Appalachian STATE UNIVERSITY
BOONE, NORTH CAROLINA

Southeastern Geology: Volume 12, No. 1
September 1970

Edited by: S. Duncan Heron, Jr.

Abstract

Academic journal published quarterly by the Department of Geology, Duke University.

SOUTHEASTERN GEOLOGY

PUBLISHED AT DUKE UNIVERSITY DURHAM, NORTH CAROLINA

VOL. 12 NO. 1 SEPTEMBER, 1970

SOUTHEASTERN GEOLOGY

PUBLISHED QUARTERLY

AT

DUKE UNIVERSITY

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STRATIGRAPHY AND GEOLOGY OF DAN RIVER TRIASSIC BASIN, NORTH CAROLINA

By

Paul A. Thayer
University of North Carolina at Wilmington
Wilmington, North Carolina

ABSTRACT

Dan River Basin, a northeast-trending asymmetrical fault trough located in Stokes and Rockingham Counties, North Carolina, contains up to 15,000 feet of nonmarine clastic strata (Dan River Group). On the basis of distinctive sedimentary features and stratigraphic position this thick sequence can be divided into three formations, herein named (from the base upward): (1) Pine Hall Formation, (2) Cow Branch Formation, and (3) Stoneville Formation.

Pine Hall Formation, the basal and basin-margin unit, unconformably overlies and locally is in fault contact with pre-Triassic metamorphic rocks on the east side of the basin. It is divisible into three intertonguing facies: (1) conglomerate, (2) sandstone, and (3) siltstone.

Cow Branch Formation conformably overlies Pine Hall Formation throughout most of the basin, and intertongues with it in the extreme northern portion. It consists of gray to black mudrocks with subordinate amounts of maroon mudrocks, fine-grained feldspathic sandstones, and coal. This formation is characterized by laterally persistent, uniformly even, medium- to very thin-bedding.

Stoneville Formation conformably overlies and intertongues with the Pine Hall-Cow Branch sequence, and is in turn truncated on the western basin-margin by Dan River fault zone. As this formation contains a wide spectrum of lithic types, textures, and structures, which reflect original differences in depositional environments, three intertonguing facies are recognized and mapped.

Comparison of sedimentary features in Dan River Group with those reported from known modern environments indicates deposition in alluvial fan, floodplain, lacustrine, and swamp environments. Coarse-grained, crudely stratified conglomerates in Pine Hall and Stoneville Formations represent alluvial fan deposition adjacent to fault scarps along the basin-margins. Cross-bedded, lenticular sand bodies in these formations accumulated on point and channel bars in high- to low sinuosity streams. Finer-grained, reddish-brown, uniformly thin-

and medium-bedded mudrocks were deposited on floodplains, mudflats, and possibly lakes. Fine-grained, dark-colored, well-bedded strata of Cow Branch Formation were deposited in lakes that formed by damming the longitudinal drainage of the basin. Lenses of coal with autochthonous plant fragments, vivianite, and ironstone concretions in the basal Cow Branch suggest accumulation in swamps.

Movements along basin-margin fault zones initiated and accompanied sedimentation, and erosion of uplifted fault blocks provided most of the detritus to the subsiding trough. After sedimentation the strata were tilted to the northwest and folded, faulted, and intruded by dolerite dikes.

INTRODUCTION

General Statement

Dan River Basin is an elongate asymmetrical fault trough that occupies approximately 150 square miles in Stokes and Rockingham Counties, North Carolina (Figure 1). The basin trends northeast from Germanton, Stokes County to the Virginia-North Carolina border; north of here it is known as Danville Basin, and continues northeast for 75 miles to Springs Mills, Appomattox County, Virginia. Width of Dan River Basin ranges from a pinchout at Germanton to a maximum of 6 miles near the horseshow-shaped bend of the Dan River in Rockingham County (Plate 1).

Upper Triassic nonmarine strata within the basin have an average strike of N60°E, and dip 32° to the NW. Sedimentary rocks along the southeastern margin of the basin rest unconformably on, and in places are faulted against a structural complex of older metamorphic rocks. The northwestern side of the basin is bounded by a zone of high-angle normal faults that dip steeply to the southeast. Movements along this fault zone initiated and accompanied sedimentation, and erosion of the uplifted fault blocks provided most of the detritus to the subsiding trough.

Located in the Piedmont Province, the basin forms a gently rolling, northeast-sloping topographic lowland that ranges from 50 to 300 feet lower than the surrounding Piedmont surface. Average local relief within the Triassic lowland is usually less than 150 feet, although near Mayodan local relief is almost 400 feet.

Elevations in the Triassic basin range from 490 feet along the Dan River at the Virginia border to 1,040 feet northwest of Mayodan. Two prominent northeast-trending hogback ridges of well indurated siltstone interbedded with sandstone are present near the northwest margin of the basin between Madison and Stoneville.

The Triassic-pre-Triassic contact along the southeastern basin margin is marked by a conspicuous northwest-facing escarpment that

GEOLOGIC MAP OF THE DAN RIVER TRIASSIC BASIN

EXPLANATION

SEDIMENTARY ROCKS

POST-TRIASSIC

- Al — ALLUVIUM

UPPER TRIASSIC — DAN RIVER GROUP

- TRS — STONEVILLE FORMATION: CLOSED CIRCLES INDICATE CONGLOMERATE FACIES; DOTS SANDSTONE FACIES; AND DIAGONAL AREAS SILTSTONE FACIES.
- TRCb — COW BRANCH FORMATION; BLACK SHALE AND MUDSTONE WITH DARK COLORED SILTSTONES AND SANDSTONES.
- TRPh — PINE HALL FORMATION: CLOSED CIRCLES INDICATE CONGLOMERATE FACIES; DOTS SANDSTONE FACIES; AND BLANK AREA MAROON SILTSTONE FACIES.

IGNEOUS ROCKS

TRIASSIC ?

- Trd — FINE TO COARSE-GRAINED DIABASE DIKES

METAMORPHIC ROCKS

PRE-TRIASSIC

- Bg — BIOTITE GNEISS
- Hg — HORNBLENDE GNEISS
- MS — MUSCOVITE SCHIST
- Q — QUARTZITE

ATTITUDE OF ROCKS

- STRIKE AND DIP OF BEDDING
- APPROXIMATE STRIKE AND DIP OF BEDDING
- STRIKE AND DIP OF FOLIATION

CONTACTS

- DEFINITE CONTACT
- APPROXIMATE CONTACT
- CONCEALED CONTACT

FAULTS

- NORMAL FAULT, EXPOSED
- NORMAL FAULT, UNEXPOSED

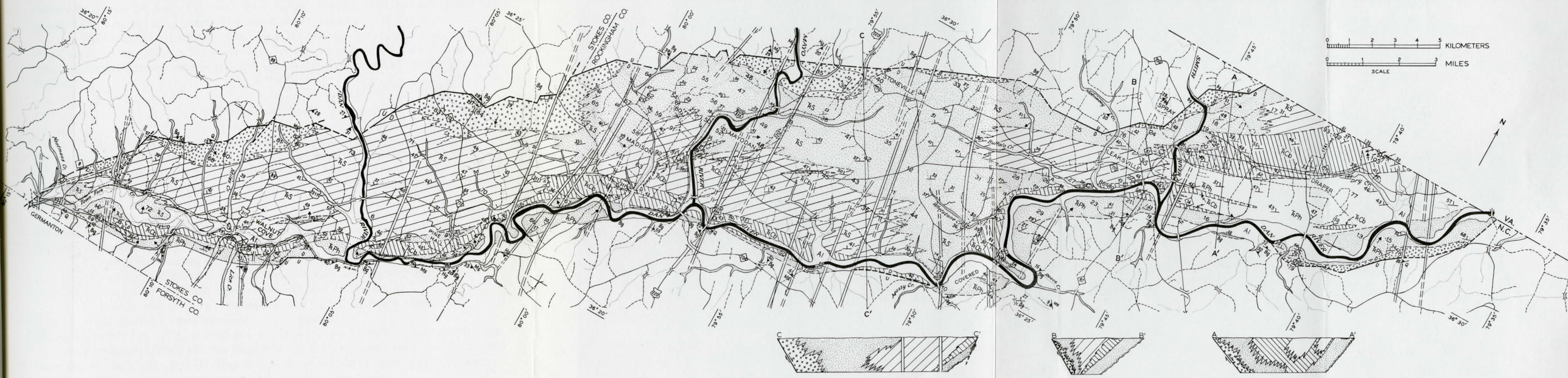
DIRECTIONAL SEDIMENTARY STRUCTURES

- CROSS BEDDING
- RIPPLE MARK
- CONVOLUTE LAMINATION
- GROOVE CAST
- PRIMARY CURRENT LINEATION

MISCELLANEOUS

- QUARRY
- 10 — SAMPLE LOCALITY
- B — LOCATION OF MEASURED SECTION

GEOLOGY BY P. A. THAYER 1963-1966



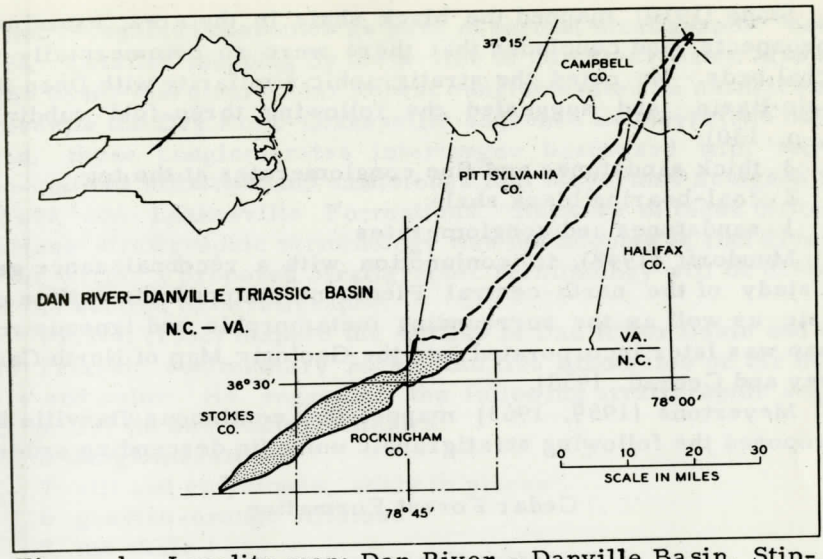


Figure 1. Locality map: Dan River - Danville Basin. Stippled part indicates study area.

varies between 50 and 100 feet in height. Prominent topographic escarpments are lacking along the northwest boundary of the basin.

This paper presents the results of a detailed stratigraphic-structural study of Dan River Basin. A future paper will deal with analyses of depositional environments and sedimentology of these Triassic rocks.

Previous Work

The history of previous reconnaissance investigations in Dan River Basin has been summarized elsewhere (Thayer, 1967, p. 5-9); only pertinent stratigraphic references will be reviewed here. Meyertons (1959, p. 7-9) reviewed the literature for the contiguous Danville Basin.

Emmons (1852, p. 159) assigned a Permian age to Dan River strata, and proposed the following stratigraphic sequence (1852, p. 144) (in descending order):

5 conglomerates, or brecciated conglomerates
4 upper sandstones, including the soft and hard kind
3 coal slates, with their subordinate deposits
2 lower sandstones, including the soft and hard kind
1 imperfect conglomerates and breccias

He later (1856, p. 273) listed the sediments as Permo-Triassic in age.

Fontaine (1883) on the basis of floral evidence said the sedimentary rocks in Dan River Basin could be no older than Late Triassic, and that the uppermost strata might possibly be Jurassic.

Stone (1910) mapped the black shale in the area, examined all coal prospects, and concluded that there were no commercially valuable coal beds. He noted the stratigraphic similarity with Deep River Triassic Basin, and suggested the following three-fold subdivision (1910, p. 130):

3 thick sandstones and fine conglomerates at the top
2 coal-bearing black shale
1 sandstones and conglomerates

Mundorff (1948), in conjunction with a reconnaissance ground water study of the north-central Piedmont, mapped the outline of the Triassic as well as the surrounding metamorphic and igneous rocks. His map was later incorporated into the Geologic Map of North Carolina (Stuckey and Conrad, 1958).

Meyertons (1959, 1963) mapped the continuous Danville Basin and proposed the following stratigraphic units (in descending order):

Cedar Forest Formation

UNCONFORMITY

Dry Fork Formation } Leakesville Formation

UNCONFORMITY

pre-Triassic metamorphic rocks

According to Meyertons (1963) the Leakesville Formation (note: Meyertons' spelling of Leaksville, even though incorrest, is retained to conform to the Code of Stratigraphic Nomenclature, Article 12a) is divisible into two intertonguing members, the Cow Branch Member and Cascade Station Member. Cow Branch Member consists of dark gray claystones, shales, siltstones, and a few sandstones. Cascade Station Member is composed of maroon, red, and brown claystones, shales, siltstones, and fine- to medium-grained sandstones, Dry Fork Formation, a contemporaneous lithofacies of Leakesville Formation, is made up of an arkosic and graywacke facies. The latter is composed of lithic conglomerates and graywackes with lesser amounts of shale. The arkosic facies consists of red and maroon feldspathic conglomerates, arkoses, and feldspathic sandstones with a subordinate proportion of reddish-colored claystones, siltstones, and shales. Cedar Forest Formation disconformably overlies the Leakesville-Dry Fork sequence and is composed of red and maroon polymictic conglomerates and siltstones.

According to Meyertons' interpretation the Leakesville and Dry Fork Formations are lithosomes, that is mutually intertonguing lithostratigraphic bodies of differing composition. This usage is not acceptable since the American Commission on Stratigraphic Nomenclature

does not recognize lithosomes as part of formal stratigraphic nomenclature. Detailed mapping by the writer in Dan River Basin also shows that the basin-marginal Cedar Forest conglomerates do not disconformably overlie the Dry Fork-Leakesville sequence as Meyertons believed. Instead, these conglomerates intertongue basinward with red- and brown-colored siltstones and sandstones that Meyertons assigned to the Dry Fork and Leakesville Formations. Because of these difficulties Meyertons' stratigraphic terminology was not adopted in Dan River Basin. The writer's proposed stratigraphic terminology will be discussed under the section on stratigraphy.

Pickett (1962) mapped the outline of Dan River Basin and divided the Triassic sedimentary rocks into five lithofacies on the basis of texture and color. He suggested the following stratigraphic sequence (1962, p. 28) (in descending order):

8 fanglomerate
7 silt and claystones, shaly in places
6 grayish-orange siltstone
5 tan shale
4 gray to black shale
3 gray mudstone, shaly in places
2 coarse-grained arkosic sandstone
1 gneiss and quartz pebble conglomerate

This sequence, which is virtually identical to the one proposed by Emmons (1852, p. 144), is not consistently mappable throughout Dan River Basin. Furthermore, Pickett's geologic map, and his descriptions of stratigraphic units are so generalized that they are of little value for detailed work.

Regional Geology

Dan River Basin is located within the northeast-trending Inner Piedmont belt of King (1955). Rocks in this belt are dominantly regionally metamorphosed gneisses and schists that have been intruded by small bodies of granitic rocks (Figure 2). Mundorff (1948, p. 7-17), Stuckey and Conrad (1958, Geologic Map of North Carolina), and Butler and Dunn (1968) have mapped and described general rock types and structure in this region. Unfortunately, stratigraphic relations and ages of these rocks are unknown at this time. Espenshade and Rankin (1970, p. 207) have recently suggested a Precambrian age for the gneissic granite, augen gneiss, biotite schist, and hornblende gneiss units exposed to the west of Dan River Basin (Figure 2). Rock types immediately surrounding the basin are indicated on the geologic map (Plate 1).

Metamorphic rocks of the Piedmont in the vicinity of Dan River Basin are chiefly muscovite and biotite schist and gneiss, quartzite, hornblende gneiss and schist, augen gneiss, garnetiferous muscovite-chlorite schist, and foliated granitic gneiss (Butler and Dunn, 1968)

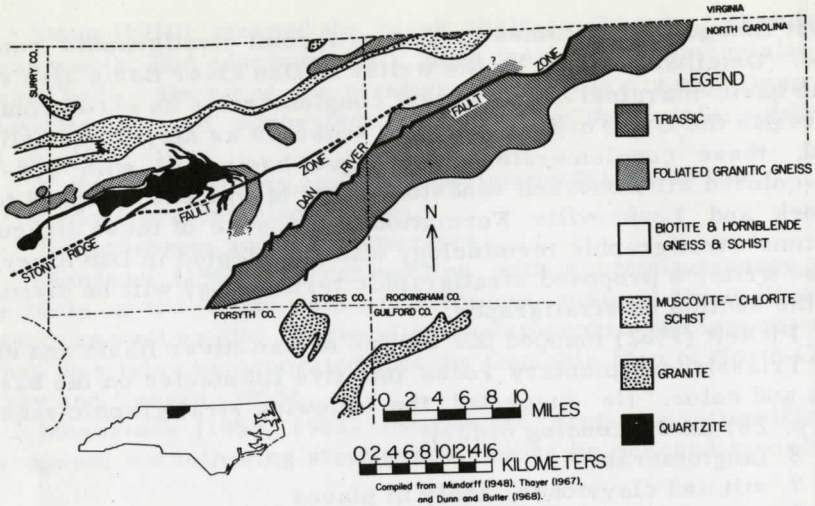


Figure 2. Generalized geologic map of north-central North Carolina.

(Figure 2). Metamorphic rank in this area of the Piedmont ranges from upper greenschist facies to lower or middle amphibolite facies (Butler and Dunn, 1968, p. 44). Small bodies of granitic rock, aplite, pegmatite, and quartz veins are intrusive into this metamorphic complex.

Schistosity and compositional layering in the area west of Dan River Basin define a large antiform (Sauratown Mountains anticlinorium) that Butler and Dunn (1968, p. 39) believe is overturned to the northwest. The axial trace, located just south of the quartzite areas on Figure 2, trends N70°E. Butler and Dunn (1968, p. 23) also recognized a major northeast-trending synclinorium (James River synclinorium) whose axial trace is located 15 miles north of Sauratown Mountains anticlinorium.

Stony Ridge fault zone (Figure 2), located about 1 mile south of the axis of Sauratown Mountains anticlinorium trends northeast for 43 miles through Surry, Stokes, and Rockingham Counties. At least part of this fault zone is coincident with the western border fault of Dan River Basin in Rockingham County (Butler and Dunn, 1968, Plate 1).

That the gneisses, schists, quartzites, and granites provided most of the detritus for the Triassic sediments is shown by actual rock fragments found in the conglomerates along the basin margins. Sandstone composition also closely mirrors source area composition.

Acknowledgments

This paper is part of a Ph. D. dissertation submitted to the University of North Carolina at Chapel Hill in 1967. The writer thanks Roy L. Ingram, who directed the study and gave valuable advice.

Others who offered help, suggestions, and criticism include Daniel A. Textoris, H. J. Bissell, J. R. Butler, and Philip S. Justus. Zan Ritchie and Albert Staheli assisted in the field. Dewey S. Kirstein of Solite Corporation, Richmond, Virginia provided cores and discussed problems of Dan River stratigraphy. My father, F. M. Thayer, prepared most of the illustrations. Cecil G. Lalicker critically reviewed the manuscript.

The North Carolina Department of Conservation and Development, Division of Mineral Resources defrayed field expenses during the summers of 1964 through 1966. Grants from the Smith Fund of the University of North Carolina paid for thin-sections and aerial photographs.

TRIASSIC SEDIMENTARY ROCKS

General Statement

Upper Triassic sedimentary rocks in Dan River Basin are continental clastic deposits consisting of interbedded conglomerate, sandstone, siltrock, clayrock (mudrock terminology from Ingram, 1953), and coal. Individual units are characterized by abrupt lateral and vertical changes in texture, color, composition, and thickness of strata. Coarse-grained clastic rocks are usually found along the basin margins; finer-grained ones occur in the central part of the basin.

More than two-thirds of the sedimentary rocks are red, reddish-brown, or various shales of purple; the remainder are greenish-gray, and gray to black. Sandstones and mudstones (massive siltstones and claystones) make up more than 70 percent (by area) of the total section; mud shale (silt shale and clay shale) constitutes approximately 20 percent; and the remaining 10 percent is conglomerate (Figure 3).

On the basis of faunal and floral evidence, Dan River strata have been correlated with the northern European Keuper Sandstone, and assigned a Late Triassic age (Carnian, Norian, and possibly Rhaetian) (McKee, et al., 1959, Table 1).

Total thickness of Triassic strata in Dan River Basin is difficult to determine accurately because of (1) extremely poor exposures owing to low relief, deep weathering, and abundant vegetation, (2) lack of key beds and the heterogenous, lensing nature of Triassic rocks, (3) lack of subsurface data, and (4) unknown amount of repetition of strata by concealed faulting (not recognized because of the above 3 factors). Thickness variations within the basin are the result of lateral variation in sedimentation, post-depositional faulting, and post-depositional erosion.

Estimates of total thickness based on outcrop width and average dip of Triassic strata yield values that range from 5, 000 feet for the narrowest part of the basin to 15, 000 feet for the widest portion. In

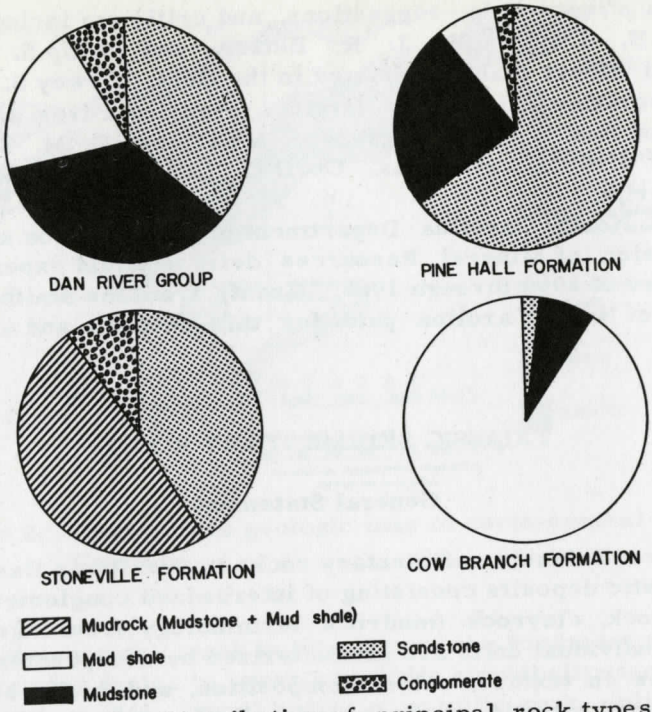


Figure 3. Distribution of principal rock types in Dan River Triassic Basin.

contrast, calculations of maximum sediment thickness from 8 gravity profiles normal to the axis of the basin yield values ranging from 4750 feet to 6250 feet (Geddes and Thayer, in preparation). A density contrast of 0.2 between Triassic strata and surrounding metamorphic rocks was used in the calculations. The gravity data indicate that the deepest part of the basin is located adjacent to the western border fault near Stoneville (Plate 1).

The amount of sedimentary fill that has been removed from Dan River Basin by post-Triassic erosion is unknown for certain, but the writer has shown elsewhere (Thayer, 1970) that Dan River Basin probably extended at least 25 miles to the southwest and was once connected with Davie County Basin. However, a dispersal pattern of sedimentation from local source areas marginal to both the fault and unconformity sides of the basins (Thayer, 1967, p. 62-63) indicates that the western North Carolina Triassic basins (Dan River-Davie County) were never connected with the eastern one (Durham-Sanford-Wadesboro) (Reinemund, 1955, p. 81; Leith and Custer, 1968, p. 484-485; Klein, 1963, p. 805-806; Klein, 1969, p. 1827-1828). The trough in which the sediments accumulated was probably several miles wider than the present outcrop belt as Meyertons (1963, Plate 1 - south part) has shown the existence of a small Triassic outlier 1 mile east of the southeastern

edge of the contiguous Danville Basin.

Lithologic Subdivision

Triassic sedimentary rocks of Dan River Basin are divided into three formations for purposes of mapping and discussion. These are (from the base upward) the Pine Hall, Cow Branch, and Stoneville Formations. The three formations are lithologic facies that interfinger throughout much of the basin and are not distinct time-stratigraphic units. In most sections across strike, however, the main bodies of the three units lie one above the other in the order named (Figure 4).

Pine Hall Formation, the lowermost unit, unconformably overlies and in places is faulted against pre-Triassic metamorphic rocks on the southeast side of the basin. It consists of tan-colored, cross-bedded sandstone, with lesser amounts of red- to brownish-colored conglomerate, siltstone, claystone, and mud shale (Figure 3).

Cow Branch Formation gradationally overlies Pine Hall Formation throughout most of the basin, but intertongues with it in the extreme northern portion (Plate 1). Here a thick lens of Cow Branch shale and mudstone overlies the lower, more laterally persistent Cow Branch unit and interfingers with Stoneville Formation. Other mappable lenses of dark-colored shale and mudstone occur within Stoneville Formation near the town of Mayodan (Plate 1) and are included in Cow Branch Formation. This formation consists of gray to black shale, claystone, and siltstone, with subordinate amount of fine- and medium-grained sandstone and coal. It is characterized by laterally persistent, uniformly even, medium- to very thin-bedding (bed thickness terminology after Ingram, 1954).

Stoneville Formation conformably overlies Cow Branch Formation throughout the southern nine-tenths of the basin, and intertongues with the upper Cow Branch lens near the town of Spray* (Plate 1) in the extreme northern part of the basin. It is truncated on the western margin of the basin by Dan River fault zone. Crudely stratified, poorly sorted lithic conglomerates radiate outward from the border faults and grade laterally into fine- to coarse-grained sandstones, siltstones, claystones, and shales. This formation is characterized by a diverse suite of textures, colors, compositions, and sedimentary structures.

Dan River Group

The name Dan River Group is here proposed for the red-, tan-, and gray-colored conglomerates, sandstones, and mudrocks of Pine

*Note: The towns of Spray, Leaksville, and Draper have consolidated since the original field work for this project was completed. The name of the new consolidated town is Eden.

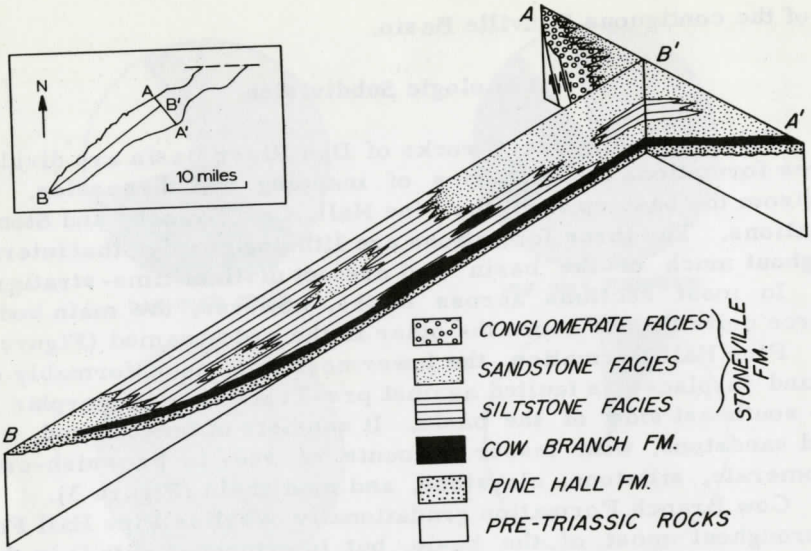


Figure 4. Schematic fence diagram showing longitudinal transverse facies changes in Dan River Group.

Hall, Cow Branch, and Stoneville Formations that unconformably overlie and are locally in fault contact with metamorphic rocks on the southeast side of the basin; they are truncated on the northwestern basin-margin by Dan River fault zone.

Klein (1962, p. 1129) has argued that the term "Newark Group" has been misused outside of its type area in New Jersey. Therefore, the name Dan River Group is recommended to conform to the Code of Stratigraphic Nomenclature (Am. Comm. Stratigraphic Nomenclature, 1961) since the term "Newark" was originally applied to these sediments in a time-stratigraphic sense (Redfield, 1856, p. 357; Russell, 1889, p. 178-182; Gilbert, 1894, p. 55-61).

Pine Hall Formation

The name Pine Hall Formation is proposed for the inter-bedded sandstone, mudrock, and conglomerate sequence that overlies with angular unconformity and in places is faulted against pre-Triassic metamorphic rocks along the southeastern margin of the basin. The upper contact of the formation is gradational and is placed at the base of the lowest persistent dark-colored mudrock of Cow Branch Formation. The upper contact rises in the stratigraphic section towards the northeast where the formation attains its maximum thickness. Near the town of Leaksville (Plate 1) the overlying Cow Branch Formation occurs as two separate tongues that overlap laterally and are vertically offset in outcrop by about three-fourths of a mile. The lower Cow Branch unit intertongues northeastward with Pine Hall Formation and the upper

intertongues southwestward with Stoneville Formation. Because of this stratigraphic offset an arbitrary cutoff between Pine Hall and Stoneville Formations has been drawn east of Leaksville near the Smith River (Plate 1). A similar arbitrary Pine Hall-Stoneville contact has been drawn at the southwestern end of the basin near Germantown where the Cow Branch is absent (Plate 1).

Pine Hall Formation is so poorly exposed that no type section can be designated. The name Pine Hall is derived from a small settlement and railroad station along the Dan River in Stokes County (Plate 1) where medium- to very coarse-grained trough (McKee and Weir, 1953) cross-bedded tan arkose (sandstone classification after Krynine, 1948), characteristic of the formation, is exposed along the Norfolk and Western Railroad tracks from 0.1 to 1.2 miles northeast of Pine Hall Railroad Station. This is designated the type area in lieu of a type section.

Outcrop width of this formation averages about one-fourth of a mile throughout most of the basin and reaches a maximum of 2.3 miles in the extreme northeastern portion. Thickness, calculated according to average dip and outcrop width, ranges from 250 feet in the southern part of the outcrop belt to almost 7,000 feet near the town of Draper. Pine Hall strata are absent in the area 6 miles southeast of Stoneville near the Dan River (Plate 1). Total area occupied by this formation is 26 square miles, more than half of which is located in the northern tenth of the basin.

Sandstone makes up 65 percent of the total unit, mudstone (chiefly siltstone) 24 percent, mud shale 8 percent, and conglomerate 3 percent (Figure 3). Dominant colors of this formation are grayish-orange (10YR 7/4), dark yellowish-orange (10YR 6/6), very pale orange (10YR 8/2), and pale reddish-brown (10YR 5/4) (colors from Goddard et al., 1948).

On the basis of textures and combinations of primary sedimentary structures Pine Hall Formation can be subdivided into three mappable intertonguing facies: (1) conglomerate, (2) sandstone, and (3) siltstone (Plate 1).

The conglomerate facies crops out in a narrow belt along the southeastern edge of the basin, south and east of Draper, on the southeast side of Dan River (Plate 1). Sediments so assigned consist chiefly of crudely stratified, poorly sorted subrounded to rounded exotic rock debris, at least 50 percent of which is made up of particles greater than 4 mm in diameter.

The sandstone facies is gradational to and intertongues with the conglomerate facies. The contact between the two is drawn where sandstone exceeds conglomerate. This facies crops out along the eastern margin of the basin and occupies a total area of 17 square miles (Plate 1). It consists of medium- and coarse-grained, poorly sorted arkose, impure arkose, and high-rank graywacke. Pebble and granule sandstones are very common in this facies. Sandstones are thick- and

medium-bedded, medium cross-bedded, and are typically grayish-orange (10YR 7/4). Subordinate proportions of pale reddish-brown (10R 5/4) and moderate reddish-brown (10R 4/6) mudrocks are included in this unit. Sedimentary structures in this facies include mudrock intraclasts, erosional channels, current ripple marks, load casts, ripple cross-stratification, and carbonized plant debris. Silicified fragments and logs of Araucarian conifers (Araucarioxylan?) are very abundant in the lower 200 feet of this unit. The trees that yielded these logs evidently grew some miles away in the uplands adjoining the basin as their branches, foliage, and fruiting structures are not present.

The siltstone facies occupies 8 square miles in the extreme northern portion of the basin (Plate 1). Scattered, poorly exposed outcrops of this facies are found along North Carolina State Highway 770 northwest of Dan River near the town of Draper. This unit is composed of pale reddish-brown (10R 5/4) and moderate reddish-brown (10R 4/6), even, uniformly thin- and medium-bedded siltstone, claystone, and shale with lesser amounts of grayish-orange (10YR 7/4) fine- to coarse-grained, poorly sorted, thin- and medium-bedded arkose, impure arkose, and high-rank graywacke. Sedimentary structures are generally rare but include mottled and disturbed bedding, calcareous concretions, green reduction spots, cut-and-fill, rib-and-furrow, primary current lineation, local graded bedding, carbonized plant(?) debris, and burrow casts.

Cow Branch Formation

Meyertons (1963, p. 9) applied the name Cow Branch Member to the black and dark gray claystones, shales, siltstones, and sandstones of his Leakesville Formation in the Danville Basin. From field examination, the writer concludes that the Cow Branch in Dan River Basin is a distinct lithologic unit and readily mappable at a scale of a mile to the inch. Therefore, the writer proposes that the Cow Branch be raised to formational rank. Meyertons' type section, located on Va. State Road 856, 0.25 mile south of Va. State Road 622, Pittsylvania County, Va. is retained as the type section (Meyertons, 1963, p. 51-52). Reference sections, supplementing the type section are presented in the Appendix (see Measured Sections C, D, E, and G). Best exposures of this formation are located in the Solite Corporation Quarries along the Virginia-North Carolina state line (Plate 1, Locality 4), and in the abandoned quarries 3 miles southwest of Leaksville (Plate 1, Locality G).

Cow Branch Formation occupies a total area of 30 square miles in Dan River Basin. It crops out in a narrow belt along the southeastern side of the basin, generally following the trend of Town Fork Creek in Stokes County and Dan River in Rockingham County. The formation averages about 600 feet in thickness along this belt, but locally ranges from one-fifth to three-fifths of a mile in outcrop width. This elongate

lens wedges out about three miles east of Leaksville, and is overlain by a thick Cow Branch lens that is up to 1.25 miles in outcrop width (Plate 1). Small Cow Branch tongues up to 2 miles long and 0.25 mile wide are locally present within the overlying Stoneville Formation near Mayodan in Rockingham County. This unit is characteristically dark-colored, chief colors being: medium light gray (N7), medium gray (N5), medium dark gray (N4), and dark gray (N3). These weather grayish-orange (10YR 7/4) to dark yellowish-orange (10YR 6/6).

Cow Branch Formation consists of massive to thinly-laminated, even, uniformly thin- and medium-bedded siltstone, claystone, and mud shale, with subordinate amounts of very fine- to medium-grained, medium-bedded sandstone (Figure 3). Thin lenticular layers of coal are found locally in the lower 200 feet of this unit along the outcrop belt from Germanton to Leaksville. Syngenetic ironstone concretions, locally up to 1 foot long and parallel to stratification, are abundant throughout the basal Cow Branch. Abundant pyrite, vivianite, and macerated plant debris are common associates of these concretions.

The formation is characterized by laterally persistent, uniformly even stratification, rhythmic laminations, small-scale cross- and ripple-bedding, mud cracks, oscillation and current ripple marks, local graded bedding, and carbonized wood chips and fragments. Irregular channel lenses, convolute lamination, load casts, groove casts and marks, flute marks, pull-aparts, burrow casts, hopper-shaped crystal casts, mottled and disturbed bedding, and raindrop imprints are found locally.

Fossils are sparsely distributed in the Cow Branch Formation. The branchiopod Isaura ovata (Lea), found locally within the formation, indicates a correlation with the Lockatong Formation of New Jersey (Reeside, et al., 1957, Chart 8a, columns 76, 89, 90, and 91). Unidentified well-preserved plant fossils have been found at several localities in the basal Cow Branch.

Stoneville Formation

The name Stoneville Formation is here proposed for the red, reddish-brown, brown, greenish-gray, and gray conglomerates, sandstones, and mudrocks that conformably overlie and intertongue with Cow Branch Formation. The Stoneville-Cow Branch contact is gradational and is drawn at the top of the highest persistent dark-colored mudrock of Cow Branch Formation. Its type section is located in Rockingham County along U. S. 220 Bypass, 1317 feet north of its intersection with Rockingham County road 2208 (see Measured section B in Appendix; Locality B on Plate 1). Strata within the formation are heterogenous, lenticular, and laterally gradational so that no outcrop gives a complete section that is typical outside of a small area. Therefore, supplementary reference sections illustrating various facies of the formation are presented in the Appendix (see Measured Sections A and

F). The name Stoneville is derived from a small town in Rockingham County 2 miles northeast of the type locality (Plate 1).

Stoneville Formation borders the northwestern margin of Dan River Basin and ranges from less than a mile to more than five miles in outcrop width. The formation occupies 92 square miles in the basin.

Generalized gross lithology (by area) of the formation (Figure 3) is: mudrocks, 43 percent; sandstone, 41 percent; and conglomerate, 16 percent. Colors are similar to those of Pine Hall Formation.

As this formation contains a wide spectrum of lithic types, textures, and structures, which reflect original differences in depositional environments, three facies are recognized and mapped: (1) conglomerate, (2) sandstone, and (3) siltstone. The three facies intertongue throughout the basin (Plate 1).

The conglomerate facies occupies 11 square miles in Dan River Basin and is restricted to the northwest border along Dan River fault zone where six fan-shaped conglomerate bodies radiate basinward from the fault zone and intertongue laterally with rocks of the sandstone and siltstone facies (Plate 1). This facies is characterized by poorly sorted, pebble- to boulder size, rounded lithic fragments that were derived from nearby metamorphic rocks along the western basin-margin (Thayer, 1967, p. 61-62). Conglomerates are very poorly bedded but locally display thick- and very thick-bedding, and medium- and large-scale trough and planar cross-stratification. Crudely stratified, poorly sorted, coarse-grained sandstones (arkose, impure arkose, and high rank graywacke) are interbedded with the conglomerate. Particle imbrication and intraformational sandstone and siltstone breccias are common accessory features.

Strata of the sandstone facies crop out along a broad elongate belt in the north-central part of the basin and in scattered areas near its southern terminus (Plate 1). This facies occupies a total area of 3[illegible] square miles and consists chiefly of grayish-orange (10YR 7/4), pale yellowish-orange (10YR 8/6), light brown (5YR 6/4), and greenish-gray (5GY 6/1) poorly sorted, medium- to very coarse-grained arkose, impure arkose, and high-rank graywacke. Sandstones display medium- to very thick-bedding, and medium- and large-scale trough cross-stratification. Sedimentary structures are abundant and include: current ripple marks, ripple-drift cross-lamination, rib-and furrow, ball-and-pillow, primary current lineation, drag marks, wood chips, and carbonized plant debris. Rhythmic alternations (fining-upwards cycles) of sandstone and mudrock are abundant with lighter-colored sandstone grading upward through a decrease in grain size and bed thickness into darker-colored mudrock. The mudrocks display even, uniformly thin- and medium-bedding, and are reddish-brown (10R 4/6) and pale reddish-brown (10R 5/4). Mudrocks constitute less than 50 percent of the total unit.

Rocks assigned to the siltstone facies are exposed in a wide belt in the southern portion of the basin and occupy a total area of 44 square

miles. This facies intertongues with and is gradational to the sandstone and conglomerate facies; the contact between them is drawn where reddish-colored siltstone (including lesser amounts of claystone and shale) exceeds sandstone or conglomerate. The siltstone unit is typically micaceous, reddish-brown (10R 4/6), massive, and shows even, uniformly thin- and medium-bedding. Where present, laminations are wavy and commonly disrupted by animal burrow casts. Sedimentary structures are scarce but include raindrop imprints, mottled and disrupted bedding, irregular-shaped calcareous concretions, mud cracks, green reduction spots, small sandstone channels, drifted twigs and leaves, local graded bedding, primary current lineation, hopper-shaped crystal casts, groove casts, and rib-and-furrow. Medium- to coarse-grained tan and gray-green, cross-bedded lenticular sand bodies are widely but sparsely distributed throughout this unit.

Lithologic Correlation with Danville Basin

As shown previously, Meyertons' stratigraphic terminology in Danville Basin could not be used in mapping Dan River Basin; therefore, the writer adopted new units. An approximate lithologic correlation between stratigraphic units in the two basins is shown below.

Danville Basin (Meyertons, 1963)	Dan River Basin (This Report)
Cedar Forest Formation	Conglomerate facies-Pine Hall and Stoneville Formations
Dry Fork Formation	Sandstone facies-Pine Hall and Stoneville Formations
Leakesville Formation	
Cow Branch Member	Cow Branch Formation
Cascade Station Member	Siltstone facies -- Pine Hall and Stoneville Formations

Depositional Environments

Combinations of primary sedimentary structures in Dan River Group were used by Thayer (1969) to determine original depositional environments. Comparison with sedimentary structures from known modern environments indicates that the combination of structures in Dan River Group are diagnostic of alluvial fan, floodplain, lacustrine, and swamp deposits. The coarse-grained, poorly sorted, crudely stratified conglomerates of Pine Hall and Stoneville Formations repre-

sent alluvial fan deposition along the basin margins. Cross-bedded, lenticular-shaped sandstones in these formations are interpreted as channel deposits that accumulated on point and channel bars in low- to high-sinuosity streams. Finer-grained, reddish-brown, uniformly thin- and medium-bedded siltstones, claystones, and shales were deposited on broad oxidizing floodplains, mudflats, and possibly lakes (Sanders, 1968, p. 285-286) adjacent to stream channels.

Fine-grained, dark-colored mudrocks of Cow Branch Formation were deposited in lakes that formed by damming the longitudinal drainage of the basin. The specific cause of the damming is unknown at this time. Rhythmic laminations, abundant pyrite, uniformly even stratification, graded bedding, and symmetrical ripple marks indicate that most of the Cow Branch accumulated below lacustrine wave base. Lenses of coal with autochthonous plant fragments, vivianite, and ironstone concretions along with lenticular sand bodies in the lower part of the Cow Branch suggest accumulation in swamps and deltas along the lake margins. The uppermost Cow Branch contains numerous tongues of reddish-brown siltstone that show abundant mudcracks, burrow casts, and a few hopper-shaped crystal casts and raindrop imprints. These features are indicative of a regressive lacustrine deposit brought about by a waning of the lake, possibly caused by a change in climatic regime.

TRIASSIC IGNEOUS ROCKS

Form and Distribution

Thirty-six dolerite dikes have been mapped within and adjacent to Dan River Basin (Figure 5). Dikes are up to 7.5 miles long and range in thickness from less than 1 foot to almost 100 feet; most, however, are between 15 and 50 feet wide. Only dikes greater than 5 feet in outcrop width have been mapped. Strike usually ranges from N5°W to N30°W and dip is almost vertical. Several of the smaller dikes, however, strike NNE to NE. In contrast, average strike of dikes in the contiguous Danville Basin varies from N11°W to N10°E (Meyertons, 1963, p. 32).

Age

Although no absolute age determinations of dolerite intrusions in the southern Appalachians have been made, they are generally believed to be Late Triassic in age (Roberts, 1928, p. 62; Reinemund, 1955, p. 60; King, 1961, p. 93; Meyertons, 1963, p. 35; and Ragland, et al., 1968, p. 59). King (1961) has suggested a similar age and origin for all dikes within the Appalachian Triassic swarm.

Dikes in Dan River Basin cut the youngest Triassic strata as well as the fault margin of the basin. The dikes are not offset at the

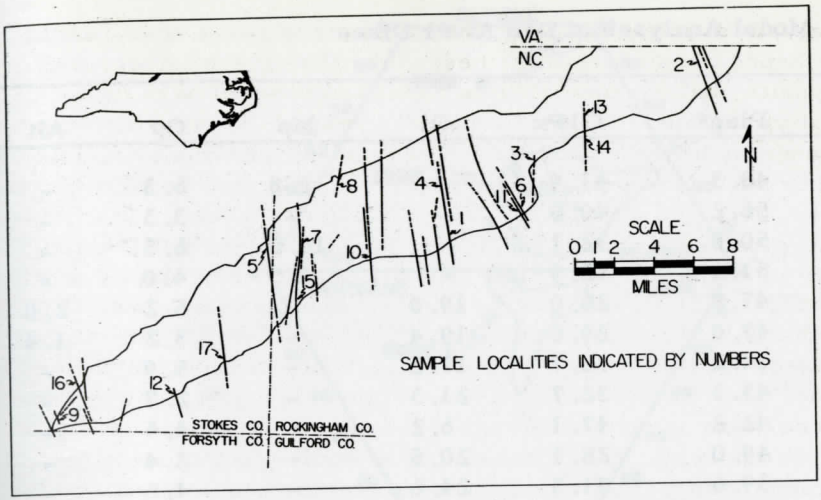


Figure 5. Location of dolerite dikes in Dan River Basin. Sample localities denoted by numbers.

border faults nor have dolerite fragments been found within the Triassic sediments. Therefore, the dikes must have been emplaced later than sedimentation and later than the final episode of border faulting that tilted Triassic strata to the northwest.

Mineralogy

Seventeen thin-sections were examined to determine mineral composition and texture of the dikes. Figure 5 shows sample localities and Table 1 summarizes modal composition. Point counts of at least 1,000 points per slide, using a 0.5 mm x 1.0 mm grid spacing, were made to determine modal variation. Primary minerals in the dikes include plagioclase, clinopyroxene, olivene, micropegmatite, apatite, and opaque minerals. Secondary minerals include biotite, fibrous uralite, calcite, iddingsite, hematite(?), sericite, antigorite, leucoxcene, and a turbid clay-like mineral. Detailed descriptions of these minerals have been presented elsewhere (Thayer, 1967, p. 115-118).

Modal Types

The writer has modified Justus' (1966, p. 27) classification of dolerite dikes in Deep River Basin and divided dikes in Dan River Basin into two groups based on modal olivine content. These are: (1) Group I dikes, which do not contain olivine, and in three of four dikes examined contained micropegmatite; and (2) Group II dikes, which are characterized by having an olivine content between 5.3 and 24.6 percent. The latter group constitutes 75 percent of the dikes studied.

Table 1. Modal Analyses of Dan River Dikes

Sample Number	Plag*	ClPx	Ol	Mp	Op	Alt
1	48.3	41.9	-	2.8	6.3	-
2	56.2	40.5	-	-	3.3	-
3	50.8	32.7	-	10.0	6.5	-
4	51.6	42.9	-	1.5	4.0	-
5	47.8	26.0	19.0	-	5.2	2.0
6	47.0	29.0	19.4	-	3.2	1.4
7	44.2	32.7	17.2	-	5.9	-
8	43.3	32.7	21.3	-	2.7	-
9	42.2	47.1	6.2	-	4.5	-
10	49.0	28.1	20.5	-	2.4	-
11	39.6	31.3	24.6	-	4.5	-
12	38.9	37.6	19.8	-	3.7	-
13	54.6	24.8	11.8	-	2.6	6.2
14	54.6	28.1	14.5	-	2.8	-
15	50.5	42.9	5.3	-	1.3	-
16	50.0	24.2	16.6	-	4.1	5.1
17	53.8	29.6	13.4	-	3.0	0.2

*Abbreviations: Plag - plagioclase; ClPx - clinopyroxene; Ol - olivine; Mp - micropegmatite; Op - opaque minerals; Alt - alteration products.

Figure 6 shows modal variation and modal types of Dan River dikes on a triangular diagram using poles of olivine; plagioclase, micropegmatite and clinopyroxene. Compositional fields of Durham and Deep River Basin dikes are also outlined on Figure 6 (after Reinemund, 1955, p. 59; Hermes, 1964, p. 1722).

All Group I dikes have isogranular texture; Group II dikes display subophitic, intergranular, and porphyritic textures. According to Justus (1966, p. 44) subophitic, intergranular, and porphyritic textures can be shared by Group I and Group II dikes, whereas ophitic texture is developed only in Group II dikes greater than 25 feet wide.

Dikes with modal olivine in excess of 50 percent (Group III) have been reported from the Durham and Deep River Basins (Reinemund, 1955, p. 58-59) -- "gabbroic diabase"; Hermes, 1964, p. 1721 -- "picritic dolerite"), but have not been found by the writer in Dan River Basin.

The varying mineral proportions in Dan River dikes could have been produced by (1) simultaneously tapping-off different horizons of a partially differentiated basaltic magma chamber, or (2) tapping-off a basaltic magma chamber during various stages of crystallization

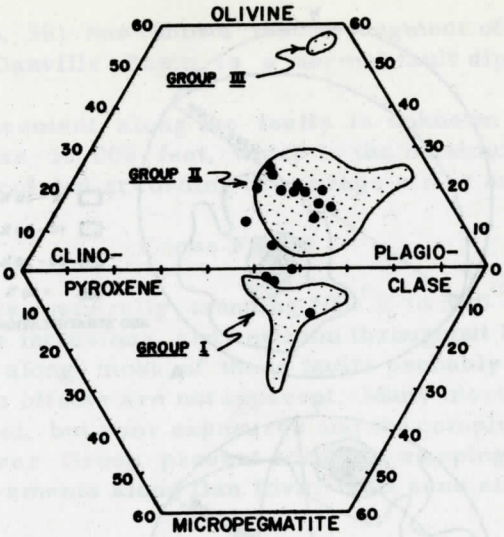


Figure 6. Composition of dolerite dikes in Dan River Basin indicated by dots. Stippled areas represent compositional fields for dikes in the Durham and Deep River Basins, N. C. (after Reinemund, 1955, p. 50; Hermes, 1964, p. 1722).

(Hermes, 1964, p. 1726-1727; Justus, 1966, p. 61-64).

Recent geochemical studies of North Carolina dolerites (Ragland, et al., 1968; Justus, et al., 1970) suggest that the intrusions most closely resemble oceanic or ocean-margin tholeiites. Emplacement of the entire eastern North American Triassic dike swarm, as well as formation of Triassic basins, may be tectonically related to a fracture system initiated by widening of the Atlantic Ocean Basin during Mesozoic time (Van Houten, 1969, p. 330; Justus, et al., 1970).

STRUCTURE

Introduction

Dan River Basin is a post-orogenic asymmetrical graben filled with continental fluvial and lacustrine sediments. It is one of the eastern North American Triassic rift valleys that formed during the Palisades Disturbance in Late Triassic time.

Sedimentary strata within the basin have an average strike of N60°E, and dip 32°NW (Figure 7A). Variation in strike and dip are common, however, and dips range from 13° to 73°NW.

The northwestern side of the basin is bounded by a line of

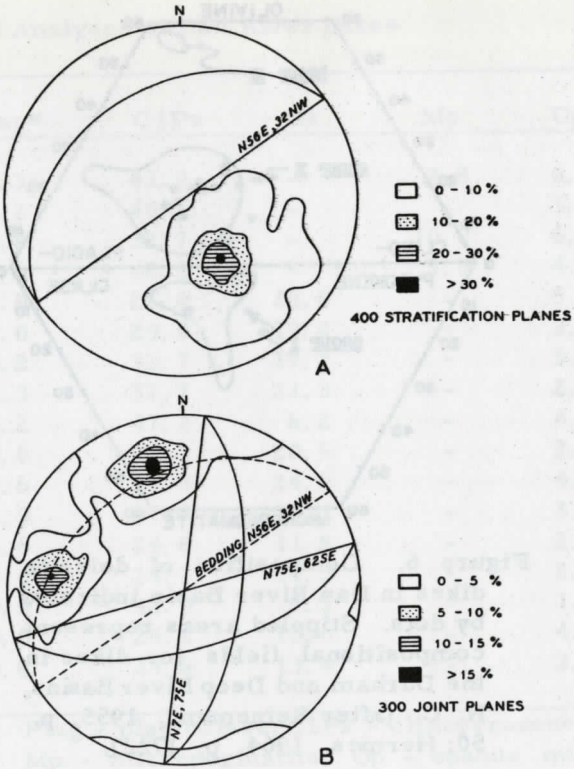


Figure 7. Contour diagrams of A. 400 stratification planes; B. 300 joint planes in Dan River Group.

southeast-dipping high-angle normal faults (Dan River fault zone) with as much as 15,000 feet of stratigraphic displacement. The southeastern edge is formed by an irregular sedimentary contact, which has been faulted in places. Cross faults, usually followed by dolerite dikes, cut the Triassic into smaller subblocks.

Dan River Fault Zone

Dan River fault zone forms the contact between the Triassic and pre-Triassic metamorphic rocks on the northwestern side of the basin. This line of faults is 35 miles long in North Carolina (Plate 1) and continues into Virginia for another 75 miles where it has been named Chatham border fault (Meyertons, 1963, p. 37).

The trace of the fault zone is sinuous and trends N40°E to N50°E; it is locally broken into a series of "step-like" faults (Plate 1) that probably formed because of differing resistance of basement rocks to faulting (Meyertons, 1963, p. 38).

The fault planes are not exposed within the map area but

Meyertons (1963, p. 38) has shown that a segment of the contiguous Chatham fault in Danville Basin is a normal fault dipping 65° to the southeast.

Total displacement along the faults is unknown for certain but may be as great as 15,000 feet, which is the maximum thickness of Triassic strata calculated according to average strike and dip.

Cross Faults

Cross faults, generally trending N50°E to N30°W, and usually followed by dolerite intrusions, are common throughout Dan River Basin. Displacement along most of these faults probably is not great as major stratigraphic offsets are not apparent. Many more of these faults are probably present, but poor exposures and the complex facies changes within Dan River Group prevent accurate mapping. Cross faults postdate latest movements along Dan River fault zone since they cut it.

Eastern Border Faults

Normal faults up to 3 miles long have been mapped along the eastern margin of the basin where the Triassic-Piedmont contact is extremely straight, where cobble- and boulder-conglomerates are present, where the strike of bedding is abruptly truncated, and where shear zones are present. These faults are believed to have steep westward dips. The latest movement along the faults was after sedimentation since clasts within eastern border conglomerates are commonly faulted. A cross fault cuts one of the eastern border faults 1.5 miles southeast of Walnut Cove (Plate 1) indicating that movements along cross faults postdate latest eastern border fault movements.

Spray Cross Structure

Spray cross structure is an anticlinal cross fold in the Triassic sedimentary rocks located 4 to 6 miles southwest of Leaksville near the large bend in Dan River. It is reflected by an abrupt change in strike of Cow Branch Formation and is associated with a re-entrant in Dan River fault zone southwest of Spray (Plate 1). Reinemund (1955, p. 82) and Wheeler (1939) noted similar anticlinal warps in other Triassic basins and believed they were due to unequal downwarping along the major bounding faults.

Joints

A contour diagram (lower hemisphere) of 300 joint planes from widely-scattered outcrops in Dan River Group and their relation to bedding is shown in Figure 7B. Two joint systems are present: (1) strike N7°E, dip 75°E, and (2) strike N75°E, dip 62°SE. There is no apparent

relationship between drainage patterns and joints in Dan River Basin.

Structural Development of Dan River Basin

Structural development of Dan River Basin, like that of other eastern North American Triassic basins (Reinemund, 1955; Meyertons, 1963; Sanders, 1963, Glaeser, 1966; Van Houten, 1969), involved the following sequence of events (in chronological order):

1. Uplift of borderlands on both sides of the basin with continuous downfaulting along the entire extent of the northwest border and localized downfaulting along the southeastern margin. Part of the faulting on the northwest margin may follow older lines of weakness (Stony Ridge fault zone) that were rejuvinated during Late Triassic time (Butler and Dunn, 1968, p. 23-24).

2. Erosion of uplifted metamorphic-igneous borderlands adjacent to the basin provided a continuous supply of detritus to both margins of the basin throughout Late Triassic time. Ponding of the longitudinal drainage of the basin, possibly caused by increased basin subsidence, gave rise to a thick lacustrine-swamp sequence (Cow Branch Formation) during the early stages of basin filling. Total thickness of the original basin-fill may have been greater than 15, 000 feet.

3. Faulting along the northwest margin after sedimentation tilted Triassic strata westward. Unequal downwarping along these faults produced large-scale gentle folds whose axes are transverse to trends of the faults and basin axis. Post-sedimentation faulting along eastern border faults south of Draper is indicated by the presence of faulted clasts within the border conglomerate. The age of this faulting relative to movements along faults on the northwestern basin margin is unknown.

4. Emplacement of dolerite dikes (Late Triassic and/or Jurassic?) along tensional fractures that transect regional structures.

5. Differential uplift of the entire region with subsequent erosion of Triassic strata in the area between Dan River and Davie County Basins.

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APPENDIX: MEASURED SECTIONS

Measured Section A. Lower portion of Stoneville Formation, approximately 500 feet above Cow Branch Formation. Top of section located 2.7 miles S. 55° W. of Leaksville along Buffalo Creek.

Unit		Thickness Feet
9	Arkose, micaceous, light buff. Medium-grained, moderately sorted, well indurated. Medium-scale cross-bedding, individual units thickly-laminated. Lower contact covered, upper sharp and planar	6.5
8	Arkose, gray. Medium- to fine-grained, moderately sorted, well indurated. Even, uniformly thick-bedded. Massive, with ball-and-pillow structure. Lower contact sharp and planar	2.0
7	Arkose, gray. Fine-grained, moderately sorted, well indurated. Gray shale interbeds less than 6" thick. Massively thick-bedded. Lower contact covered	17.0
6	Arkose, micaceous, gray. Fine-grained, moderately sorted, well indurated. Massively thick-bedded. Lower contact covered	8.0
	Covered	20.0
5	Siltstone, grayish-blue. Poorly sorted, well indurated. Massively thick-bedded. Muscovite flakes to 1 mm parallel to layering. Lower contact covered	14.0
4	Impure arkose, gray. Fine grained, moderately sorted, well indurated. Small-scale cross-bedding. Thickly-laminated with thin parting. Lower contact sharp and even	5.0
3	Shale, gray, weathers grayish-blue. Poorly indurated. Thickly-laminated with thin parting. Lower contact sharp and even	2.0
2	Arkose, gray. Medium-grained, poorly sorted, well indurated. Medium-scale cross-bedding with individual units weathering out as wedges. Lower contact sharp and undulatory	22.0
1c	Arkose, micaceous gray. Medium-grained, moderately sorted, well indurated. Medium- to thick-bedded. Asymmetrical ripple marks common. Load casts at base of unit. Lower contact sharp and undulatory	10.0
1b	Shale, gray. Very thin-bedded with thin parting. Mud plumes up to 2 cm long are injected into the overlying sandstone giving rise to flame structure. Lower contact covered	6.0

Unit		Thickness Feet
1a	Arkose, micaceous, gray. Same as unit 1c. Lower contact covered.....	4.0
	Total thickness of measured section	116.5

Measured Section B. Type Section of Stoneville Formation. Top of section located on west side of U. S. 220 Bypass 1317 feet north of its intersection with Rockingham County Road 2208.

Unit		Thickness Feet
24	Impure arkose, dark gray. Fine-grained, poorly sorted, well indurated. Light gray silty layers in middle of unit. Thick-bedded. Few calcite concretions. Well-jointed. Upper contact covered, lower gradational.....	15.3
23	Arkose, light gray. Coarse-grained, very poorly sorted, well indurated. Pebbly layers up to 6 inches thick scattered throughout. Maximum pebble size 3 inches. Thick-bedded. Well jointed. Lower contact sharp and planar.....	9.2
22	Impure arkose, light gray. Very fine- to fine-grained, poorly sorted, well indurated. Very thin- to thin-bedded. Small- scale ripple-drift cross-stratification, disrupted contorted layering, flaser bedding, and burrows to 0.5 inch in diameter are common. Lighter-colored calcareous concretions are scattered throughout and bedding wraps around them. Well jointed. Basal contact covered.....	18.0
21	Impure arkose, dark gray. Fine- to medium-grained, poorly sorted, well indurated. Pebbly layers scattered throughout. Massively very thick-bedded. Unit poorly exposed. Basal contact gradational.....	22.3
20	Arkose, gray. Coarse-grained layers alternating with fine-grained, darker-colored sandy layers. Poorly sorted and well indurated. Medium-bedded becoming thick-bedded upward. Layering is flat and even, showing slight rippling near base. Calcareous concretions averaging 1.5 inches in length, parallel to the stratification, are common in darker-colored, finer-grained layers. Burrows and disrupted stratification common. Basal contact covered.....	16.4
19	Impure arkose, gray. Coarse-grained, very poorly sorted, well indurated. Conglomerate at base with maximum particle size 6 inches, showing faint imbrication. Thick-bedded and massive. Lower contact covered.....	8.6
18	Arkose, light gray. Very coarse-grained, poorly sorted, well indurated. Thick-bedded, and massive. Poorly jointed. Lower contact gradational...	22.2
17	Arkose, light gray. Coarse-grained, poorly sorted, well indurated. Interlayers of fine-grained, moderately sorted micaceous arkose. Medium-bedded. Calcareous concretions common in finer-grained layers. Well jointed. Lower contact gradational.....	37.4
16	Impure arkose, light gray. Coarse-grained, very poorly sorted, well indurated. Thick-bedded showing no internal laminations. Scattered pebbly layers 4 to 5 inches thick with maximum particle size 3 inches. Well jointed. Lower contact gradational.....	10.1
15	Siltstone, micaceous, light gray. Massive, well indurated, with abundant calcareous concretions. Interlayered with medium-bedded, medium-grained moderately sorted tan arkose layers up to 2 inches thick. No internal structures. Well jointed. Lower contact gradational.....	26.8
14	Arkose, gray. Very coarse- to coarse-grained, very poorly sorted, well indurated. Grain size decreases upward. Massive, very thick-bedded. Lower contact covered.....	19.1
13	Siltstone, maroon. Poorly sorted, well indurated. Medium- to thick-bedded, showing no internal laminations. Abundant burrows to 0.5 inch in diameter. Irregular-shaped calcareous concretions are common and weather light gray. Well jointed. Lower contact covered.....	6.9
12	Arkose, gray. Medium- to coarse-grained, poorly sorted, well indurated. Grain size decrease upward. Thick-bedded, massive. Well jointed. Lower contact flat and sharp.....	15.4

Unit		Thickness Feet
11	Siltstone, maroon, interlayered with light gray, very fine-grained arkose. Thin-bedded showing thick internal laminae. Ripple and flat bedded. Calcareous concretions are common and parallel to layering. Burrows and churned-up layering common. Lower contact covered.....	4.1
10	Arkose, gray. Medium-grained, moderately sorted, well indurated. Massively thick-bedded. Very poorly exposed. Well jointed. Lower contact covered.....	29.6
9	Siltstone, maroon, interlayered with thickly-laminated maroon and tan, very fine-grained sandstone. Siltstone is massive and thick-bedded; sandy layers show rippled bedding and convolute lamination. Abundant calcareous concretions less than 3 inches long. Burrows and disrupted laminations common. Poorly exposed. Well jointed. Lower contact gradational.....	25.9
8	Impure arkose, gray. Coarse- to medium-grained, poorly sorted, well indurated. Conglomerate at base 2.5 feet thick resting on scoured surface. Grain size decreases upward; sorting becomes better upward. Medium-bedded, with no internal laminations. Well jointed. Lower contact sharp and undulatory.....	10.9
7	Siltstone, maroon. Massively thick-bedded. Concretions less than 1 inch long are abundant. Well jointed. Lower contact covered.....	7.7
6	Arkose, light gray. Coarse-grained, poorly sorted, well indurated. Basal 3 inches is conglomeratic with pebbles up to 5 inches long showing slight imbrication. Grain size decreases upward. Thick-bedded. Unit poorly exposed, and shows spheroidal weathering. Lower contact wavy and scoured.....	9.6
5	Siltstone, maroon, with scattered layers of buff-colored, fine-grained impure arkose. Well indurated. Very thick-bedded. Abundant burrows less than 0.5 inch in diameter. Unoriented carbonate concretions averaging 2 inches in length are abundant. Lower contact gradational.....	11.9
4	Arkose, gray. Medium- to coarse-grained, poorly sorted, well indurated. Basal 6 inches is conglomeratic. Thick-bedded near base becoming thin-bedded near top. Calcareous concretions averaging 1 inch in length in upper 1 foot. Lower contact wavy and sharp.....	6.8
3	Arkose, maroon. Medium- to fine-grained, poorly sorted, well indurated. Thick-bedded. Oval-shaped calcareous concretions less than 1 inch long are abundant. Well jointed. Lower contact gradational.....	4.1
2	Arkose, gray. Coarse-grained, poorly sorted, well indurated. Medium- to thick-bedded. Several conglomeratic layers less than 6 inches thick. Well jointed. Lower contact gradational.....	8.2
1	Arkose, maroon. Fine- to very fine-grained, poorly sorted, well indurated. Massively thick-bedded. Calcareous concretions have weathered out leaving irregular holes on surface. Well jointed. Lower contact covered..	30.2
	Total thickness of measured section	376.7

Measured Section C. Near base of Cow Branch Formation. Top of section located 0.4 mile southwest of the Stokes-Rockingham County line along the Norfolk and Western Railroad tracks.

Unit		Thickness Feet
25	Siltstone, micaceous, interbedded with medium-grained, moderately sorted buff sandstone. Lower half of unit is thin-bedded sandstone with numerous interbeds of thickly-laminated micaceous siltstone. Upper half of unit is massive and medium-bedded sandstone. Lower contact gradational.....	5.0
24	Shale, black. Thinly-laminated. Very poor exposure. Lower contact covered.....	1.5
23	Impure arkose, buff. Fine-grained, poorly sorted. Flat, even, medium-bedded with thin internal laminae. Lower contact gradational.....	1.5

Unit		Thickness Feet
22	Siltstone, micaceous, dark gray. Shows very thin partings. Poorly exposed. Lower contact sharp and planar.	3.2
21	High-rank graywacke, micaceous. Medium-grained, poorly sorted. Medium-bedded. Planar stratification with thin-laminations. Several thin layers (less than 6 inches) of black fissile shale in middle of unit. Load casts and flame structures at base of sand layers. Lower contact sharp and planar.	3.8
20	Shale, black. Thinly-laminated. Thin, even stratification. Lower contact sharp and even.	2.5
19	Arkose, gray, medium-grained, interbedded with thin-bedded black shale. Arkose is poorly sorted and well indurated. Even, uniformly medium-bedded. Lower contact sharp.	9.5
18	Shale, black. Thinly-laminated. Fissile shale in lower half becoming silty in upper portion of unit. Even stratification in lower part becoming convoluted in upper half with pull-apart and flame structures. Lower contact sharp and even.	2.5
17	Arkose, micaceous, gray. Medium-grained, moderately sorted. Even, uniformly medium-bedded. Thin internal laminations. Convolute lamination and load casts at base. Lower contact planar and sharp.	15.5
16	Shale, black. Even, uniformly thin-bedded. Dark gray nodular limestone layer 4 inches thick near top. Lower contact even and sharp.	5.0
15	Impure arkose, micaceous, dark gray. Fine-grained, poorly sorted. Even, uniformly thin-bedded; thinly laminated with minor convolutions. Lower contact covered.	2.0
14	Shale, black. Bedding planes covered with muscovite; framboidal pyrite common. Very thin parting. Lower contact sharp and planar.	0.5
13	Arkose, gray. Medium-grained, poorly sorted, well indurated. Even, uniformly medium-bedded. Lower contact gradational.	6.5
12	Shale, black. Very thin parting. Macerated plant fragments and silt-sized irregular-shaped grains of pyrite common. Lower contact sharp and even.	1.0
11	Arkose, light gray. Medium-grained, poorly sorted, well indurated. Thin, dark-colored shale interbeds. Even, uniformly medium-bedded. Convolute laminations and ripple-drift cross-stratification at base. Load casts well developed on base of sand units. Lower contact sharp and even.	13.0
10	Silty claystone, micaceous black. Lenticular limestone layers less than 1 inch thick in lower two-thirds of unit. Very thin- to thin-bedded. Lower contact sharp and even.	6.2
9	Siltstone, micaceous, light gray. Well indurated. Thin to thick laminations. Ripple bedded. Lower contact sharp and even.	2.2
8	Shale, black, organic-rich. Silt-sized muscovite grains abundant. Very thin parting. Lower contact sharp and even.	6.8
7	Impure arkose, light gray. Medium-grained, poorly sorted, well indurated. Thin interbeds of black shale less than 1 inch thick. Medium-bedded with even laminations. Ripple marks in lower half of unit. Lower contact even and sharp.	5.0
6	Arkose, gray. Medium- to coarse-grained, very poorly sorted, well indurated. Massively very thick-bedded. Clasts of underlying black shale in basal portion. Basal contact wavy and sharp.	3.0
5	Impure arkose, gray. Medium-grained, poorly sorted, well indurated. Dark gray fissile shale interbeds less than 1 inch thick scattered throughout. Thick, uniformly even laminations in upper two-thirds of unit; lower third shows convolute laminations and ripple marks. Lower contact even and sharp.	4.0
4	Silty shale, black, carbonaceous. Basal part is organic shale grading upward into flat-bedded, fine-grained arkose. Lower contact even and sharp.	3.0
3	Impure arkose, micaceous, gray. Fine-grained, poorly sorted, well indurated. Thin interbeds of black shale. Thin- to medium bedded. Ripple-drift cross-stratification and convolute lamination common. Lower contact wavy and sharp.	3.5
2	Arkose, gray. Coarse-grained, very poorly sorted, well indurated. Uniformly thin-bedded. Bottom contact sharp and even.	2.8

Unit		Thickness Feet
1	Impure arkose, micaceous, buff. Fine-grained, poorly sorted, well indurated. Even, uniformly thin- to medium-bedded. Thick, parallel laminations near base grading upward into convoluted laminations with minor load-casting. Medium parting giving rise to thin slabs. Lower contact covered..	5.5
	Total thickness of measured section	115.0

Measured Section D. Near middle of Cow Branch Formation. Top of section begins 511 feet northwest of the west side of the dolerite dike on the northwest side of the bridge over the Dan River on U. S. 220 Bypass.

Unit		Thickness Feet
13	Mudstone, black. Even, uniformly medium-bedded. Calcite occurs as veins and joint fillings. Numerous slickensides coated with manganese oxides. Upper and lower contacts covered.....	6.3
12	Shale, black. Very thin parting; thickly-laminated, thin-bedded. Well jointed, yielding pencil-shaped fragments. Lower contact sharp and flat...	3.5
11	Mudstone, black. Even, uniformly thick-bedded; massive. Zone of ironstone concretions in lower 1 foot of unit. Well jointed and joints filled with white calcite. Lower contact gradational.....	8.6
10	Shale, very dark gray. Uniformly thin-bedded with thick color laminations. Few ironstone concretions up to 2.5 inches long arranged parallel to stratification. Manganese coated slickensides common. Calcite veins abundant. Well jointed. Lower contact covered.....	3.3
9	Mudstone, dark gray. Massive with faint thick laminations near top of unit. Slickensides and calcite veins common. Ironstone concretions have weathered out leaving holes. Lower contact covered.....	2.9
8	Shale, black. Thin- to medium-bedded with thick color laminations. Light-tan weathering ironstone concretions are abundant. Calcite fills abundant joint planes. Lower contact sharp and planar.....	6.4
7	Mudstone, dark gray. Massive, yielding hackly fragments. Lower contact covered.....	3.0
6	Shale, very dark gray. Thinly-laminated, becoming massive in the upper third of unit. Mudcracks abundant along bedding planes. Dissication breccia abundant at scattered horizons. Manganese-coated slickensides common. Lower contact covered.....	9.1
5	Mudstone, very dark gray. Lenticular thick-laminations. Few mudcracks and disrupted, brecciated layers. Few joints with minor calcite veins. Lower contact covered.....	3.9
4	Shale, black, weathers yellowish-brown. Thickly-laminated. Slickensides abundant; well jointed. Lower contact covered.....	16.8
3	Mudstone, gray. Well indurated. Thickly-laminated; laminations parallel near base becoming wavy near top of unit. Abundant mudcracks and brecciated layering. Lower contact sharp and even.....	6.5
2	Mudstone, dark gray. Well indurated. Even, uniformly thick-bedded. Scattered intraclasts of black shale. Abundant slickensides. Lower contact sharp.....	4.9
1	Shale, black. Very thin-bedded with thin-laminations. Ironstone concretions up to 8 inches long are parallel to stratification. Well jointed yielding pencil shaped fragments. Calcite fills joint planes. Lower contact covered.	22.1
	Total thickness of measured section	97.3

Measured Section E. Middle of Cow Branch lens within Stoneville Formation. Located in old quarry on the east side of the Mayo River 0.2 mile northeast of the Mayo Spruce Underwear Factory. Top of section located on west wall of quarry.

Unit		Thickness Feet
9	Shale, black, weathered light tan. Thick planar laminations, convoluted in places. Very thin parting. Well jointed. Upper and lower contacts covered	4.0
8	Impure arkose, gray. Very poorly sorted. Thick parallel laminations in upper half; wavy in lower half. Upper bedding surface shows groove marks. Lower contact sharp and planar	1.0
7	Clay shale, black. Same as unit 9. Lower contact sharp and planar	0.5
6	Impure arkose. Very fine-grained, poorly sorted, well indurated. Very thick-bedded, massive. Slickensides parallel to bedding surfaces. Lower contact sharp and even	6.5
5	Mudstone, dark gray. Thickly-laminated showing ripple-bedding. Convolutions and ripple marks common. Load casts at base of silty layers. Lower contact sharp and planar	5.0
4	Impure arkose, gray. Very fine-grained, moderately sorted, well indurated. Thin black shale interbeds are ripple-bedded and mud-cracked. Sandstone shows ripple and flaser bedding. Convolutions well developed locally. Lower contact sharp and parallel	2.0
3	Clay shale, black. Same as unit 9. Lower contact sharp and even	9.0
2	Arkose, buff. Medium-grained, moderately sorted, well indurated. Medium-bedded and massive. Lower contact covered	2.0
1	Shale, black, interbedded with dark gray siltstone. Shale shows thin color laminations; very thin parting yielding flat chips. Unit becomes siltier towards top. Convoluted layers common. Bottom contact covered	13.0
	Total thickness of measured section	43.0

Measured Section F. Middle of Stoneville Formation. Top of section is located 1.2 miles north of the Mayodan Railroad Station along the Norfolk and Western Railroad tracks.

Unit		Thickness Feet
12	Silty mudstone, grayish-red. Locally contains thin interbeds of very fine-grained sandstone. Medium- to thick-bedded showing no internal laminations. Burrows averaging 0.2 inches diameter are abundant. Lower contact gradational	12.5
11	Siltstone, maroon with interbeds of shale less than 1 inch thick. Flat, uniformly medium-bedded. Zone of calcareous concretions in lower third of unit; some weathered out leaving honey-comb surface. Well jointed. Lower contact wavy	19.5
10	Arkose, micaceous. Very fine-grained, poorly sorted, well indurated. Several shale layers less than 1 inch thick. Massively thick-bedded. Weathered out calcareous concretions near base. Lower contact sharp and planar	15.5
9	Arkose, maroon. Medium-grained, moderately sorted, well indurated. Massive and thick-bedded. Well jointed. Lower contact sharp and planar	13.5
8	Siltstone, maroon, locally shaly. Well indurated. Even, uniformly medium-bedded. Abundant calcareous concretions less than 0.75 inches diameter. Lower contact sharp and planar	8.5
7	Arkose, maroon. Well indurated. Pebbly at base and very poorly sorted grading upward through flat-bedded, fine-grained sandstone to massive siltstone at top of unit. Very thick-bedded at base becoming thin-bedded at top of unit. Lower contact sharp and even	25.5
6	Siltstone, maroon, with shale interbeds. Well indurated. Medium- to thick-bedded. Bottom contact covered	14.5
5	Shale, maroon. Poorly indurated; breaks readily into small angular chips. Massive maroon siltstone in lower fourth of unit. Uniformly medium-bedded. Lower contact sharp and even	14.5
4	Siltstone, maroon with gray lenses of convoluted, thinly-laminated gray sandstone. Thick-bedded sandstone in middle of unit. Thin-bedded at base	

Unit		Thickness Feet
	with thin laminations. Load casts well developed at base of sandy layers. Burrows abundant in silty layers. Lower contact sharp and even.....	30.0
3	Siltstone, micaceous, maroon. Well indurated. Uniformly thin-bedded. Ripple-drift cross-laminations and convoluted laminations common. Lower contact sharp and even.....	5.5
2	Shale, black, weathers light-yellow. Even, uniformly very thin-bedded. Lower contact sharp and even.....	3.5
1	Shale, gray, interlayered with fine-grained sandstone. Thin-bedded, thickly laminated. Very poorly exposed. Lower contact covered.....	10.0
	Total thickness of measured section	173.0

Measured Section G. Upper portion of Cow Branch Formation. Located in Kings Quarry 2.8 miles southwest of Leaksville. Top of section located on west quarry wall.

Unit		Thickness Feet
16	Shale, black, weathers light tan. Poorly indurated. Even, uniformly thick laminations. Thin parting. Calcareous concretions weathered out leaving clayey ferruginous holes. Well jointed. Lower contact sharp and even....	1.5
15	Silty mudstone, black. Massive, well indurated; breaks conchoidally. Thick, uniformly even bedding. Calcite veins to 0.5 inch thick fill joints. Lower contact sharp and even.....	14.5
14	Shale, dark gray, weathers light tan. Poorly indurated. Thick, uniformly even laminae. Tan weathering calcareous concretions up to 4 inches long are subparallel to bedding. Calcite veins, generally perpendicular to bedding, are abundant. Lower contact sharp and even.....	5.5
13	Mudstone, micaceous, dark gray. Massive, breaking conchoidally, well indurated. Thick-bedded. Slickensides along bedding planes. Well jointed. Lower contact sharp and undulatory.....	8.0
12	Shale, black, organic. Poorly indurated showing very thin parting. Thin and thick wavy laminations. Tan calcareous concretions up to 1 inch long are abundant. Powdery chalk-white sulfate bloom coats surface. Well jointed. Calcite veins common. Lower contact gradational.....	5.5
11	Silty mudstone, dark gray. Massive, breaking conchoidally, well indurated. Thick-bedded. Mudcracks abundant on a few bedding surfaces. Calcite veins common. Lower contact gradational.....	9.5
10	Shale, dark gray. Massive towards top of unit. Well indurated. Thick, uniformly even laminations. Abundant calcareous concretions. Mudcracks and dessication breccia common. Well jointed. Lower contact sharp and planar.....	5.5
9	Mudstone, gray. Shaly in upper third of unit; massive in lower two-thirds. Well indurated. Abundant muscovite flakes to 2 mm long are parallel to bedding planes. Tan weathering calcareous concretions. Grades downward into underlying unit.....	3.0
8	Shale, black, fissile. Upper 1 inch is coaly and shows chalk-white sulfate bloom. Poorly indurated. Thick wavy laminations. Calcareous concretions common. Macerated plant fragments, ostracodes, and branchipods are abundant. Lower contact sharp and even.....	5.0
7	Mudstone, very dark gray. Massively medium-bedded. Well indurated. Few calcareous concretions. Abundant calcite veins. Well jointed. Lower contact sharp and even.....	2.0
6	Shale, black, weathers light tan. Poorly indurated. Thick, wavy laminations. Calcareous concretions to 4 inches are common in lower 6 inches. Well jointed. Lower contact sharp and even.....	2.0
5	Mudstone, medium-gray, becoming silty towards top. Well indurated. Massive, but locally shows thick, even laminations. Medium- to thick-bedded. Few carbonate concretions. Abundant slickensides and calcite veins. Lower contact sharp and even.....	8.0

Unit		Thickness Feet
4	Mudstone, black. Well indurated. Thick even and wavy laminations. Medium-bedded. Abundant carbonate concretions. Well jointed with white calcite filling joint planes. Lower contact sharp and even.....	6.0
3	Mudstone, dark gray. Massive, well indurated. Medium-bedded. Abundant calcite veins. Lower contact sharp and even.....	1.0
2	Mudstone, black, with thin stringers of coal. Thickly-laminated; medium-bedded. Few calcite veins. Lower contact sharp and even.....	3.0
1	Mudstone, gray. Massive, well indurated. Medium-bedded. Calcite veins common. Lower contact covered.....	4.0
	Total thickness of measured section	84.0

CLAY MINERALOGY OF CORES FROM THE CONTINENTAL MARGIN OF NORTH CAROLINA

By

J. W. Pierce
Division of Sedimentology
Smithsonian Institution
and
Department of Geology
George Washington University
Washington, D. C.

ABSTRACT

Samples from seven piston cores along a traverse from the upper continental rise off North Carolina southeastward onto the Hatteras Abyssal Plain were studied for changes in clay mineralogy.

Illite is the predominant mineral in the samples followed by chlorite and kaolinite. Montmorillonite is present in only 34 of the 196 samples analyzed and then in only very minor amounts. The amounts reported here are representative of the less than 20μm size fraction and the relative amount of montmorillonite would be increased by study of only the less than 2μm fraction.

The amount of illite increases seaward and the amount of kaolinite decreases. This suggests that illite has a more distant but persistent source. Kaolinite apparently is derived from the nearby southeastern United States and is contributed in pulses.

The uppermost sample of each core is relatively high in illite and low in kaolinite. Downward in the cores, this is followed by a section higher in kaolinite. It is suggested that such fluctuations may be correlative to changes in sea level.

Changes in the amounts of the different minerals at greater depths in the cores may also be correlative with changes in sea level although the correlations are not as obvious. Further work needs to be done in correlating changes in the clay mineral suite with sea level fluctuations to test the validity of this hypothesis.

INTRODUCTION

The clay minerals present in the Recent sediments of the Coastal Plain of the southeastern United States are known through the work of Brown and Ingram (1954), Powers (1954), Griffin and Ingram (1955),

Nelson (1960, 1963), Heron and others (1964, 1965, 1969), and Neiheisal and Weaver (1967). These papers give a broad knowledge of the distribution of clay minerals in this area. Although details may vary from place to place, the information is sufficient to determine what clays are present in the Recent sediments and are being carried by present-day rivers.

The regional distribution of clay minerals on the floor of the Atlantic Ocean is also reasonably well known. Biscaye (1965) reported the distribution, for the surficial sediments, over the entire Atlantic. Terlecky (1966) worked on the clays present in short gravity cores taken on a traverse between the continental shelf of the southeastern United States and the Bermuda Rise. A paper by Murray and Sayyab (1955) reported the results of work on the clays of seven cores on the continental margin and adjacent abyssal plain. Berry and Johns (1966) reported on the distribution of clay minerals in the North Atlantic and Arctic Oceans.

The purpose of this study is to determine the changes in the clay mineralogy in samples of seven piston cores taken along a transect approximately normal to the continental margin. Changes both laterally and vertically show up in the analysis of the mineralogy of the core samples. The section starts on the continental rise and progresses southeastward, with the southeasternmost station being well out on the Hatteras Abyssal Plain (Table 1, Figure 1).

Table 1. Station Location, Water Depth, and Length of Usable Core for the Seven Coring Stations.

Station	Location Lat. N.	Long. W.	Water Depth (m)	Length of Core (cm)
E8206	34°02.0'	75°40.0'	2400	632
E8207	33°55.4'	75°26.3'	3010	1190
E8208	33°42.0'	75°03.0'	3500	989
E8209	33°27.5'	74°41.5'	4000	1190
E8210	33°11.0'	74°20.0'	4400	1148
E8212	32°56.0'	73°58.7'	4700	1502
E8219	32°26.3'	73°31.0'	5080	580

Acknowledgments

Cores for this study were obtained through use of the Duke University R/V EASTWARD on cruise E 41-67. The R/V EASTWARD is supported through NSF Grant GB 8130. Appreciation is expressed to Duke University for permission to participate in this cruise.

Appreciation is also expressed to Orrin H. Pilkey for permis-

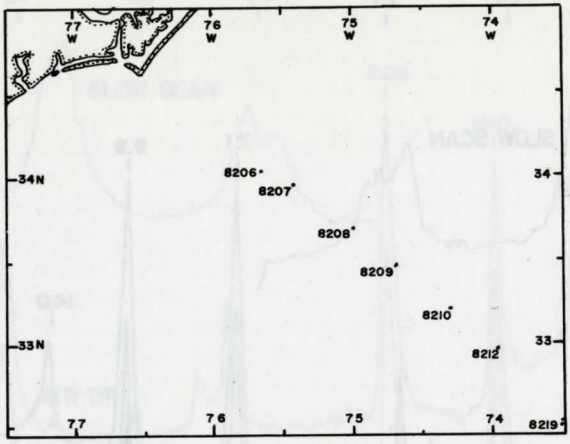

Figure 1. Chart showing location of coring stations.

sion to sample the cores and publish the results of the analyses.

Financial support was provided through the Smithsonian Institution Research Awards 3307 and 3369.

METHODS

The cores were taken with a modified Ewing piston corer. Usable core length ranged from 580 cm to 1502 cm. Flow-in was present at the bottom of several cores owing to movement of the piston. This flow-in was not sampled.

The coring stations were on a traverse from the upper part of the continental rise of North Carolina southeastward onto the Hatteras Abyssal Plain (Figure 1, Table 1). Water depth varied from 2400 meters to 5080 meters with depths increasing southeastward.

The cores were sampled at or near what appeared to be lithologic breaks. If the core appeared to be homogenous over long sections, samples were taken at 100 cm intervals or less. One hundred ninety-six samples were taken of the seven cores.

Material greater than 20μm in equivalent diameter was separated by wet-seiving and settling in the laboratory. Slides, for X-ray diffraction analysis, were made of each sample by suction through ceramic plates (Gibbs, 1965). This method was chosen in an attempt to prevent segregation by settling and a bias to the slides in favor of the smaller crystallites. Separation of the clay material into fractions of less than 2 μm and from 2-20μm was not done because the changes in the entire range of clay materials was desired, rather than in only the smaller-size fraction. Clay mineral aggregates, primarily of illite,

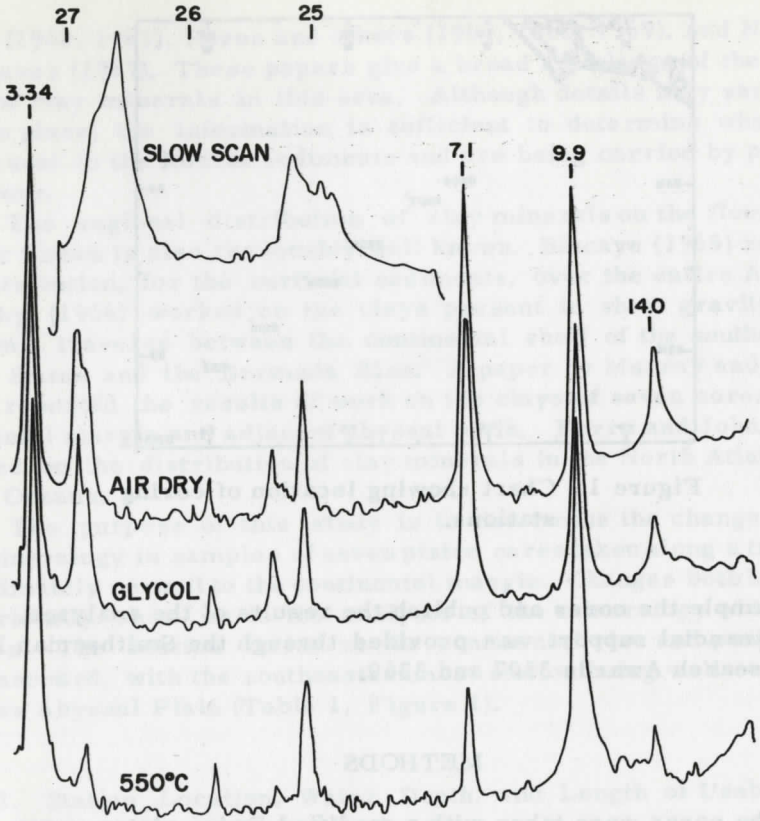

Figure 2. Diffractogram of sample from depth of 552 cm in core from station E8210. Very little mixed-layer minerals are present and no expandables. Normal scan patterns have spacings in angstroms while slow scan shows degress 2θ.

kaolinite, and chlorite, can and do occur in the size fraction greater than 2μm (Whitehouse and others, 1958; Biscaye, 1965).

X-ray diffraction patterns, using Ni-filtered Cu Kα radiation were made of slides that had undergone four different treatments. Patterns were made of the untreated sample, after exposure to a saturated atmosphere of ethylene glycol, after heating to a temperature of 400°C, and after heating to a temperature of 500°C or 550°C. Changes in the position of the diffraction maxima induced by the treatments permitted determination of the different minerals present in the samples (Figures 2 and 3).

Identification of Minerals

The minerals present were identified by X-ray diffraction maxima characteristics of the minerals arranged in oriented aggre-

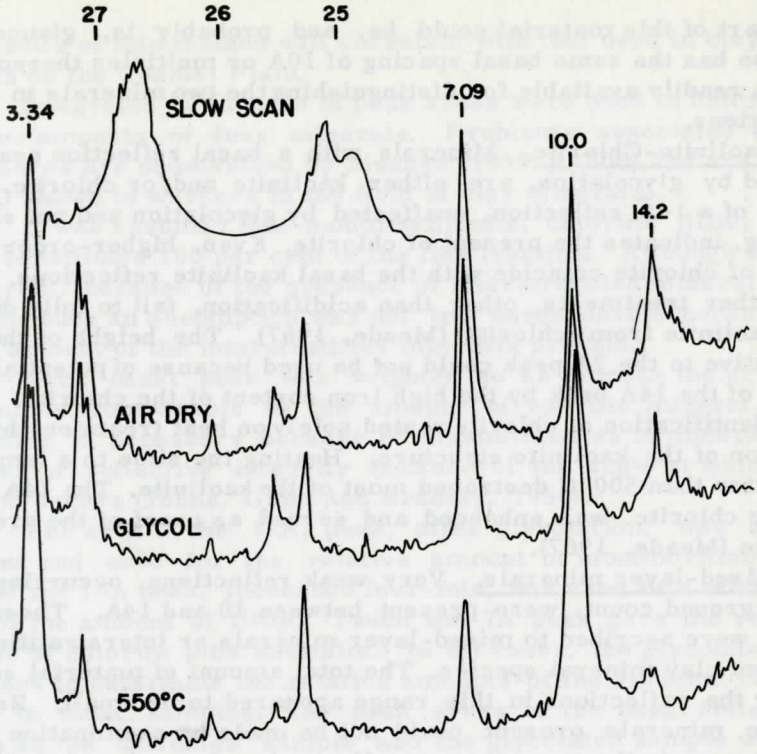

Figure 3. Diffractogram of sample from depth of 702 cm in core form station E8212. Some expandables present. Normal scan patterns have spacings in angstroms while slow scan shows degrees 2θ.

gates. The clay mineral groups identified were montmorillonite, illite, chlorite, kaolinite, and mixed-layer minerals. The presence of other minerals was noted in a few samples. Seldom did the amount of these other minerals aggregate enough to affect the ratios of the major constituents except for quartz, feldspars, and the carbonate minerals. All of these appear to be ubiquitous to all samples. The amounts of quartz, feldspar, and carbonate were not determined; quartz and feldspar because their presence in the ceramic slides precluded the determination.

Montmorillonite. Material with an untreated basal spacing of approximately 14A that expands to approximately 17A upon treatment with ethylene glycol was assigned to the montmorillonite group. The basal spacing of this mineral collapsed to about 10A upon heating. No attempt was made to determine the specific mineral in the group. Minerals of this group do not constitute a significant part of any sample.

Illite. Material with basal reflections of 10, 5, 3.3, and 2.5A not affected by glycolation and that does not shift spacing upon heating, was considered illite, which is used in preference to hydromica.

Part of this material could be, and probably is, glauconite, which also has the same basal spacing of 10A or multiples thereof. No method is readily available for distinguishing the two minerals in small size fractions.

Kaolinite-Chlorite. Minerals with a basal reflection near 7A, unaffected by glycolation, are either kaolinite and/or chlorite. The presence of a 14A reflection, unaffected by glycolation and not shifted by heating, indicates the present of chlorite. Even, higher-order basal spacings of chlorite coincide with the basal kaolinite reflections. Heating and other treatments, other than acidification, fail to fully differentiate kaolinite from chlorite (Meade, 1967). The height of the 14A peak relative to the 7A peak could not be used because of potential suppression of the 14A peak by the high iron content of the chlorite.

Identification of chlorite rested solely on heat treatment through destruction of the kaolinite structure. Heating the slide to a temperature greater than 500° C destroyed most of the kaolinite. The 14A peak, caused by chlorite, was enhanced and served as proof of the presence of chlorite (Meade, 1967).

Mixed-layer minerals. Very weak reflections, occurring on a high background count, were present between 10 and 14A. These reflections were ascribed to mixed-layer minerals or interstratification of different clay mineral species. The total amount of material represented by the reflections in this range appeared to be small. Resolution of the minerals present could not be made by examination of the diffractograms in the area corresponding to basal spacing of about 26A. Because of these reasons and the many problems associated with determination of specific minerals which may be interlayered to give such spacing, little effort was made to resolve which minerals were actually present.

Semi-quantitative aspects. Identification of the more common mineral groups is rather straightforward in a simple suite such as found in these samples. Some method of portrayal for four-component mixtures is necessary so that changes can be shown both vertically and laterally. Many methods have been used for "quantiative" or relative amounts of minerals present (Johns, Grim, and Bradley, 1954; Griffin and Goldberg, 1963; Biscaye, 1965; Keller and Richards, 1967; Meade, 1967; Neiheisal and Weaver, 1967). None of these methods appear to have any advantage over any other although, for comparability, it would seem best to select a method previously used in the area under study (Pierce and Siegel, 1969). This would seem to hold until true quantitative methods are attained in clay mineral studies.

In order to reduce errors caused by segregation during slide preparation, the method of suction through ceramic slides was employed (Gibbs, 1965). Secondly, for comparability with previous work in the area, relative amounts of the different minerals were calculated by Biscayes' method (outlined below). Terlecky (1966) employed slightly different weighting factors. Unfortunately, it is not known how well

the results of this method will correlate with that used in clay mineral studies on the Coastal Plain.

Integrated intensities of peak areas were used to determine the relative amounts of four minerals. Problems associated with such procedures are enumerated by Biscaye (1965, p. 808) and are relatively well known to workers in the field of clay minerals.

It was assumed that montmorillonite, chlorite, illite, and kaolinite constituted 100 per cent of the fine fraction. Although not exactly correct, because of the presence of interstratified minerals, it was felt that such an assumption was not too unreasonable because of the small amount of the interstratified minerals present.

Each basal peak was weighted so as to make the areas more reasonably comparable to the amount of specific mineral present. Weighting is necessary because of dissimilarities in minerals and to changes in reflective intensity because of the angle at which the reflection occurs (Johns, Grim and Bradley, 1954).

The area of the 17A, peak, after glycolation, was taken unchanged and used for the relative amount of montmorillonite. The area of the 10A peak, increased four-fold, was used as a relative measure of the amount of illite. Twice the 7A peak gave the relative amounts of chlorite plus kaolinite. In all cases, the glycolated pattern was used to determine the relative amounts of the different clay minerals. In most samples, the peak areas of the basal reflections as shown on the untreated sample and the glycolated sample were compared. In nearly all cases, the relative areas of the reflections remained constant although in most cases the absolute size of the reflections changed, owing to the absorption of the X-rays by the ethylene glycol.

The four weighted peak areas were summed, the weighted peak area of each mineral multiplied by 10 and divided by the sum of all the weighted areas. This gave the relative amount of montmorillonite, illite, and kaolinite plus chlorite as parts in ten. Although Biscaye (1965) and Terlecky (1966) reported "percentage", parts in ten are reported here to strongly emphasize the semi-quantitative aspects of the relative amounts.

The ratio of chlorite to kaolinite was determined through resolution of the 3.5A peak into two peaks (Biscaye, 1964). This doublet can be resolved into 3.58A kaolinite and a 3.54A chlorite peaks through use of a scanning rate of 1/4 degree 2θ per minute instead of the normal scan rate of one degree per minute. A receiving slit (0.003") narrower than normal (0.006") assists in resolution of this doublet into two peaks.

The ratio of chlorite to kaolinite was determined by the integrated area under the resolved peaks. The relative amount of kaolinite plus chlorite, from the area of the 7A peak, was then apportioned to the two minerals according to this ratio.

GENERAL DISTRIBUTION OF MINERALS

Illite was the predominant mineral in all but one of the 196 samples that were analyzed. In this one sample, kaolinite was dominant with illite being second in abundance. The relative amount of illite was more than 5 parts in 10 in 190 of the 196 samples. The six remaining samples were all from cores E8206 or E8207, those stations being along the west end of the traverse and on the continental rise (Figure 1). Illite averaged 6 to 7 parts in ten in all of the cores (Table 2). The range of the relative amount of this mineral was from a low value of 4 to a high value of 7 parts in ten. Average values increase eastward with the lowest average occurring on the continental rise and the higher values farther east on the abyssal plain.

Such a lateral distribution is not surprising and is similar to that reported by Biscaye (1965) and Terlecky (1966). Biscaye (1965, Figure 6) shows that the surface sediments on the floor of the North Atlantic are over one-half illite. There is a decrease in the relative amount of this mineral as the coast of the southeastern United States is approached.

Terlecky (1966) reports that minerals with a basal spacing of 10A increase seaward although some of his samples from the continental slope and rise may have contained glauconite. This conclusion was based on a poorly developed 5A reflection and the development of a green coloration upon drying. In all cases, none of the samples from the present study assumed a green coloration upon dehydration. Terlecky states that, beyond the area of glauconite, illite increases and is the dominant mineral from the lower rise and the abyssal plain.

The deficiency in illite as the continental shelf is approached may be due to dilution by other minerals being contributed from the nearby land mass. Biscaye (1965) attributes the decrease in illite to dilution by other minerals while Terlecky attributes the apparent decrease to a diminution of the intensity of the illite reflection by addition of glauconite to the sample.

The second most abundant mineral is chlorite, which averaged between 2 and 3 parts in ten. There is little change in the average amount of chlorite along the traverse. It is interesting to note that the relative amount of kaolinite exceeds that of chlorite in only eleven samples. None of these eleven samples were from the three easternmost coring locations that were well out on the abyssal plain.

Kaolinite was third in relative abundance. The average amounts varied from slightly more to slightly less than one part in ten. As a generality, there is a decrease in average amount of kaolinite seaward away from the continental margin. Terlecky (1966) reports a slight decrease in the amount of kaolinite in a seaward direction.

The surprising aspect of the samples from these cores was the apparent lack of montmorillonite. Only 34 of the 196 samples contained sufficient montmorillonite to be regarded as more than a trace.

Table 2. Average Values, in Parts in Ten, of the Relative Amounts and the I-K, I/C, and C/K Ratios for each Core.

Core	Relative Amts. Parts in ten			Ratios		
	I	K	C	I/K	I/C	C/K
8206	6	1	3	5	2	2
8207	6	1	3	7	3	3
8208	7	1	2	8	3	3
8209	7	1	2	6	3	2
8210	7	1	2	7	3	2
8212	7	1	2	7	3	2
8219	7	1	2	9	3	3
Mean of Means	6.5	1.0	2.5	7.0	2.8	2.5

Most of the samples gave some evidence of a mineral that expanded to a basal spacing of between 16 and 17A but the amount was so minor that great difficulty was experienced in separating it from the high background counts in this low 2θ angle. Only one sample contained sufficient montmorillonite to be considered as having one part in ten.

The results are quite surprising in that Biscaye (1965) shows between 10 and 19 percent montmorillonite in this area. The samples from the gravity cores studied by Terlecky (1966) from this same area had between 20 and 35 percent montmorillonite.

The question that naturally arises is whether the differences are real or whether it is a bias introduced by sample treatment and slide preparation. The major differences between the methodology of Biscaye and Terlecky were slide preparation and the size fractions studied.

Biscaye sedimented clay samples onto glass slides while Terlecky applied a thick slurry sedimented onto a glass slide. Suction through ceramic slides was used in this study. As pointed out by Gibbs (1965), sedimenting on glass tends to enhance the amount of finer clays, namely montmorillonite. Work by Pierce and Siegel (1969) substantiates this in that the method of slide preparation is significant.

It should also be pointed out that both the illustration of Biscaye (Figure 7) and the results of Terlecky deal only with the less than 2μm fraction of the sample. This greatly enhances the relative amounts of the clays occurring in the finer fraction at the expense of other minerals that generally have larger crystallites. The present study was interested in the mineralogy of all clay material, not only clay size (<2μm).

The question also arises of the effect of possible poor orienta-

tion owing to failure to remove presence of carbonate grains. To check this, three samples, in which the 3.03A calcite peak was prominent, were X-rayed both before and after removal of carbonate by buffered sodium acetate solution at pH 5.0 (Jackson, 1956). Calculation of the relative amounts of montmorillonite before and after showed very little change. All samples calculated at less than 1 part per ten both before and after carbonate removal.

The results reported here agree more closely, with respect to the relative amount of montmorillonite, to those of Murray and Sayyab (1955). These authors found that illite and chlorite were dominant with only minor amounts of montmorillonite present.

Both the method of slide preparation and the size fraction used in the analysis will tend to give apparent differences in the relative amount of montmorillonite present. It is believed that the small amount of montmorillonite reported in this study is closer to the true value when the total of all clay material is examined. In comparability with the results of work on the <2μm size fraction, the amount of montmorillonite reported here is grossly understated.

VERTICAL CHANGES

All cores showed some changes, with depth, in the relative amounts of the minerals present. There is considerable "noise" present to the changes which may be random fluctuation when the individual samples are compared (Figures 4 and 5). Using a running average of five samples to reduce this "noise", it appears that most of the cores show a slight trend from top to bottom. Near the top of each core, except for the uppermost sample, the relative amount of illite is low while kaolinite is high, in comparison with the average for the whole core. In the center of the cores, illite becomes high and kaolinite low. In the case of the coring stations nearest the continental shelf, this trend is quite marked. This trend is dampened as distance from the continental shelf increases although it appears to still be present in E8219, the farthest eastward of the coring stations.

E8206 (Figure 4) -- Station E8206 is located on the lower part of the continental slope where the water depth is 2400 meters. Montmorillonite is present in detectable amounts in only two samples.

Both of these samples had relatively low amounts of illite and higher than average amounts of kaolinite. This would suggest that the occurrence of montmorillonite is related to that of kaolinite. Chlorite was present in lower than average amounts in the samples containing detectable amounts of montmorillonite.

Kaolinite and illite appear to bear roughly on inverse relationship. Chlorite also appears to have an inverse relationship to illite although the correlation is not as good.

E8207 (Figure 4) -- This station is on the continental rise at a

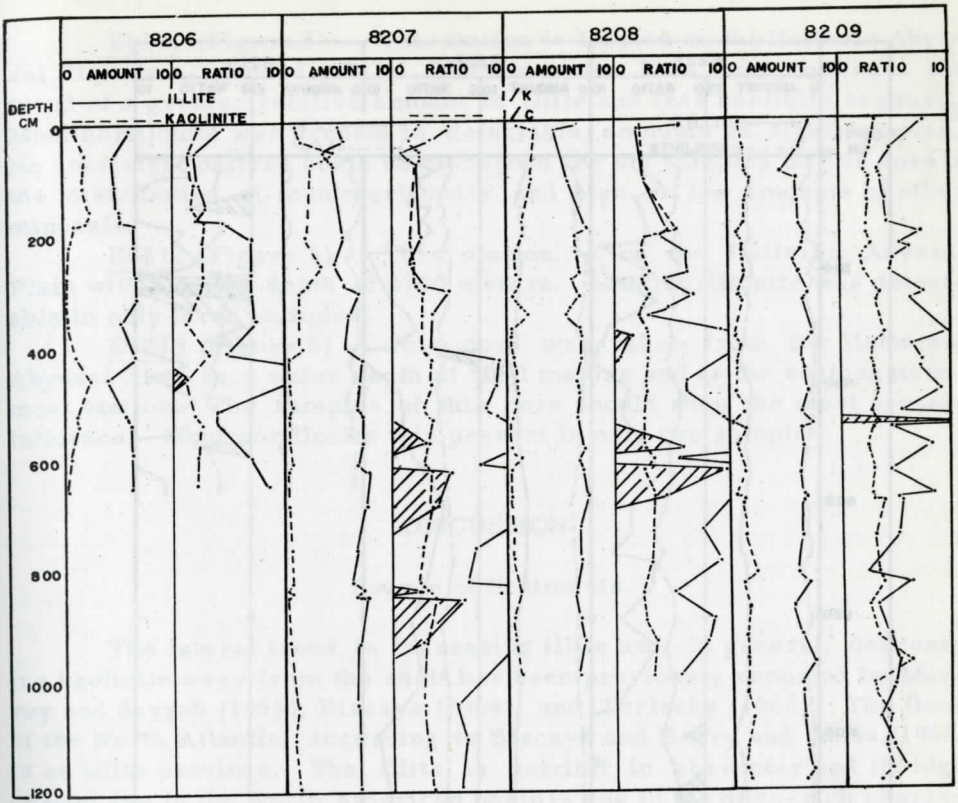

Figure 4. Graph of the relative amounts and ratios for four of the seven cores. The relative amounts of kaolinite and illite and the illite-chlorite and illite-kaolinite ratios are shown for each core. Diagonal lines in ratio log indicates ratio between 10 and 20.

water depth of 3010 meters. Montmorillonite is present in detectable amounts in three samples, all of which had less than an average amount of chlorite while two had higher than average kaolinite.

E8208 (Figure 4) -- This core is from the continental rise where water depth is 3500 meters. Average values for the whole core, in general, follow the trend of an increase in relative amounts of illite and chlorite with a corresponding decrease in kaolinite away from the continental shelf.

Montmorillonite was present in detectable amounts in eight samples, although the apparent amount present is quite small. No apparent relation seems to exist in this core between the occurrence of montmorillonite and the other minerals.

E8209 (Figure 4) -- This station is near the junction of the continental rise and abyssal plain where the water depth is 4000 meters.

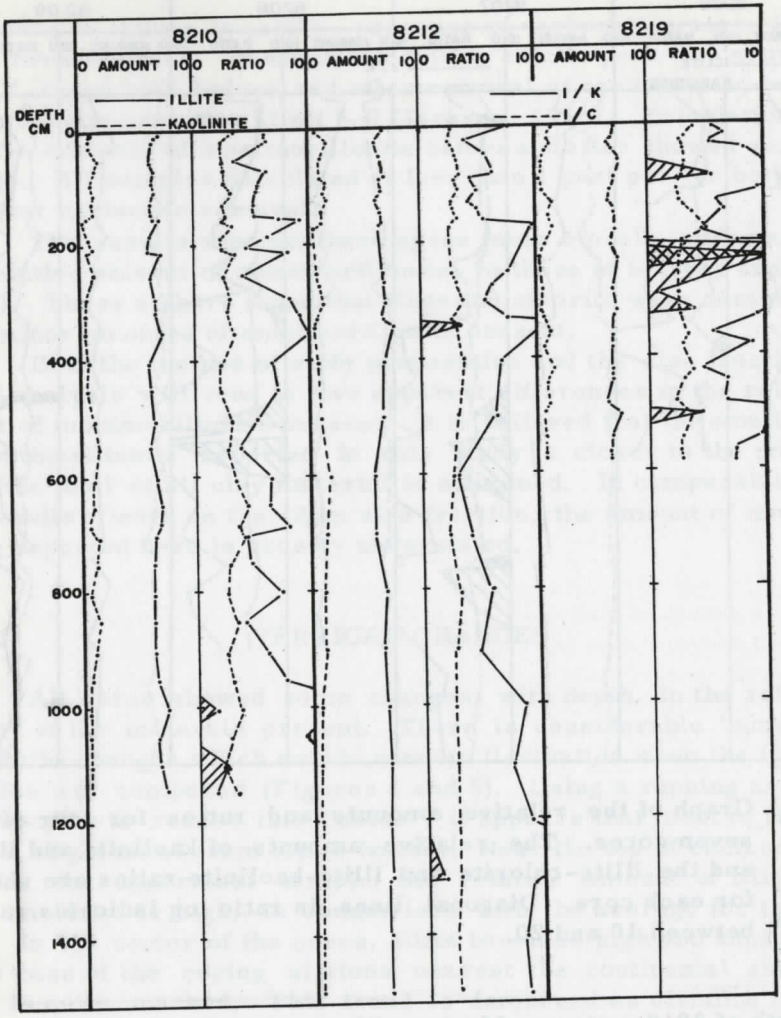

Figure 5. Graph of the relative amount and ratios of three of the seven cores. The relative amounts of kaolinite and illite and the illite-chlorite and illite-kaolinite ratios are shown for each core. Diagonal lines in ratio log indicates ratio between 10 and 20 while hatching indicates ratio between 20 and 30.

Montmorillonite was present, in detectable quantities, in eight samples, none of which had more than a trace. No correlation could be detected between the occurrence of montmorillonite and the other minerals.

E8210 (Figure 5) -- This station is located on the Hatteras Abyssal Plain in a water depth of 4400 meters. This core continues the trend of a greater relative amount of illite and less kaolinite seaward. Montmorillonite was present in detectable amounts in eight samples. No consistent pattern could be discerned for the samples of this core in the distribution of montmorillonite and high or low amounts of other minerals.

E8212 (Figure 5) -- This station is on the Hatteras Abyssal Plain with a water depth of 4700 meters. Montmorillonite was detectable in only three samples.

E8219 (Figure 5) -- This core was taken from the Hatteras Abyssal Plain in a water depth of 5080 meters and is the southeasternmost station. The samples of this core should show the most oceanic influence. Montmorillonite was present in only two samples.

DISCUSSION

Source of Sediments

The lateral trend in increasing illite and, in general, decreasing kaolinite away from the shelf has been previously reported by Murray and Sayyab (1955); Biscaye (1964), and Terlecky (1966). The floor of the North Atlantic, according to Biscaye and Berry and Johns (1966) is an illite province. The illite is detrital in character and its high percentage in the North American basin is due to the mica-rich character of rocks in eastern North America (Biscaye, p. 817).

However, analyses reported in the literature suggest very strongly that the sediments of the Coastal Plain and the suspended sediment in the rivers along the southeastern United States are low in illite or it is not present (Brown and Ingram, 1954; Griffin and Ingram, 1955; Nelson, 1960; Heron and others, 1964, 1965; and Neiheisal and Weaver, 1967). These studies would tend to indicate that the rocks of the southeastern United States can not act as a source of illite.

The Coastal Plain of the northern United States apparently contains more illite (Powers, 1954 and Groot and Glass, 1960). The glacial tills of the northern United States and Canada also contain relatively high amounts of mica (Grim, 1968, p. 548).

When illite is present in the rivers it is generally only in the lower parts of their estuaries in significant quantities and is not being carried into the estuaries by the rivers. A recent paper by Meade (1969) suggests a landward transport of continental shelf and beach material into the estuaries of the U. S. Atlantic coast. Thus, the sea may be the source of the illite as well as the chlorite found in the estuaries.

The source of illite is enigmatic. Griffin and Goldberg (1963) attributed some of the 17A glycol-expandable material to stripped illite and chlorite. An increase in the amount of illite was associated with a

decrease in 17A glycol-expandable material. This suggested a fixation of potassium and magnesium ions and a reversion to nonexpendable illite and chlorite.

Biscaye (1965) could find little evidence to support this in his study of clay minerals from the floor of the Atlantic Ocean. He attributes the abundance of illite to its abundance in soils and its relative resistance to weathering. Variations in the amounts are explained by him to be dilution by an influx of other minerals. He found little variation in the relative amounts of illite except in areas of dilution.

Illite is not coming from the Coastal Plain or Piedmont of the southeastern United States. For this area of the continental margin and Hatteras Abyssal Plain, the northern Coastal Plain, the glacial tills of the United States and Canada, and the crystalline rocks of the eastern United States are assumed to be the source.

The decrease in kaolinite seaward would obviously suggest a nearby continental source for this mineral. The Piedmont has a clay-mineral suite in which kaolinite dominates, while the Coastal Plain has a suite in which montmorillonite dominates (Heron and others, 1964). The Piedmont rivers draining the Piedmont generally are larger and carry a greater load than do those from the Coastal Plain. This would suggest that kaolinite is, or has been in the past, contributed in greater amounts than montmorillonite.

The source for the chlorite probably is the Maritime provinces of Canada. This is suggested by Biscaye (1964, p. 812, Fig. 5) by the high relative amounts of this mineral off New England and Nova Scotia and the relative lower amounts along the coast of the southeastern United States. A similar source is suggested by Heezen, Hollister, and Ruddiman (1966).

The number of samples containing montmorillonite in more than trace amounts was so small that its distribution is difficult to explain from the available data. The relatively low amounts (all except one sample considerably less than 1 part in 10) when compared to studies by Biscaye (1965) and Terlecky (1966) would tend to indicate that montmorillonite is being masked by other minerals preferentially by the slide preparation method and/or size fraction considered. On the other hand, the results with respect to montmorillonite are not a great deal different than that reported by Murray and Sayyab (1955).

The amount of montmorillonite detected in this study is of such a low relative amount (1-5 percent) that there is some doubt that it should be reported. Because of the low amount detected, the distribution appears to be erratic and there seems to be little obvious correlation between it and other minerals present in the samples. This may be due to a composite origin, although this is doubtful for the North Atlantic. Biscaye (1964, p. 820) believes that montmorillonite has similar origins and sedimentation processes as kaolinite and gibbsite. Little correlation between the two was found in the present study. Published work on the southeastern United States indicates montmorillonite

is predominant with kaolinite second in abundance in Coastal Plain rivers and in the marine section of the Cretaceous (Heron and others, 1965). As explained under kaolinite, rivers draining the Piedmont of the southeastern United States are larger and carry a larger load than Coastal Plain rivers. This could account for larger amounts of kaolinite being contributed to the sea.

If montmorillonite was in reality stripped illite and chlorite as suggested by Griffin and Goldberg (1963, p. 736), one would expect montmorillonite to be absent from samples with large amounts of illite and chlorite. By uptake of potassium and magnesium ions, these stripped minerals would revert to true illite and chlorite. No correlation seems to exist between the presence of montmorillonite and low amounts of either illite or chlorite.

It is possible that the amount of montmorillonite may be relatively low in comparison to the other clay minerals when the entire sample of less than 20 m is considered. Also slide preparation by suction through ceramic plates may not preferentially enrich the surface of the slide in montmorillonite.

In addition to the low amounts of this mineral present, the possibility of composite origin and multiple source may make correlation with other minerals difficult. In short, little could be determined from the distribution of montmorillonite with regard to stratigraphy, source, or history of the sediments in these cores.

Vertical Distribution

In general, the vertical distribution of illite and chlorite seems to be closely related as to sedimentation processes and source. Kaolinite appears to dilute, by periodic influx, the absolute amounts of illite and chlorite contributed to the area.

The persistency of the low I/K ratio near the top of every core, except for the uppermost sample, would seem to suggest that rather recently there has been a much larger influx of kaolinite than in the past or is now occurring. Periodic influxes of kaolinite in the past are also suggested in most of the cores. The dilution of kaolinite is not as clear at depth in the cores as near the top although it does appear in most cores.

Some variation exist in the relative amounts of illite and chlorite that need further explanation. If both minerals are being transported from the north into this area by rather persistent currents, one would expect that the ratio of the minerals would remain relatively constant. In general, this is the case.

There are some samples, though, in which this ratio undergoes large fluctuations when compared to adjacent samples. According to Heezen, Hollister, and Ruddiman (1966), the material making up the lower continental rise is brought into this area by the Western Boundary Counter-Current. The source is the Maritime area of Canada and New

England. Supposedly, this current would carry a relatively homogenous suite of minerals. Each unit of the material would undergo the same amount of differential sorting during transport.

An influx of sediments from the shelf or from a submarine canyon south of New England could introduce a charge of different sediment into this current. This would result in different ratios between illite and chlorite. Inasmuch as illite is more prevalent in the rocks in the mid-Atlantic area than is chlorite, such a charge could be the answer to some of the abnormally high illite to chlorite ratio values.

On the abyssal plain, one would expect that turbidites would be more predominant than on the rise. These deposits would have a different ratio of minerals than would be expected in a long prevailing current. Silt layers consisting of mineral grains, were present throughout much of core E8219 and in the lower 200 cm of core E8212. No such layers were noted in the other cores. Little correlation appeared to exist between silt layers and the clay mineralogy.

The data are rather meager to attempt to correlate the relative amounts of the different clay minerals present with specific geologic events. No radioactivity dates are available from the cores and the rate of deposition along this continental margin is incompletely known. Nevertheless, certain possibilities in the utilization of clay - mineral stratigraphy are evident.

The uppermost sample of nearly every core consisted of brownish lutite, rather soft and with a high content of water. Color usually changed to gray and olive at a depth of a few centimeters and remained so over most of the rest of the core although thin brown layers were present at depth in many of the cores.

The uppermost sample was usually higher in illite and lower in kaolinite than that immediately below. It is suggested that the uppermost sample in the cores came from material deposited since the last rise in sea level.

The material immediately below this sample, with relatively low amounts of illite and high amounts of kaolinite may have been deposited during the last low stand of sea level. During the time, the rivers from the adjacent land mass would deposit their load on the edge of the continental shelf. This would bring an increased contribution of kaolinite to the edge of the shelf and onto the continental rise.

Variations in the lower parts of the cores may correlate with other fluctuations of sea level. Until more work is done correlating the fauna with mineralogic changes, the validity of these interpretations cannot be ascertained. Absolute dating of the time of deposition is also needed.

CONCLUSIONS

The amount of montmorillonite in these cores is relatively low

when compared to Biscaye (1965) and Terlecky (1966) but reasonable in comparison to the findings of Murray and Sayyab (1955). The amount of montmorillonite reported here is believed to be representative of the less than 20μm fraction but the less than 2μm fraction would contain relatively more than is reported here.

Illite is the predominant mineral in the cores followed by chlorite and kaolinite respectively. There is a general decrease in the relative amount of kaolinite away from the continental rise and a corresponding increase in illite. This suggests the source of the kaolinite is the southeastern United States with that of illite being a more distant but persistent source.

The illite to chlorite ratio has few large variations suggesting a relationship between these two minerals as to source and/or transport processes.

The stratigraphy of the cores suggest that changes in the relative amounts of illite and chlorite may be related to fluctuations in sea level that affect the amount of kaolinite contributed from the nearby land mass.

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STRATIGRAPHIC DIVISIONS OF UPPER DEVONIAN GREENLAND GAP GROUP ("CHEMUNG FORMATION") ALONG ALLEGHENY FRONT IN WEST VIRGINIA, MARYLAND, AND HIGHLAND COUNTY, VIRGINIA

By

John M. Dennison
Geology Department
University of North Carolina at Chapel Hill
Chapel Hill, North Carolina 27514

and

Cooperating Geologist
West Virginia Geological and Economic Survey
Morgantown, West Virginia 26505

ABSTRACT

Detailed measurements of 11 stratigraphic sections along Allegheny Front extending 96 miles from Corriganville, Maryland, to U. S. Route 250 in Highland County, Virginia, permit reclassification of the strata formerly mapped as "Chemung Formation" in this outcrop belt. The following stratigraphic nomenclature is proposed for the outcrop belt:

Hampshire Formation (1000-2070 feet)
Greenland Gap Group (2325-3885 feet)
Foreknobs Formation (1321-2264 feet)
Unnamed member (0-700 feet)
Pound Sandstone Member (23-193 feet)
Blizzard Member (278-580 feet)
Briery Gap Sandstone Member (28-133 feet)
Mallow Member (741-1100 feet)
Scherr Formation (456-2025 feet)
Brallier Formation (575-2170 feet)

The Greenland Gap Group and its listed components are all new stratigraphic names, and they are here formally proposed with reference sections in accord with the Code of Stratigraphic Nomenclature.

Facies relations within the Greenland Gap Group and between it and the Brallier Formation are documented in a stratigraphic cross section. The Greenland Gap Group is marine throughout in the outcrop

belt studied, with the exception of a nonmarine tongue at one section. The Scherr Formation is dominated by turbidite strata with significant sandstone; southwestward the Scherr Formation becomes finer by facies change and passes into the upper portion of the Brallier Formation. Progressive infilling of the basin produced the Foreknobs Formation. The Mallow Member contains some turbidity current deposits of rather deep water origin near the base, with more shallow marine depositional environments near the top. The Briery Gap Sandstone Member is considered a barrier deposit. The Blizzard Member is shallow marine to brackish and contains a thin sequence of nonmarine strata in the Route 50 section. Slightly deeper water of a marine transgression resulted in winnowed barrier deposits of the Pound Sandstone Member. Filling of the depositional basin resulted in upward transition to the nonmarine Hampshire Formation.

INTRODUCTION

Since 1961 the author has been intermittently studying Devonian stratigraphy along Allegheny Front in Maryland, West Virginia, and Virginia (Figure 1). The data result in a stratigraphic perspective different from that of earlier workers. Environmental interpretations are made in more detail, and new stratigraphic names become necessary as the strata are divided into new units, whose facies and temporal relations can be plotted in detail. In this paper formal stratigraphic names are proposed in a manner consistent with the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961 with amendments).

Acknowledgments

This paper is based principally on field work supported by the West Virginia Geological and Economic Survey during the summers of 1961-64 and spring of 1969, with numerous return visits to solve specific problems, aided in part by a grant from the University of North Carolina Research Council. The basic ideas of the present paper were summarized for the West Virginia Academy of Science on April 19, 1968. Orville D. Naegele, Jack W. Travis, John R. Dennison, and Kay B. Dennison assisted in measuring sections. Field conferences with A. Lee McAlester, Donald M. Hoskins, and the late Vinton E. Gwinn helped clarify interpretations of areas north of the region studied for this paper. George V. Cohee offered advice on formally proposing the new stratigraphic names. Many of the ideas developed in preliminary drafts of this paper benefitted from the healthy criticism of Robert B. Erwin, James W. Head, Lawrence S. Matteson, Kenneth L. Segroves and Walter H. Wheeler.

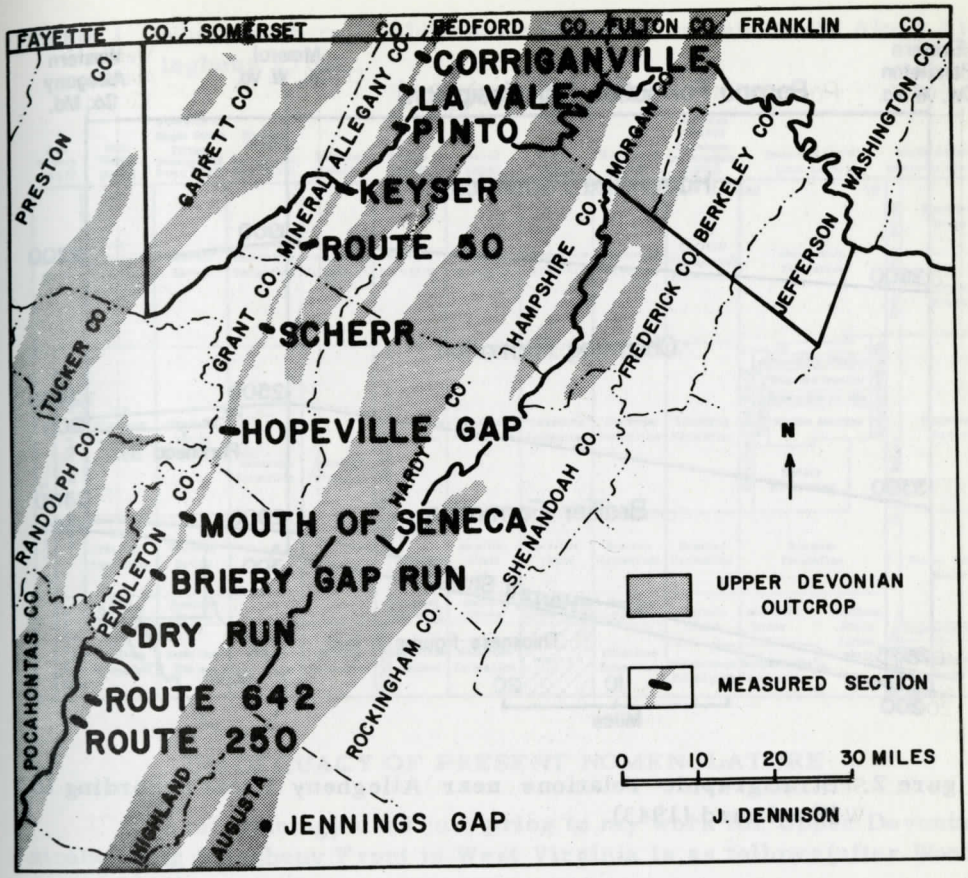

Figure 1. Location of sections studied along Allegheny Front.

PREVIOUS MEASUREMENTS ALONG ALLEGHENY FRONT

Previous workers measured few stratigraphic sections along Allegheny Front in the area shown in Figure 1. The section at Keyser is the most studied, measured by White (1881), Swartz (1913b, p. 528-529), Reger (1924, p. 139-140), and Dennison (1963a). Reger's section was reinterpreted (incorrectly) by Woodward (1943, p. 469), who did not realize that Reger terminated the basal portion of his section over a thousand feet above the base of the Portage Series as mapped by Reger. Reger (1924, p. 152-153) measured another section at Claysville (Route 50 section of present paper), and Woodward (1943, p. 512) accepted Reger's formation boundaries and stratigraphic thicknesses. Unfortunately the Route 50 section is complicated by the Kittlelick fault which causes omission of much of the Brallier Formation (Dennison, Travis, and Ferguson, 1967), so that the Portage-Chemung (equals Brallier-Chemung) contact was incorrectly placed by Reger.

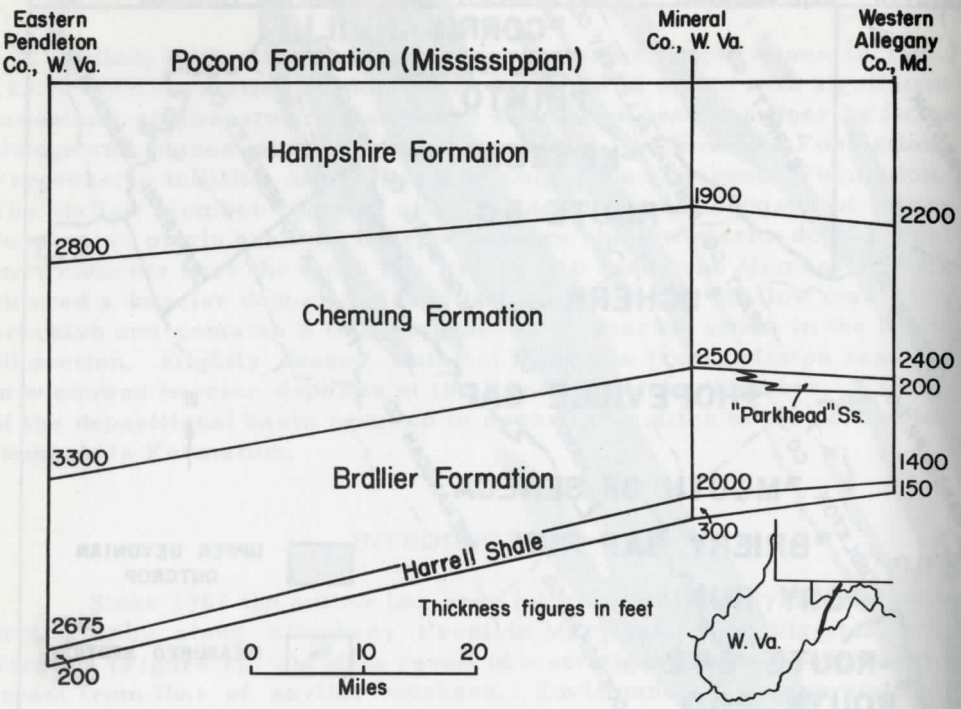

Figure 2. Stratigraphic relations near Allegheny Front according to Woodward (1943).

In Allegany County the section at La Vale was measured by Swartz (1913b, p. 523-528), who referred to it as the section near Allegany Grove. This section is complicated by the Cresaptown fault which causes omission of much of the Brallier Formation (Dennison and Naegele, 1963, p. 34; Dennison, Travis and Ferguson, 1967, p. 179, 183). The section at Corriganville was measured by Prosser (1913, p. 371-375), who designated it the Jennings Run section.

No previous sections had been measured along Allegheny Front in Grant, Pendleton, or Highland Counties. Woodward (1943, p. 471) considered the Chemung Formation to be 3,300 feet thick on Shenandoah Mountain in eastern Pendleton County, some 16 miles east of Allegheny Front.

Figure 2 of the present paper is based on Woodward's interpretation (1943, plates C and D) of stratigraphic thicknesses at and near Allegheny Front. It summarizes Upper Devonian stratigraphic knowledge prior to my work in the area.

Table 1. Nomenclature Evolution for Upper Devonian Strata Along Allegheny Front.

W.B. Rogers (1837)	W.B. Rogers (1879)	White (1881) Reger (1924) Tilton, Prouty and Price (1927)	Darton (1892) Darton and Taff (1896)	O'Harra (1900)	Swartz (1913)	Butts (1918)	Butts (1940)	Woodward (1943)	Dennison (1963b) Dennison and Naegele (1963)	Dennison (1970) (this paper)	North American Devonian Standard
member No. 9	12 Catskill formation	Catskill Series	Hampshire formation	Hampshire formation	Catskill formation	Catskill formation	Hampshire formation	Hampshire formation	Catskill ("Hampshire") Formation	NE SW Hampshire Formation	Chautauquan Series: Bradford Stage; Cassadaga Stage
member No. 8 — ochreous portion of No. 8	11 b Chemung formation	Chemung Series	Jennings formation	Jennings formation	Jennings formation: Chemung member	Chemung formation	Chemung formation	Chemung formation	Chemung Formation	Greenland Gap Group: Foreknobs Fm.: Pound Ss. Member; Blizzard Member; Briery Gap Ss. Mbr.; Mallow Member; Greenland Gap Gp.; Scherr Formation	Senecan Series: Cohocton Stage
	11 a Portage formation	Portage Series			Porkhead member; Woodmont member	Brallier shale	Brallier shale	Brallier formation	Brallier Formation	Brallier Formation	Finger Lakes Stage
olive slate of No. 8	10 c Genesee formation	Genesee Series	Romney shales		Genesee member	Harrell shale	Millboro sh. (upper part)	Harrell shale	Harrell Shale	Harrell Shale; Millboro Shale (upper part)	Taghanic Stage
	10 b Hamilton formation	Hamilton Series		Romney formation	Romney fm.: Hamilton member	Hamilton formation	Hiatus?	Hamilton formation	Mahantango Formation	Mahantango Formation	Erian Series: Tioughnioga Stage

INADEQUACY OF PRESENT NOMENCLATURE

The terminology used just prior to my work for Upper Devonian strata along Allegheny Front in West Virginia is as follows (after Woodward, 1943):

Hampshire Formation (1000-2070 feet)
Chemung Formation (2325-3885 feet)
Brallier Formation (575-2170 feet)
Harrell Shale (30-280 feet)

Thickness ranges are from the data for the present paper, summarizing results from all 11 sections.

Table 1 summarizes the nomenclature evolution for these strata in the Allegheny Front region.

The name Hampshire Formation is derived from Hampshire County, West Virginia (Darton, 1892, p. 17). In the earliest U. S. Geological Survey mapping (Darton, 1892, p. 17) recognized a single upper Devonian marine formation of light colored shales and sandstones beneath the Hampshire, calling it the Jennings formation for Jennings' gap (indicated on Figure 1) and Jennings branch in western Augusta County, Virginia. The Jennings formation overlies a basal series of dark shales which Darton named the Romney shales. Darton did not indicate detailed age assignments. He did not name divisions within the Jennings formation. Darton's type locality is not to be confused with

the excellent section (labeled Corriganville on Figure 1) along Jennings Run in Allegany County, Maryland, where the Jennings formation was described in detail by Prosser (1913, p. 371-375).

Darton and Taff (1896) described the lower part of the Jennings as containing light-colored shales, but O'Harra (1900, p. 107) assigned to the Jennings formation thin and black shales which are now designated as Harrell Shale in Allegany County.

The Chemung Formation was named by James Hall (1839) from Chemung Narrows in south-central New York. The sandstones and shales of the New York Chemung had a distinct fauna, characterized by Cyrtospirifer. The name Chemung (Chemung Series) was introduced into West Virginia by I. C. White (1881) because rocks occupying a homotaxial position in West Virginia carried the same general fauna as the New York Chemung.

Beneath the Chemung of West Virginia is an interval of interbedded siltstone and shale that White identified with the Portage Formation of New York. C. K. Swartz (1913a, p. 412-415) apparently considered Maryland too distant from New York to extend New York Portage terminology to the Potomac River without detailed mapping in the intervening region. He proposed the term Woodmont Shale Member of the Jennings Formation for the interval in western Maryland from the top of the Genesee Member of the Jennings Formation (now called Harrell Shale) to the base of the Parkhead Member of the Jennings Formation, which lithologically resembles the Chemung Member but lacks its characteristic Cyrtospirifer fauna. In the vicinity of Altoona, Pennsylvania, Charles Butts encountered a problem similar to the difficulty Swartz recognized in Maryland. Butts (1918) divided pre-Chemung Upper Devonian strata in that part of Pennsylvania into the Harrell and Brallier formations (lithologically similar, respectively, to the Genesee and Portage formations of New York, but not directly traceable around the Catskill Mountains from central New York southward into Pennsylvania). The names Harrell and Brallier have been widely used in the central Appalachian region.

At abandoned Woodmont Station in Maryland the dark Harrell Shale is absent, and Swartz (1913b, p. 468-471) shows the Woodmont Member there resting directly on his Hamilton Member of the Romney Formation. More recent study there by Dennison shows that the western black shale facies has changed eastward to shale and siltstone facies. Thus the type section of the Woodmont Member encompasses beds with the same age as the Harrell Shale and most of the Brallier Formation along Allegheny Front.

More recent work in New York has revealed by interpretation of intertonguing strata that the Portage and Chemung are contemporaneous facies, each with a characteristic facies fauna. Paleontologic resolution of time is difficult, but not impossible (Greiner, 1957, McAlester, 1962). Detailed lithostratigraphic studies in New York by Sutton, Humes, Nugent, and Woodrow (1962) and Sutton (1963) and by others

have resulted in a new Upper Devonian nomenclature there, with recognition of much thinner formations so that intertonguing relationships can be discerned within the original Chemung and Portage Formations of New York. New York stratigraphy has been so thoroughly reorganized that the current correlation charts for Devonian strata in that state (Rickard, 1964; Oliver, deWitt, Dennison, Hoskins, and Huddle, 1967 and 1969) do not give formal group or formational status to the facies units formerly called Catskill, Chemung, and Portage.

This state of affairs in New York effectively curtails usage of the term Chemung Formation in West Virginia, since Chemung Formation has been abandoned as a formal stratigraphic term in the area where it was first proposed. The present author has informally used the term "Chemung" Group in West Virginia since 1964 for those stratigraphic units that were mapped as Chemung Formation on county maps at 1:62,500 scale and discussed by Woodward (1943) under the formal name Chemung Formation. The "Chemung" Group strata average over a half-mile thickness in West Virginia, thick enough to be divided into new formations for modern-scale mapping, if recognizable lithologic divisions are present. Consequently the present writer advocates that new names should be proposed for divisions of the "Chemung" Group in West Virginia and adjacent states as detailed stratigraphic and mapping studies progress. The present paper is an attempt to accomplish this along Allegheny Front.

PROPOSED NOMENCLATURE

For the exposures along Allegheny Front in West Virginia and Maryland, the following nomenclature is proposed:

- Hampshire Formation (1000-2070 feet)
- Greenland Gap Group (2325-3885 feet)
  - Foreknobs Formation (1321-2264 feet)
    - Unnamed member (0-700 feet)
    - Pound Sandstone Member (23-193 feet)
    - Blizzard Member (278-580 feet)
    - Briery Gap Sandstone Member (28-133 feet)
    - Mallow Member (741-1100 feet)
  - Scherr Formation (456-2025 feet)
- Brallier Formation (575-2170 feet)
- Harrell Shale (30-280 feet; passes laterally into Millboro Shale)

The formational breakdown of the old "Chemung" Group is taken from a single measured section along W. Va. Route 42, 0.7 mile northwest of Scherr, Grant County (Figure 1, 3, and 4). Measured Section 1 (appendix to this paper) is a summary type section for the Scherr and Foreknobs Formations, which comprise the Greenland Gap Group. This summary section is condensed from bed-by-bed descriptions which

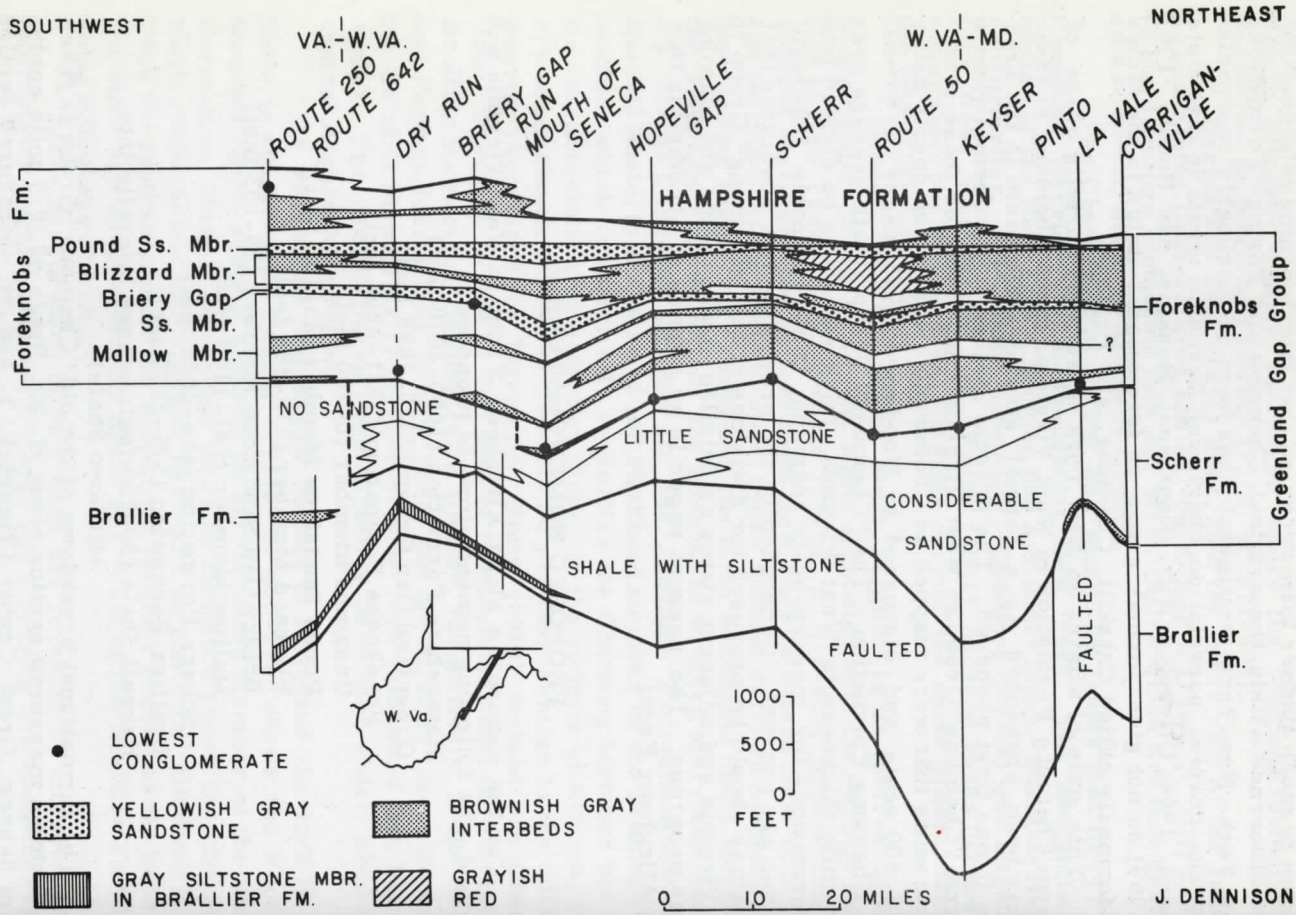

Figure 3. Relations of the Greenland Gap Group to Hampshire Formation above and Brallier Formation below. The top of the Pound Sandstone is considered essentially isochronous and is used as a datum for this stratigraphic cross section.

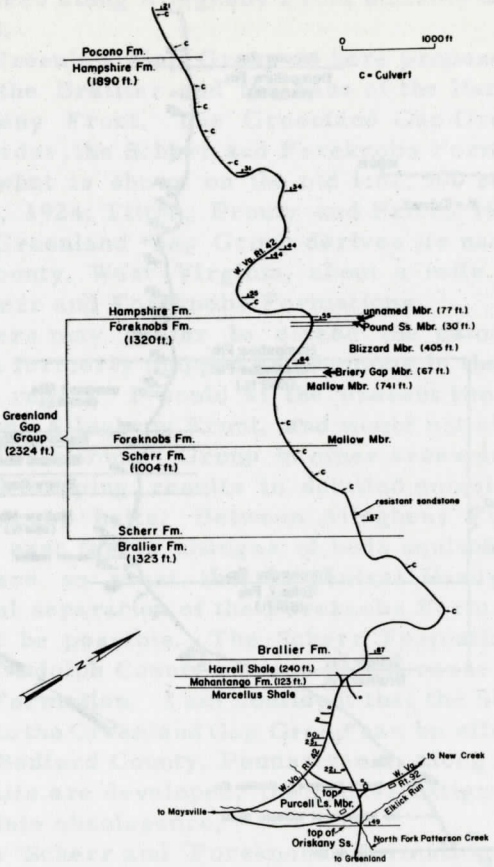

Figure 4. Map of type section of Greenland Gap Group, Scherr Formation, and Foreknobs Formation along West Virginia Route 42.

were plotted in the field as stratigraphic columns with a 1:133 scale after thickness control by plane table mapping had been established. The author has traced the Scherr and Foreknobs Formations along Allegheny Front, mapping in detail across Allegany County, Maryland, and Mineral and Grant Counties, West Virginia, and in reconnaissance across Pendleton County, West Virginia.

Geographic names are scarce along Allegheny Front, so members of the Foreknobs Formation are proposed from another section measured in the same detailed 1:133 scale along a road beside Briery Gap Run in Pendleton County, West Virginia (Figure 1, 3, and 5). This road leads from U. S. Route 33 near Judy Gap toward Spruce Knob. Measured Section 2 (appendix) serves as type section for the named

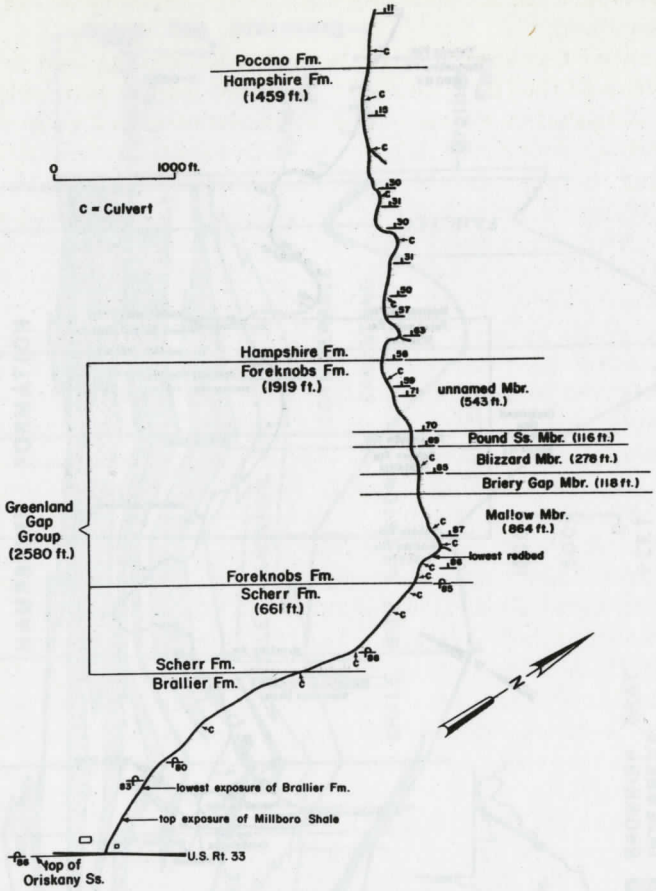

Figure 5. Map of type section of Pound Sandstone Member, Blizzard Member, Briery Gap Sandstone Member, and Mallow Member of Foreknobs Formation along Briery Gap Run, Pendleton County, West Virginia.

members of the Foreknobs Formation. Photographs (Plate 1, 2, and 3) illustrate lithologies of members of the Foreknobs Formation at the Briery Gap Run type section.

A number of stratigraphers, notably James W. Head, have advocated to me in conversation that the "Chemung" Group should be completely abandoned in West Virginia usage, because Chemung no longer is valid as a formal stratigraphic name in New York nor is it used as a mapping unit in modern New York field mapping. Complete abandonment of the formal name of Chemung along Allegheny Front in the area of this study is now possible, because the Scherr and Foreknobs Forma-

tions have been traced along Allegheny Front entirely across West Virginia and Maryland.

The name Greenland Gap Group is here proposed for the strata between the top of the Brallier and the base of the Hampshire Formations along Allegheny Front. The Greenland Gap Group is composed of, in ascending order, the Scherr and Foreknobs Formations, roughly corresponding to what is shown on the old 1:62, 500 scale county geologic maps (Reger, 1924; Tilton, Prouty and Price, 1927) as Chemung Formation. The Greenland Gap Group derives its name from Greenland Gap, Grant County, West Virginia, about a mile east of the type sections of the Scherr and Foreknobs Formations.

Some workers may prefer to extend the name Greenland Gap Group to all strata formerly mapped as Chemung in the West Virginia-Virginia-Maryland region. I would at the present time use Greenland Gap Group only along Allegheny Front, and would not object strongly to continuing usage of "Chemung" Group in other areas during an interim period until careful mapping results in detailed nomenclature in other Upper Devonian outcrop belts. Between Allegheny Front and the next outcrop belt to the east facies changes of beds equivalent to the Foreknobs Formation are so great that in central Hardy and Hampshire Counties meaningful separation of the Foreknobs Formation from Scherr Formation may not be possible. The Scherr Formation may be unrecognizable in the Randolph County outcrop belt because of facies merger into the Brallier Formation. I am confident that the Scherr and Foreknobs Formations in the Greenland Gap Group can be effectively mapped northward across Bedford County, Pennsylvania, along Allegheny Front. As new mapping units are developed, the rock-stratigraphic term Chemung should pass into obsolesence.

The names Scherr and Foreknobs Formations have appeared three times in published stratigraphic columns (Oliver and others, 1967, p. 1006; Cardwell, Erwin, and Woodward, 1968; Oliver and others, 1969) in anticipation of the present more detailed description which formally establishes these formation names.

The base of the Foreknobs Formation is marked by massive sandstone, and north from Mouth of Seneca (Figure 3) it is indicated by associated conglomerate. The published geologic map of the Keyser Quadrangle (Dennison, 1963a) shows the contact of the presently proposed Scherr and Foreknobs Formations by a line of small circles corresponding to the position of the lowest conglomerate in the Chemung Formation as shown on that map.

The clastic strata of the Greenland Gap Group represent the progressive filling of the Devonian exogeosyncline depositional basin from deep-water turbidity current deposits to progressively shallower-water sediments that pass upward into nonmarine strata of the overlying Hampshire Formation. In a general way the Scherr Formation is comprised of somewhat sandy turbidity current deposits overlying more distal and probably deeper-water siltstone turbidites of the Brallier

Formation. The Foreknobs Formation consists of shallow marine and brackish strata deposited in an environment with prominent wave action (especially in upper part) rather than turbidity currents.

SCHERR FORMATION

The name Scherr Formation is taken from the village of Scherr, Grant County, West Virginia. Hills west of the village are formed by the Scherr Formation and Brallier Formation. The Scherr Formation contains chiefly siltstone, with considerable fine sandstone and shale; all weather light olive gray. The general lithology of the lower portion of the Scherr Formation is illustrated in Plate 1, Figure 1. Sandstone abundance in the Scherr decreases upward in the Formation and toward the southwest (Figure 3). The Scherr Formation is definitely finer and less massive than the overlying Foreknobs Formation.

In earlier papers (Dennison and Naegele, 1963; Dennison, 1963b; Dennison, Travis, and Ferguson, 1967, p. 180) the Scherr Formation was informally called the lower silty part of the Chemung Formation.

The base of the Scherr Formation is marked by abrupt introduction of beds containing a small percentage of sandstone. Brallier strata may contain massive siltstone beds along Allegheny Front, but sandstone has not been observed there in the Brallier Formation.

Swartz (1913b, p. 526) recognized the Parkhead Sandstone Member in his section of Jennings Formation measured at Allegany Grove (same as my LaVale section). I do not believe that the Parkhead sandy facies extends west to Allegheny Front in Maryland, and I have identified the characteristic lithology and Cyrtospirifer fauna of the Scherr Formation in the same beds which Swartz recognized there as Parkhead.

Massive siltstones in the lower Brallier Formation (Figure 3) have been locally mapped as Chemung Formation near Mouth of Seneca (Tilton, Prouty, and Price, 1927) and detailed mapping should rectify this error.

The upper beds of the Scherr Formation lack significant sandstone and are essentially a repetition of Brallier lithology, although Cyrtospirifer chemungensis is locally present in the coarsest beds of the upper portion of the Scherr Formation.

The basal beds of the Scherr Formation contain Cyrtospirifer chemungensis (Conrad) and Cornellites chemungensis (Conrad), which indicate age assignment to the lower Cohocton Stage. These two fossils disappear laterally, accompanying facies change as the Scherr passes southwestward into the upper portions of the Brallier Formation. Brallier Formation beds lack these fossils in the northeastern part of the area, so their lowest appearance in West Virginia and Maryland along Allegheny Front is interpreted as a time surface because the coarsest Brallier strata are lithically similar to the finer-grained beds contain-

ing this fauna in the Scherr Formation.

The sandstone in the Scherr Formation disappears to the southwestward along Allegheny Front, and so does the C. chemungensis facies fauna. Scherr Formation is clearly recognizable at Briery Gap Run (Measured Section 2) and at Dry Run. At U. S. Route 250 in Highland County, Virginia, along the same strike belt, the Scherr Formation cannot be mapped (because the critical sandstone lithology is absent), although its stratigraphic position can be identified by a coarsening of siltstones and by tracing a brownish gray "redbed" marker zone (Figure 3). Details of the facies change from Scherr Formation to upper Brallier Formation have not been worked out, but careful measurement of the Dry Run section and a preliminary study at Virginia Route 642 indicate that a nomenclature change is appropriate at the West Virginia-Virginia border along Allegheny Front, with the Scherr Formation being restricted to the West Virginia side of the border (Figure 3).

The abrupt coarsening of strata at the base of the Scherr Formation, followed above by a progressive decrease in grain size, is thought to represent a single pulse of source area uplift or eustatic lowering of sea level, so the sand influx marking the base of the Scherr Formation probably approximates a time-line. Depositional trends of lithofacies and isopachs probably are nearly north-south, not deviating more than 30 degrees from the strike of Allegheny Front. The southwestward decrease in grain size of the Scherr clastics, ultimately resulting in facies passage of the Scherr Formation of West Virginia into the uppermost Brallier Formation of Virginia, results from the slight obliquity of depositional strike to the present structural strike of the Allegheny Front outcrop belt.

A zone with brownish gray "redbeds" intercalated with a much greater abundance of non-red, marine silty and sandy strata occurs at the very base of the Scherr Formation at Corriganville and LaVale. Redbed deposition is a unique event in that part of the stratigraphic column and is interpreted as a time-line correlation marker between the two sections.

Similar brownish gray "redbed" siltstone in the middle portion of the Brallier Formation at Route 642 and at Route 250 allows time correlation between those sections and also with a nearby section which exposes most of the Scherr Formation time equivalents in the Brallier Formation at Townsend's Draft 12 miles southwest of Route 250 along Allegheny Front.

If these two sets of redbeds are contemporaneous, then the base of the Scherr Formation along Allegheny Front is slightly younger in Pendleton County than in Maryland. However, the coarsest siltstone pulse in the middle Brallier at Route 250 is a physically continuous extension southwestward of the time-line formed by the maximum sandy pulse in the basal Scherr Formation at Briery Gap Run. That time-line extends continuously northeastward as the climax of the marked influx

of sand in the lowermost Scherr Formation at LaVale and Corriganville. In other words, a line bisecting a single clastic pulse (lithologic tongue) is a good approximation of a time-line. It is analogous to a volcanic ash layer introduced as a clastic sediment from an outside source. Similarly the redbeds in the vicinity of Route 250 and the ones at Corriganville are individual time pulses, each much like a handfull of red sand suddenly thrown into a laboratory sedimentation flume.

There is strong temptation to speculate that the two sets of redbeds are synchronous and represent a eustatic lowering of sea level, so that oxidized hematitic strata were carried farther westward into the basin than usual by the Fulton Lobe (Willard, 1939, p. 273) and by the here-named Augusta Lobe of the Devonian Delta complex distributary system. These lobes are named from counties in Pennsylvania and Virginia, respectively, located on Figure 1 (Willard established the precedence of using county names to designate delta lobes).

The Scherr Formation accumulated as foreset beds in the Catskill Delta complex as indicated by prominent display of criteria for turbidity current deposition, including flute and groove casts, graded bedding, and sharply bounded sandstones produced by turbidity current pulses that deposited individual beds.

FOREKNOBS FORMATION

The name Foreknobs Formation is taken from the topographic feature called the Fore Knobs of Allegheny Front on the Greenland Gap and Elk Garden 15-minute topographic quadrangles. The higher set of knobs is capped by the Pocono Formation, but a lower set of knobs is formed by the upper beds of the Foreknobs Formation (Pound Sandstone Member). A lower elevation topographic prominence (seldom a distinct hill, but forming a break in slope) is caused by the rather resistant Briery Gap Sandstone Member. The Foreknobs Formation contains abundant massive sandstones; considerable siltstone; substantial "redbeds" of brownish-gray sandstone, siltstone, and shale containing scattered marine fossils; and occasional quartz-pebble conglomerate or conglomeratic sandstone beds. The Foreknobs "redbeds" are definitely more brownish in color than those of the Hampshire Formation. The marine fossils in the Foreknobs "redbeds" are the brachiopod Camarotoechia and small pelecypods, which constitute a nearshore faunal association (Bretsky, 1969, p. 52-54). The intervals designated on Figure 3 as brownish gray interbeds actually contain less than half reddish-colored sandstone, siltstone, and shale, with the majority of the interval consisting of interbeds which weather light olive gray. Wood fragments are commonly associated as driftwood in brackish water and open-marine fossiliferous strata of the Foreknobs Formation. True reddish gray redbed strata of nonmarine origin occur as a tongue in the Blizzard Member of the Foreknobs Formation in the Route 50 section (Figure 3).

The base of the Foreknobs Formation is marked by an abrupt upward increase in percentage, thickness, and massiveness of sandstones, and north of Mouth of Seneca the base is generally marked by conglomeratic strata. Brownish gray "redbeds" appear 9 feet (LaVale section) to 314 feet (Keyser section) above the base of the Mallow Member of the Foreknobs Formation, with the exception of the Dry Run section where no reddish strata occur below the Blizzard Member (Figure 3). The basal contact of the Foreknobs Formation at the Briery Gap Run section is illustrated in Plate 1, Figure 2.

The top of the Foreknobs Formation is placed at the highest occurrence of marine fossils, and is generally marked by abrupt upward passage into dominately grayish red sediments of the type that characterize the Hampshire Formation. The upward change to nonmarine deposition is fairly abrupt at any one locality, but the formation boundary is probably time-transgressive, becoming younger to the southwest along the trend of the stratigraphic cross section in Figure 3. At Route 50 the upper Foreknobs contains some non-marine redbeds, which resulted in too low a Hampshire-Chemung contact in the section measured and mapped by Reger (1924, p. 152-153) and reevaluated by Woodward (1943, p. 512).

In earlier papers (Dennison and Naegele, 1963; Dennison, 1963b) the Foreknobs Formation was referred to as the upper sandy part of the Chemung Formation.

Within the Foreknobs Formation are four subdivisions which here are assigned member names and which can be traced persistently in all ten sections studied along Allegheny Front from Corriganville, Maryland, to Route 250 in Highland County, Virginia. These have been previously described (Dennison and Naegele, 1963, p. 20-22; Dennison, 1963b, p. 223-225) as the upper massive sandstone and the lower massive sandstone of the Chemung Formation, with an intervening silty interval, and as that part of the upper sandy portion of the Chemung beneath the lower massive sandstone. It is desirable to give them formal names as indicated in Measured Sections 1 and 2 and in Figures 3, 4, and 5. The names Briery Gap Sandstone Member, Blizzard Member, and Pound Sandstone Member are taken from three streams named on the Circleville 15-minute topographic quadrangle. The Mallow Member is named for Mallow Knob, on the Onego quadrangle, a mile north of Riverton. Mallow Knob and the three streams are all located within two miles of the type section described as Measured Section 2. Marine strata above the Pound Sandstone Member occur in most of the sections and are assigned to an unnamed member of the Foreknobs Formation; the member remains unnamed until further work is done along Allegheny Front southwest of Route 250 to establish the facies relations between it and the Hampshire Formation.

Note that a discontinuity occurs along the basal contact of the Foreknobs Formation between Briery Gap Run and Mouth of Seneca (Figure 3), with the base of the Mallow Member of the Foreknobs

Formation abruptly rising some 250 stratigraphic feet. The criterion for the base of the Foreknobs Formation is the lowest occurrence of massive sandstones. Northeast of Mouth of Seneca the lowest massive sandstone nearly coincides with the lowest quartz pebble conglomerates in the Greenland Gap Group. At Route 250, Route 642, Dry Run, and Briery Gap Run the lowest massive sandstones are thought to be a bit higher in the section and slightly younger than at Mouth of Seneca, reflecting a facies decrease in sand abundance southwestward away from the clastic source area. Note also that the position of the lowest conglomerate rises in the section southwestward from Mouth of Seneca, reflecting the general decrease in grain size southwestward. The conglomerates probably originated as lag gravels in shoaling areas. In stratigraphic units composed of lensing beds of many lithologic types, vertical discontinuities in formation boundaries, such as the one shown in Figure 3, are an expected result of selecting a single criterion for a formation boundary.

Mallow Member

The Mallow Member of the Foreknobs Formation is totally marine and consists of much olive gray-weathering siltstone, some shale, and much fairly massive sandstone in units several feet thick; some brownish-gray, probably brackish-water siltstones and sandstones; and a few quartz-pebble conglomerates and conglomeratic sandstones in beds usually less than a foot thick. The Mallow Member ranges from 741 feet thick at Scherr to 1100 feet at Mouth of Seneca. Interbedded sandstones and siltstones of the Mallow Member are illustrated in Plate 2, Figure 1.

Within the Mallow Member two nearly continuous horizons containing brownish gray, marine "redbeds" persist from Route 250 to Corriganville, except for a general absence of "redbeds" in the Dry Run section. The middle of each of the reddish horizons is thought to approximate a time-line resulting from a eustatic lowering of sea level, or possibly a general regional uplift of the source area, or a climatic change.

At Mouth of Seneca a lens of brownish gray "redbeds" at the very base of the Mallow Member is associated with the lowest conglomeratic horizon in the Foreknobs Formation.

These stratigraphic intervals with significant amounts of brownish gray "redbed" strata separated by intervals lacking "redbeds" permit time zonation within the Mallow Member. The "redbed" intervals can be traced from section to section, or their stratigraphic position can be identified by projection into areas where "redbeds" are lacking.

The abrupt influx of coarse clastics at the base of the Foreknobs Formation (Mallow Member) from Mouth of Seneca to Corriganville is thought to be nearly synchronous along the outcrop belt, reflecting a significant uplift of the Devonian clastic source areas to the east. The

base of the Mallow Member is probably somewhat diachronous across the total distance represented in Figure 3, becoming slightly younger to the southwest of Mouth of Seneca. The top contact of the Mallow with the Briery Gap Member is isochronous so far as can now be resolved.

The depositional environment of the Mallow Member became progressively shallower as the basin became filled to above wave base. Turbidity current features abound in the lower part of the Mallow Member, but shallow-water current structures dominate near the top, particularly cross-bedding and shale-chip conglomerates at the base of channeled sandstones.

Briery Gap Sandstone Member

The Briery Gap Sandstone Member is massive, medium-grained to conglomeratic, fairly well-sorted, cross-bedded, yellowish gray weathering sandstone with very little interbedded siltstone and shale. The lithology at the type section is shown in Plate 2, Figure 2. Cyrtospirifer is the most common marine invertebrate, and plant debris fossils are abundant. The top and bottom contacts are placed where a dominance of sandstone gives way to olive or reddish siltstones and shales interbedded with less than half sandstone. At Route 250 in Virginia the sandstones are not as massive as in West Virginia and Maryland, but instead contain considerable interbedded siltstone; thus Route 250 may represent the southernmost recognizable extent of the Briery Gap Member.

The Briery Gap Sandstone is thought to represent barrier deposits rather than cheniers, based on large geographic extent, thickness, and the steep inclination of cross-stratification (Hoyt, 1969). The Briery Gap Sandstone is clearly coarser, better sorted, and thicker than any of the massive sandstones in the underlying Mallow Member. The Briery Gap probably formed by winnowing removal of fine clastic materials, leaving a near-shore deposit of rather clean sand. The apparent blanket-like nature of the sandstone along this outcrop belt probably results from a eustatic change in sea level which permitted winnowing of poorer-sorted sediments into barrier deposits trending nearly parallel to Allegheny Front.

Blizzard Member

The Blizzard Member resembles the Mallow Member in its heterogeneity. The Blizzard consists of interbedded sandstone, siltstone, and some shale, which are greenish gray or light olive gray in color interbedded with some brownish gray, plus some scattered beds of quartz-pebble conglomerate and conglomeratic sandstone. Sedimentary structures such as cross-bedding and absence of flute casts suggest that the Blizzard Member formed in shallower water than did the lower part of the Mallow Member which exhibits conspicuous turbi-

dite features. The Blizzard Member ranges in thickness from 278 feet at Briery Gap Run to 580 feet at Mouth of Seneca. At Route 50 the upper portion of the Blizzard Member contains abundant reddish gray, nonmarine redbeds which accumulated as a Hampshire-type lithology distributary lobe (Figure 3).

The partly covered exposure of Blizzard Member at Mouth of Seneca is complicated by drag folds related to general flattening of dip to the northwest. The Blizzard Member is unusually thick at Mouth of Seneca, even after tectonic thickening is interpreted, probably as a result of excessive contemporaneous subsidence at that site.

A brownish gray "redbed" horizon near the middle of the Blizzard Member may reflect a eustatic lowering of sea level. Nonmarine redbeds at Route 50 near the middle and top of the Blizzard Member support the interpretation of a time of lowered sea level.

Pound Sandstone Member

Like the Briery Gap Sandstone, the Pound Sandstone Member is fine-to medium-grained, cross-bedded sandstone with some conglomeratic layers. The Pound Sandstone is better sorted than most Foreknobs sandstones and weathers light olive gray with few siltstone partings. Fossils include plant stem fragments, brachiopods (Cyrtospirifer) and pelmatozoan plates. The upper and lower contacts are drawn where silty or shaly layers break up the dominance of sandstone. Plate 3, Figure 1 shows the type section of the Pound Sandstone. Thicknesses of the Pound Sandstone range from 23 feet at LaVale to 193 feet at Mouth of Seneca.

Because its lithology is similar to the Briery Gap Sandstone, the Pound Sandstone is also interpreted as a barrier deposit sandstone, produced by waves winnowing finer sediments. The Pound Sandstone probably resulted from a eustatic rise in sea level, causing a brief return to marine sedimentation in the Route 50 section.

The Pound Sandstone and Briery Gap Sandstone Members are nearly parallel to each other (Figure 3), nearly parallel to the base of the Foreknobs Formation, and essentially parallel to "redbed" marker zones traceable within the Mallow and Blizzard Members of the Foreknobs Formation. Consequently the Cyrtospirifer-dominated Briery Gap and Pound sandstones are thought to be approximately isochronous along Allegheny Front, each probably corresponding to an event of rapid transgression of the sea over intertidal sandy mudflats, with subsequent winnowing of the mudflat sediments to produce fairly well-sorted, massive, cross-bedded sandstones of a barrier deposit. The apparent isochronous top of the Pound Sandstone is arbitrarily chosen as a horizontal reference line for preparing the stratigraphic cross section of Figure 3.

Lithologies like the Briery Gap or Pound sandstones would make excellent petroleum reservoirs in the subsurface. Named "sands" that

are productive of oil and gas in the Upper Devonian of West Virginia may be similar sandstone deposits formed later and westward by winnowing action of sudden marine transgression along the front of the advancing delta complex. The Allegheny Front exposures deviate only slightly from the general north-south trend of the late Devonian facies patterns, so the Briery Gap Sandstone and Pound Sandstone appear as almost blanket sands along Allegheny Front. At right angles to depositional strike they change facies abruptly, so these sandstones have not been identified in the next outcrop belt to the west along the east limb of the Deerpark or Elkins Valley anticlines. Almost certainly the boundaries of the Briery Gap, Blizzard, and Pound Members locally transgress time somewhat, but the available evidence does not demonstrate transgression. The three members probably form approximate time bands within the Foreknobs Formation along Allegheny Front.

Unnamed Member

The member consists of marine sandstones and siltstones, mostly light olive gray with some brownish gray "redbeds" and rare conglomeratic layers. The general lithology of the unnamed member of the Foreknobs Formation is illustrated in Plate 3, Figure 2. It is zero (Route 50) to 700 feet (Route 250) thick, with the top becoming younger to the southwest. The marine unnamed member passes by facies change laterally northeastward into the Hampshire Formation. The base of the Hampshire Formation is at the top of the uppermost marine strata. Usually the basal Hampshire strata are nearly entirely reddish gray nonmarine beds, but in the Dry Run and Route 250 sections a unit about 100 feet thick of massive, light olive gray to yellowish gray weathering sandstone with wood fragments but no marine fossils overlies a few feet of Hampshire-type redbeds.

It is preferred, at this time, to assign no formal name to the member. Additional studies southwest of the area treated in this paper should reveal the geometric and stratigraphic nature of the unnamed member, and only then should additional formal nomenclature be considered. Southwest of Highland County there could be several members within the marine Greenland Gap Group (or "Chemung" Group) above the stratigraphic position of the Pound Sandstone Member.

A conspicuous streak containing brownish gray "redbeds" in the Route 250, Dry Run, and Briery Gap Run sections (Figure 3) probably is a time-line formed by eustatic lowering of sea level; the streak passes laterally into the bright redbeds of the Hampshire Formation at Mouth of Seneca and northeastward, illustrating a classic nonmarine-marine facies change.

Along Allegheny Front in the area studied no fossils in the uppermost member of the Foreknobs Formation appear younger than Cohocton Stage. That contrasts with the Valley Head Sandstone Member of the "Chemung" Group at Valley Head, Randolph County, where Cry-

tospirifer sulcifer (Hall) and C. inermis (Hall) both occur, indicating (Greiner, 1957) a probable assignment to the Cassadaga State for "Chemung" (or Foreknobs?) beds about 300 feet beneath the base of the Hampshire Formation.

DISCUSSION OF STRATIGRAPHIC RESULTS

Field Techniques

The field techniques used in this investigation produced far better stratigraphic resolution than had been expected. Although vegetative cover is extensive in this mountainous region, it has been possible to obtain sections with an average spacing of 10 miles displaying over 80 percent exposure of the Devonian delta strata. This probably provides better stratigraphic control than is available in upstate New York where the classic development of the Devonian delta has been described. Glacial drift blankets most of upstate New York, so Devonian delta sections there are usually small exposures only tens of feet thick; these have been related into composite stratigraphic columns by geographic and structural position, aided by the presence of a few marker beds that can be identified in the small outcrops.

Sections for this study were located along major streams, road cuts, and railroad cuts. Exposures are not continuous, but piecing together by plane table of a swath of outcrops a half-mile wide allows one to obtain almost continuous stratigraphic sections. Air photo control and field mapping were used to eliminate the complexities of local faulting. During this stratigraphic study several faults were discovered and delineated in the Devonian outcrop belt along Allegheny Front (Dennison, 1963a; Dennison and Naegele, 1963; Dennison, Travis, and Ferguson, 1967). Major thickness control was obtained by plane table mapping and marking selected stratigraphic points with yellow spray paint, which produces reference marks that last for several years. Details of stratigraphy were then interpolated by taping and plotted on 1:133 scale stratigraphic columns with lithologic descriptions written alongside. It is possible to use these sections years later to locate field sites with a stratigraphic error of commonly less than a foot, as well as readily to make additions to original field notations. The field techniques outlined have resulted in the most detailed descriptions of reference exposures of Upper Devonian strata in the Appalachian region. Plane table techniques are sometimes considered old-fashioned, and are seldom used by modern geologists. However, I commend these stratigraphic techniques to others working with thick Appalachian units.

Very few of the stratigraphic divisions outlined in this paper were evident in field examination. Only after having the complete bed-by-bed stratigraphic section in field notes and plotting the relations at various scales in stratigraphic cross sections was it possible to cor-

relate details of lithologic time-lines. The results were much more successful than anticipated, and stratigraphic character can be predicted at new localities (such as the Dry Run section which was described in the spring of 1969).

New Stratigraphic Nomenclature

The stratigraphic nomenclature proposed in this paper has been found very effective in mapping and interpreting the Devonian Delta strata along Allegheny Front from Allegany County, Maryland, to Highland County, Virginia. The Scherr and Foreknobs Formations are easily mapped. Members within the Foreknobs can be readily identified in good exposures, but vegetative cover prohibits their detailed mapping between outcrops, although generalized mapping can be done from air photos.

At present the author wishes to use the detailed nomenclature only along Allegheny Front. Careful additional outcrop and subsurface work is needed to establish the relation of Allegheny Front stratigraphy to other Devonian belts.

The Greenland Gap Group (or "Chemung" Group) crops out along the axis of the Bedford syncline about six miles east of Allegheny Front, but only the Scherr Formation is preserved there. At present the author would hesitate to separate the Foreknobs Formation in the great thickness of "Chemung" Group strata exposed farther east in the Town Hill, the Sideling Hill, or the Meadow Branch synclines, respectively located some 17, 25 and 40 miles east of Allegheny Front. Detailed stratigraphic studies will be necessary in those synclines before subdivision of the "Chemung" is possible.

In the Elkins Valley anticline, in Randolph County west of Allegheny Front, Reger (1928, p. 50-53; 1931, p. 368-382) named the Elkins and Valley Head Sandstone Members of the Chemung Formation. The Elkins Member probably correlates with the lower Foreknobs Formation at Allegheny Front, and the Valley Head Sandstone is probably slightly younger than any strata in the Foreknobs Formation along Allegheny Front in the area described in this paper.

In Tucker County, in the first outcrop west of Allegheny Front, Price (in Reger, Price, and Tucker, 1923, p. 245-256) described and named the Hendricks Sandstone Member of the Chemung just beneath the base of the nonmarine Hampshire Formation. Attempts have been made to locate the Hendricks Sandstone in Allegheny Front outcrops (Reger, 1924, p. 140, 153; Tilton, Prouty, and Price, 1927, p. 171-172; Woodward, 1943, p. 469, 512), but the present author discredits those attempts. Almost certainly the Hendricks Sandstone of Tucker County is younger than any Foreknobs strata described in this paper along Allegheny Front, except possibly the uppermost Foreknobs unnamed member in Highland County, Virginia. A thorough study of Chemung Group stratigraphy is urgently needed in Randolph and Tucker

counties to clarify relations between the Allegheny Front strata and the Hendricks, Elkins, and Valley Head Sandstones. Correlation with Allegheny Front via intervening well control will be essential.

Of greater economic significance, the Upper Devonian gas and oil sands of West Virginia almost certainly are lithologically like some of the strata in the Foreknobs Formation along Allegheny Front. The stratigraphic positions of the Gordon, Fourth, Fifth, Bayard, Speechley, Balltown, Bradford, Riley, and Benson sands have never been certainly identified in published descriptions of outcrops along Allegheny Front. Benson gas sand production discoveries have been extended eastward almost to the western edge of the map of Figure 1. The time is right to begin linking the economics of subsurface stratigraphy with the theoretical and academic approach to outcrop stratigraphy. Combining subsurface and surface stratigraphy will provide a regional framework illustrating three-dimensional lithologic variations, similar to that constructed by Dennison (1961) for older Devonian rocks of the Onesquethaw Stage.

Stratigraphic Principles

Several stratigraphic principles have been used in this paper without comment on their philosophic significance.

For years, time resolution was best done by paleontology. In the Appalachians that was especially true when correlations were made between New York reference sections and other stratigraphic sections 20 to 50 miles apart. Closely spaced and very detailed stratigraphic sections allow physical correlations which give better time resolution than the sole use of fossils permits. Faunas and floras are ecologically controlled, and facies fossils baffle correlation attempts. Since few fossils cross the non-marine to marine transition zone, strict biostratigraphic correlation of these contemporaneous beds is almost always impossible. Environmentally controlled marine assemblages are also difficult to correlate.

Other stratigraphers are also discovering independently in recent years that closely spaced, very detailed stratigraphic sections permit one to use physical correlation to establish time-zonation with greater resolution than fossils allow. A generation of geologists without extensive field experience in studying stratigraphic details sometimes considers facies patterns schematic and believes that all rock units are facies in which time correlations are impossible except by paleontologic specialists or by use of bentonites. The time-lines interpreted from the facies of Figure 3 have resulted in comments of incredulity from certain "arm-chair" geologists who have not experienced the frustrations and rewards of detailed stratigraphic work. It is personally quite rewarding to encounter elsewhere an emerging breed of detailed physical and paleoecologic stratigraphers who have discovered in diverse places and in many parts of the stratigraphic column that

detailed physical stratigraphic work allows the most precise correlations now available to geologists working in a region the size of several counties. Field geology does indeed have a place in modern science.

The abrupt discontinuities in the basal contact of formations and members in Figure 3 may disturb some readers. It is unconventional, admittedly. In stratigraphic units composed of heterogeneous lithologies, some one criterion must be selected for definition of rock-stratigraphic boundaries. By the very nature of such a criterion, there will be abrupt discontinuities in rock-stratigraphic boundaries once the detailed stratigraphy has been established in rocks that exhibit facies changes. Use of a vertical cutoff has recently been adopted in the revised Code of Stratigraphic Nomenclature (Cohee, Deford, and Willman, 1969, Figure 2).

Geologists generally abhor the idea of state-line stratigraphic nomenclature changes, even though examples of such procedure are legion. It is purely fortuitous, but nevertheless very convenient, to place the southernmost extent of the Scherr Formation along Allegheny Front at the West Virginia-Virginia border. The criterion of sandstone beds marking the base of the Scherr Formation does disappear somewhere between Route 642 and Dry Run, so the use of the state boundary as the site of an arbitrary vertical cutoff is quite appropriate and is consistent with the Stratigraphic Code revision.

The top of the Brallier Formation climbs stratigraphically more than any other unit illustrated in Figure 3. The position of the top of the Brallier at Route 250 projected as a time-line to Corriganville is 1900 feet stratigraphically above the top of the Brallier at Corriganville. For other units much time-line or "layer-cake" physical stratigraphy can be read into Figure 3, but the essential fact of facies climbing of time boundaries is still strongly present. Facies changes are not schematic rock unit boundaries zig-zagging steeply across time-lines, but instead facies changes tend to be marked by long lithologic tongues which can be traced tens of miles. This is especially true along the line of section of Figure 3, which probably deviates less than 30 degrees from the average trend of depositional strike.

Suggestions for Further Work

This paper proposes new stratigraphic nomenclature along Allegheny Front. It is also a summary of the best physical stratigraphic framework in the central Appalachians for Upper Devonian delta stratigraphy. The framework is ready to be used as a basis for further studies.

More detailed environmental interpretation is needed. Studies of cross-beds and other current features are underway. No better opportunity exists in the Appalachians for detailed petrologic studies of Devonian delta facies changes. The time is right for rigorous faunal studies, particularly paleoecologic. Plant fossils are present in many

sections. Careful search may reveal good floral compressions. Stem petrifactions have been noted in many exposures. Preliminary study of outcrop samples from the Scherr and Briery Gap Run sections reveals that palynologic zonation may be possible (Kenneth L. Segroves, personal communication), and it should be possible to establish good correlations between palynologic zonation and marine faunas.

As exciting as the possibilities are for continued detailed study along this described portion of the Allegheny Front outcrop belt, the most interesting opportunities lie outside the area of present study emphasis. The writer aspires to extend the investigation southward, ultimately to develop a line of sections showing how the typical Catskill Delta non-marine strata in the Hampshire Formation of Maryland eventually change facies into the marine, black Chattanooga Shale of Tennessee. The Ridge and Valley outcrop belts provide opportunity for outstanding facies studies unavailable elsewhere. In the classic Devonian outcrops of upstate New York only a single east-west outcrop belt occurs. In the central Appalachians are several outcrop belts, which will permit true three-dimensional factual facies interpretations and concomitant paleoecologic studies. It is hoped that the present investigation can be used as a start toward this three-dimensional goal. The task is obviously too large for one person to accomplish. Additional workers are needed in the region. It is the sincere hope that this summary of eight years of stratigraphic work will entice others to apply their particular talents to a challenging opportunity.

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APPENDIX: TYPE SECTIONS

Measured Section 1

Along W. Va. Route 42 with base of section 0.3 mile northwest of Scherr, Grant County, West Virginia. This is designated as the type section for the Scherr and Foreknobs Formations and for the Greenland Gap Group, all of which are proposed here. Base of Scherr Formation is at 39°11'45" N. Lat., 79°10'48" W. Long. Measured by J. M. Dennison and O. D. Naegele in 1962. Figure 3 is map of locality.

	Thickness feet
Hampshire Formation (1890 feet, total thickness)	
20. Grayish red to brownish gray, micaceous, fine to very fine, quartz sandstone and grayish red to brownish gray micaceous siltstone which weathers lumpy to chippy. Contains a few greenish gray to light olive gray sandstones. No marine fossils	1789
19. Covered.	27
18. Sandstone, very fine, thinly bedded, weathers light olive gray	7
17. Covered.	10
16. Sandstone, thinly bedded, very fine, weathers light olive gray	3
15. Sandstone, very fine, thin- to medium-bedded, brownish gray	29
14. Sandstone, very fine, yellowish gray	1
13. Covered.	15
Greenland Gap Group (2325 feet)	
Foreknobs Formation (1321 feet)	
Unnamed member (77 feet)	
12. Sandstone and siltstone, weathers yellowish gray, contains Cyrtospirifer and other marine fossils	24
11. Siltstone, brownish gray to light olive gray	28
10. Siltstone and sandstone, weathers light olive gray, contains Cyrtospirifer	25
Pound Sandstone Member (30 feet)	
9. Sandstone, rather massive, weathers yellowish gray to light olive gray, contains plant stem fragments, brachiopods, and pelmatozoan plates; has some siltstone layers	30
Blizzard Member (405 feet)	
8. Sandstone, siltstone, and shale, interbedded greenish gray and brownish gray; contains a few thin beds of conglomerate	405

Briery Gap Sandstone Member (67 feet)

7. Sandstone, rather massive, conglomeratic, weathers yellowish gray; contains marine fossils 67

Mallow Member (741 feet)

6. Interbedded sandstone, siltstone, and shale, greenish gray with considerable brownish gray; a few thin beds of conglomerate 471

5. Sandstone, siltstone, and shale interbedded; greenish gray. Some conglomeratic layers are associated with sandstones. Sandstones are more massive than unit below; bottom of Mallow Member is marked by base of massive sandstones which are several feet thick, along with some conglomerates 270

Scherr Formation (1004 feet)

4. Shale and siltstone, with no sandstone in float; weathers light olive gray. Very poorly exposed, yet unit 4 as a weak resistance horizon is continuous at least 20 miles along strike in both directions 380

3. Mostly siltstone, much shale, but almost no sandstone; medium dark gray, weathers light olive gray; partly covered 292

2. Mostly siltstone, with considerable shale and fine-grained sandstone; medium dark gray when fresh, weathers light olive gray. Distinct basal contact is placed at base of ball-and-pillow structure (Pettijohn and Potter, 1964, p. 285) sandstone just beneath sandstone beds 0.5 and 0.8 foot thick 332

Brallier Formation (1323 feet, total thickness)

1. Mostly shale with some interbedded siltstone in distinctly bounded beds; medium dark gray, weathers light olive gray 1323

Measured Section 2

Near Judy Gap, Pendleton County, West Virginia. In cuts along road beside Briery Gap Run; road leads from U. S. Route 33 toward Spruce Knob. Base of Scherr Formation is at 38°43'37" N. Lat., 79°27'42" W. Long. This type section is proposed here for the following members of the Foreknobs Formation: Mallow Member, Briery Gap Sandstone Member, Blizzard Member, and Pound Sandstone Member. Measured by J. M. Dennison, O. D. Naegele, and J. W. Travis in 1962 and 1963. Figure 4 is map of locality.

	Thickness feet
Hampshire Formation (1459 feet, total thickness)	
38. Siltstone and sandstone, mostly grayish red to brownish gray; some light olive gray sandstone, increasing in abundance upward; no marine fossils	1427
37. Sandstone, very fine, light olive gray, some shale chips, thickly bedded, unfossiliferous	14
36. Sandstone, very fine, brownish gray; some silty streaks	18
Greenland Gap Group (2580 feet)	
Foreknobs Formation (1919 feet)	
Unnamed member (543 feet)	
35. Siltstone, thickly laminated, weathers light olive gray	19
34. Sandstone, fine to medium-grained, thickly bedded, cross-bedded, spiriferid brachiopods, light olive gray to brownish gray	25
33. Sandstone and siltstone, light olive gray	18
32. Sandstone and siltstone, brownish gray	25
31. Sandstone, some conglomeratic, and siltstone; marine fossils; weathers light olive gray	145
30. Sandstone, brownish gray	2
29. Sandstone and siltstone, with some quartz conglomerate, shaly at base; weathers light olive gray	231
28. Covered; terrain suggests shale or siltstone	78
Pound Sandstone Member (116 feet)	
27. Sandstone, fine- to medium-grained, cross-bedded, wood fragments and brachiopods, weathers light olive gray; contains a few siltstone partings	116
Blizzard Member (278 feet)	
26. Siltstone with some sandstone; Cyrtospirifer, Camarotoechia, pelmatozoan plates; weathers light olive gray, except brownish gray at 32-38, 40-41, 115-119 feet above base of member	278
Briery Gap Sandstone Member (118 feet)	
25. Sandstone, conglomeratic in part, cross-bedded, some shale chips; some siltstone partings and a 7-foot shale bed; all weathers light olive gray	118
Mallow Member (864 feet)	
24. Siltstone with some sandstone; top 9 feet contains some conglomeratic sandstone; scattered brachiopods and pelmatozoan plates; weathers light olive gray	301

23. Siltstone and some sandstone, weathers brownish gray and light olive gray 66
22. Siltstone, thickly laminated, weathers light olive gray 16
21. Covered. 134
20. Siltstone and some sandstone, weathers light olive gray; trace has almost brownish gray color 284
19. Sandstone, very fine, beds medium to thick, brownish gray 16
18. Siltstone, with some sandstone; weathers light olive gray 38
17. Sandstone, very fine, thin- to medium-bedded; brachiopods and pelmatozoan plates; weathers light olive gray 9

Scherr Formation (661 feet)

16. Shale, with some siltstone in beds to 0.7 foot thick; weathers light olive gray 24
15. Shale, with some siltstone which is thickly laminated to thinly bedded; weathers light olive gray 91
14. Siltstone, in 0.7 foot bed, weathers light olive gray 0.7
13. Shale, with siltstone which is thinly bedded to thickly laminated; weathers light olive gray 124
12. Shale and siltstone, with some siltstone beds 0.3-2.0 feet thick; weathers light olive gray 333
11. Siltstone, mostly medium-bedded, weathers light olive gray 35
10. Siltstone and shale, weathers light olive gray 38
9. Sandstone, in beds 0.8 and 1.0 foot thick, separated by siltstone parting; weathers light olive gray 2
8. Siltstone, thin- to medium-bedded, with some shale; both weather light olive gray 13

Brallier Formation (787 plus feet)

7. Shale, with some siltstone which is thickly laminated to thin-bedded and trace of medium-bedded; both weather light olive gray 32
6. Shale, with some siltstone, thickly laminated to thinly bedded; both weather light olive gray 55
5. Siltstone, medium-bedded, weathers light olive gray 2
4. Shale, with some thickly laminated to thinly bedded siltstone; both weather light olive gray 158
3. Covered. 262
2. Shale, with some siltstone, thickly laminated to thinly bedded; weathers light olive gray; contains short covered intervals 278
1. Covered.

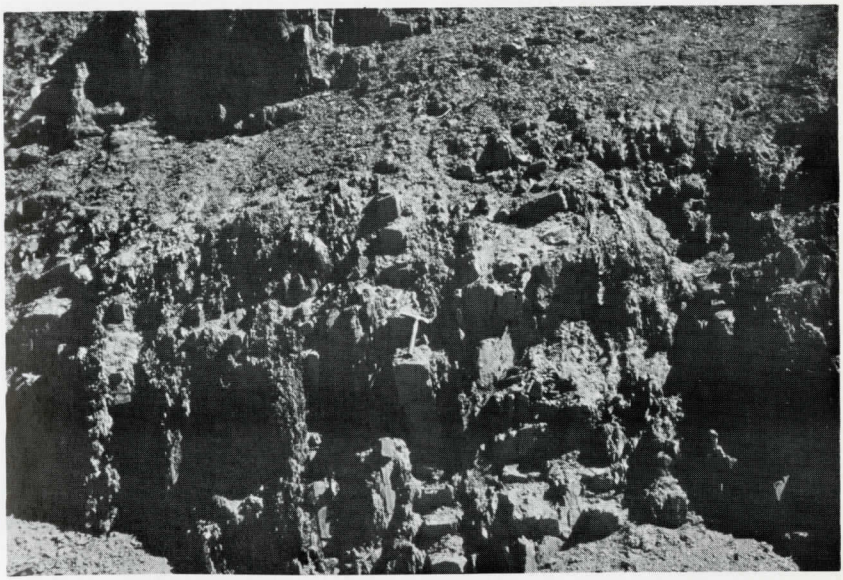

Plate 1, Fig. 1. — Scherr Formation (150 feet above base) at Briery Gap Run section. This is most sandy portion of Scherr Formation in this section.

Plate 1, Fig. 2. — Arrow marks contact of Scherr Formation (right) and more massive Foreknobs Formation (Mallow Member) at Briery Gap Run section.

Plate 2, Fig. 1. — Interbedded sandstone and siltstones of Foreknobs Formation Mallow Member in type section at Briery Gap Run.

Plates 2, Fig. 2. — Briery Gap Sandstone Member of Foreknobs Formation in type at section Briery Gap Run.

Plate 3, Fig. 1. — Massive sandstone at left is type section of Pound Sandstone Member of Foreknobs Formation. Curve in road is at type section of less resistant Blizzard Member, and ridge causing road to deflect to right edge of picture is type exposure of Briery Gap Sandstone Member along valley of Briery Gap Run.

Plate 3, Fig. 2. — Interbedded sandstones and siltstones of upper, unnamed member of Foreknobs Formation in Briery Gap Run section.