for the presence of length-slow chalcedony, but only the length-fast type was identified. Further, we found no evidence of diatoms or other organisms which might have secreted opaline tests.

Supplemental STOP 12a

Banded red and greenish grey limestone overlain by fossil-bearing black shale crops out in the north ditch of the off ramp of the westbound lane of Interstate 40 connecting with Davis Drive.

Measured Section - STOP 12a

The following section is exposed along approximately 800 ft. of the north ditch of the westbound lane of Interstate 40 just east of the Davis Drive exit. Attitude of bedding is about N 15 E 6 SE.

		Approximate Vertical Thickness
1.	Covered to exit sign	2.5 ft.
2.	Red to blue-grey mudstone	9.5 ft.
3.	Blue-grey shale	1.5 ft.
4.	Buff shale	0.2 ft.
5.	Light tan arkosic sandstone	2.0 ft.
6.	Buff to yellow-brown shale	1.5 ft.

7.	Black shale with fresh water fauna and plant fragments	2.5 ft.
8.	Buff to light green argillaceous limestone and calcareous shale with red specks	10.5 ft.
9	As above, but more resistant argillaceous limestone	5.0 ft.
10 .	Red mudstone	4.0 ft.
11 .	Grey cherty and speckled limestone in red mudstone	1.0 ft.
12 .	Red mudstone and shale	15.0 ft.
13 .	Purple mudstone with rubbly limestone pellets and chert	0.5 ft.
14 .	Red mudstone with a few pieces of chert float	15.0 ft.
15 .	Covered	8.5 ft.
16 .	Buff to yellow brown shale	4.0 ft.
	Total	83.2 ft.

The following description of fossils collected from the black shale (item 7) is by F. M. Swain:

Intersection of Davis Drive and Interstate 40

Up to 6 or 7 m of interbedded red and grey shale and

thin freshwater limestone and arkose. No fossils other than possible algal structures in grey argillaceous limestone. Shale contains:

Darwinula subquadrata Swain and Brown, 1972 (abundant)

Darwinula rogersii (Jones, 1862) (frequent)

Howellisaura sp.¹

Bivalvia

Fish bones, scales

Plant leaf impressions

¹ See Appendix 2

- 15.4 0.5 *CONTINUE STRAIGHT AHEAD* on Davis Road after STOP 12. *TURN LEFT* on Cornwallis Road toward Durham. Chert unit crosses Cornwallis Road about 0.2 miles to the right of the Davis-Cornwallis intersection near the railroad track.
- 16.1 0.7 Cross over Durham Freeway.
- 17.0 0.9 *TURN RIGHT* on T. W. Alexander Road. Outcrop of black fissile shale (fossil site) is 0.1 mile farther down Cornwallis Road in front of Troxler Laboratory.
- 17.7 0.7 Park on right shoulder.

STOP 13 - Fossiliferous Limestone

Thin argillaceous limestone up to 1 ft. thick crops out on both sides of the road at this point. The bedding attitude is N 10 - 15 E dipping at a low angle to the southeast.

Although this zone is approximately down strike from an abundant branchiopod-bearing shale, it does not resemble it and most likely lies stratigraphically above.

A short section measured in the north side ditch just east of the culvert shows:

		Approximate Vertical Thickness
1.	Red to brown flaggy (lacustrine) sandstone	+1 ft.
2.	Pink to red micaceous sandstone	1.0 ft.
3.	Brown, fine-grained micaceous sandstone	0.4 ft.
4.	Red blocky argillite	0.5 ft.

5.	Red to blue-grey fissile fossiliferous shale	0.2 ft.
6.	Blue-grey to red mottled shale containing 1 inch layers of yellow-brown silty beds	1.7 ft.
7.	Blue-grey to red mottled shale	0.3 ft.
8.	Blue-grey fossiliferous shale	0.1 ft.
9.	Tan to buff argillaceous and fossiliferous limestone	1.0 ft.
10.	Blue-grey silty shale	0.5 ft.
11.	Covered from top of concrete trough to culvert	0.5 ft.
	Total	7.2 ft.

F. M. Swain reports some *Howellisaura* sp. in brown weathered shale collected from the outcrop on the south side of the road.

Continue on Alexander Road.

- 18.3 0.6 Note limy redbeds at railroad overpass. Limestone nodules (caliches) occur here (Wheeler and Textoris, written commun., 1977) within red and brown mudstone and sandstone in zones which stratigraphically represent the periphery of the postulated playa lake. The nodules (fig. 22b) consist of micritic and coarser calcite spar cement within which are peloids and the beginnings of pisolites, pieces of the surrounding silicate matrix that often serve as nuclei for the pisolites — although some consist of spar, and textures which resemble disruption by rootlets.
- 18.8 0.5 *TURN LEFT* on SR 1959 toward Bethesda.
- 19.2 0.4 *TURN RIGHT* on Lumley Road (SR 1966) at the Gospel Independent Baptist Church.
- 19.6 0.4 Chert occurs sparingly in brown soil in overgrown bank and field on right.
- 20.1 0.5 *TURN LEFT* and *PARK* on Bonnie Brae Road (SR 1983). Walk east on Lumley Road to house on left and STOP 14.

STOP 14 - Bedded Chert

Chert crops out along the road for a distance of 650 ft. in light brick red to dark maroon mudstone. One piece of float approximately 18 inches thick was found here about 3 years ago. The unit is terminated on the east by a diabase dike at the top of the hill near the entrance to the Stirrup Hill Village development. The chert at that point appears to have been altered by the intrusive diabase. Wheeler and Textoris report that

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“both megascopically and in thin section the limestones and chert of the two localities (STOP 12 and this stop) proved to be identical”.

Continue ahead on Bonnie Brae Road.

- 20.5 0.4 *TURN LEFT* on SR 1983.
- 20.6 0.1 *BEAR LEFT* on SR 1983.
- 20.8 0.2 *TURN RIGHT* on Lumley Road. Retrace route to Gospel Baptist Church.
- 21.6 0.8 *TURN RIGHT* on SR 1959 toward Bethesda.
- 22.5 0.9 *TURN LEFT* at stoplight on SR 1954 at Bethesda Baptist Church.
- 23.6 1.1 *Fossil locality H* near diabase dike 0.15 mile east of Durham Freeway overpass.
- 24.2 0.6 Southern High School fossil locality I in shale and impure “limestone” in right bank.
- 25.0 0.8 *TURN RIGHT* on SR 1995.
- 25.2 0.2 *TURN LEFT* on SR 2020.
- 25.6 0.4 *TURN LEFT* on Glover Road - SR 1940.
- 25.9 0.3 *TURN RIGHT* on Tangier Road (gravel).
- 30.0 0.1 STOP 15

STOP 15 - Interbedded Lacustrine Sandstone and Shale

This is the apparent base of the lacustrine unit at Bethesda. Green to grey, silty, micaceous, flaggy siltstones are interbedded with silty, fossiliferous shale and arkosic sandstone. This unit disappears 1.5 miles to the NE near U.S. Highway 70. It may have been removed by channel scour, graded into a more silty unit, or have been faulted out. Although it appears to thin in that direction, our present interpretation is that it is terminated to the NE by a northwest-trending fault. The arkosic sandstones are thin and nearly planar and show little apparent crossbedding or scour.

The following section was measured in the east cut of Tangier Road opposite the house of Mr. Fish.

		Approximate Vertical Thickness
1.	Pink to green flaggy sandstone	2.0 ft.
2.	Grey-green silty micaceous shale containing a few plant remains and a sparse fresh-water fauna	1.0 ft.
3.	Red speckled sandstone showing some channel scour at this point. Ranges from 5 to 12 inches thick	0.4 ft.

4.	Grey-green, micaceous, slightly silty shale. Has a few plant fragments and conchostracans	1.0 ft.
5.	Laminated, red speckled, medium-grained sandstone. No crossbedding obvious. Very micaceous and flaggy.	0.7 ft.
6.	Silty grey shale containing few fossils except at extreme top where they are abundant	0.9 ft.
7.	Buff to green micaceous siltstone	0.3 ft.
8.	Fossiliferous grey shale	0.2 ft.
9.	Grey to green silty and micaceous shale becoming finer-grained and more micaceous at the top where fossils also increase in abundance. Contains a few plant fossils	1.9 ft.
10	Medium-grained, red speckled sandstone	0.4 ft.
11	Green laminated micaceous shale	0.5 ft.
	Total	9.3 ft.

F. M. Swain found the following fossil assemblage from bed #9 above:

Darwinula subquadrata Swain and Brown, 1972 (very abundant)

Darwinula rogersii (Jones, 1862) (common)

Howellisaura sp. (common)

Fish bones

- 30.1 0.1 *TURN RIGHT* on Glover Road after turning around.
- 30.4 0.3 *TURN RIGHT* on SR 1926 toward Bethesda.
- 30.7 0.3 *TURN RIGHT* on SR 1955 at Old Fashioned Tabernacle Baptist Church sign.
- 31.1 0.4 STOP 16

STOP 16 - Fossiliferous Shale Overlying Diabase Sill

This site and the one passed at mile 23.6 (Fossil Locality H) are the best localities for studying this particular faunal zone. The preservation is excellent in the baked shale produced by the intrusion of a diabase sill just beneath. Diabase is also present at the other site. The fossiliferous zone exposed here is stratigraphically above STOP 15 and the site opposite Southern High School. This zone should be correlative with one recently uncovered about half way between Lowes Grove and the EPA Building on N.C.

Highway 54 which is 2300 ft. east of the one reported in the literature near the intersection of N.C. Highway 54 and N.C. Highway 55. Like the fossiliferous shale at the previous stop, this zone is terminated along strike at or near U.S. Highway 70. The attitude of the bedding here is about N 40 E 5 SE. The following section was measured opposite the church and parsonage in the south cut:

		Approximate Vertical Thickness
1.	Red, resistant, medium-grained micaceous sandstone	1.5 ft.
2.	Red, very silty shale or mudstone	2.5 ft.
3.	Tan to buff siltstone	0.2 ft.
4.	Red silty shale	1.7 ft.
5.	Red flaggy micaceous siltstone	2.5 ft.
6.	Blue-black to deep maroon fissile fossiliferous shale	2.2 ft.
7.	Blue-black, gummy, weathered hornfels	1.0 ft.
8.	Weathered contact of diabase sill	2.0 ft.
	Total	13.6 ft.

F.M. Swain reports the following fauna:

Darwinula rogersii (Jones, 1862) (common)

Darwinula? sp. 1, Swain and Brown, 1972 (frequent)

Howellisaura sp. (Closely spaced growth lines in ventral third) (common)

Unionidae sp. (common)

Turn around after stop and return to road to Bethesda.

- 31.5 0.4 *TURN RIGHT* on SR 1926 toward Bethesda.
- 32.3 0.8 Bethesda. *TURN LEFT* at stop light on SR 1959.
- 32.5 0.2 U.S. Highway 70 intersection. *CONTINUE STRAIGHT AHEAD* across U.S. Highway 70 to SR 1917 toward Oak Grove.
- 32.7 0.2 *TURN RIGHT* on SR 1811. The chert unit crops out on the right side of the road in the next 0.1 mile.
- 35.5 2.8 *TURN RIGHT* into housing development on unpaved street. Park on right.
- 35.6 0.1 STOP 17

STOP 17 - Alternate Stop--Chert Outcrop

Here chert similar to that seen at STOP 14 trends about N 40 E 5 SE in the ditches on both sides of the road. It is associated with a maroon to lavender mudstone. The chert and the playa it represents have swung in an arc from Morrisville through the Research Triangle Park and Bethesda to this point. It apparently ends about 1.5 miles ENE from this point and 4 miles from the Jonesboro fault zone. See Figure 2.

- 35.7 0.1 *TURN RIGHT* and continue on SR 1811 after turning around.
- 36.1 0.4 *TURN RIGHT* on N.C. Highway 98 toward Wake Forest.
- 36.5 0.4 *TURN RIGHT* on SR 1905 at Olive Baptist Church sign.
- 37.4 0.9 *BEAR LEFT* on SR 1905.
- 39.7 2.3 *TURN RIGHT* on SR 1901.
- 40.0 0.3 *TURN LEFT* on Leesville Road (SR 1906).
- 41.1 1.1 Wake County line. SR 1906 becomes SR 1839.
- 41.3 0.2 Cross eastern border fault zone. The ridge ahead that the road follows for the next 2 miles is capped at elevations about 500 feet by pebbly, limonitic upland sediment (J. M. Parker, III, personal communication).
- 42.8 1.5 *BEAR RIGHT* on SR 1829 to Leesville.
- 43.8 1.0 Leesville. *TURN RIGHT* in Leesville on SR 1837 toward airport.
- 44.0 0.2 *KEEP RIGHT* on SR 1837.
- 46.2 2.2 STOP 18.

STOP 18 - Notch in Trace of Border Fault

J. M. Parker, III

DANGEROUS TRAFFIC AT INTERSECTION. Because of traffic and lack of time, observations will be confined to the northeast side of U.S. Highway 70.

The map (fig. 23) shows locations of exposures of Triassic fanglomerate and low-rank metamorphic rocks of slate belt types and the observed and inferred positions of the border fault. The contact is exposed in the ditches along SR 1837 about 500 ft. northeast of U.S. Highway 70. Bedding in the Triassic rocks here is vague but seems to dip steeply westward. It is horizontal, however, on U.S. Highway 70 just west of the intersection. The metamorphic rocks to the east include phyllite (derived probably from lithic tuff), greenstone, various gneisses, and granitic rock. Clasts in the fanglomerate are of rock types common nearby except that hematite ironstone has not been found in

DURHAM TRIASSIC BASIN

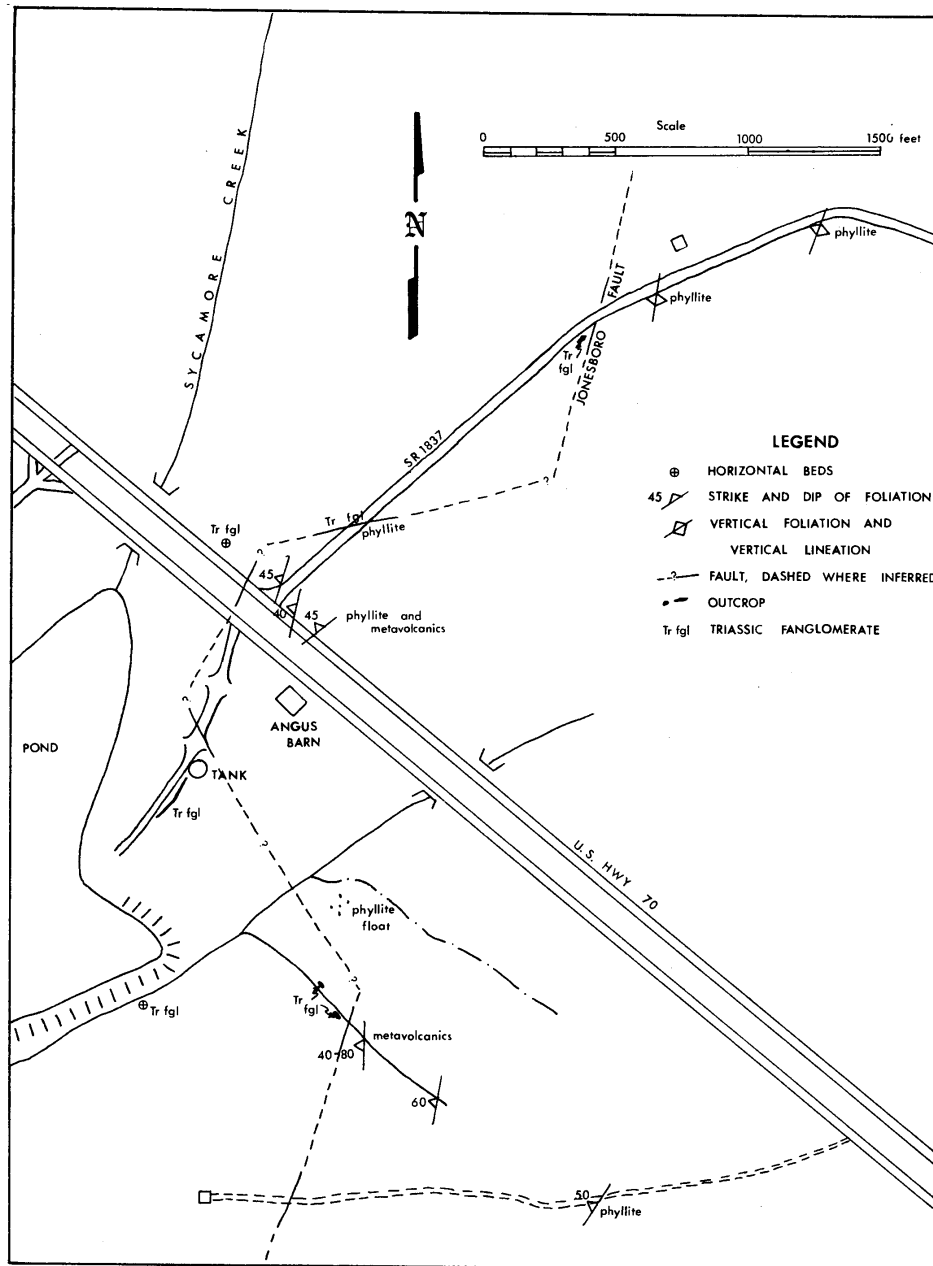


Figure 23. Geologic map of Jonesboro fault at STOP 18. (J. M. Parker, III, in preparation).

place.

Four bends in the contact create an angular notch in the fault trace. The Jonesboro fault seems to have been offset westward some 900 ft. along two transverse post-Triassic strike-slip faults. The inferred fault south of U.S. Highway 70 probably extends southeastward a mile to displace magnetite-ilmenite quartzite in northern Umstead Park. No evidence has been detected for the continuance of the inferred fault (north of the highway) into rocks either east or west of

the Jonesboro fault.

This locality is the same as STOP 1 of the 1959 Piedmont trip of the Southeastern Section of the Geological Society of America.

APPENDIX 1

DIAMOND-DRILL RECORDS

Drill hole: RDH 2.
 Location: Approximately 11,800 feet S. 71° W. of main shaft of Cum-
 nock mine.
 Surface altitude: 249.
 Date: 1945.
 Drilled for: Walter Bledsoe & Co.
 Logged by: W. E. Berry, Duke University.

Description 1	Depth from surface				Thickness	
	From—		To—		Feet Inches	
	Feet	Inches	Feet	Inches	Feet	Inches
Surface soil:						
No core.....	0		26		26	
Sanford formation (Triassic):						
Shale, red.....	26		29	7	3	7
Siltstone, red, sandy, calcareous.....	29	7	32		2	5
Shale, red.....	32		45	7	13	7
Siltstone, red, calcareous nodules.....	45	7	48		2	5
Siltstone, red, non-calcareous.....	48		53		5	
Shale, red, few calcite layers.....	53		66	7	13	7
Sandstone, gray, non-calcareous.....	66	7	67		1	5
Sandstone and shale, non-calcar- eous.....	67		69	8	2	8
Sandstone, gray, hard, finely arkosic.....	69	8	70	10	1	2
Sandstone, gray, hard, coarse, few pebbles up to 3/8 in.....	70	10	80		9	2
Sandstone, gray, hard, calcareous in part.....	80		90	7	10	7
Sandstone, gray, shaly, non- calcareous.....	90	7	95		4	5
Sandstone, gray, hard, coarse calcareous nodules and pebbles up to 3/8 in.....	95		109	5	14	5
Siltstone, gray, and pebbles non- calcareous.....	109	5	110		1	7
Siltstone, gray, non-calcareous.....	110		112	9	2	9
Shale, red.....	112	9	129	3	16	6
Siltstone, mottled 148 to 149 ft.....	129	3	181	11	52	8
Shale, red.....	181	11	187		5	1
Siltstone, red, few calcareous nodules.....	187		221		34	
Sandstone, gray and red, non- calcareous, too variegated.....	221		245		24	
Shale, red, some irregular open- ings in shale.....	245		259	6	14	6
Siltstone, red limestone nodules, up to 1/4 in.....	259	6	282	3	22	9
Shale, red.....	282	3	284	5	2	2
Siltstone, red, grading into in- clined gray calcareous sand- stone at bottom.....	284	5	308	2	23	9
Shale, gray and red variegated.....	308	2	313		4	10
Siltstone, reddish-brown.....	313		316		3	
Sandstone, gray, fine-grained, in- clined, some shale lenses slight- ly calcareous to 4 in.....	316		332	3	16	3
Shale, gray.....	332	3	333	4	1	
Shale, or siltstone, dark gray.....	333	4	337	8	4	4
Siltstone, gray, lumps of red shale.....	337	8	340	6	2	10
Sandstone, red and gray, slightly calcareous.....	340	6	352		11	6
Sandstone, gray, calcareous, few flakes of coal at 356 ft 11 in.....	352		363	5	11	5
Shale, gray to red variegated, soft, occasional siltstone bands, few calcareous sandstone lumps.....	363	5	406		42	7
Sandstone, gray, fine.....	406		407	11	1	11
Shale, gray.....	407	11	408	4	5	
Shale, (rotten) red, broken up, soft.....	408	4	422	1	13	9
Siltstone, red and gray mottled.....	422	1	437	8	15	7
Siltstone, gray.....	437	8	438	5	9	
Siltstone, red.....	438	5	439		7	
Siltstone, red, occasional red layer.....	439		450		11	
Siltstone, red, many calcareous nodules, few gray layers.....	450		459	9	9	9
Shale, mottled red and gray, non- calcareous.....	459	9	464	9	5	
Siltstone, red, calcareous.....	464	9	484	4	19	7
Siltstone, gray, non-calcareous.....	484	4	486		1	8
Shale, red and gray variegated.....	486		496	6	10	6
Sandstone, red, variegated, cal- careous.....	496	6	507		10	6
Siltstone, red.....	507		516	10	9	10
Shale, gray.....	516	10	519	10	3	
Sandstone, variegated red and gray.....	519	10	520	10	1	
Siltstone, red, calcareous layers.....	520	10	524	9	3	11
Siltstone, gray.....	524	9	526	6	1	9
Siltstone, red.....	526	6	530		3	6
Siltstone, gray, few red nodules.....	530		554		24	
Siltstone, red and gray mottled.....	554		556	6	2	6
Siltstone, gray.....	556	6	561	5	4	11
Shale, gray.....	561	5	571		9	7
Siltstone, gray, calcareous.....	571		576	11	5	11

DIAMOND-DRILL RECORDS

Drill hole BDH 2—Continued

Description 1	Depth from surface				Thickness	
	From—		To—		Feet Inches	
	Feet	Inches	Feet	Inches	Feet	Inches
Sanford formation (Triassic)—Con.						
Shale, gray, silty.....	576	11	586	3	9	4
Sandstone, gray, some calcite and pyrite, some limy layers.....	586	3	630		43	9
Diabase upper contact much broken up; lower contact quite even; coarse in center.....	630		806	6	176	6
Shale, black (baked hard).....	806	6	807	1	7	
Sandstone, variegated red and gray, calcareous.....	807	1	820		12	11
Cummock formation (Triassic):						
Siltstone, (?) calcite bands on part- ings.....	820		834		14	
Sandstone, hard, dense, calcare- ous, some flecks of carbon- gray black, approximately 500 ft to coal (?).....	834		834	8	8	
Sandstone, gray, hard, dense, graphitic (?).....	834	8	835	6	10	
Siltstone, gray, non-calcareous.....	835	6	851		15	6
Shale, gray, non-calcareous.....	851		853		2	
Shale, black, soft, many calcite partings, little pyrite.....	853		898		45	
Shale, gray, calcareous.....	898		912	3	14	3
Shale, black, calcareous.....	912	3	915	6	3	3
Shale, gray, calcite partings, sandy and pyrite at 921 ft.....	915	6	921		5	6
Shale, black, calcareous <i>Ostracods</i> 925 ft.....	921		929		8	
Shale, gray, calcareous.....	929		933		4	
Shale, black, calcite partings.....	933		940		7	
Shale, gray, calcareous.....	940		947		7	
Shale, black.....	947		952	10	5	10
Shale, dark gray.....	952	10	1,005	6	52	8
Shale, black, much broken 1,006 ft. 6 in.....	1,005	6	1,007	6	2	
Shale, dark gray to black.....	1,007	6	1,037	5	29	11
Shale, dark gray to black, calcite partings.....	1,037	5	1,172		134	7
(?) hard, dense, slightly calcare- ous, looks like diabase but lacks cleavages, possibly dense sand- stone.....	1,172		1,175		3	
Shale, black.....	1,175		1,176		1	
Sandstone or siltstone, looks like diabase.....	1,176		1,177	6	1	6
Shale, black.....	1,177	6	1,193	6	16	
Shale, gray, calcareous.....	1,193	6	1,195		1	6
Shale, black, calcite partings.....	1,195		1,205		10	
Shale, more or less black.....	1,205		1,210		5	
Shale, gray, black, calcite partings shickensided 1219 ft. <i>Fault</i> 1/4 in. band pyrite 1,220 ft.....	1,210		1,220		10	
Shale, black, waxy, carbonace- ous.....	1,220		1,220	6	6	
Shale, black, carbonaceous.....	1,220	6	1,229	10	9	4
Shale, black, calcareous nodules.....	1,229	10	1,234	9	4	11
Shale, black, carbonaceous.....	1,234	9	1,234	11	2	
Shale, black, <i>Coprolites</i>	1,234	11	1,236		1	1
Shale, black, carbonaceous.....	1,236		1,236	4	4	
Shale, black.....	1,236	4	1,237	10 1/2	1	6 1/2
Sandstone, gray, hard.....	1,237	10 1/2	1,243	4 1/2	5	6
Shale, dark gray (draw slates).....	1,243	4 1/2	1,244	1 1/2	9	
Coal (Main bench, Cumnock Coal Bed).....	1,244	1 1/2	1,247	9	3	7 1/2
Blackband.....	1,247	9	1,249	7 1/2	1	10 1/2
Coal (Lower bench, Cumnock Coal Bed).....	1,249	7 1/2	1,251		1	4 1/2
Shale, black.....	1,251		1,251	6	6	
Coal (Lower bench, Cumnock Coal Bed).....	1,251	6	1,252	3 1/2	9 1/2	
Shale, black.....	1,252	3 1/2	1,254	6	2	2 1/2
Shale, gray, soft.....	1,254	6	1,258		3	6
Sandstone, gray.....	1,258		1,259		1	
Shale, gray, soft.....	1,259		1,261	9 1/2	2	9 1/2
Sandstone, gray, fine-grained.....	1,261	9 1/2	1,261	10 1/2	1	
Shale, gray, soft, calcareous nod- ules, <i>Ostracods</i>	1,261	10 1/2	1,263		1	1 1/2
Coal.....	1,263		1,263	3	3	
Shale, gray, soft (fire clay).....	1,263	3	1,264	1 1/2	10 1/2	
Sandstone, gray, fine-grained, bedding irregular, few thin non- calcareous shale layers.....	1,264	1 1/2	1,268	9	4	7 1/2
Shale, black, sandy layers and calcite partings.....	1,268	9	1,271	4	2	7
Sandstone, gray, fine-grained, non-calcareous.....	1,271	4	1,273	7	2	3
Shale, black, calcareous partings.....	1,273	7	1,275	9 1/2	2	2 1/2
Coal (Gulf Coal Bed).....	1,275	9 1/2	1,276	6	8 1/2	
Shale parting.....	1,276	6	1,276	7 1/2	1 1/2	1 1/2
Coal (Gulf Coal Bed).....	1,276	7 1/2	1,277	11	1	3 1/2

APPENDIX 2

Ostracoda from Triassic of North Carolina

F. M. Swain

Letters refer to localities on fig. 24 from which collections were obtained June 17 and 18, 1977 in addition to those listed in the road log. Fossils listed below ostracods are brachiopods, bivalves, fish and plant remains.

A. Intersection of Davis Drive and Interstate 40, STOP 12a; up to 6 or 7 m of interbedded red and grey shale and thin freshwater limestone and arkose. No fossils other than possible algal structures in grey argillaceous limestone. Shale contains:

Darwinula subquadrata Swain and Brown, 1972 (abundant)

Darwinula rogersii (Jones, 1862) (frequent)

Howellisaura sp.¹

Bivalvia

Fish bones, scales

Plant leaf impressions

¹ *Howellites*, a brachiopod or conchostracan, was proposed by Bock, 1953 with *H. princetonensis* Bock, 1953 as type species. *Howellites* was preoccupied for a brachiopod (Bancroft, 1945) and Bock renamed his genus *Howellisaura* Bock, 1953. *H. berryi* (Bock, 1953) from the Cumnock Formation, Chatham County, North Carolina was stated to be similar to *H. princetonensis* (Bock, 1953) except that *berryi* is slightly smaller (adult males 5 mm, adult females, 3.5 mm) and slightly rounder than *princetonensis*. In the present collection, the specimens that seem to belong to the *princetonensis-berryi* group are 7-8 mm in length and are thus closer to *princetonensis* in size. Because of uncertainty as to which of the two species the forms belong, they are herein referred to as *Howellisaura* sp. The name *Cyzicus* Audouin, 1837 is commonly used for these Triassic Conchostraca, but that genus is based on living species, and Bock's *Howellisaura* which applies specifically to the Triassic forms may be here preferable to *Cyzicus* until the two genera have been clearly shown to be the same.

B. Intersection of Davis Drive and Old N.C. Highway 54, STOP 12; red calcareous mudstone with thin interbeds of cherty and non-cherty limestone, about 2 m exposed.

No fossils seen.

C. Troxler Laboratory, intersection of Cornwallis and Alexander Drives, Research Triangle area; 1 m of dark grey-black shale, many ostracods with red mudstone and red sandstone above and below.

Darwinula subquadrata Swain and Brown, 1972 (common)

Darwinula? sp. 1, Swain and Brown, 1972 (frequent)

Howellisaura sp. (frequent)

Fish bones and scales (frequent)

D. Near the intersection of the Durham Freeway and Alexander Drive, STOP 13; thin calcareous and siliceous shale, limestone, and fissile grey and red shale, badly weathered.

No ostracodes seen.

Howellisaura sp. in brown weathered shale.

E. Cornwallis Road and Bethesda-Nelson Road, near railroad track; 1 m red and grey mudstone with nodular limestone and chert.

No fossils seen.

F. Intersection of T. W. Alexander Drive and Southern Railroad; about 2 m red and green mudstone and rubbly varicolored limestone.

No fossils seen. Some of limestone may be of algal origin.

G. Lumley Road near Lakeshore Golf Course, STOP 14; SR 4507 and 0.5 mile east; chert horizon in red shale.

No fossils seen; some of chert has circular structures and may represent petrified wood.

H. Road to Southern High School, 0.15 mile east of the Durham Freeway overpass; 1 m of black shale with abundant *Howellisaura*, clams, and ostracodes.

Darwinula subquadrata Swain and Brown, 1972 (frequent)

Darwinula? sp. 1, Swain and Brown, 1972 (rare)

Darwinula rogersii (Jones, 1862) (rare)

Candona? sp. (rare)

Howellisaura sp. (abundant)

Fish bones (rare)

Unionidae sp. (common)

I. Opposite Southern High School; black and grey shale, weathered tan and pink, 1.5-2 m exposed, thin impure "limestone", overlain by sandy and silty beds.

Darwinula subquadrata Swain and Brown, 1972 (abundant)

Darwinula rogersii (Jones, 1862) (common)

Darwinula? sp. 1, Swain and Brown, 1972 (frequent)

Howellisaura sp.

Fish bones

Plant impressions

J. Providence Baptist Church Road (SR 1955) south of Page Road, STOP 16; 1 m of black to maroon shale with *Howellisaura*, clams, and ostracodes, overlain by 1 m of feldspathic sandstone.

Darwinula rogersii (Jones, 1862) (common)
Darwinula? sp. 1, Swain and Brown, 1972 (frequent)

Howellisaura sp. (common)
 Unionidae sp. (common)

K. Intersection of SR 1940 and 1941, 0.1 mile east of the Durham Freeway on SR 1942 (Tangier Road), STOP 15; about 2 m of sandy and platy shale with fossils at base.

Darwinula subquadrata Swain and Brown, 1972 (very abundant)
Darwinula rogersii (Jones, 1862) (common)

Howellisaura sp. (common)
 Fish bones
 Plant impressions

L. Off N.C. Highway 98, 0.3 mile west of the intersection of N.C. Highway 98 and SR 1811, STOP 17; chert deposit.

No fossils seen, but some of the nodular structures in the chert may be of a paleontological nature.

M. 0.55 mile south on Dr. Nichols Road from Olive Branch Road in bank by house; 1.5 m red and grey clay, possible *Howellisaura*.

Plant impressions

N. On N.C. Highway 55, halfway between the EPA Building and Lowes Grove Grade School; 1 m of red and grey shale; *Howellisaura* and ostracodes in grey shale.

Darwinula subquadrata Swain and Brown, 1972 (common)
Darwinula rogersii (Jones, 1862) (frequent)

Howellisaura sp. (frequent) (many with abundant closely spaced cross furrows)
Isaura sp.² (with rugose growth ridges and widely spaced pits or nodes along growth ridges) (frequent)

² The forms now included in *Isaura* Joly, 1841 have been generally referred to *Estheria* Ruppel, Strauss-Duchheim, 1837, not Robinson-Desoidy, 1830 [*fide* Bock, 1953]. The present specimens appear to represent the general group of *Isaura ovata* (Lea, 1856), of the Lockatong Formation.

O. Intersection of N.C. Highway 55 and N.C. Highway 54, large borrow pit; about 7 m of red shale, arkose, and nodular reddish limestone.

No fossils seen; some of limestone may be of algal origin.

P. 0.2 miles south of the intersection of N.C. Highway 55 and N.C. Highway 54, on N.C. Highway 55; red shale in graded area, badly weathered, with thin fossil layer; 1 m thick exposure.

Darwinula rogersii (Jones, 1862) (abundant)
Darwinula subquadrata Swain and Brown, 1972 (very abundant)

Howellisaura sp.
 Bivalve?

Q. One mile south of Lowes Grove on Alston Avenue near Sedgwick Road, intersection of SR 1977 and 1945; few red fissile shale chips with fossils in graded area near housing project; no exposure.

Darwinula subquadrata Swain and Brown, 1972 (abundant)
Darwinula rogersii (Jones, 1862) (frequent)

Howellisaura sp. (abundant)

R. Triangle Brick Company, pit ("Carpenter locality"), STOP 11; 0.5 m grey fissile shale beneath 1 m arkose; about in middle of exposure (Swain and Brown, 1972).

Darwinula subquadrata Swain and Brown, 1972 (abundant)
Darwinula? Sp. 1, Swain and Brown, 1972 (rare)
Darwinula? Sp. 2, Swain and Brown, 1972 (rare)

Howellisaura sp.

S. Gravel road south of the Triangle Brick Plant; about 1 m reddish shale, sandstone and arkosic sandstone, thin *Howellisaura* layer. Fossils in silty red shale.

Darwinula subquadrata Swain and Brown, 1972 (rare)

Howellisaura sp. (abundant)

T. Near base of Triassic, Pea Ridge Road north of Moncure, STOP 6b, Corps of Engineers Recreation Area.
 Tan sandy and non-sandy clay, no fossils seen.

DURHAM TRIASSIC BASIN

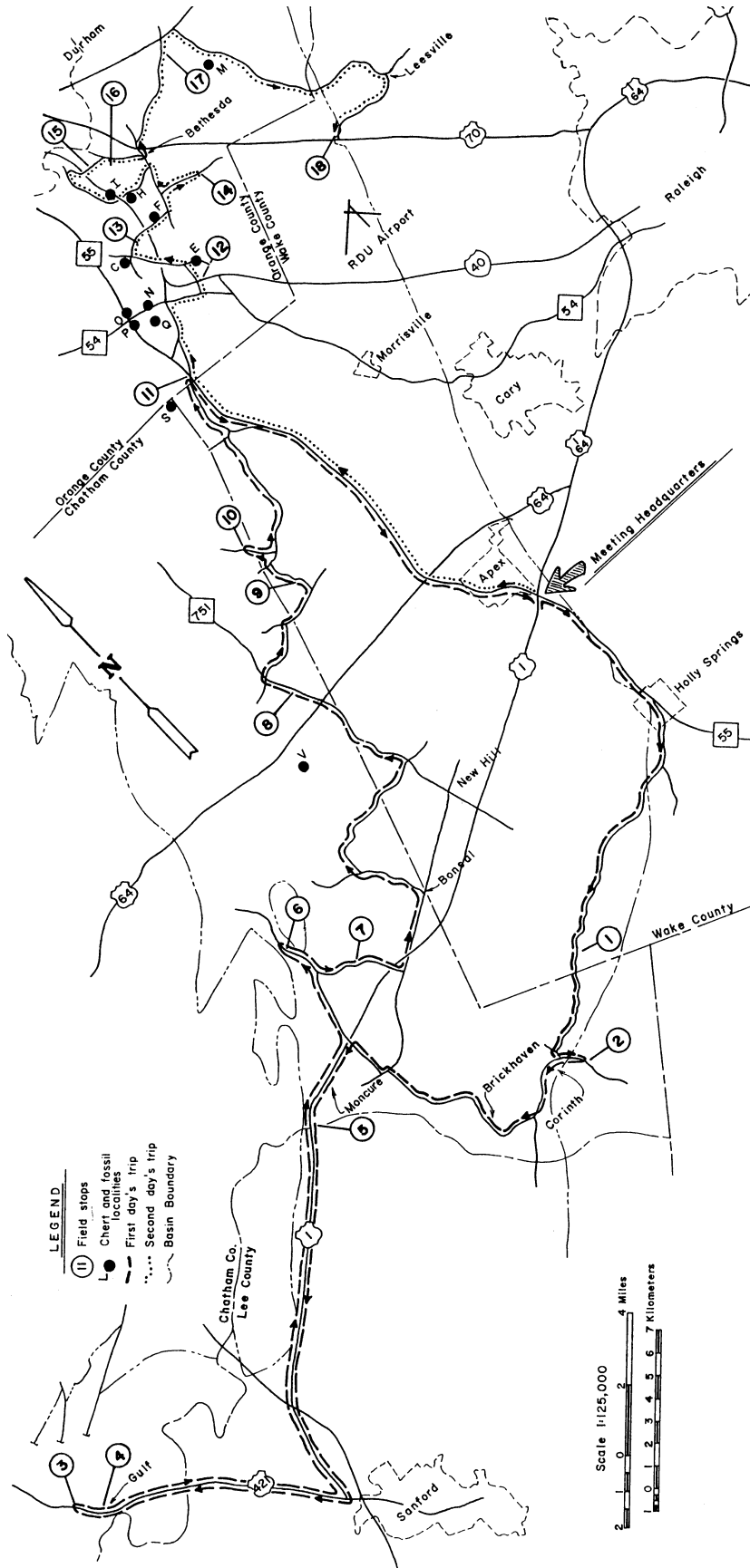


Figure 24. Map of field trip route, stops, and fossil localities.