GEOLOGY OF THE SOUTHEAST DURHAM AND SOUTHWEST DURHAM 7.5-MINUTE QUADRANGLES, NORTH CAROLINA

By

Charles W. Hoffman and Patricia E. Gallagher

BULLETIN 92

NORTH CAROLINA GEOLOGICAL SURVEY

DIVISION OF LAND RESOURCES

DEPARTMENT OF NATURAL RESOURCES
AND COMMUNITY DEVELOPMENT

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STATE OF NORTH CAROLINA

JAMES G. MARTIN, GOVERNOR

DEPARTMENT OF NATURAL RESOURCES
AND
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GEOLOGY OF THE SOUTHEAST DURHAM AND SOUTHWEST DURHAM 7.5-MINUTE QUADRANGLES, NORTH CAROLINA

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ABSTRACT

The Southeast Durham and Southwest Durham 7.5-minute Quadrangles include a 26 kilometer transect of the Durham Triassic basin from the Jonesboro fault on the southeastern side of this half-graben structure to a bounding unconformity on the northwestern side. The basin is filled with non-marine, primarily fluvial, clastic deposits of the Late Triassic Chatham Group. The Chatham Group rocks are intruded by Early Jurassic diabase as dikes and sheets. Bordering rocks are pre-Mesozoic intrusive, metavolcanic and metasedimentary rocks of the Carolina slate belt.

Within the Triassic sedimentary rocks, three lithofacies associations comprised of seven distinct lithofacies form three belts that generally conform to the trend of the basin. The western association is comprised of a single lithofacies consisting of sandstone with interbedded siltstone. The central association is comprised of two lithofacies, sandstone with interbedded siltstone and siltstone with interbedded sandstone. The eastern association is comprised of four lithofacies; sandstone, pebbly sandstone, sandstone with interbedded conglomerate, and conglomerate. The western lithofacies association consists of mud-clast-rich, trough crossbedded, arkosic sandstone interspersed with locally thick siltstone beds. The unit is interpreted to represent sandy braided streams flowing within fine-grained interstream areas. The central lithofacies association consists of arkosic, fining-upward, meandering stream deposits in the northern part of its area. To the south, in the upper part of its section, this lithofacies association grades to a muddy system dominated by fine-grained overbank fluvial and lacustrine deposits with intercalated sandstone. The eastern lithofacies association consists of conglomerates along the border fault and grades basinward through interbedded sandstone and conglomerate to pebbly sandstone and then to muddy sandstone. Adjacent facies exhibit both intertonguing and gradational relationships. This set of lithofacies is interpreted to represent basin-margin alluvial fan deposits that prograded from a southeastern highland.

INTRODUCTION

LOCATION

The Southeast Durham and Southwest Durham 7.5-minute Quadrangles encompass an area of approximately 300 square kilometers. The quadrangles include a large part of the Durham Triassic basin and small areas of the adjacent Piedmont region (figure 1). A significant amount of the study area is urban and suburban. Large portions of Durham, Research Triangle Park, and Raleigh-Durham International Airport are located within the study area as are developing sections of Raleigh and Chapel Hill.

OBJECTIVES, SCOPE, AND METHODS

Adequate land use planning and resource management require, among many other things, sound baseline information on a variety of properties that are directly related to geology. Such information includes soil types and their ability to bear weight, maintain a slope, or transmit fluid; groundwater quality and quantity; mineral resource potential (especially aggregates for highway and building construction); and potential geologic hazards such as landslides or radon gas. In the rapidly urbanizing Research Triangle area, where proper planning is basic to maintaining a desirable quality of life, the need for accurate geologic maps at a suitable scale is vital.

This study was undertaken to meet these

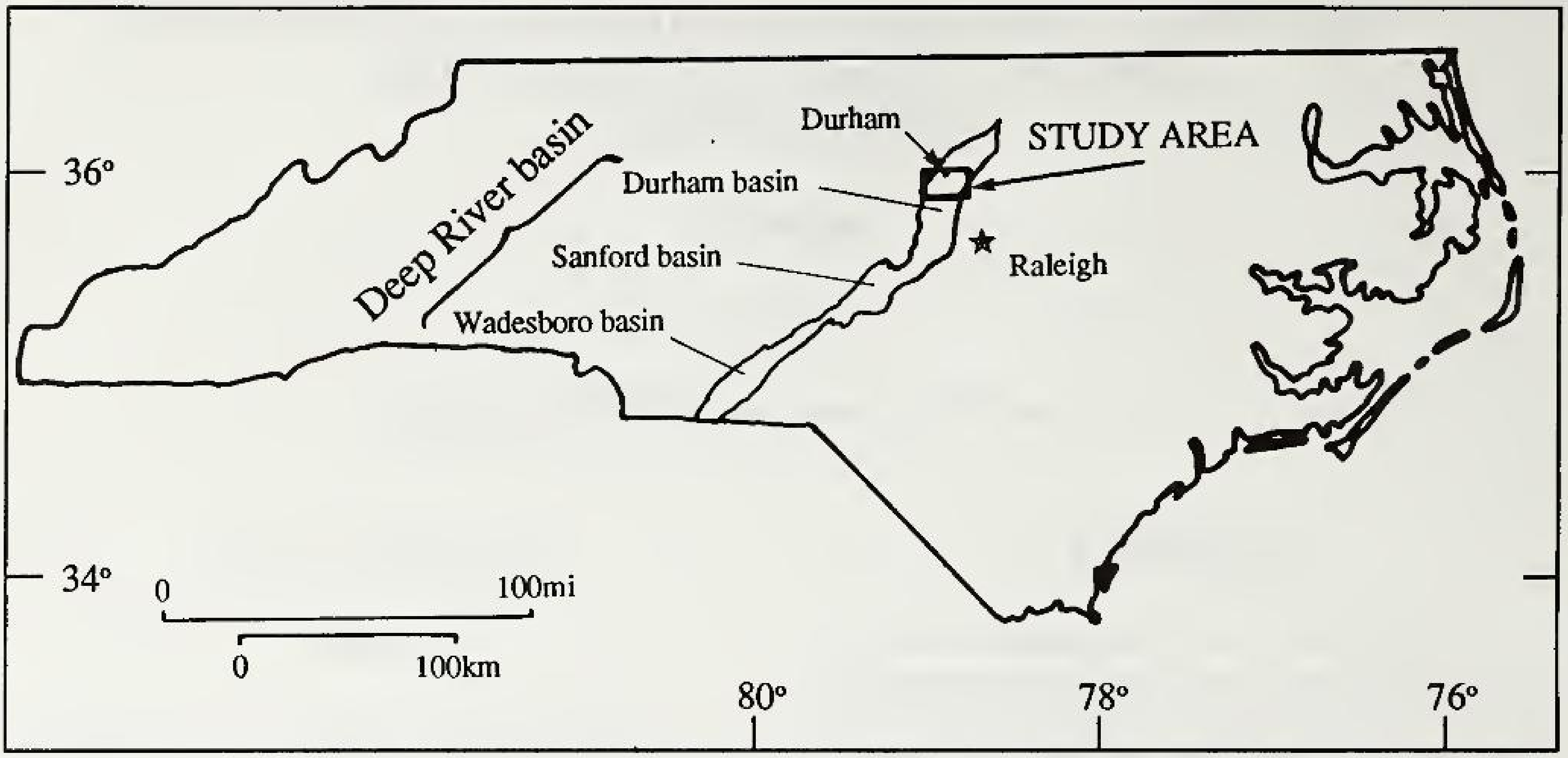


Figure 1. Map of North Carolina showing location of study area within the Durham Triassic basin.

needs. The specific objective was to provide detailed surface geologic mapping of the study area. Toward this end, lithofacies within the Triassic sedimentary rocks of the two quadrangles were identified and mapped. The lithofacies are defined chiefly by field criteria including mineralogical composition and sedimentary textures and structures. Binocular and petrographic examination of selected samples was conducted to support and refine the field descriptions. Thin-section point count data are tabulated in Appendix A.

Additionally, Jurassic diabase bodies and the contact between Triassic sedimentary rocks and pre-Mesozoic crystalline rocks were mapped. The distribution of pre-Mesozoic crystalline rock lithologies was compiled from existing sources (Parker, 1979; Wilson and Carpenter, 1981; North Carolina Geological Survey, 1985). Other than to delineate the contact between these rocks and the Triassic sedimentary rocks, the crystalline rocks were not investigated. The distribution of alluvium was interpreted from topographic and soils maps.

The quadrangle maps included in this report (Plates 1 and 2, in pocket) have been reduced in scale for publication. Full size (1:24,000 scale) diazo prints of the quadrangle maps (with topography) are available separately as North Carolina Geological Survey Open-File Reports 89-1 (Southeast Durham Quadrangle) and 89-2 (Southwest Durham Quadrangle).

Outcrop within the two quadrangles is limited and generally poor because of deep weathering and extensive soil development. Total outcrop area is estimated to be less than two percent. Except in the upper reaches of tributary streams, alluvium masks outcrop within most portions of the drainage system. These streambed outcrops usually provide little vertical exposure but do yield representative samples for grain size and textural observations. Roadside ditches and road cuts also expose some bedrock, however primary depositional features such as bedding orientation and sedimentary structures are obscured by weathering in most of these outcrops. Three quarries operated by Borden Brick and Tile Company (a division of Cherokee Sanford Group) are within the study area and provided some of the better sections during the study. Key exposures examined for the project are listed in the Locality Register (Appendix B).

Additionally, information was provided by temporary exposures created by construction activity. Construction in progress during this project included excavation for the Southern Parkway (no Wake County Secondary Route (SR) number assigned to date) from Alexander Drive (SR 2028) at Miami Boulevard (SR 1959) to U.S. 70, major expansion of Burroughs-Wellcome and Glaxo pharmaceutical companies in Research Triangle Park, excavation for a sewer line along Stirrup Iron Creek from Chin Page Road (SR 1969) to Page Road (SR 1973), initial development of ACC park north of U.S. 70 between Mt. Herman Road (SR 1646) and Sycamore Creek, and numerous smaller scale activities. Excavation for the 10,000 foot runway (5R - 23L) at Raleigh-Durham International Airport and for Interstate 40 from the Durham Freeway (N.C. 147) to U.S. 15-501 pre-dated this project but engineering data and interviews with personnel associated with those activities were utilized.

CONVENTIONS

Several conventions used in this report may not be familiar or evident to some readers. One is the terminology and symbols used to identify the sedimentary lithofacies. These are based on a system used by the U.S. Geological Survey for Newark Supergroup rocks of the eastern United States early Mesozoic basins (Smoot, Froelich, and Luttrell, 1988). The standardized symbols and terms facilitate interbasin and intrabasinal comparisons of depositional units. In this report the age (Tr = Triassic) and group (c = Chatham Group) are common to all of the Triassic lithofacies. Trc is followed by a symbol for the major or characteristic lithology (c = conglomerate, sc = pebbly sandstone, s = sandstone, and si = siltstone) to further designate the lithofacies. Subscript numerals differentiate similar lithologies of different facies and interbedded lithologies are separated by a slash (/) with the dominant lithology being given first. For example, "s/si" denotes sandstone with interbedded siltstone.

This report does not apply formal nomenclature below group rank. Until additional detailed facies mapping is completed over a wider area and until subsurface relationships are better understood, it is inappropriate to apply formal nomenclature below group rank to rocks of the Durham basin.

Many of the rock descriptions, mainly in the figured geologic sections, include standard color names based on the Rock-Color Chart prepared by The Rock Color Chart Committee (1948) and distributed by the Geological Society of America.

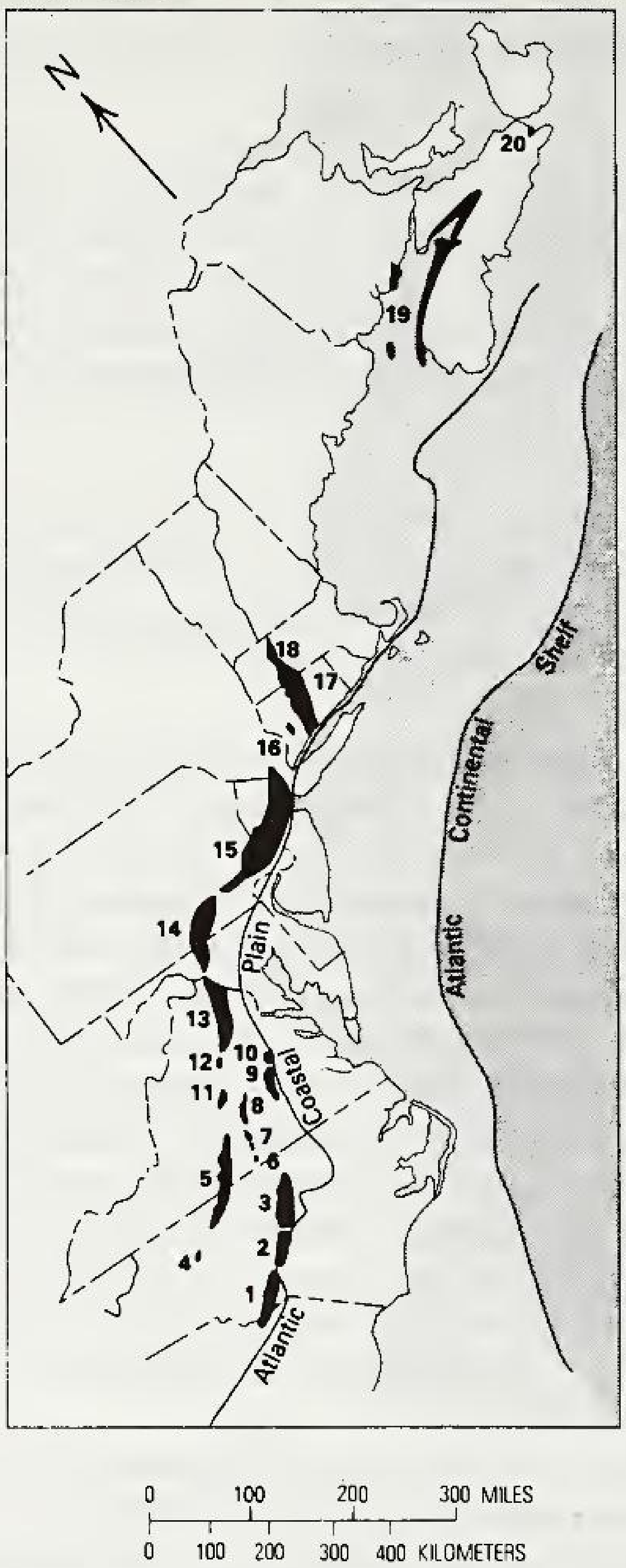
Both English and metric units are used. Distances that are likely to be measured with a motor vehicle's odometer are given as miles; otherwise metric units are used.

Another convention is in the identification of streets, roads, and highways. Generally, the street or road name is given first and followed in parentheses by the state route number. This is because much of this area is urban or becoming urban and signs and local recognition are generally based on street or road names rather than route numbers (although the quadrangle maps generally show only the route numbers). In some cases, streets within private developments are not state maintained and Secondary Route (SR) numbers do not apply.

GEOLOGIC SETTING

The Durham basin is part of a series of extensional basins in eastern North America that developed during rifting in the early Mesozoic. This rifting event resulted in the separation of the North American and African plates. Approximately 20 "synrift" basins, collectively identified as the Newark rift system, are exposed along the North American continental margin from South Carolina to Nova Scotia (figure 2). Many other, presumably coeval, basins have been interpreted to lie beneath the late Mesozoic and Cenozoic sediments of the Atlantic Coastal Plain and adjacent continental shelf (for example Benson, 1984).

Newark rift system basins contain Late Triassic and Early Jurassic non-marine clastic



EXPLANATION

1. Wadesboro (N.C. – S.C.)
2. Sanford (N.C.)
3. Durham (N.C.)
4. Davie County (N.C.)
5. Dan River and Danville (N.C. – Va.)
6. Scottsburg (Va.)
7. Basins north of Scottsburg (Va.)
8. Farmville (Va.)
9. Richmond (Va.)
10. Taylorsville (Va.)
11. Scottsville (Va.)
12. Barboursville (Va.)
13. Culpeper (Va. – Md.)
14. Gettysburg (Md. – Pa.)
15. Newark (N.J. – Pa. – N.Y.)
16. Pomperaug (Conn.)
17. Hartford (Conn. – Mass.)
18. Deerfield (Mass.)
19. Fundy or Minas (Nova Scotia – Canada)
20. Chedabucto (Nova Scotia – Canada)

Figure 2. Newark rift system basins of eastern North America (from Froelich and Olsen, 1984).

deposits of fluvial and lacustrine origin with interbedded evaporites and basaltic flows. These rocks form the Newark Supergroup (Froelich and Olsen, 1984). Interbedded basalt flows belonging to the Newark Supergroup are limited to basins from Virginia northward. A second Early Jurassic episode of intrusion by diabase dikes, sheets, and sills occurred. These intrusions are concentrated mainly in the Carolinas and are sparse to absent in the more northern basins (Manspeizer and Cousminer, 1988). Due to their cross-cutting relationships and post-depositional emplacement, these rocks are not included in the Newark Supergroup.

The Durham basin, and the Sanford and Wadesboro basins to the south, form a 240-kilometer-long by up to 26-kilometer-wide structure known as the Deep River basin (figure 1). The individual basins are separated by cross-trending structural highs named the Colon cross structure (between Durham and Sanford basins) and the Pekin cross structure (between Sanford and Wadesboro basins). Sedimentary rocks of the Deep River basin of Chatham County were named the Chatham series by Emmons (1857). Subsequently, the term Chatham Group has been used to include all the Late Triassic (Carnian) rocks of the Deep River basin (Froelich and Olsen, 1984; North Carolina Geological Survey, 1985).

The Durham basin is a half-graben structure within crystalline rocks of the Piedmont region. It is down-faulted on the southeastern margin and bounded on the west mainly by an unconformity. Locally, the western border is formed by minor southeast dipping high-angle normal faults. The eastern border fault was named the Jonesboro fault (Campbell and Kimball, 1923) for an exposure in Lee County. It dips northwestward at a high angle.

PREVIOUS WORK

Very little detailed geologic work has been published on the Durham basin. Harrington (1951) mapped the basin's western border at a scale of approximately 1:125,000. The 1977 Carolina

Geological Society Field Trip Guidebook (Bain and Harvey, 1977) contains a reconnaissance geologic map of the Durham basin at a scale of 1:250,000 which has been extensively referenced by subsequent investigators. Bain and Harvey's map was used in the compilation of the Geologic Map of North Carolina (North Carolina Geological Survey, 1985).

Wheeler and Textoris (1978) described several occurrences of chert and limestone within the Durham basin. They concluded that the chert and limestone were precipitated under semi-arid to arid conditions in and along the margins of playa lakes that formed during wet climatic periods and evaporated during subsequent dry periods. Their study constitutes the only published detailed petrographic analysis of Durham basin chert and carbonate.

In his report on the geology of Wake County, Parker (1979) mapped a portion of the Durham basin along with the crystalline rocks of the county. He recognized three belts or facies within the Triassic sedimentary rocks: a fanglomerate belt adjacent to the eastern border fault, a sandstone-mudstone belt basinward of the fanglomerate, and a limestone-chert belt basinward of the sandstone-mudstone. He regarded these belts as lateral equivalents that persisted vertically through the sedimentary section. The metavolcanic and metasedimentary rocks immediately adjacent to the Durham basin on its southeast side was termed the Cary sequence.

Bain and Brown (1980) characterized the structure and sedimentation of the "Durham Triassic basin" (Deep River basin of current usage) using a variety of geophysical tools including seismic reflection and refraction, gravity, resistivity, and aeromagnetic surveys. Their study is the most extensive work on the structural aspects of the Deep River basin. Most of their work specific to the Durham basin, however, was conducted south of the Southeast and Southwest Durham Quadrangles. One key finding was that the basin's eastern border is a step-faulted zone several kilometers wide. From this observation Bain and Brown (1980) inferred that, contrary to conventional thinking, some of the border conglomerates may be older than more basinward strata. They also inferred that the basin was faulted longitudinally and transversely to create individual horsts and grabens as small as 1 kilometer wide by 3 kilometers long and that most of these are rotated east to southeast by post-depositional faulting. Displacement of at least 300 to 600 meters was inferred along the largest intrabasin fault, the Bonsal-Morrisville fault, which trends northeast-southwest and terminates at approximately the Durham-Chatham County line about 2 miles south of Nelson.

Wilson and Carpenter (1981) compiled the work of Harrington (1951) and Parker (1979) along with unpublished mapping of the Durham basin as part of a five-county report. In their report, the name Sanford Formation was applied to all Triassic strata of the Durham basin. Bain and Harvey (1977) had previously argued that the stratigraphic nomenclature of the Sanford basin (Sanford, Cumnock, and Pekin Formations) proposed by Reinemund (1955) was not applicable to the rocks of the Durham basin. The bulk of Wilson and Carpenter's (1981) report dealt with crystalline rocks of the Piedmont that surround the Durham basin.

Diabase of the eastern United States early Mesozoic basins has been the object of many studies on many scales (see summary in Froelich and Gottfried, 1985). Investigations by Ragland and others (1968) and Weigand and Ragland (1970) contain data on the petrography and geochemistry of some Durham basin diabase dikes. Several of the dikes examined in those reports are located in the project area.

Gore (1986) compiled a field trip guidebook for the Durham and Sanford basins which includes contributions by several other authors. That publication reviews much of the previous work and presents new data as well.

GEOLOGY

IGNEOUS AND METAMORPHIC ROCKS

Carolina Slate Belt Rocks

The Durham basin is bordered on both sides by metavolcanic and metasedimentary rocks of the Carolina slate belt (North Carolina Geological Survey, 1985). Parker (1979) described crystalline rocks of a 1.5- to 3.0-kilometer-wide belt adjacent to the Jonesboro fault as "dacitic and andesitic metatuffs and flows with phyllite, metasiltstone, pebbly arkose, and ilmenite-magnetite quartzite." Several small adamellite bodies are interspersed within the mixed lithology unit. The term "Cary sequence" was used by Parker (1979) for these rocks.

To the west of the Durham basin, within the northwest corner of the study area, Wilson and Carpenter (1981) mapped two units. They named one " felsic igneous complex" and the other "felsic crystal tuffs and felsic tuffs."

Diabase

Early Jurassic diabase dikes and sheets intrude the Triassic strata of the Durham basin. The diabase is dark gray to black, fine to medium crystalline, and composed mainly of an interlocking mosaic of equigranular plagioclase feldspar, clinopyroxene (commonly augite), and olivine (Froelich, written communication, 1988). Aphanitic "chill margins" were observed in a few outcrops. Coarse crystalline textures occur in some of the thicker diabase bodies. A distinctive "knobby" weathering texture caused by very large (1 to 2 centimeters) clinopyroxene oikocrysts is noticeable in some outcrops of a large diabase body in the Oak Grove area. Diabase commonly weathers into spheroidal boulders with a dark-yellowish orange (10YR 6/6) surface stain and yields a characteristic yellow-orange soil.

Weigand and Ragland (1970) classified Mesozoic dolerite dikes of eastern North America. They recognized both quartz-normative and olivine-normative bodies and subdivided the quartz-normative type into high-TiO_2, low-TiO_2, and high Fe_2O_3*[1] sub-types . They observed that quartz-normative dikes are the dominant variety from Nova Scotia to Maryland, olivine-normative dikes are dominant in the Carolinas, and both types occur in approximately equal proportions in Virginia and Georgia. Figure 3 shows weight percent TiO_2 versus mafic index ($Fe_2O_3^*/(Fe_2O_3^*+MgO)$) for representative eastern North American diabase dikes reported elsewhere (Ragland and others, 1968; Weigand and Ragland, 1970) along with new values for two diabase bodies from the Southeast and Southwest Durham Quadrangles. Two of the plotted values, DDH-1 and DDH-2, are from drill core from the Oak Grove diabase sheet. These fall within the typical compositional range for olivine-normative dikes (samples provided by Nello Teer Company; analyses performed by J. D. Arthur, Florida State University, and provided by A. J. Froelich). Another plotted value, JY(2), is from the large north-south trending dike in the south-central portion of the Southwest Durham Quadrangle. This dike plots as a high-TiO_2 quartz-normative type (samples collected as part of this study; analyses performed by J. Taggart, A. Bartel, and D. Siems, U.S. Geological Survey, and provided by A. J. Froelich).

Contact metamorphic aureoles of hornfels or "baked" sedimentary rocks occur in strata intruded by diabase. These blackened and hardened zones are commonly about half as wide as the dike and typically exhibit closely spaced parallel fractures. Such fracture patterns locally continue straight across the sedimentary-igneous contact without interruption and are interpreted as cooling features. Where diabase intruded lithologies of varying porosity, for example a unit of interbedded sandstone and mudstone, the thickness and intensity of alteration within the contact aureole is highly irregular. Coarse-grained arkose is especially distinctive where thermally metamorphosed. Superficially, the baked arkose resembles granite.

[1] $Fe_2O_3^* = Fe_2O_3 + FeO$

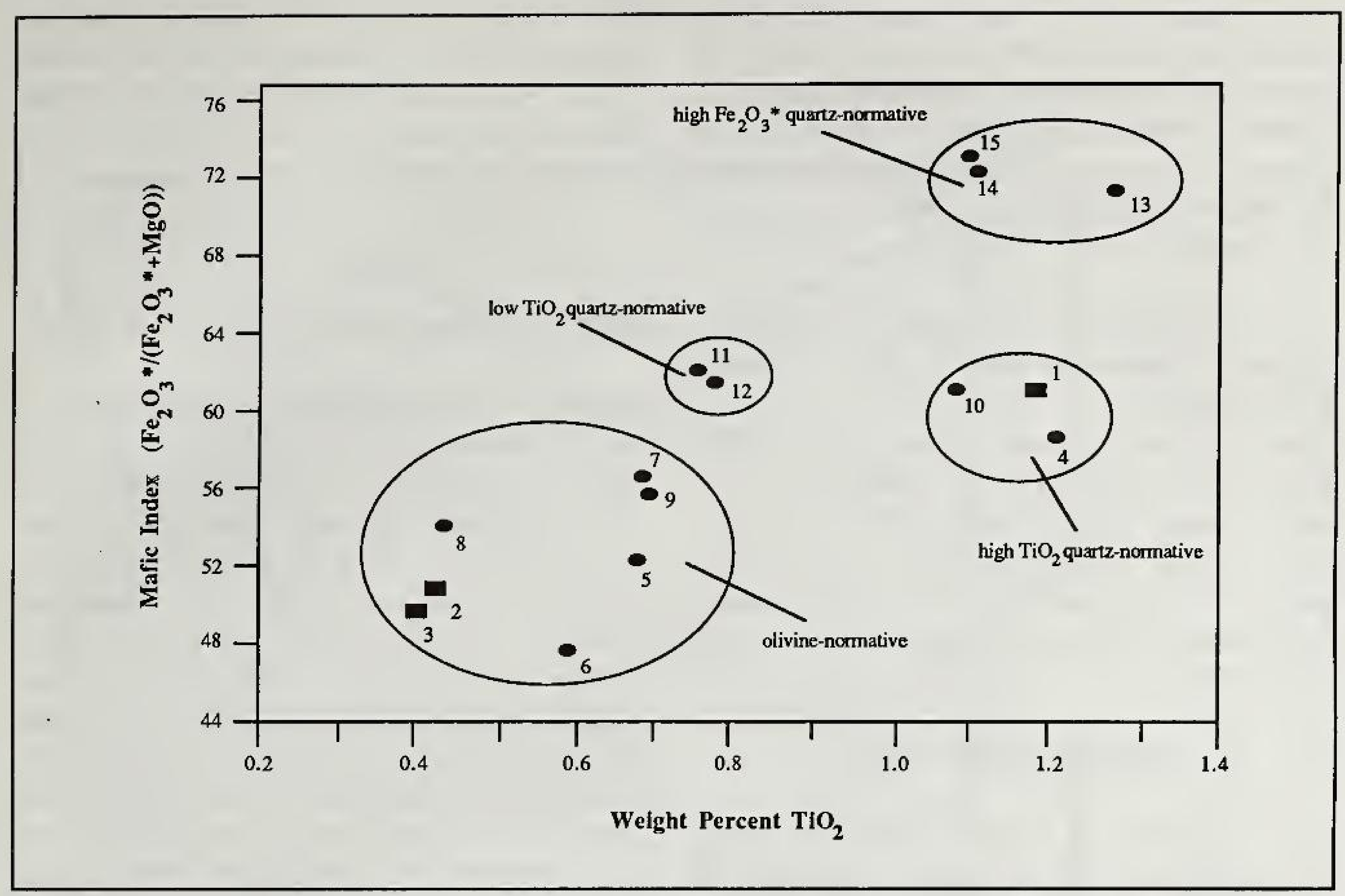


Figure 3. Plot of weight percent TiO_2 versus Mafic Index (weight percent Fe_2O_3*/(Fe_2O_3* + MgO)) for representative diabase dikes reported by Weigand and Ragland (1970) and Ragland and others (1968) (●) and for newly analyzed samples (■). Four major diabase chemical types are shown. See Appendix C for table of analyses and key to samples.

Diabase dikes occur throughout the two quadrangles. The dikes are generally linear; however, detailed mapping shows that some are sinuous. Thickness is highly variable, both within individual dikes and from one dike to another. Observed dikes were as thin as 5 centimeters and as thick as over 100 meters. Dikes are usually steeply dipping to vertical.

The Durham and Sanford basins contain the southernmost known occurrences of sheet-like diabase bodies within the eastern U.S. early Mesozoic basins (Froelich and Gottfried, 1985). Froelich and Gottfried (1985) define the term "sheet" (as applied to Newark Supergroup diabase bodies) to "embrace all of a great variety of forms displayed by the intrusive diabase other than vertical or steeply inclined dikes ...." The term "sill" has been used by some workers (Wilson and Carpenter, 1981; North Carolina Geological Survey, 1985) to describe the larger diabase bodies of the Durham basin. Structural observations and drill data, however, indicate that these bodies are discordant to the sedimentary strata. For example, the Oak Grove diabase sheet dips northward at a moderate angle of 25°-40° (Nello Teer Company, unpublished data). Thus, the term "sheet" is more appropriate.

Our mapping in the Southwest Durham Quadrangle has significantly enlarged the mapped outcrop area of the BP dike of Ragland and others (1968). They studied the body in the vicinity of its outcrop in the large roadcut on U.S. 15-501 Bypass just south of the Cornwallis Road interchange. This body lies along the trend of a prominent aeromagnetic anomaly (U.S. Geological Survey, 1974) that continues eastward and aligns with the Oak

Grove diabase sheet. The aeromagnetic anomaly passes through urban area; therefore, it is difficult to confirm the continuity of diabase outcrop. It seems reasonable to infer diabase as the underlying cause of this anomaly, but some sort of structure or lithologic variation within basement rocks can not be ruled out.

Soil maps were of limited use for delineating the occurrence and extent of diabase. Iredell and Mecklenburg soil types are generally recognized as indicating mafic parent material. Mapping for this project, however, found significantly more diabase than is suggested by the distribution of Iredell and Mecklenburg soils on the Durham and Wake County soils maps (U. S. Department of Agriculture, 1976; U.S. Department of Agriculture, 1970.

SEDIMENTARY ROCKS

Mapping of Triassic sedimentary rocks delineated seven lithofacies that are grouped into three lithofacies associations (figure 4). The three associations form three belts that generally conform to the trend of the basin. The western association (Lithofacies Association I) is comprised of a single lithofacies consisting of sandstone with interbedded siltstone (Trcs/si_1). The central association (Lithofacies Association II) is comprised of two lithofacies, sandstone with interbedded siltstone (Trcs/si_2) and siltstone with interbedded sandstone (Trcsi/s). The eastern association (Lithofacies Association III) is comprised of four lithofacies, sandstone (Trcs), pebbly sandstone (Trcsc), sandstone with interbedded conglomerate (Trcs/c), and conglomerate (Trcc).

Floodplain alluvium (Qal) is also shown on the geologic maps although specific investigation of this material was beyond the project's scope. The mapped distribution of alluvium is largely interpretive and is based on a combination of topographic and soils information. Relatively flat, locally broad, surfaces are evident along most streams and tributary drainages of the study area. These areas approximately coincide with the Chewacla-Wehadkee-Congaree or the Altavista soil associations (U. S. Department of Agriculture, 1976). With modification, alluvium is mapped where both the topography and soils maps suggest alluvial deposits.

Lithofacies Association I

Trcs/si_1 - Sandstone With Interbedded Siltstone

Description. Lithofacies Association I consists of a single facies identified as the Trcs/si_1 facies. This unit consists of fine- to medium-grained, pinkish-gray (5YR 8/1) to light-olive-gray (5Y 6/1), feldspathic sandstone and reddish-brown bioturbated siltstone and mudstone. Fine- to very fine-grained biotite is a common accessory that helps to distinguish the sandstones of this facies from sandstones of the other lithofacies. Muscovite is also common, though it is not distinctive to this lithofacies. Widespread red clayey soils, abundant and large mud clasts in sandstone channel deposits, and some exposures which contain thick siltstone beds indicate that siltstone is, volumetrically, a significant component of this facies.

Sandstone preferentially outcrops and thus is the dominant lithology exposed through the area underlain by this facies. Overall, outcrops of this facies are less abundant but usually larger than those of the other lithofacies associations. The outcrops of Lithofacies Association I also exhibit more large-scale sedimentary structures than outcrops of the other lithofacies associations.

In aggregate, sandstone sequences are usually thick (5 meters or more) and are composed of individual depositional units that are characterized by rapid vertical and lateral changes. The smaller scale sequences are typically 1.5 to 2.0 meters thick and exhibit poorly defined, fining-upward trends from erosional or channel-form basal contacts. Sandstone immediately overlying the basal scours is very coarse grained to pebbly and contains abundant mudstone clasts. Mudstone clasts range up to 50 centimeters in diameter and are commonly scattered along scour surfaces. The

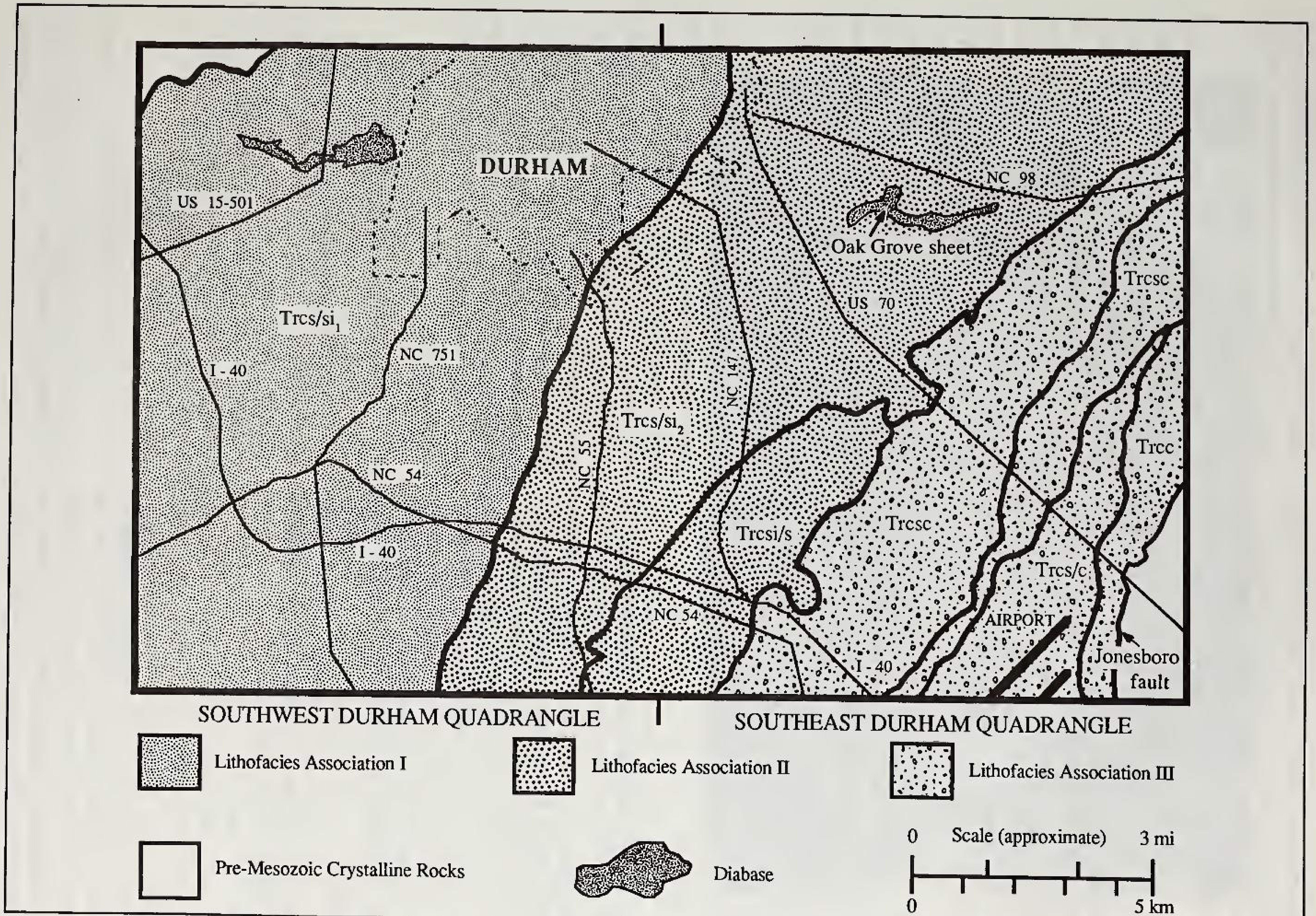


Figure 4. Generalized distribution of lithofacies and major diabase bodies on Southeast Durham and Southwest Durham Quadrangles.

upper portions of fining-upward sequences, where they are not truncated or removed by another depositional sequence, consist of bioturbated siltstone and mudstone.

Trough crossbedding is abundant in the sandstones of this facies. Individual sets decrease in thickness from between 30 and 40 centimeters near the base of a sequence to between 10 and 15 centimeters in the upper portions. Tabular foresets are less abundant, but individual sets up to 1.5 meters thick occur near the tops of fining-upward sequences in a few outcrops.

Paleocurrent determination by trough crossbed orientations from a limited number of localities show a broad scatter with a strong southerly component. Within a single outcrop the trough crossbeds generally show little variability in direction. Tabular foresets, where preserved, have orientations that vary considerably (up to 90 degrees) from the trough crossbed orientation of the same outcrop.

Bioturbation is extensive in the finer grained portions and within the thinner sandy beds of this facies. Both root structures and burrows (*Scoyenia*) were observed. Rooted zones usually exhibit light-green to whitish reduction haloes along root traces. Locally, thin zones of nodular carbonate also occur in the muddy to silty beds of the Trcs/si_1 facies. Voids within the basal portions of some sandstones are interpreted as weathered-out carbonate and/or mud clasts that were reworked from underlying mudstone.

Localities. Representative outcrops of the Trcs/si_1 facies occur at Localities 1 and 2 on the Southwest Durham Quadrangle. Locality 1 (figure 5) is a construction and road cut at the junction of Pearson Drive (SR 1221) and Mimosa Drive approximately 0.3 miles west of Fayetteville Road (SR 1118). Locality 2 (figure 6), a cut along the abandoned Norfolk Southern Railroad right-of-way at the Fayetteville Road overpass about 1.4 miles south of Interstate 40, was described by Textoris and Holden (1986). This outcrop is one of the localities within this facies in which nodular carbonate horizons occur. Supplemental localities for the Trcs/si_1 facies are numbers 3, 4, and 5.

Interpretation. Sandstone sequences within this facies resemble those of sandy braided rivers described by Cant (1978) in that 1) large scale, poorly defined mud-clast-rich trough crossbeds grade vertically to smaller scale trough crossbeds, 2) fining-upward sequences are poorly developed, 3) intercalated sets of tabular crossbeds have paleocurrent directions at high angles to the directions indicated by the trough crossbeds, and 4) ripple cross-laminated, fine-grained sandstone and siltstone beds are thin to absent at the tops of fining-upward sequences. By this model the tabular foresets represent mid-channel sand sheets and bars deposited in waning flow conditions over the trough crossbeds formed by dunes during high flow stages.

Unlike Cant's model, however, the Trcs/si_1 facies sandstones are surrounded by apparently thick sequences of heavily bioturbated siltstone and mudstone. The sparse but well-developed character of sandstone outcrops suggests that onset and termination of braid channel sedimentation happened suddenly and not by lateral migration. This might be explained by channel avulsion on a muddy floodplain in a manner similar to that described by Smith and Smith (1980) for anastomosing streams.

Lithofacies Association II

Lithofacies Association II is comprised of two lithofacies, a dominantly sandstone facies (Trcs/si_2) and a dominantly mudstone facies (Trcsi/s). The Trcs/si_2 facies is the more widespread facies. In the south-central portion of the map area, the Trcs/si_2 facies grades upward into the Trcsi/s facies.

The contact between Lithofacies Association I and Lithofacies Association II appears to be gradational. This change occurs through a zone wherein the lithologic and sedimentary character-

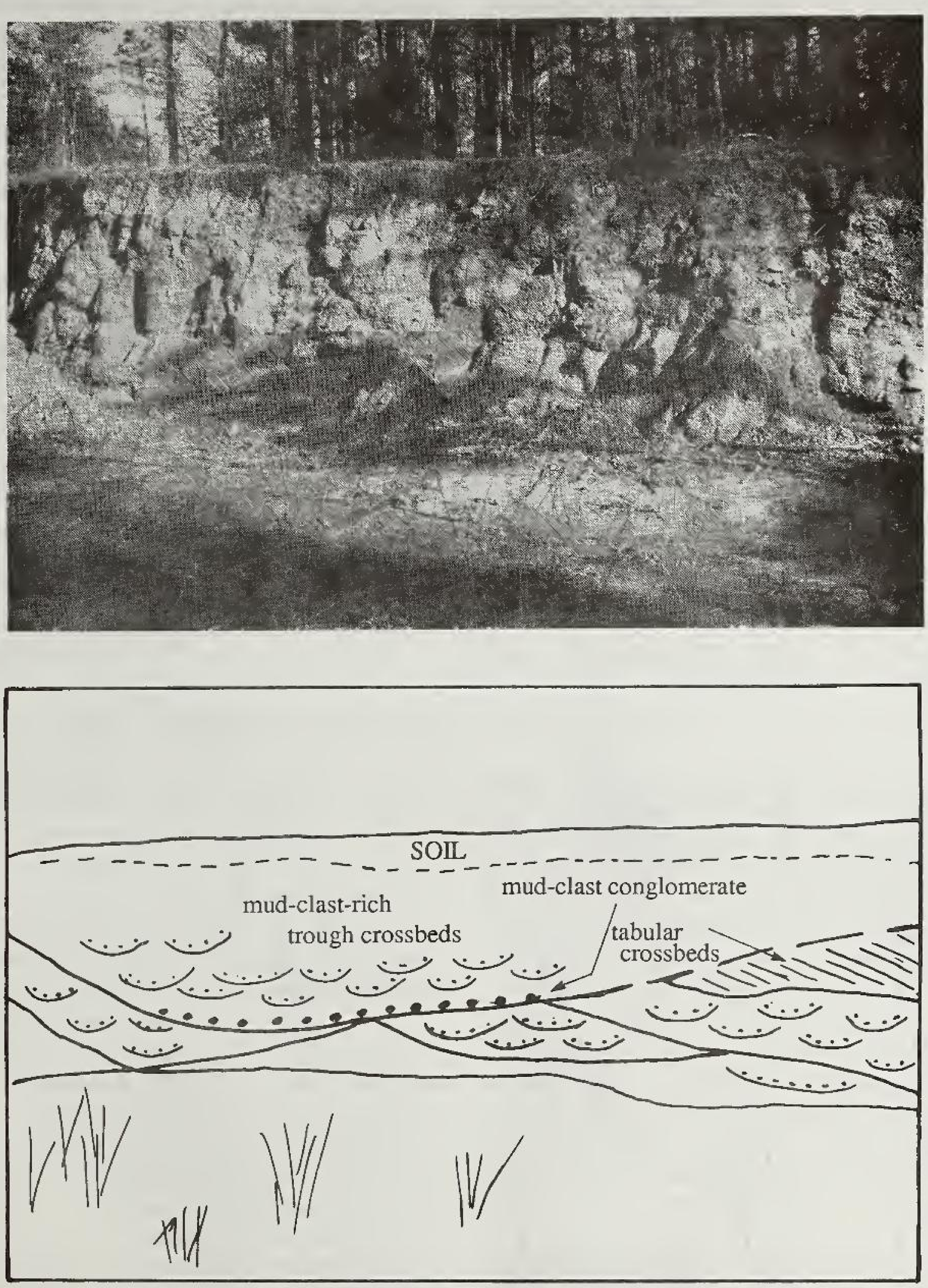


Figure 5. Outcrop of Trcs/si_1 facies exposed at Locality 1. Paleoflow is into the page and toward the left.

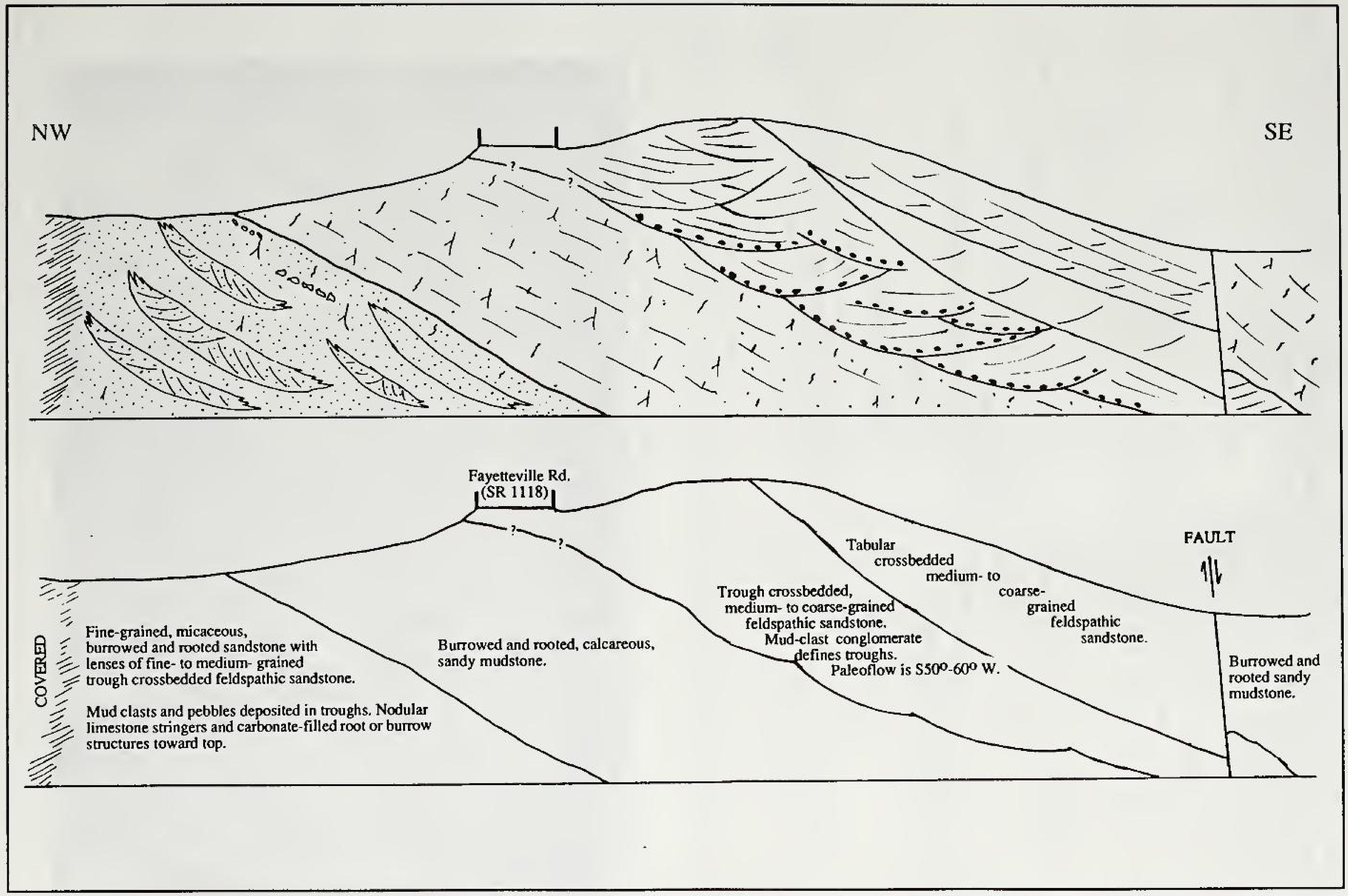


Figure 6. Generalized sketch of exposed Trcs/si_1 facies at Locality 2 along abandoned Norfolk Southern Railroad right-of-way at Fayetteville Road (SR 1118). Not drawn to scale - length is approximately 150 meters and maximum height is approximately 10 meters. Paleoflow is out of page and to the left.

istics of both associations occur. Some outcrops or individual beds within this zone are more distinctly like one facies or the other, but there is no apparent systematic vertical change.

$Trcs/si_2$ - Sandstone With Interbedded Siltstone

Description. The dominantly sandstone facies ($Trcs/si_2$) consists of medium- to coarse-grained, typically grayish-pink (5R 8/2) to pale-red (10R 6/2), very feldspathic sandstone that grades upward through finer-grained sandstone into reddish-brown, bioturbated siltstone and mudstone. Muscovite mica is a very common accessory mineral. Sandstones of this facies are distinguished from the $Trcs/si_1$ sandstones by their generally coarser grain size, noticeably abundant pink potassium feldspar which gives these sandstones a slightly different hue (more red), and relatively less biotite. A better developed and more consistent rhythmic character of fining-upward sequences also helps distinguish the $Trcs/si_2$ facies from the $Trcs/si_1$ and other facies of the study area.

Depositional sequences in this facies are typically 2 to 5 meters thick. Coarse- to very coarse-grained pebbly sandstone with very coarse-grained muscovite generally marks the base of cycles. Both flattened and rounded mud clasts commonly overlie scour surfaces. Typically, these clasts are only 1 to 2 centimeters in diameter as compared to the much larger clasts of the $Trcs/si_1$ sandstones. Sequences normally fine upward through medium- and fine-grained sandstone into siltstone or mudstone.

Sedimentary structures are commonly absent or difficult to see due to weathering. Where crossbedding is obvious, it grades upward from trough to planar form and decreases in size. Fine-grained sandstone and siltstone with ripple cross-lamination and bioturbation gradationally overlie crossbedded sandstone within fining-upward sequences. The few exposures where trough cross-beds provide paleocurrent data indicate a southwest flow direction.

Bioturbation is very common within the muddier beds of this facies and in the thinner sandy zones between muddier beds. Root structures and burrows are both present. Thin, discontinuous lenses of laminated to thin-bedded shale containing the fossil branchiopod conchostracan (*Cyzicus*) occur locally within the $Trcs/si_2$ unit.

In many outcrops of this facies, nodular and "bedded" limestone zones occur in the thicker mudstone and siltstone horizons. Limestone nodules are commonly associated with root structures. The "bedded" limestone occurs as discontinuous stringers up to several centimeters thick, is usually dense, and has a laminated structure. Although these stringers appear to be primary features within massive mudstone, they rarely yield a strike and dip conformable with those obtained for enclosing sedimentary strata. It would thus seem that they are possibly diagenetic features.

Chert occurs locally within the $Trcs/si_2$ facies. This is as a replacement of nodular limestone; as float in soil; and, rarely, as pebbles in channel lag deposits.

Localities. Two key outcrops for this facies are Locality 7, a roadcut on the west side of Van Road (SR 2052) approximately 0.3 miles north of its intersection with Holden Road (SR 1911) (figure 7); and Locality 8, the abandoned Hoover Road quarry of Borden Brick and Tile Company which is reached via an unnamed dirt road that runs west from East End Avenue opposite Rowena Avenue (figure 8). Supplementary localities are numbers 9, 10, and 11. Locality 11 is the Borden Brick and Tile Company (a division of Cherokee Sanford Group) Stone Road Quarry. A significant amount of stratigraphic section (over 100 meters) was exposed in the various parts of this quarry. Part of this section was described by Gore (1986).

Interpretation. Within the $Trcs/si_2$ facies, well developed, cyclical, fining-upward sequences consist of pebbly, trough crossbedded bases which grade upward through finer-grained, ripple- to parallel-laminated sands into rooted and burrowed,

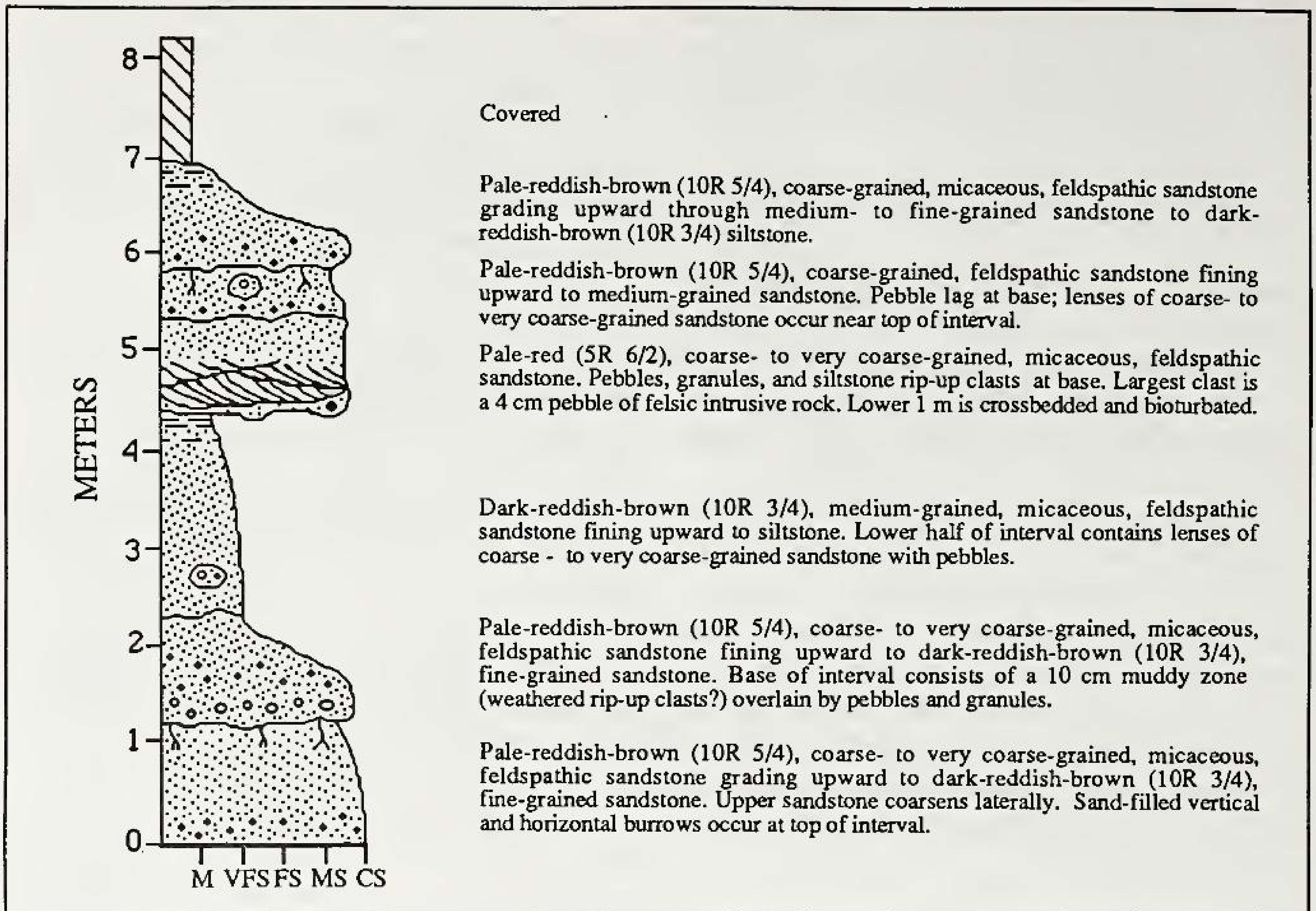


Figure 7. Section of Trcs/si_2 facies exposed along Van Road (SR 2052) (Locality 7).

sometimes calcareous, siltstone and mudstone. These characteristics are consistent with lateral point bar aggradation within a meandering fluvial system surrounded by a vegetated floodplain (Cant,1982; Walker and Cant,1984). The carbonates appear to be pedogenic and are partially replaced by chert. The abundant potassium feldspar and mica, along with the coarse to very coarse grain size of the Trcs/si_2 facies, especially in the more northern portion of this facies, suggests a granitic source area.

Trcsi/s - Siltstone With Interbedded Sandstone

Description. The upper part of the Trcs/si_2 facies grades southward into the Trcsi/s facies that generally underlies the Research Triangle Park area. Temporary exposures made during construction of the Southern Parkway from Miami Boulevard (SR 1959) east to about Page Road (SR 1973) and subsurface data obtained from the North Carolina Department of Human Resources (Soil and Material Engineers, 1987) were important supplements to the otherwise sparse outcrop data for this facies.

Siltstone is the dominant lithology of the Trcsi/s facies. It is typically reddish brown with light-green to whitish-gray mottling along both fossil and modern root structures (similar mottling is also developed along fractures within the soil zone). Bedding is usually massive; however, this may be due to either weathering or intense bioturbation which has destroyed primary structures. *Scoyenia* burrows are very abundant. Laminated to thin-bedded reddish-brown shale containing conchostracans and ostracods occurs at several localities.

Sandstones within this facies are fine- to medium grained and are usually less than a meter thick. Sandstone composition is difficult to discern in the field because of the relatively fine grain

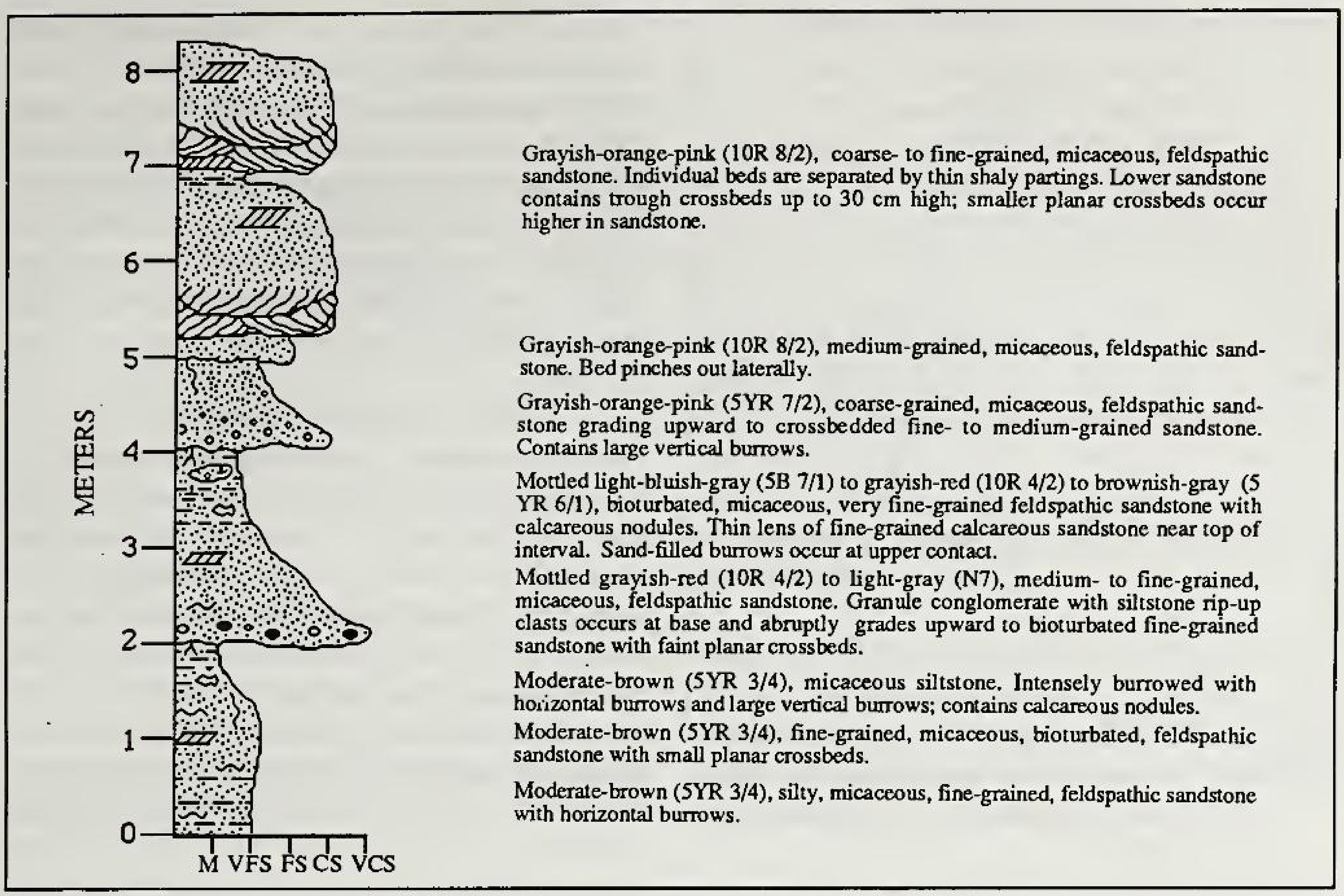


Figure 8. Composite section of Trcs/si$_2$ facies exposed in abandoned Hoover Road Quarry of Borden Brick and Tile Company (Locality 8).

size. In coarser lenses, sandstones are clearly feldspathic. Two sandstone samples from this facies that were examined petrographically are arkose (figure 9).

In a few exposures the sandstones exhibit small-scale planar crossbedding and ripple cross lamination. Otherwise, flow structures were not observed. Fining or coarsening trends within individual sandstone beds are usually very subtle or absent. Subsurface data and surface exposures suggest that many of the sandstone beds are lenticular in cross-section. However, in several instances beds persist laterally within a given outcrop (for example Locality 12) for tens of meters. This persistence of such thin beds suggests a sheet-like geometry.

Nodular and "bedded" carbonate horizons as described above for the Trcs/si$_2$ facies are extensive within the Trcsi/s facies. Most outcrops contain some carbonate either in this form or as cement within siltstone beds. Chert, also more abundant in this facies than others, is most often found as float; however, a number of outcrops contain in-place chert stringers or nodular-like "bedded" masses. These are nearly always associated with carbonate. The major difference between the Trcsi/s and Trcs/si$_2$ facies with respect to carbonate and chert is the relative abundance rather than any characteristic related to depositional setting. Wheeler and Textoris (1978) hypothesized that chert and limestone of the Research Triangle Park area (Trcsi/s facies of this report) were deposited in and along the margins of playa lakes. The fact that chert and limestone lithologies occur across several facies of the basin and that these facies are clearly the result of sustained fluvial deposition argues against this hypothesis.

Subsurface data (Soil and Material Engineers, 1987) from the main IBM facility located

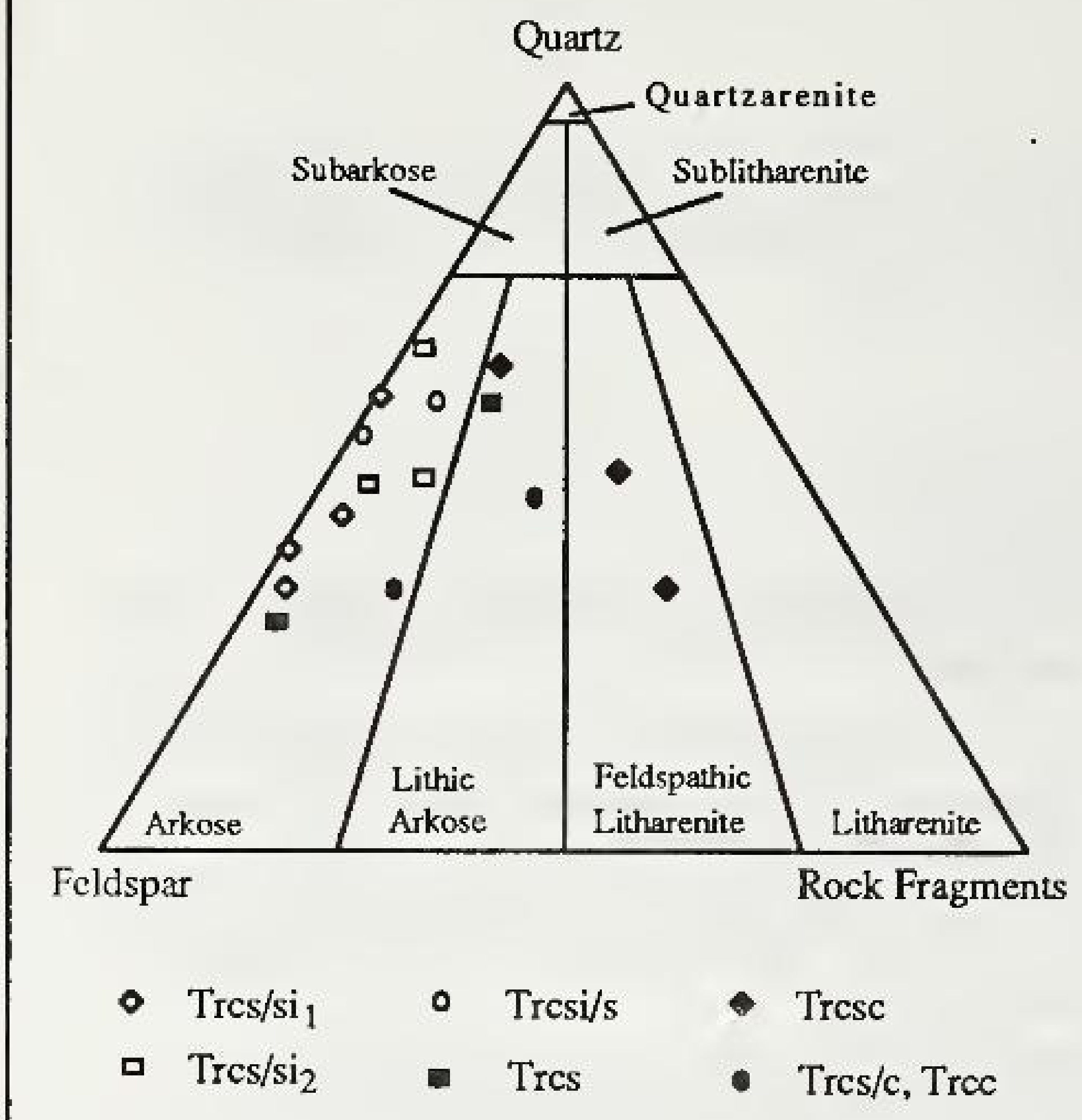


Figure 9. Ternary plot of sandstone composition from point-count data. Classification after Folk (1974).

west of Miami Boulevard (SR 1959) and south of Alexander Drive (SR 2028) is consistent, at least in a qualitative sense, with what is indicated for this facies by outcrop. Drill cuttings and core descriptions document a section that is predominantly mudstone with interbedded, reddish-brown to tan, pink, or pinkish-brown, fine- to medium-grained sandstone. Numerous thin carbonate horizons were reported.

Localities. Representative outcrops of the Trcsi/s facies are found at Locality 12, along N.C. 55 south of its intersection with Alexander Drive (SR 2028), and Locality 13, ditch and roadcut exposures in the vicinity of the intersection of N.C. 54 and Davis Drive (SR 1999).

Interpretation. Laminated shale beds in theTrcsi/s facies indicate deposition in quiet standing water. In a sewer excavation (now filled) along Stirrup Iron Creek, northeast of the Miami Boulevard (SR 1959) - Interstate 40 interchange, a few fish scales were found with conchostracans and ostracods. These fossils were deposited in a brownish-gray laminated shale overlying a coarsening-upward sandstone sequence containing climbing ripples. This is interpreted as a lake margin deposit. Olsen (1977) observed a 1-meter-thick laminated siltstone bed south of this study area which contains abundant fossils, including fish scales and bones. That bed was interpreted as being of lacustrine origin set within an overall fluvial sequence (Olsen, 1977; Renwick, 1987).

The Trcsi/s facies is interpreted as representing mostly fluvial overbank deposits with locally developed, areally limited, ephemeral, shallow, freshwater lakes. Abundant root structures and carbonate nodules suggest that exposed surfaces were vegetated and that soils developed on them. The Trcsi/s facies may represent a local lowland away from the main fluvial belt of the $Trcs/si_2$ facies or it could represent a change to muddier conditions in the later part of deposition of Lithofacies Association II. The change could be due to basin filling or an increased input of fine-grained sediment from another source area (possibly the east). Another consideration is that the drainage system of this lithofacies association may have flowed into a large lake to the south. A relative rise of that lake's level would tend to decrease stream gradients within its feeder fluvial system.

Lithofacies Association III

Lithofacies Association III is comprised of four lithofacies that are texturally and mineralogically distinct from the sedimentary rocks of the first two lithofacies associations. Namely, muscovite, which is very common in the rocks of Lithofacies Associations I and II, is absent from these rocks. Also, lithic fragments are more common. Matrix is a more significant component and matrix-supported textures are common. The facies of this association progress from massive, boulder-dominated deposits (Trcc) adjacent to the Jonesboro fault through gradually finer grained cobble, pebble, and sandstone deposits (Trcs/c and Trcsc) to muddy sandstone (Trcs) toward the central portion of the basin.

Trcs - Sandstone

Description. A dominantly sandstone facies (Trcs) comprises the most distal and finest grained facies of Lithofacies Association III. This facies generally consists of reddish-brown, poorly- to moderately sorted, fine- to medium-grained sandstone and muddy sandstone. Matrix-supported granules and coarse sand grains are common. Locally, some beds and lenses are moderately well sorted and relatively low in mud content, but siltstone and mudstone are typically minor constituents. Composition, like texture, is highly variable. Quartz is the dominant constituent. Lithic fragments are generally present and in places are abundant. Noticeably absent from this facies is muscovite. This property serves to distinguish Trcs sandstones from sometimes otherwise very similar Trcs/si_2 sandstones. The two samples of this facies that were examined petrographically plotted as arkose and lithic arkose (figure 9).

Beds are typically 1 to 2 meters thick and are commonly tabular bodies that display good lateral continuity (figure 10). Relatively thin (5 to 20 centimeters), sometimes burrowed, muddy sandstone zones usually cap the beds of this facies. Gradation from cleaner sandstone to these fine-grained zones is usually abrupt. A lack of internal stratification appears to be due to intense bioturbation. The section exposed by the excavation shown in figure 10 contains a 25-centimeter-thick, heavily burrowed mudstone bed. Another example of bioturbation within the Trcs unit is illustrated in figure 11 (Locality 15). Root mottling similar to that observed in the other lithofacies associations is common within this facies.

Localities. A representative section for the Trcs facies is exposed at Locality 16, a road cut on the west side of Miami Boulevard (SR 1959) about 300 meters north of Interstate 40 (figure 12). Supplemental localities are numbers 17 and 18.

Figure 10. Exposure of Trcs facies in sewer excavation east of Page Road (SR 1973) at Interstate 40 (Locality 14).

Figure 11. Excavated block of bioturbated sandstone from Trcs facies along Southern Parkway (locality 15). Rock hammer in lower right for scale.

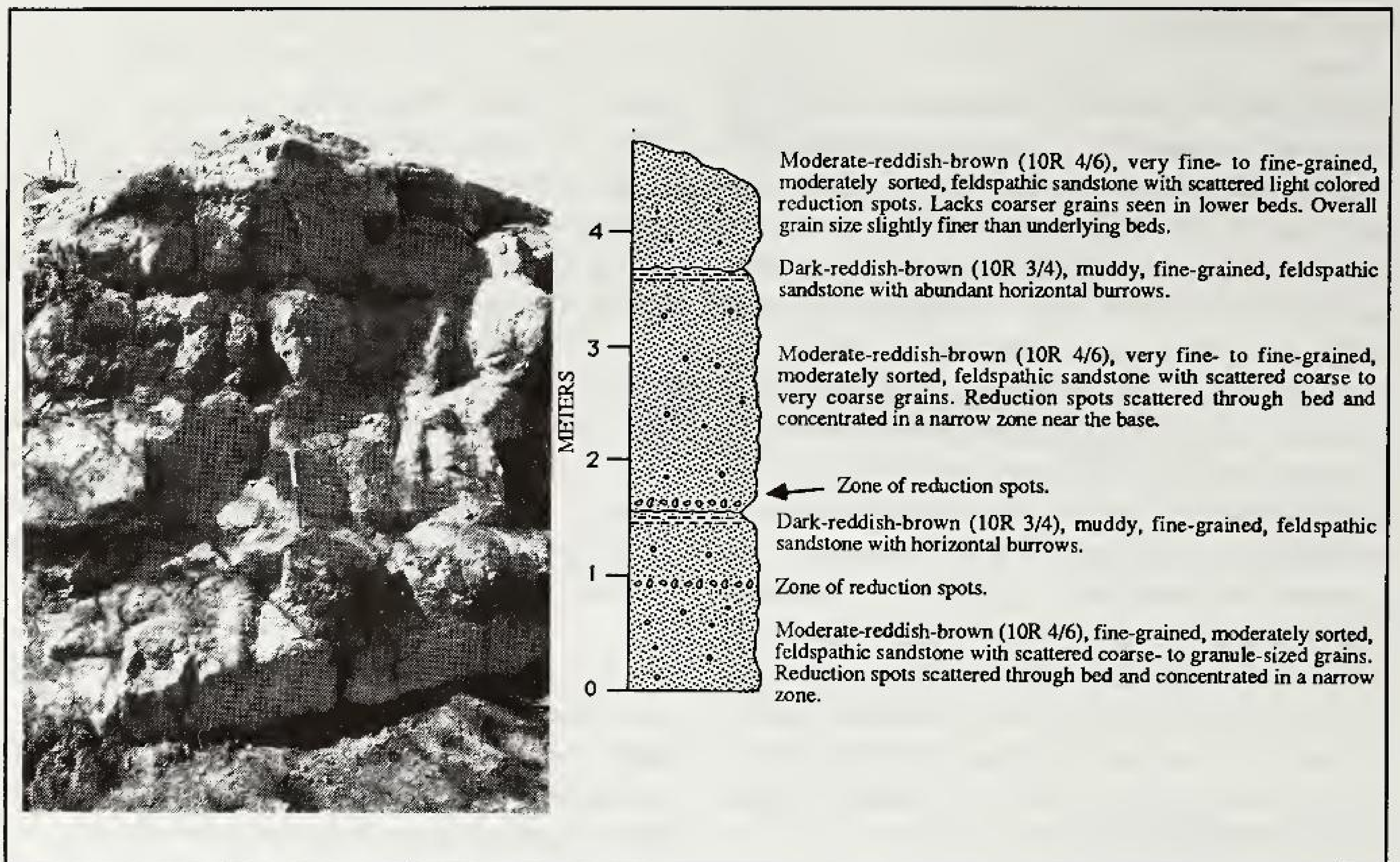


Figure 12. Section of Trcs facies exposed at Locality 16 along west side of Miami Boulevard (SR 1959) about 300 meters north of Interstate 40.

Interpretation. The Trcs facies is somewhat enigmatic. It has physical characteristics, namely lithology, color, and texture, that place it in Lithofacies Association III; yet the unit's fluvial characteristics suggests a close relationship with Lithofacies Association II deposits. An intertonguing relationship between Lithofacies Association II and Lithofacies Association III is indicated by interbedding of micaceous, arkosic sandstones and mudstones of the Trcs/si_2 facies with muddy, matrix-supported, poorly sorted, sandstons of the Trcs facies. This relation is exhibited at Locality 17, the Borden Brick and Tile Highway 70 quarry, along the road into the quarry, and in the northeast-trending drainage east of the quarry. Locally, the two lithofacies associations also exhibit a mixing of lithologic and sedimentologic characteristics.

The Trcs facies appears to reflect deposition in broad shallow channels incised into muddy flats. The eradication of internal stratification by bioturbation indicates relatively thin depositional units or relatively long periods of non-deposition between sedimentation events or both. Muddy, matrix-supported sandstones may also represent distal debris flow deposits or hyperconcentrated stream flow deposits (Nilsen, 1982; Pierson and Scott, 1985)

Trcsc - Pebbly Sandstone

Description. Sandstone of the Trcs facies grades upsection and southeastward to pebbly sandstone of the Trcsc facies. The Trcsc facies consists of reddish-brown, poorly sorted sandstone with at least 5 percent gravel (chiefly granules with subordinate amounts of pebbles and cobbles). Coarse clasts are generally matrix supported and scattered throughout sandstone beds. Siltstone and mudstone are minor components in this facies. Two of the three point-counted samples from this facies are feldspathic litharenites; the third is a lithic arkose (figure 9).

Bedding on the order of 1 to 3 meters thick is defined by concentrations of pebbles and cobbles along basal contacts. These contacts are usually scour surfaces with conglomeratic zones that range up to 50 centimeters thick. The conglomeratic portions grade rapidly upward into poorly sorted sandstone. Such beds are laterally continuous for only a few meters. Internal stratification is limited to rare occurrences of pebble and cobble trains, commonly only one or two clast diameters thick, which define flat to slightly inclined lenses within sandstones. Root mottling is common in this facies.

Localities. A representative section of the Trcsc facies is exposed at Locality 20, a roadcut on the north side of Kemp Road (SR 1902) just east of its junction with Virgil Road (SR 1903) (figure 13). Supplementary outcrops are at Localities 19, 21, and 22. This facies is very poorly exposed through the southern half of its mapped extent. Here, a few scattered outcrops and the relative abundance and size of gravel float were used to infer the distribution of the unit.

Interpretation. The Trcsc facies appears to have been deposited in broad, shallow channels. The poor sorting and general lack of stratification within the sandstones may indicate deposition by streams with high sediment concentrations (hyperconcentrated flow) or it could be due to bioturbation disrupting previously better stratified deposits. Some of the deposits may also have been formed by low-viscosity debris flows (Nilsen, 1982). The coarser grain size and paucity of muddy interbeds suggest higher energy flow conditions for this facies versus for the Trcs facies.

Trcs/c - Sandstone With Interbedded Conglomerate

Description. Pebbly sandstone of the Trcsc facies grades upsection and southeastward toward the basin margin into a coarser grained facies consisting of sandstone with interbedded conglomerate (Trcs/c). The presence of well-defined conglomerate beds, as opposed to basal conglomeratic lags, distinguishes this facies from the Trcsc facies. An arbitrary cut-off of less than 50 percent conglomerate was used to distinguish the Trcs/c facies from the overlying conglomerate facies (Trcc). Most outcrops of Trcs/c facies exhibit considerably less conglomerate than this 50 percent limit.

Rock fragments are a noticeable component of the pebbly sandstone facies. Two samples that were point counted plot as arkose and lithic arkose (figure 9). Sorting is poor and matrix-supported granule and larger size clasts are very abundant in the sandstone beds. Within the conglomerate beds, both matrix- and clast-supported textures occur. Conglomerate clasts, generally coarser than in the Trcsc facies, are mostly cobble size. The average clast size tends to be larger in the area north of Leesville Road (SR 1906) where the width of the outcrop belt decreases. Also to the north, bedding is more regular with distinctly interbedded sandstone and conglomerate. Clasts in the northern area are chiefly coarse-grained intermediate to felsic intrusive rock. South of Leesville Road, clasts primarily reflect metavolcanic and metasedimentary source materials.

Outcrops of this facies are relatively sparse and small. Therefore the relative abundance of cobble- to boulder-size float was used in some areas to delineate the unit. Outcrop observations in the adjacent Cary and Bayleaf Quadrangles were useful in projecting contacts through areas of limited access or exposure.

Localities. At Locality 23, the Trcs/c facies is exposed along the sides and bottom of Rocky Branch for a distance of several hundred meters. Here the facies consists of alternating tabular sandstone and conglomerate beds that are approximately equal in thickness (usually 1 to 2 meters). A second reference locality is number 24, the east bank of Little Brier Creek approximately 500 meters north of Globe Road (SR 1644), and a supplemental locality is number 25. At these two outcrops, the conglomerates are channel shaped and define scour surfaces on underlying pebbly sandstone beds. These gravels fine upward into pebbly sandstone. Figure 14 illustrates an outcrop (now covered) of the Trcs/c facies located about 300 meters south of

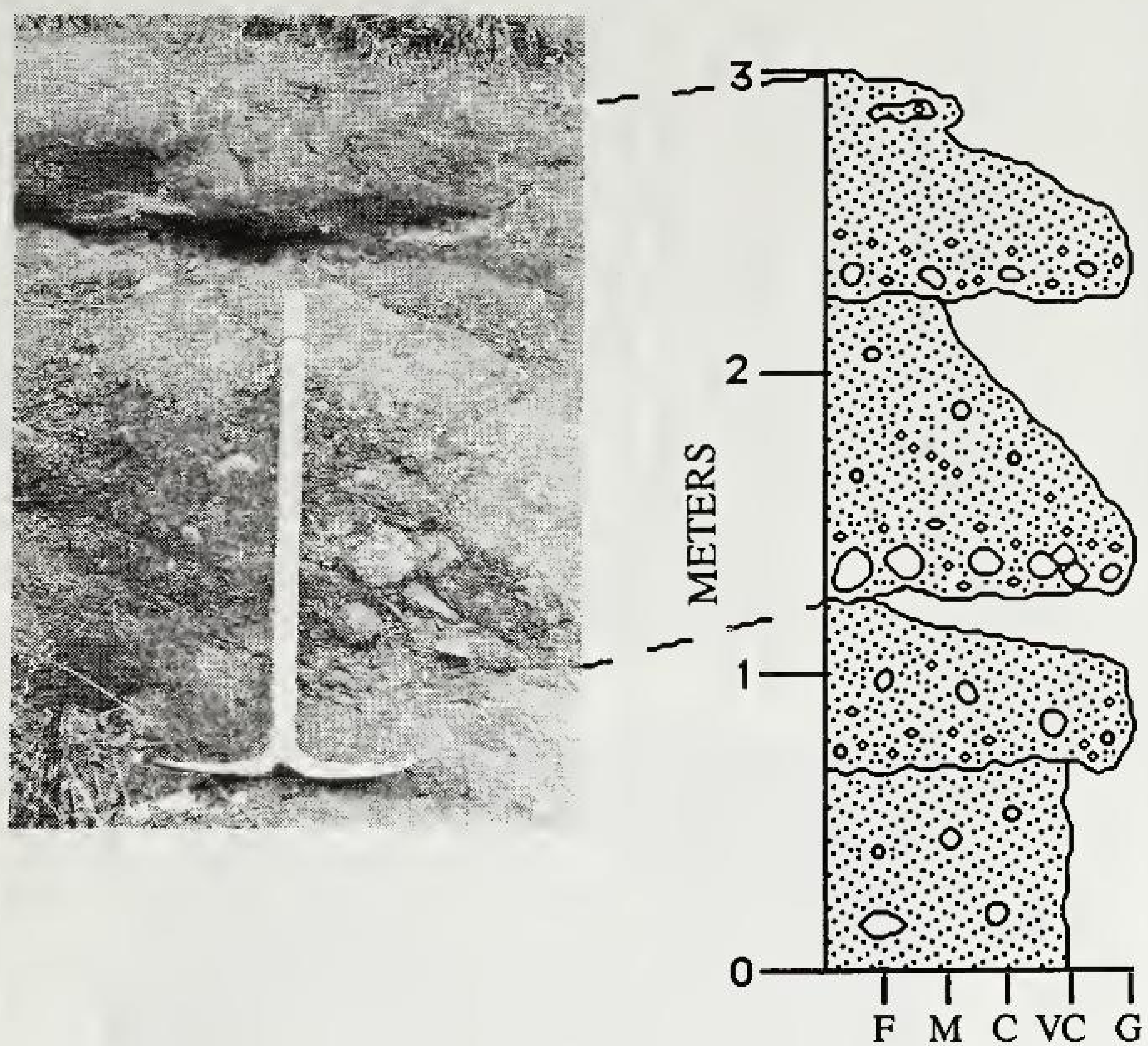


Figure 13. Outcrop of Trcsc facies along Kemp Road (SR 1902) east of its junction with Virgil Road (SR 1903) (Locality 20).

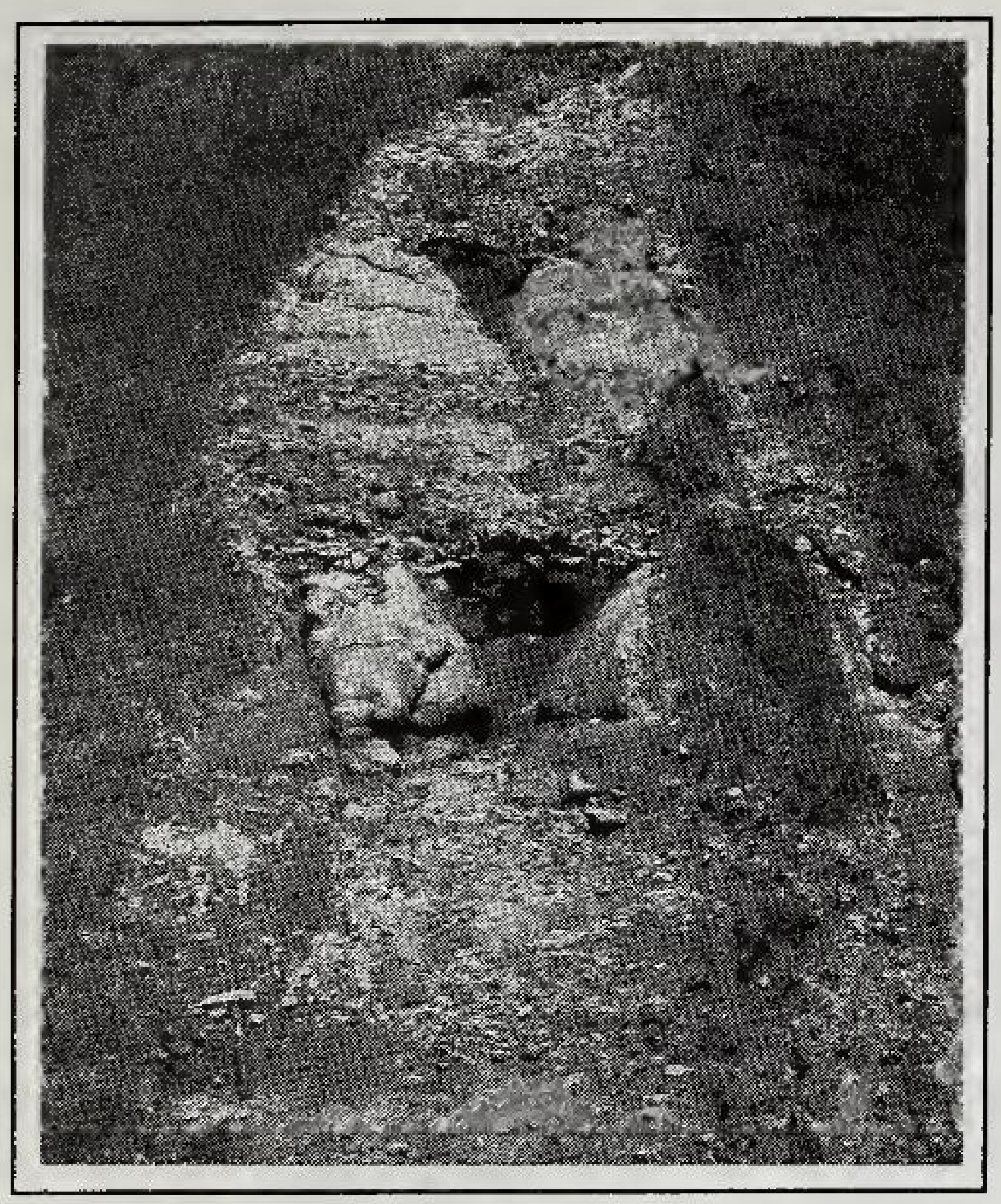


Figure 14. Interbedded sandstone and conglomerate of Trcs/c facies at Raleigh-Durham International Airport (now covered). Rock hammer in lower left of photo for scale.

the Southeast Durham Quadrangle on Raleigh-Durham International Airport property.

Interpretation. The Trcs/c facies appears to have been deposited in broad, relatively shallow channels by streams with high sediment concentrations or as debris flows or both. Streams that deposited this facies were apparently larger and deeper than those that deposited the Trcsc facies.

Trcc - Conglomerate

Description. The Trcs/c facies grades upsection and southeastward toward the border fault into a dominantly conglomerate facies (Trcc). The Trcc facies is composed mainly of cobble- to boulder-size clasts that occur in thick to massive beds with a subordinate amount of very coarse-grained to gravelly sandstone as matrix, beds, and lenses. Both clast-supported and matrix-supported textures are found within the conglomerates of this facies. Clasts are generally rounded and their size and composition are highly variable.

Localities. The coarsest-grained deposit observed is at Locality 26 where massive Triassic conglomerate is in fault contact with deeply weathered, foliated crystalline rocks of the pre-Mesozoic Carolina slate belt (figure 15). Bedding is not apparent within the conglomerate adjacent to the fault. Clast orientation is chaotic with material ranging from boulder to coarse sand size being thoroughly intermixed. The largest boulders at this locality (many are over a meter in diameter) are metamorphosed felsic volcanic rock. Specular hematite clasts (ranging up to boulder size), quartzite, and foliated metamorphic clasts are common.

About 300 meters southwest of this first locality is another Trcc outcrop (Locality 27) in which the conglomerate adjacent to the border fault is again exposed. Here, several crudely defined beds of granule to pebbly sandstone and conglomerate are exposed in an excavated ditch behind the Trusswood manufacturing facility loading yard off Running Oak Road (figure 16). Maximum clast size is about 50 centimeters with average clast size about 10 centimeters. Clasts are chiefly foliated metamorphic rocks, metavolcanics, and quartz.

The Trcc facies exhibits systematic compositional and textural changes along strike. North of the Leesville road area, felsic intrusive (granitic to dioritic) clasts predominate. Sandstone interbeds, averaging about 0.5 meters thick, are more distinct in the northern area. Sorting within the conglomerate beds, which are generally 1 to 2 meters thick, is somewhat better toward the north. Average clast size in the northern conglomerates is about 10 to 12 centimeters and these clasts are usually more spherical than the clasts of the southern area. A representative outcrop (Locality 28) of the northern conglomerate occurs in the bank of Rocky Branch east of Virgil Road (SR 1903) where a small power line crosses the drainage.

Interpretation. The Trcc facies, with its poor sorting and matrix-supported character, is inter-

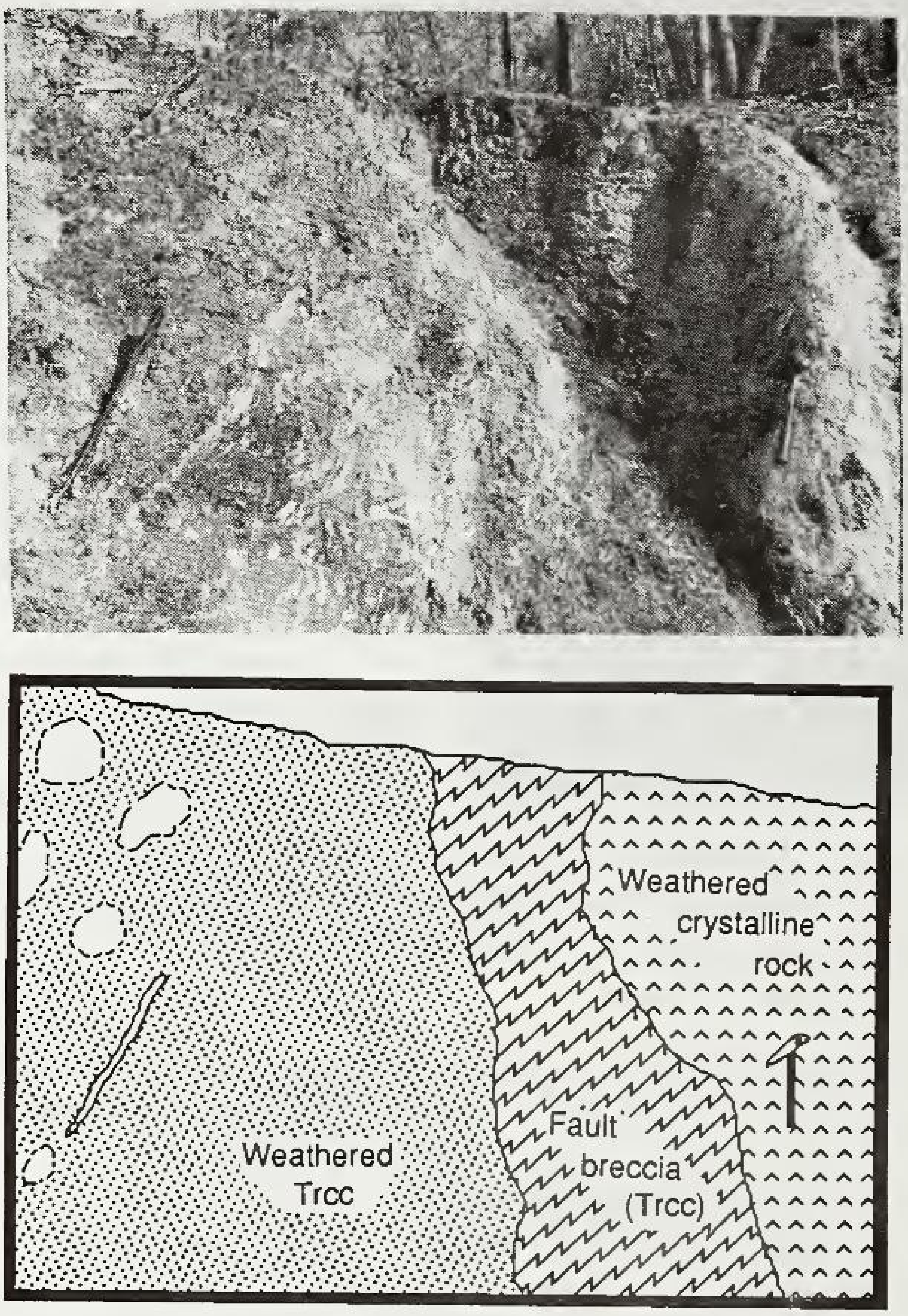


Figure 15. Jonesboro fault exposed at Locality 26 in Leesville Industrial Park off Westgate Road (SR 1837). Breccia zone is about 1.5 meters wide. View is northeast along trend of fault. Gullying along fault creates illusion of a southeast dip in this photo.

preted as primarily representing debris flow deposits. Lenses of grain-supported conglomerate are interpreted as deposits of small channels. These channels either were incised into debris flows or flowed around them. To the north, channel deposits are more dominant in this facies.

The Trcsc, Trcs/c, and Trcc facies are interpreted as the deposits that developed adjacent to the eastern border fault as alluvial fans extending northwestward into the basin. Several paleocurrent measurements based on imbricated pebble orientations indicate northwestward flow. This information, together with the consistent eastern source or provenance, the gradational fining of the facies away from the eastern border fault, the basinward transition from debris-flow-dominated to fluvial-dominated deposition, and the basinward transition from thicker channel conglomerates to thinner, sheet-like sandstones are all consis-

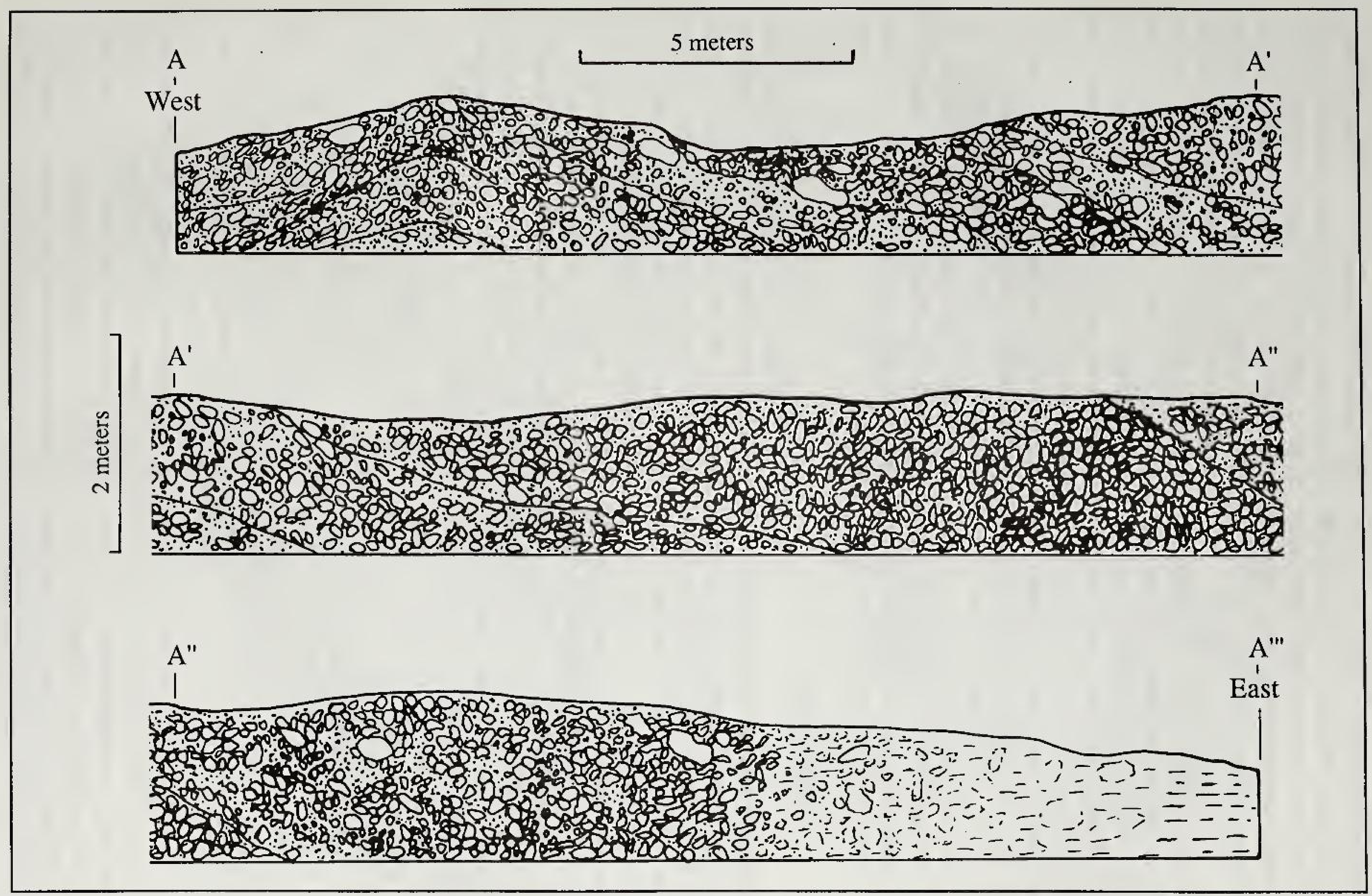


Figure 16. Ditch excavation on north side of Trusswood lot, Leesville Industrial Park (Locality 27). Ditch is 60 meters long and exposes crudely bedded Trcc facies. Note small fold toward west end. Jonesboro fault is at east end where foliated saprolite occurs within the deeply and intensely weathered zone.

tent with an alluvial fan model (Nilsen, 1982). The systematic lithologic change of the conglomerate deposits along strike suggests that there were multiple feeder systems operating along the border fault to produce a complex deposit.

Variable width of outcrop for the respective fan facies may be attributed to at least two causes. First, variable original thicknesses, either depositional or erosional, may have developed within the individual fan facies. Second, post-depositional reactivation of normal faults of the border fault zone would alter the outcrop width of the various facies. The rounded nature of the conglomerate clasts, especially of very large clasts adjacent to the border fault, suggests reworking and supports the latter consideration. Both options are viable and they are not mutually exclusive.

STRUCTURE

Strike and dip measurements were difficult to obtain from the generally poor and highly weathered exposures. Those strike and dip measurements shown on Plates 1 and 2 include several which are only approximate. The most reliable measurements—where bedding orientation was unequivocal—tended to be measurements that most consistently agreed with regional strike of about N40°-50°E with a 7-10° southeast dip. Intrabasinal block faults which have been demonstrated elsewhere in the basin (Bain and Brown, 1980) can not reasonably be interpreted from our structural data; but neither can their likelihood be excluded. Only minor (outcrop scale) faults such as the fault that occurs at Locality 2 or the one reported by Gore (1986) for Locality 11 were observed. These are generally high-angle normal faults with displacements on the order of 1 to 10 meters. None of these are mappable at 1:24,000 scale.

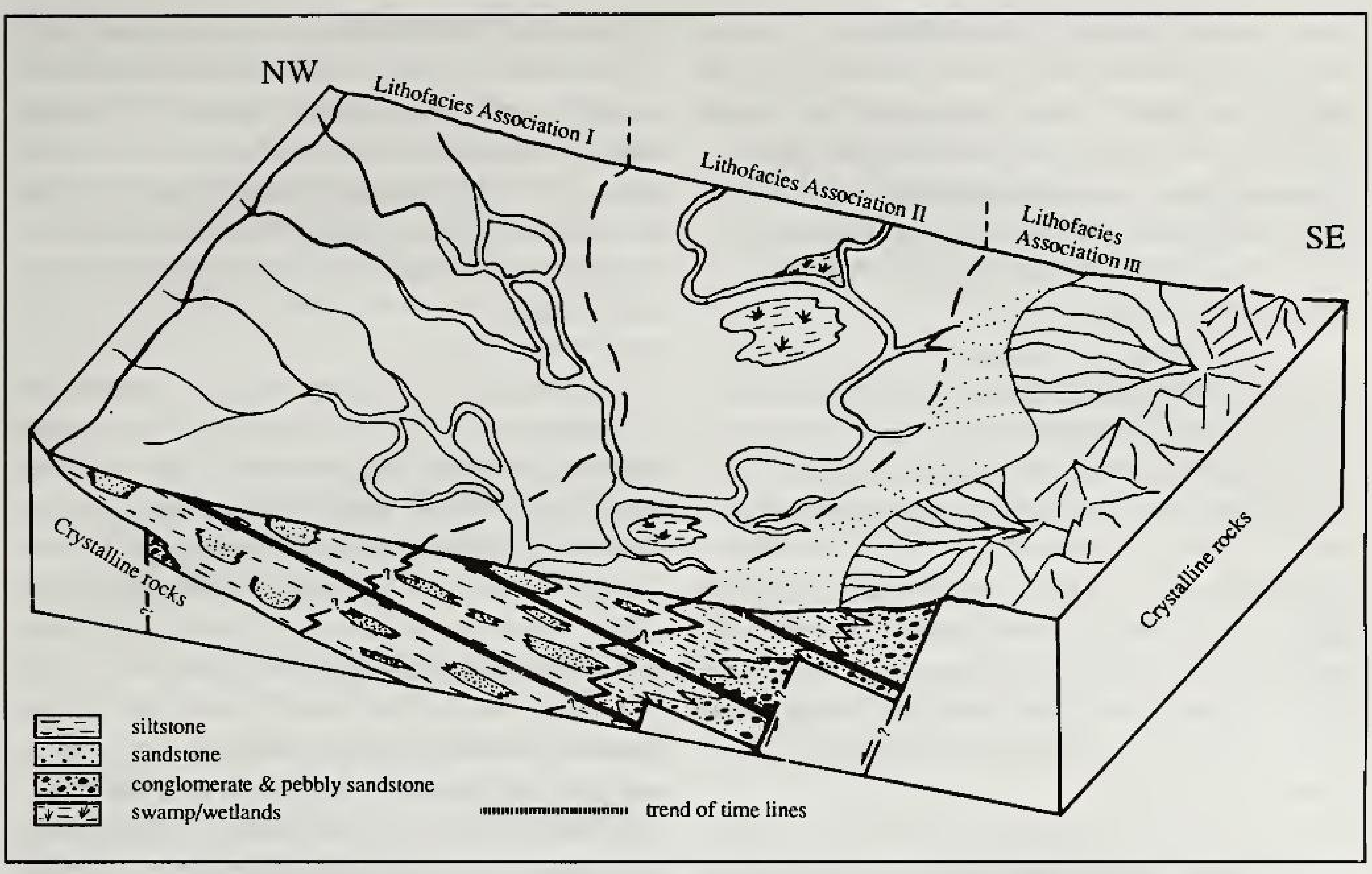
The western border of the basin is not exposed in the study area. A roadside ditch on the northeast side of Cornwallis Road (SR 1308) about 0.1 miles northwest of the intersection with Erwin Road (SR 1306) contains outcropping felsic intrusive rocks in close proximity (less than 2 meters) to typical arkosic sandstone of the $Trcs/si_1$ facies but their contact relationship is not evident. Angular quartz cobbles, suggestive of conglomeratic deposits, are common as float in sandy soil developed on Triassic sedimentary rocks in the area northwest of Erwin Road and east of the Orange-Durham County Line. An exposure at Nello Teer Company's Durham Quarry, located about 4.5 to 5.0 kilometers from the area described above, provides some indication as to the nature of the basin's western border. In the quarry, up to 10 meters of arkosic sandstone with interspersed beds of conglomerate unconformably overlie felsic volcanic rocks of the Carolina slate belt. The unconformity dips southeastward. Neither the quarry exposure nor outcrops in the Durham Southwest Quadrangle provide evidence of a western border fault along this segment of the Durham basin.

Using a 7°-10° southeast dip, a 26 kilometer width of the basin, and a 65° dip for the eastern border fault, the projected maximum thickness for the rocks of the Durham basin is 3.0 to 4.2 kilometers. Given that the eastern border is step-faulted (Bain and Brown, 1980), the maximum thickness could be considerably less than this value. Bain and Brown (1980), on the basis of gravity and aeromagnetic modeling, estimated the maximum thickness of the Durham basin to be about 2 kilometers. This is not inconsistent with the observations of this study.

DISCUSSION

DEPOSITIONAL MODEL

The three lithofacies associations define three belts of different provenance and depositional style: a western belt of arkosic anastomosing braided stream deposits, a central belt of arkosic meandering stream deposits, and an eastern belt of conglomeratic alluvial fan deposits. The paleogeographic reconstruction of this portion of the Durham basin can be interpreted several ways depending upon how the stratigraphic relationships of these belts are viewed. Figure 17 illus-



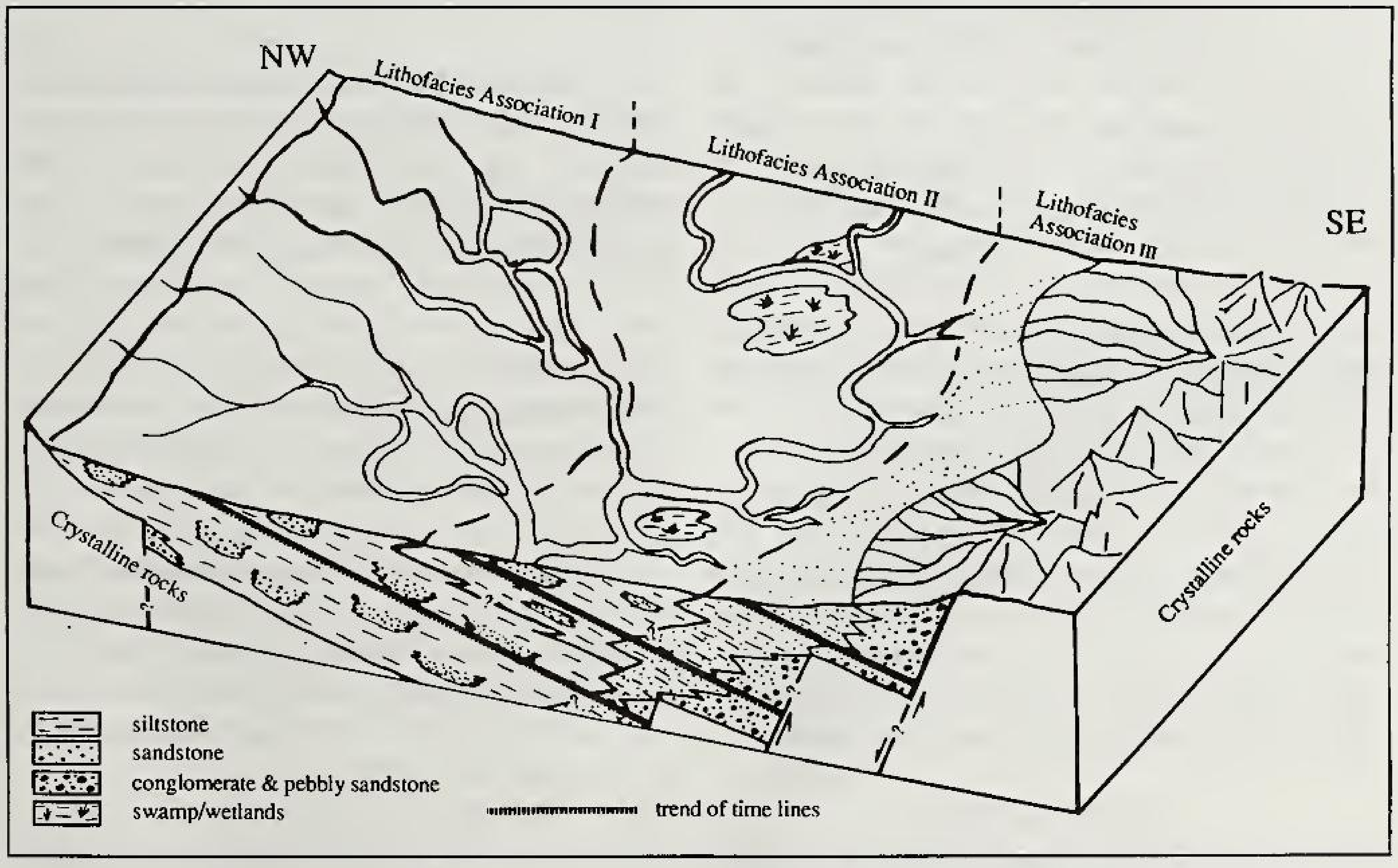


Figure 17. Sketch diagrams of possible depositional models. Upper sketch represents lateral facies model wherein the three lithofacies associations are deposited throughout the depositional history of basin. Lower sketch shows Lithofacies Association I as an early stage depositional unit underlying Lithofacies Association II. Both models presume persistent alluvial fan deposition (Lithofacies Asssociation III) along southeastern basin margin.

trates the two principle interpretations. In one sketch, each of the belts represent laterally equivalent facies. By this model the central belt fluvial deposits intertongue with alluvial fan deposits draining from an eastern highland and with fluvial deposits draining from a lower relief western highland. Small lakes formed in the central lowland in interchannel areas.

Alternatively, as shown in the other sketch, the western and central belts may each represent a period of deposition in the basin. By this model, the western belt was deposited during an early stage of basin development and the central belt was deposited subsequently. In this scenario, the western belt rocks would extend southeastward beneath the central belt rocks and intertongue with early stage alluvial fan deposits. The western belt rocks would also represent, at least in part, an axial fluvial system in this model.

Resolving between these two models is difficult with the data presently available. The map pattern of the lithofacies belts, the gradational nature of the contact between the western and central belts, and the intertonguing nature of the contact between the central and eastern belts are consistent with both models. The available paleocurrent data are insufficient to constrain either model. One consideration is that the lateral facies model requires that the fluvial drainage systems persist during accumulation of several kilometers of section within a tectonically active basin. This is unlikely, and significant lateral shifts in the facies would be expected. The degree to which these shifts would occur is unpredictable. The impact of such shifts on the model would be to alter the amplitude and frequency of the intertonguing between the two facies. In the final analysis, any model, based solely on outcrop study, will probably not apply to the full history of the basin.

PALEOCLIMATE

The paleoclimate of the Durham basin sedimentary rocks has been discussed in several papers including Wheeler and Textoris (1978), Textoris and Holden (1986), and Traverse (1986). The first two of these papers concluded that there were alternating wet and dry climatic cycles during deposition of these rocks. On the other hand, Traverse (1986), citing palynological evidence, interprets a "drying-upwards" trend from four Sanford basin samples which span from early to late Carnian.

One striking aspect of the Durham basin sedimentary rocks is the abundance of primary sedimentary structures indicative of generally wet conditions. Mainly these are root casts and burrowing. Virtually every facies except the conglomerate is extensively bioturbated. Smoot and Olsen (1985) classified massive mudstones of the Newark Supergroup into mudcracked, sand-patch, root-disrupted, and burrowed types. The first two types were considered indicative of dry paleoclimatic conditions while the latter two were considered indicative of wet conditions. Durham basin mudstones are almost exclusively the burrowed and root-disrupted types.

The interpretation of nodular limestone as caliche is one of the major points cited by proponents an arid or semi-arid paleoclimate (Textoris and Holden, 1986). Smoot and Olsen (1985) described small spherical nodules of micritic calcite concentrated in root tubes and surrounding matrix of their root-disrupted massive mudstones (wet conditions). The possibility that nodular limestone may be formed in a humid setting precludes the need to interpret a dry paleoclimate on the basis of nodular limestone.

In summary, the evidence pertinent to interpretation of the paleoclimate remains equivocal, but the field observations of this study appear to favor the interpretation that the sedimentary rocks exposed in the Durham basin were deposited under dominantly wet conditions.

CONCLUSIONS

Triassic sedimentary rocks exposed in the

Southeast Durham and Southwest Durham 7.5-minute Quadrangles comprise seven distinct lithofacies that may be grouped into three lithofacies associations with distinctive lithological and sedimentological characteristics. Adjacent facies are gradational and intertonguing. These rocks were intruded during the Early Jurassic by dikes and sheets of diabase. Either of two main depositional models may account for the field relationships seen in outcrop. This mapping of the sedimentary and igneous rocks of a portion of the Durham basin is a considerable revision and refinement of previous reconnaissance work. Much additional work and data are required to reliably characterize the geologic history of this basin.

ACKNOWLEDGEMENTS

This project was proposed and conducted under the Cooperative Geologic Mapping Program (COGEOMAP) between the United States Geological Survey and the North Carolina Geological Survey (Agreement Number 14-08-0001-A0433). Work began in February, 1987, and had a duration of 12 months. A report was submitted by the North Carolina Geological Survey to the U. S. Geological Survey in February, 1988, as part of the contract between the two agencies. This report is a revision of that contractual report with limited additional field and laboratory work.

Joe Smoot and Al Froelich of the U.S. Geological Survey were cooperating investigators who provided field consultation during the mapping and supplied unpublished manuscripts, field notes and sketches, and geophysical data to aid in preparation of the contractual report. Vic Cavaroc of North Carolina State University, as well as Smoot and Froelich, reviewed the contractual report. Their efforts were significant and greatly improved this report.

North Carolina Geological Survey colleagues Al Carpenter, Jeff Reid, Leonard Wiener, and Carl Merschat provided helpful review of this report.

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APPENDIX A - MINERALOGICAL COMPOSITION OF SANDSTONES

FACIES	QTZ	POLY QTZ	K-SPAR	PLAG	MUSC	BIO	RX	MTRX	Fe OX	OTHER	TOTAL	QTZ	FELD-SPAR	RX
Trcsi/s	67	25	3	52	3	0	11	12	14	13	200	58.2%	34.8%	7.0%
Trcsi/s	53	33	36	34	5	3	1	15	10	10	200	54.8%	44.6%	0.6%
Trcsi/s	47	17	29	34	6	1	7	29	28	2	200	47.8%	47.0%	5.2%
Trcs/si$_2$	53	38	33	43	1	0	20	9	1	2	200	48.7%	40.6%	10.7%
Trcs	51	46	14	34	5	0	19	31	0	0	200	59.1%	29.3%	11.6%
Trcs	31	18	72	38	4	0	6	27	2	2	200	29.7%	66.7%	3.6%
Trcsc	41	41	14	21	0	1	48	24	4	6	200	49.7%	21.2%	29.1%
Trcsc	17	12	9	10	0	0	36	109	5	2	200	34.5%	22.6%	42.9%
Trcsc	75	13	10	28	1	0	16	38	8	11	200	62.0%	26.8%	11.3%
Trcs/c	28	14	34	34	3	0	20	49	18	0	200	32.3%	52.3%	15.4%
Trcc	47	20	11	34	0	1	35	29	13	10	200	45.6%	30.6%	23.8%
Trcs/si$_2$	18	21	45	10	4	0	0	2	0	0	100	41.5%	58.5%	0.0%
Trcs/si$_2$	30	35	26	7	1	0	1	0	0	0	100	65.7%	33.3%	1.0%
Trcs/si$_1$	34	9	42	6	0	0	4	0	0	5	100	45.3%	50.5%	4.2%
Trcs/si$_1$	31	4	51	6	3	2	0	0	0	3	100	38.0%	62.0%	0.0%
Trcs/si$_1$	20	10	47	7	2	1	1	4	0	8	100	35.3%	63.5%	1.2%

APPENDIX A - LOCALITY REGISTER

LOC NO	MAP UNIT	LOCALITY DESCRIPTION	LATITUDE	LONGITUDE
1	$Trcs/si_1$	S side of Pearson Rd (SR 1221) at Coral Dr about 0.2 mi W of Fayetteville Rd (SR 1118)	355610	785506
2	$Trcs/si_1$	Cut along abandoned Norfolk Southern RR at Fayetteville Rd (SR 1118)	355319	785636
3	$Trcs/si_1$	Exposure behind Uzzle Cadillac on S side of U.S. 15-501 - 0.5 mi W of N.C. 751	355810	785710
4	$Trcs/si_1$	Cut along abandoned Norfolk Southern RR 700m N of Scott King Rd (SR 1103)	355250	785606
5	$Trcs/si_1$	Cut behind houses along Ancroft Rd N of Riddle Rd (SR 1171) NE of Keene	355709	785359
6	$Trcs/si_2$	Small SW trending drainage within an aborted subdivision - SE of int. of un-maintained Rondelay Dr and Flanders St	355811	784725
7	$Trcs/si_2$	W side of Van Rd (SR 2052) just N of Hutson Rd - about 0.3 mi N of Holden Rd (SR 1911)	355816	784828
8	$Trcs/si_2$	Borden Brick and Tile Company Hoover Road Pit - N of East End Ave along dirt road opposite Rowena Ave	355834	785135
9	$Trcs/si_2$	Bluff on S bank of Little Lick Creek about 500m upstream from Durham City sewage treatment plant	355907	784826
10	$Trcs/si_2$	NE side of Ellis Rd (SR 1954) N of So-Hi Dr (SR 1951) - just N and across from Southern High School	355638	785200
11	$Trcs/si_2$	Borden Brick and Tile Company Stone Road Pit - N of Stone Rd (SR 1956) and E of Wrenn Rd (SR 1955)	355701	785127
12	Trcsi/s	Roadcut on east side of N.C. 55 0.2 mi S of Alexander Dr (SR 2028)	355237	785329

APPENDIX B - LOCALITY REGISTER (*continued*)

LOC NO	MAP UNIT	LOCALITY DESCRIPTION	LATITUDE	LONGITUDE
13	Trcsi/s	Exposures at intersection of N.C. 54 and Davis Dr (SR 1999)	355328	785146
14	Trcs	Excavation for sewer pump station in Stirrup Iron Creek E of Page Rd (SR 1973) and I-40 (back-filled)	355257	785003
15	Trcs	Cut on S side of Southern Parkway (SR # not available) 0.4 mi W of U.S. 70	355502	784747
16	Trcs	W side of Miami Blvd (SR 1959) just N of I-40 interchange	355337	785054
17	Trcs	Borden Brick and Tile Company Highway 70 Pit - N of U.S. 70 at end of dirt road 0.3 mi W of Leesville Rd (SR 1906)	355642	784837
18	Trcs	Bluff at sharp bend in unnamed tributary to Lick Creek E of Doc Nichols Rd (1908) - about 700m N of AT&T cable	355715	784723
19	Trcsc	N side of Kemp Rd (SR 1902) 0.15 mi W of Virgil Rd (SR 1903)	355753	784552
20	Trcsc	N side of Kemp Rd (SR 1902) just E of Virgil Rd (SR 1903)	355753	784542
21	Trcsc	Upper reach of Martin Branch E of Olive Branch Rd (SR 1905) downstream of AT&T cable	355627	784607
22	Trcsc	Bluff on E side of uppermost part of Martin Branch on W side of Olive Branch Rd (SR 1905)	355616	784631
23	Trcs/c	Approx. 300m of streambed in Rocky Branch - above NE-SW power line SE of substation	355659	784523
24	Trcs/c	E side of Little Briar Creek about 500m N of Globe Rd (SR 1644) - behind Sheriff's Dept. pistol range	355320	784742

APPENDIX B - LOCALITY REGISTER (*continued*)

LOC NO	MAP UNIT	LOCALITY DESCRIPTION	LATITUDE	LONGITUDE
25	Trcs/c	Bank of Little Brier Creek about 100m N of Lumley Rd (SR 1645)	355405	784720
26	Trcc	High-Tech Fabricators - Midway-West Dr - construction cut at E corner of building	355429	784526
27	Trcc	Trusswood plant - Running Oak Dr off Westgate Rd (SR 1837) - ditch excavation on N side of wood lot	355422	784535
28	Trcc	E bank of Rocky Branch - domestic utility line crosses stream and Virgil Rd (SR 1903) about 0.75 mi N of Carpenter Pond Rd (1901)	355621	784520

APPENDIX C - GEOCHEMICAL DATA FOR DIABASE

Sample	SiO_2	Al_2O_3	Fe_2O_3*	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	Total
1 JY(2)	52.20	14.05	11.55	7.47	10.80	1.94	0.53	1.18	0.17	99.88
2 DDH-1(4)	48.48	13.78	12.37	12.22	11.10	1.75	0.16	0.42	0.20	100.48
3 DDH-2(8)	48.47	13.82	12.03	12.44	11.09	1.55	0.18	0.40	0.19	100.16
4 JY(5)	52.50	14.56	10.60	7.63	10.02	2.04	0.58	1.20	0.19	99.32
5 BP(20)	48.36	16.34	11.00	10.16	9.97	2.10	0.27	0.68	0.19	99.07
6 DU-6(4)	47.83	15.93	10.57	11.69	9.67	2.05	0.13	0.60	0.21	98.66
7 D5(4)	48.08	16.55	11.94	9.67	10.09	2.09	0.18	0.69	0.19	99.46
8 W&R, #9	48.20	15.40	11.50	9.95	10.57	2.21	0.39	0.45	0.17	100.16
9 W&R, #12	47.20	15.70	11.90	9.85	11.30	1.87	0.20	0.69	0.19	100.16
10 W&R, #6	52.50	14.10	11.50	7.54	10.59	2.11	0.74	1.07	0.18	98.20
11 W&R, #8	52.60	14.90	11.60	7.27	10.76	2.22	0.53	0.75	0.20	98.20
12 W&R, #7	51.10	15.00	12.00	7.69	10.85	2.25	0.43	0.77	0.22	98.20
13 W&R, #2	51.60	15.10	13.50	5.62	10.42	2.54	0.68	1.27	0.20	98.20
14 W&R, #3	53.10	14.00	14.20	5.59	9.69	2.54	0.68	1.09	0.22	98.20
15 W&R, #4	53.00	13.70	13.70	5.33	9.60	2.42	0.51	1.08	0.22	98.20

Number in parentheses represents number of analyses averaged for value.

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1. Durham basin, N.C., this study, JY dike, SW Durham Quad
2. Durham basin, N.C., this study , Oak Grove sheet, SE durham Quad
3. Durham basin, N.C., this study , Oak Grove sheet, SE Durham Quad
4. Durham basin, N.C., Ragland and others (1968, Table 3)
5. Durham basin, N.C., Ragland and others (1968, Table 3)
6. Durham basin, N.C., Ragland and others (1968, Table 3)
7. Sanford basin, N.C. Ragland and others (1968, Table 3)
8. Pennsylvania, Weigand and Ragland (1970, Table 1, sample 9)
9. Georgia-Alabama, Weigand and Ragland (1970, Table 1, sample 12)
10. Virginia, Weigand and Ragland (1970, Table 1, sample 6)
11. Georgia-Alabama, Weigand and Ragland (1970, Table 1, sample 8)
12. Connecticut-Pennsylvania, Weigand and Ragland (1970, Table 1, sample 7)
13. Connecticut, Weigand and Ragland (1970, Table 1, sample 2)
14. Virginia, Weigand and Ragland (1970, Table 1, sample 3)
15. North Carolina, Weigand and Ragland (1970, Table 1, sample 4)

Base map by U. S. Geological Survey
Geology mapped in 1987-1988

Projection and 10,000 foot grid ticks: North Carolina coordinate system (Lambert conformal conic). 1000-meter Universal Transverse Mercator grid ticks, zone 17, shown in blue. 1927 North American Datum. To place on the predicted North American Datum 1983 move the projection lines 11 meters south and 23 meters west as shown by dashed corner ticks

UTM GRID AND 1987 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

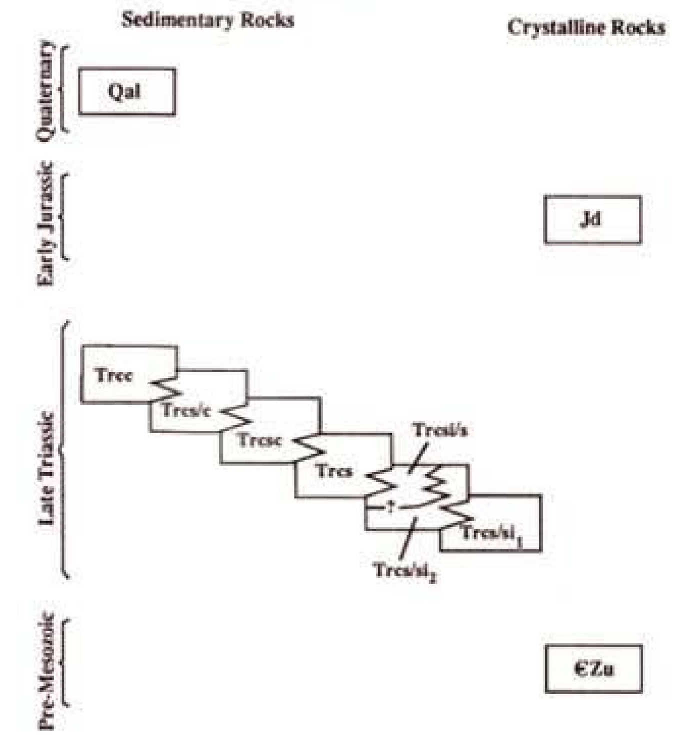
Approximate scale 1:50,000

ROAD CLASSIFICATION
Primary highway, hard surface — Light-duty road, hard or improved surface
Secondary highway, hard surface — Unimproved road
Interstate Route — U. S. Route — State Route

QUADRANGLE LOCATION

PHOTOREVISED 1987

MAP UNITS



DESCRIPTION OF MAP UNITS

Qal - Alluvium: unconsolidated clay, silt, sand, and gravel. Distribution inferred from topographic and soils maps.

Jd - Diabase: dikes and sheets; dark-gray to black, fine- to medium-grained. Locally, diabase is coarse-grained.

Trcc - Conglomerate: massive to thick-bedded; primarily cobble to boulder size clasts; reddish-brown, very coarse-grained to pebbly, lithic, feldspathic sandstone as matrix, lenses, and subordinate beds.

Trcs/c - Sandstone With Interbedded Conglomerate: dominantly reddish-brown, coarse-grained to pebbly, poorly sorted, lithic, feldspathic sandstone with subordinate beds of pebble to cobble conglomerate.

Trcsc - Pebbly Sandstone: reddish-brown, pebbly, poorly sorted, coarse-grained, lithic, feldspathic sandstone; locally contains laterally discontinuous pebble and cobble trains and conglomeratic channel lags.

Trcs - Sandstone: reddish-brown, medium-bedded to massive, poorly to moderately sorted, muddy, fine- to medium-grained, lithic, feldspathic sandstone; bioturbation is common, especially as burrowing within mudstone interbeds; light-green to whitish reduction spots are also common.

Trcsi/s - Siltstone With Interbedded Sandstone: reddish-brown, extensively bioturbated, micaceous siltstone; locally calcareous with thin, discontinuous stringers of limestone and chert or zones of calcareous concretions and nodules; contains sparse laminated to thin-bedded reddish-brown shale with conchostracans and ostracods; interbedded sandstone is typically fine to medium grained, micaceous, feldspathic, and usually less than one meter thick.

$Trcs/si_2$ - Sandstone With Interbedded Siltstone: cyclical depositional sequences comprised of grayish-pink to pale-red, micaceous, coarse- to very coarse-grained, pebbly, cross-bedded arkose that fines upward through medium- and fine-grained, micaceous, feldspathic sandstone to reddish-brown, bioturbated siltstone and mudstone. Sequences are typically 2-5 meters thick.

$Trcs/si_1$ - Sandstone With Interbedded Siltstone: pinkish-gray to light-olive-gray, fine- to medium-grained, micaceous, feldspathic, crossbedded sandstone; fine- to very fine-grained biotite is a distinctive accessory mineral; unit includes interbedded reddish-brown, bioturbated siltstone and muddy, fine-grained sandstone.

€Zu - undifferentiated crystalline rocks of the Carolina Slate Belt: metamorphosed volcanic, volcaniclastic, and intrusive rocks.

SYMBOLS

- Geologic contact
- Geologic contact, approximately located - for sedimentary units symbol also represents gradational and intertonguing relationship.
- Geologic contact, buried
- Fault - dashed where approximately located; U and D indicate relative displacement
- Strike and dip
- Approximate strike and dip - magnitude shown if measured
- Direction of paleoflow
- •10 Locality referred to in text of N.C. Geological Survey Bulletin 92
- Jd Dike - dashed where approximately located or where interpreted from aeromagnetic data
- •Jd Diabase outcrop - no trend determined

GEOLOGIC MAP OF SOUTHEAST DURHAM 7.5-MINUTE QUADRANGLE

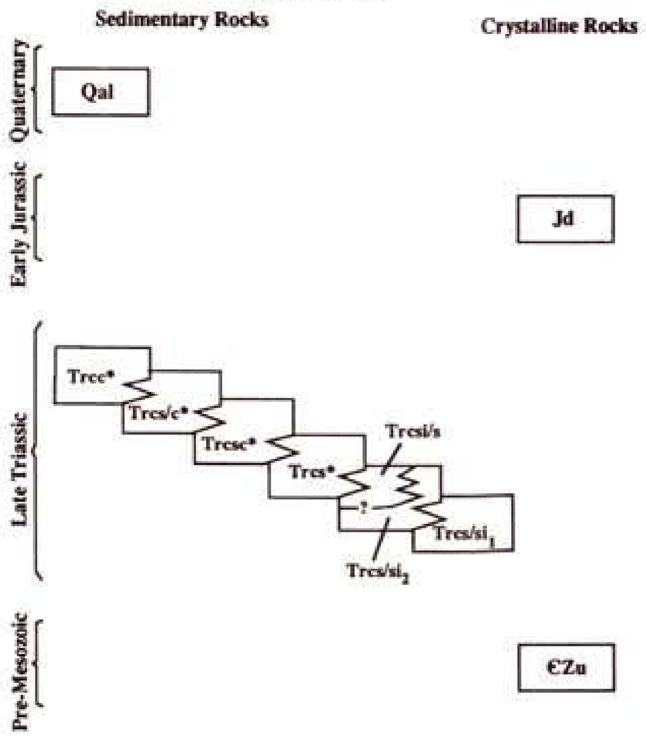
By

Charles W. Hoffman and Patricia E. Gallagher

NORTH CAROLINA GEOLOGICAL SURVEY
DIVISION OF LAND RESOURCES

DEPARTMENT OF NATURAL RESOURCES
AND COMMUNITY DEVELOPMENT

MAP UNITS



* Unit does not occur on this quadrangle; see Plate 1 - Geologic Map of Southeast Durham 7.5-minute Quadrangle

DESCRIPTION OF MAP UNITS

Qal - Alluvium: unconsolidated clay, silt, sand, and gravel. Distribution inferred from topographic and soils maps.

Jd - Diabase: dikes and sheets; dark-gray to black, fine- to medium-grained. Locally, diabase is coarse-grained.

Trcc* - Conglomerate: massive to thick-bedded; primarily cobble to boulder size clasts; reddish-brown, very coarse-grained to pebbly, lithic, feldspathic sandstone as matrix, lenses, and subordinate beds.

Trcs/c* - Sandstone With Interbedded Conglomerate: dominantly reddish-brown, coarse-grained to pebbly, poorly sorted, lithic, feldspathic sandstone with subordinate beds of pebble to cobble conglomerate.

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Trcs/si$_2$ - Sandstone With Interbedded Siltstone: cyclical depositional sequences comprised of grayish-pink to pale-red, micaceous, coarse- to very coarse-grained, pebbly, cross-bedded arkose that fines upward through medium- and fine-grained, micaceous, feldspathic sandstone to reddish-brown, bioturbated siltstone and mudstone. Sequences are typically 2-5 meters thick.

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Base map by U. S. Geological Survey

Geology mapped in 1987-1988

Projection and 10,000-foot grid ticks: North Carolina coordinate system (Lambert conformal conic). 1000-meter Universal Transverse Mercator grid ticks, zone 17, shown in blue. 1927 North American Datum. To place on the predicted North American Datum 1983 move the projection lines 11 meters south and 22 meters west as shown by dashed corner ticks

UTM GRID AND 1987 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

Approximate scale 1:50,000

1973
PHOTOREVISED 1987

GEOLOGIC MAP OF SOUTHWEST DURHAM 7.5-MINUTE QUADRANGLE

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