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Appalachian Basin Symposium—Program and Extended Abstracts

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Appalachian Basin Symposium— Program and Extended Abstracts

Arthur P. Schultz, editor and basin coordinator

U.S. Geological Survey Circular 1028

Twenty extended abstracts describing Appalachian thermal history, structure, and stratigraphy in studies that are part of ongoing research funded by the U.S. Geological Survey Evolution of Sedimentary Basins Program

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1989

Free on application to the Books and Open-File Reports Section,
U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225

Library of Congress Cataloging in Publication Data

Appalachian Basin Symposium (1988 : Reston, Va.)
Appalachian Basin Symposium program and extended abstracts edited by Arthur P. Schultz.
p. cm. — (U.S. Geological Survey circular ; 1028)
Bibliography: p.
Supt. of Docs. no.: I 19.4/2:1028
1. Geology—Appalachian Basin—Congresses. 2. Appalachian Basin—Congresses. I. Schultz, Arthur P. II. Title. III. Series.
QE78.3.A67 1989 557.5—dc19 89–600079

FOREWORD

The abstracts in this circular were presented during a daylong symposium on the geology of the central part of the Appalachian basin held on November 9,1988, in Reston, Va. Participants of the symposium included U.S. Geological Survey geologists from the Office of Energy and Marine Geology and the Office of Regional Geology as well as scientists from local State surveys and universities. The symposium was held during the final stages of a 5-year multidiscipline basin analysis effort and is part of the USGS Evolution of Sedimentary Basins Program. This program focuses the research of a wide variety of disciplines into a combined stratigraphic, structural, and basin evolution synthesis. USGS Bulletin 1839 is a multichaptered series containing the full descriptions of the research presented at the symposium. The first four chapters of this bulletin have been published, and the remaining are in review or final preparation.

Approximately 60 geologists attended the symposium. Stratigraphic syntheses included description of rocks ranging from lowermost Cambrian through the Pennsylvanian. Three talks presented differing interpretations of Carboniferous rocks from the same area. Other stratigraphic studies included work on Silurian stratigraphy and the Taconic unconformity, descriptions and interpretations of the syn-orogenic Ordovician Fincastle Conglomerate, and changes in Silurian facies in the Appalachian Valley and Ridge province. Fluid migration and basin thermal history were addressed in two presentations. The importance of considering fluid migration in thermal modeling was stressed. Basin tectonics and structure were the topics of several talks and posters. Included were discussions on the genesis of the Pennsylvanian salient, lateral ramps in the central and southern Appalachians, dome and basin features associated with thrusting in the southern Appalachians, and gravity slides in the Valley and Ridge province. Completing the program were a presentation of research on Eocene igneous rocks in the central Appalachian Valley and Ridge province and a review of the economic geology of the Big Chimney quadrangle, Kanawha County, West Virginia.

PROGRAM

Wednesday, November 9, 1988

9:00 AM Introductory remarks—Arthur P. Schultz, Appalachian Basin Coordinator

9:10 AM Tectonically induced fluid migration in sedimentary basins: A new factor to be considered in the assessment of thermal history—by Paul P. Hearn, Jr., Harvey E. Belkin, and John F. Sutter

9:30 AM Reevaluation of conodont color alteration patterns in Ordovician rocks, east-central Valley and Ridge and western Blue Ridge provinces, Tennessee—by Randall C. Orndorff, Anita G. Harris, and Arthur P. Schultz

9:50 AM Stratigraphic framework of Cambrian and Ordovician rocks in the central Appalachian basin—by Robert T. Ryder

10:10 AM The depositional environment of the Middle Ordovician Fincastle conglomerate—by Chrysa M. Cullather

10:30 AM COFFEE BREAK

11:00 AM Regional stratigraphy of Silurian rocks and an enigmatic Ordovician diamictite, southeastern New York—by Jack B. Epstein

11:20 AM The origin of the Pennsylvania salient and CDP seismic imaging of the Cornwall-Kelvin displacement along the U.S. Atlantic continental margin—by Robert C. Milici and Kenneth C. Bayer

11:40 AM Lateral ramps and the structure of the central and southern Appalachians, with implication for thrust belts worldwide—by Howard A. Pohn

12:00 M LUNCH BREAK

1:30 PM Carboniferous petrographic trends in the central Appalachian basin: An orogenic interpretation—by Joseph T. O'Connor

1:50 PM Interpretations of sedimentary patterns in the Pennsylvanian of the central Appalachian basin—by Charles L. Rice

2:10 PM Depositional trends in late Paleozoic coal-bearing strata of the central Appalachian basin—by Kenneth J. Englund and Roger E. Thomas

2:30 PM POSTER SESSION: Art Exhibits Hallway

Eocene igneous intrusive rocks of the central Appalachian Valley and Ridge province—by C. Scott Southworth and Karen J. Gray

The geologic framework of the continental shelf and slope of Virginia, with emphasis on petroleum geology—by Kenneth C. Bayer and Robert C. Milici

Petrographic characteristics of the New River Formation of the central Appalachian basin—by Joseph T. O'Connor and Nelson L. Hickling

Economic geology of the Big Chimney quadrangle, Kanawha County, West Virginia—by John F. Windolph, Jr.

Stratigraphy, sedimentology, and economic potential of the Chilhowee Group in the central and southern Appalachians—by K.Y. Lee

Provenance and depositional history of the Fincastle Conglomerate of southwestern Virginia—by Nelson L. Hickling and Harvey E. Belkin

Anticlines of the Copper Creek–Narrows thrust block, southwestern Virginia—by Robert C. McDowell

Silurian stratigraphic changes and their effect on the distribution of large bedrock landslides, Appalachian Valley and Ridge province—by Calvin R. Wiggs and Arthur P. Schultz

Central Appalachian Transect: Geology of the Radford, Virginia, 1° quadrangle—by Mervin J. Bartholomew, Arthur P. Schultz, and Robert C. McDowell

Cenozoic epidermal gravity tectonics of the Colorado Front Range and Appalachian Valley and Ridge province—by Arthur P. Schultz

4:00 PM SYMPOSIUM ENDS

Appalachian Basin Symposium—Program and Extended Abstracts

Arthur P. Schultz, editor and basin coordinator

Tectonically Induced Fluid Migration in Sedimentary Basins: A New Factor To Be Considered in the Assessment of Thermal History

Paul P. Hearn, Jr., Harvey E. Belkin, and John F. Sutter

A growing body of evidence now suggests that large volumes of fluids were expelled from deeply buried foreland basin sediments during plate collisions along the margins of the North American craton. Hot (100 to 200 °C) saline (10 to 20 weight percent NaCl equiv.) fluids apparently were driven out of peripheral basins and migrated considerable distances onto the craton during geologically brief periods of time. Temporally asynchronous but analogous fluid-migration events are believed to have occurred along the entire extent of the Marathon, Ouachita, Appalachian, and Caledonide orogenic belts. Similar events are believed to have occurred in the Alberta basin and in tectonically active basins of the continental interior. These conclusions are supported by a large body of data, including K-Ar and $^{40}Ar/^{39}Ar$ analyses of secondary minerals, paleomagnetic data, computer simulations of basin paleohydrology, fluid-inclusion analyses, and petrographic observations. The large-scale transfer of heat associated with the upward migration of hot basinal fluids is capable of producing abnormally high thermal gradients. While these anomalous gradients are geologically short lived, they persist long enough to be reflected in fluid-inclusion, conodont-alteration, fission-tract, and vitrinite-reflectance data. Also, potassium metasomatism, commonly associated with brine migration, may produce increased ordering in illite-smectite assemblages. As a consequence, some depth-of-burial estimates based on these thermal indicators may be erroneously high. In numerous instances, the lack of agreement between stratigraphic estimates of burial depth and estimates based on thermal-maturity indicators has been cited as evidence that stratigraphic estimates are erroneously low. Clearly, the assumption that burial-induced heating is the sole influence on the thermal history of sediments is often not valid, and models that ignore thermal overprints from fluid migration events may lead to significant errors.

Manuscript approved for publication February 10, 1989.

Reevaluation of Conodont Color Alteration Patterns in Ordovician Rocks, East-Central Valley and Ridge and Western Blue Ridge Provinces, Tennessee

Randall C. Orndorff, Anita G. Harris, and Arthur P. Schultz

An anomalously low, unexplained, conodont color alteration index (CAI) was reported for Ordovician rocks in the Tuckaleechee Cove window of the Blue Ridge province in previous investigations. These data encouraged hydrocarbon explorationists to consider the eastward extension of Valley and Ridge rocks beneath the metamorphosed thrust sheets of the Blue Ridge as a potential hydrocarbon province. Reevaluation of old and new CAI data in the easternmost thrust belt of the Valley and Ridge province and in windows through the Blue Ridge in central eastern Tennessee show that (1) although the CAI anomaly in the Tuckaleechee Cove window is of less magnitude than first reported, the CAI values for rocks in this window are still lower than CAI values in correlative rocks northward and northeastward at the eastern limit of the Valley and Ridge province; (2) CAI patterns in central eastern Tennessee are more complex than those shown by earlier investigations based on considerably fewer localities; these more complex patterns appear to be related to primary depositional trends in Middle and Upper Ordovician chiefly clastic rocks; (3) CAI values in Ordovician rocks of the Tuckaleechee Cove window are slightly lower than those in correlative rocks in nearby windows; this pattern persists in the Dumplin Valley thrust belt opposite the windows and appears to mimic thickness patterns of Middle and Upper Ordovician rocks; and (4) the area of hydrocarbon potential for Valley and Ridge rocks beneath the crystalline rocks of the Blue Ridge is somewhat less than previous estimates; these rocks, however, still have thermal potential for natural gas but are probably beyond the thermal limit for liquid hydrocarbons.

Stratigraphic Framework of Cambrian and Ordovician Rocks in the Central Appalachian Basin

Robert T. Ryder

Twelve restored stratigraphic cross sections through the subsurface of parts of Ohio, Pennsylvania, Kentucky, West Virginia, Virginia, and Tennessee provide new details of Cambrian and Ordovician stratigraphy, sedimentation, and tectonics in a broad segment of the Appalachian basin. Drilled thickness of the Cambrian and Ordovician sequence ranges from a maximum of about 14,500 ft (4.5 km) along the axis of the rift-controlled Rome trough in West Virginia to a minimum of about 2,900 ft (0.9 km) on the relatively stable shelf in Ohio. The partly drilled Cambrian and Ordovician sequence in the Rome trough of southwestern Pennsylvania is estimated to be as thick as 17,000 ft (5.2 km). Sparse subsurface data combined with outcrop data suggest that the Cambrian and Ordovician sequence thins across the eastern margin of the Rome trough, but to a much lesser degree than on the western margin, before it thickens to at least 20,000 ft (6.1 km) in the thrust-faulted eastern segment of the Appalachian basin.

Rift deposits, consisting primarily of the Rome Formation and the Conasauga Group, occupy as much as one-half of the Cambrian and Ordovician sequence. Near the central and eastern parts of the Rome trough, the sandstone- and multicolored-shale-dominated Rome Formation with several persistent carbonate units underlies the carbonate- and gray-shale-dominated Conasauga Group. However, along the western margin of the Rome trough, where a major east-dipping normal fault is present, the Rome Formation commonly climbs upsection at the expense of the Conasauga Group, and where more than one border fault is involved, the Rome Formation steps westward across progressively higher fault blocks. Generally, the Rome Formation terminates against the westernmost fault system of the Rome trough, and the name St. Simon Sandstone is applied to the basal sandstone on the adjoining hanging-wall block.

In the thrust-faulted eastern margin of the basin, the Rome Formation thickens abruptly across one or more east-dipping normal faults and is as much as 5,000 ft (1.5 km) thicker than in the Rome trough. In this part of the basin, the Rome Formation overlies the Shady Dolomite of Early and Middle Cambrian age, which in turn overlies the Chilhowee Group of earliest Cambrian age. Although the Rome Formation in the thrust-faulted eastern margin of the basin is older than in the Rome trough, its lithology remains dominated by sandstone, multicolored shale, and several persistent carbonate units. Judging from these data, the Rome Formation is a time-transgressive unit whose age, distribution, and thickness are controlled by basement-involved extensional faults that, in general, are progressively younger toward the west. Consequently, the age of the Rome Formation varies from Early Cambrian along the eastern margin of the basin, to latest Early and Middle Cambrian in the Rome trough, to earliest Late Cambrian on the faulted western margin of the Rome trough.

Previously named limestone and shale units in the Middle and lower Upper Cambrian Conasauga Group from outcrops in the thrust belt of eastern Tennessee are recognized and correlated in the Rome trough. In central West Virginia, the Maryville Limestone, the middle limestone unit in the Conasauga, thickens at the expense of the overlying Nolichucky Shale, the upper shale of the Conasauga. The upper part of the Maryville Limestone in central West Virginia consists of dolomite that extends northwestward across the western margin of the Rome trough and into Ohio as a sandy dolomite unit that has been identified erroneously as the Rome Formation.

The Upper Cambrian and Lower Ordovician Knox Group, Lower and lowermost Middle Ordovician Beekmantown Group, and the Upper Cambrian Gatesburg Formation thicken markedly eastward across the western margin of the Rome trough. The thickness of this predominantly dolomitic sequence is controlled by postrift subsidence that was greatest under the Rome trough and the rifted Appalachian continental margin farther east. The combined thickness of the Beekmantown Group and Gatesburg Formation in southwestern Pennsylvania and adjacent West Virginia is as much as 6,000 ft (1.8 km). The upper 1,000 ft (0.3 km) of the Beekmantown Group here consists of anhydritic dolomite and limestone of earliest Middle Ordovician age.

The upper and lower sandy members of the Gatesburg Formation in Pennsylvania and West Virginia correlate, respectively, with the Lower Ordovician Rose Run Sandstone in eastern Ohio and northeastern Kentucky and the Upper Cambrian Kerbel Formation in eastern and northern Ohio. The upper sandy member of the Gatesburg Formation includes the Olin Sandstone, which has been identified in Pennsylvania as a separate unit in the lowermost Gatesburg. The Rose Run Sandstone has a thickness of about 100 ft (30 m) throughout eastern Ohio and northeastern Kentucky but thickens to as much as 300 ft (91 m) in (1) the Rome trough of southwestern Pennsylvania and adjacent West Virginia and (2) near its source area in northwestern Pennsylvania. Thin quartzose sandstone units near the top of the Upper Cambrian Copper Ridge Dolomite of the Knox Group in southwestern Virginia and near the base of the Lower Ordovician Chepultepec Dolomite of the Knox Group in eastern Tennessee correlated with the Rose Run Sandstone. The conflict created by an Upper Cambrian age for the upper sandy member of the Gatesburg Formation and by a Lower Ordovician age for the Rose Run Sandstone and the Chepultepec Dolomite has yet to be resolved.

The well-documented Knox unconformity at the top of the Knox Group can be traced across the Rome trough in Kentucky and can be extended along the western part of the

Rome trough in Pennsylvania and West Virginia on the basis of a thin sandstone unit in the overlying Middle Ordovician rocks. In the Rome trough of Pennsylvania and West Virginia, the Knox unconformity is located within the Beekmantown Group rather than at its more common position at the top of the Knox Group.

The remaining part of the Ordovician sequence above the Beekmantown Group is composed of a Middle Ordovician limestone sequence, the Black River and Trenton Limestones, and an Upper Ordovician shale and sandstone sequence derived from the rising Taconic orogen to the east, the Antes Shale, Reedsville Shale, Bald Eagle Sandstone, and Juniata Formation. The combined thickness of these Middle and Upper Ordovician sequences is as much as 5,500 ft (1.7 km) in Pennsylvania and West Virginia. These Middle and Upper Ordovician sequences maintain their lithologic character into central Ohio, but their combined thickness decreases to about 2,000 ft (0.6 km) there. The Middle Ordovician Black River and Trenton Limestones of Ohio, Pennsylvania, and West Virginia correlate with the High Bridge Group and Lexington Limestone, respectively, in eastern Kentucky and with the Stones River and Nashville Groups, respectively, in east-central Tennessee. The 3,000- to 4,000-ft- (0.9- to 1.2-km-) thick Upper Ordovician shale and sandstone sequence in Pennsylvania and West Virginia thins to 1,000 ft (0.3 km) or less in eastern Kentucky and east-central Tennessee, where much of the sequence consists of argillaceous limestone. Thickness and facies variations in the Middle and Upper Ordovician sequence largely reflect the rapidly subsiding foreland basin west of the Taconic orogen rather than waning postrift subsidence under the Rome trough and the rifted Appalachian continental margin.

The Depositional Environment of the Middle Ordovician Fincastle Conglomerate

Chrysa M. Cullather[1]

The Fincastle Conglomerate is the northeasternmost of six Middle Ordovician conglomerates located west of the Blue Ridge structural front in the southern Appalachians. These conglomerates and their associated sands and shales are an important record of the early tectonic history of the Blue Ridge and the Appalachian basin. They are interpreted as a clastic wedge derived from a southeastern source area. The Fincastle Conglomerate is distinct from the other Middle Ordovician conglomerates because it consists dominantly of terrigenous clasts.

The Fincastle Conglomerate is restricted to the overturned Pine Hills syncline, located 0.96 km north of the town of Fincastle, Va. The syncline trends N. 30° E. for about 3 km and is truncated to the southwest by the Salem fault. The total exposed thickness ranges from 15 to 50 m. Shales, siltstones, and litharenites are discontinuously interbedded with granule to boulder conglomerates. The conglomeratic zones range in thickness from 0.30 to 4.09 m. The grains of the litharenites and the clasts of the conglomerates are thought to have been derived from the Early Cambrian Chilhowee Group, Cambrian and Ordovician limestones, and sediments from within the basin of deposition.

Eight facies units can be recognized. These are (1) matrix-supported granule to boulder conglomerate and coarse-grained pebbly sandstone, (2) clast-supported granule to boulder conglomerate, (3) fine- to medium-grained sandstone, (4) laminated to bedded siltstone, (5) massive and finely laminated shale, (6) discontinuously interbedded conglomerate, coarse-grained sandstone, and shale, (7) interbedded shale and sandstone, and (8) convolute bedded shale. These units are interpreted as having been deposited by submarine gravity flows. Sedimentary structures include normal and reverse grading, convolute bedding, load casts, loaded flute marks, and intraformational shale clasts. Cross-lamination, ripple marks, and imbrication are very rare. The dominant depositional processes thought to be responsible for the facies of the Fincastle Conglomerate are classified as mass sediment movement. The processes interpreted as being active during the Middle Ordovician include debris flows, high-, medium-, and low-density turbidity currents, grain flows, liquefied and fluidized flows, slumping, and rockfalls. The nature of these lithofacies, the sedimentary structures, and the implied depositional mechanisms indicate that the Fincastle Conglomerate was deposited from an eastern source in a submarine channel at the base of a Middle Ordovician paleoslope.

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Regional Stratigraphy of Silurian Rocks and an Enigmatic Ordovician Diamictite, Southeastern New York

Jack B. Epstein

Fluvial, tidal-flat, and shallow-marine rocks of Silurian age in a generally fining-upward sequence were deposited northwestward of a linear highland that was uplifted during Taconic orogenesis from eastern Pennsylvania to southeastern New York. The regional stratigraphic relations of these strata generally have been poorly understood. The sequence in the northern part of the area near High Falls, N.Y., is firmly established and consists of, from the base upwards, the Shawangunk Formation (conglomerate, sandstone, shale), High Falls Shale (red beds), Binnewater Sandstone of Hartnagel (1905), and Rondout Formation (dolomite and limestone) (fig. 1). However, current mapping southwest of High Falls suggests that the

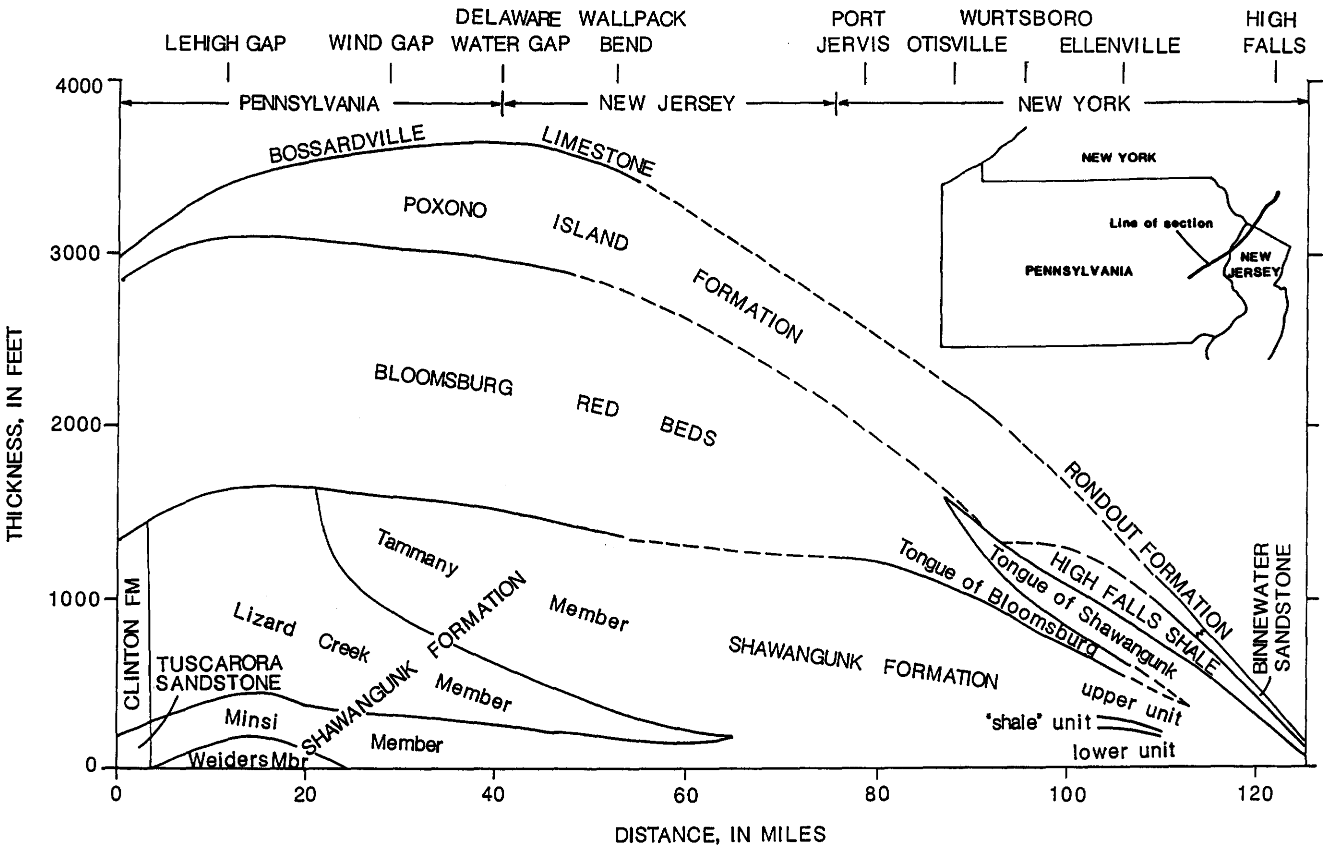

Figure 1. Generalized stratigraphic section showing the regional relations of Silurian rocks between southeastern New York and eastern Pennsylvania. Dashed lines indicate inferred contacts in areas of nonexposure or incomplete mapping.

facies mosaic from New York through New Jersey and into Pennsylvania is more complex than previously reported.

The Silurian sequence thins markedly from Pennsylvania to southeastern New York (fig. 1). The Shawangunk Formation of eastern Pennsylvania consists of three quartzite-conglomerate units (Weiders, Minsi, and Tammany Members) and a unit containing appreciable shale and some red beds (Lizard Creek Member). Farther southwest in Pennsylvania, only a basal quartzite (Tuscarora Sandstone) and shale-sandstone sequence (Clinton Formation) can be recognized. In New Jersey, the shales of the Lizard Creek become less abundant, and the member cannot be mapped to the northeast, but scattered intervals of shale, some containing red beds, persist into southeastern New York. These shales are generally not mappable, except locally, and appear to lie at various levels within the Shawangunk. The "Otisville Shale," named previously for beds that were believed to contain enough shale to be a distinct formation near Otisville, N.Y., fails the test of mappability and should be abandoned.

The contact between the Bloomsburg Red Beds and Shawangunk Formation has been traced without complication from eastern Pennsylvania to Port Jervis, N.Y. Between Wurtsboro and Ellenville, red beds and gray sandstone and shale overlie the Shawangunk. Because of a similar sequence of red and gray rocks at High Falls, many workers have identified these units as the High Falls and Binnewater, respectively. Detailed and reconnaissance mapping suggests, on the contrary, that the red-bed sequence between Wurtsboro and Ellenville is a tongue of the Bloomsburg, and not the High Falls, and the overlying gray sandstone and shale are a tongue of the Shawangunk, and not the Binnewater. The High Falls Shale, which is very poorly exposed, crops out above the tongue of the Shawangunk near Wurtsboro. The tongue of the Bloomsburg disappears northeastward by gradual change in color from grayish red, through olive gray, into gray. In the past, the name "Guymard Quartzite" was applied to a portion of the tongue of the Bloomsburg, but this unit, like the "Otisville Shale," is unmappable and stratigraphically inappropriate. The rocks in the tongue of the Shawangunk contain quartzites that are more distinctly crossbedded than those in the lower part of the formation. The tongue also contains scattered red beds and polymictic conglomerates, some of which are similar to rocks in the Green Pond Conglomerate exposed in an outlier about 25 mi (40 km) southeast of the main outcrop belt. It is possible that the Shawangunk tongue of the main outcrop belt becomes thicker and encompasses most of the section in the Green Pond outlier.

The High Falls Shale at High Falls contains not only red shales similar to those of the Bloomsburg but also abundant dolomite, fine-grained limestone, and green shale. Ripple marks and desiccation cracks are abundant. These rocks are very similar to rocks within the Poxono Island Formation of eastern Pennsylvania, so the two formations probably grade into each other. The High Falls and Poxono Island are very poorly exposed, and the location of the boundary between them has not been defined. The Binnewater Sandstone, which consists predominantly of crossbedded sandstone near High Falls, loses its character about 6 mi (9.6 km) to the southwest and pinches out within the Poxono Island. Thus, the Binnewater, High Falls, and Poxono Island are all part of a complex carbonate-siliciclastic marginal marine sequence.

The consequence of this study has been to better define the stratigraphic variations in Silurian rocks in southeastern New York. It demonstrates that the name "High Falls Shale" is incorrectly used on the most recent New Jersey State geologic map for rocks that should be referred to as the Bloomsburg Red Beds. Present studies are concentrating on the petrology and sedimentology of these rocks.

A thin diamictite (interpreted to be colluvium), generally less than 1 ft (0.3 m) thick and interbedded with a sticky clay containing slickensided quartz vein fragments (fault gouge), and a deposit of semiconsolidated shale fragments from the Martinsburg Formation (shale-chip gravel) have been found at several localities between the Martinsburg and Shawangunk Formations in southeastern New York. The diamictite is dark yellowish orange and consists of a poorly sorted, semiconsolidated mixture of angular to rounded clasts in a sand-silt matrix. The clasts comprise fragments of the underlying Martinsburg, quartz pebbles similar to those found in the overlying Shawangunk, and exotic pebbles and cobbles that are dissimilar to rock types immediately above or below the unconformity. Many cobbles show evidence of exposure to weathering prior to incorporation in the diamictite. The source of the pebbles is enigmatic and is still under investigation.

These data add an interesting, hitherto unrecognized, chapter to Late Ordovician paleogeography in the central Appalachians during the Taconic hiatus, a period of 20 to 30 million years. They suggest Taconic uplift of deep-water Martinsburg shales and graywackes, subaerial exposure, deposition of colluvium and shale-chip gravel, and incorporation of exotic pebbles and cobbles in the diamictite. Much of this material was subsequently removed during pre-Shawangunk erosion, and only scattered occurrences remain. The exotic clasts were derived from a source that is no longer exposed nearby. Perhaps the source was in Taconic thrust sheets that were subsequently eroded. These deposits were later covered by the coarse clastic sedimentary rocks of the Shawangunk Formation during Middle Silurian time.

REFERENCE CITED

Hartnagel, C.A., 1905, Notes on the Siluric or Ontario section of eastern New York: New York State Museum Bulletin 80, p. 342–358.

The Origin of the Pennsylvania Salient and CDP Seismic Imaging of the Cornwall-Kelvin Displacement along the U.S. Atlantic Continental Margin

Robert C. Milici[1] and Kenneth C. Bayer

Except for the Pennsylvania salient, the major salients and recesses of the central and southern Appalachians show little or no relationship to deflections of regional gravity and magnetic trends. Nevertheless, it has been postulated that all of these salients and recesses have a common origin and are inherited from the configuration of the Late Proterozoic North American continental margin that was formed upon the opening of the Iapetus Ocean. In contrast, we postulate that the Pennsylvania salient is a unique, younger feature. As such, it was formed by differential movement along an east-west-trending right-lateral shear during the early Mesozoic opening of the Atlantic Ocean.

The latter hypothesis relates movement along this east-west-trending fracture zone (the Cornwall-Kelvin displacement) to the Kelvin seamounts, the deformed Mesozoic strata in the narrow neck between the Newark and Gettysburg Mesozoic basins, and the conspicuous right-lateral bending of major geologic and geophysical features from the Pennsylvania salient to the Atlantic Ocean. The fracture zone apparently propagated both landward and seaward from the postrift continental margin. On the continent, the zone is buried beneath strata of Cretaceous age and younger; however, it can be identified on CDP (Common Depth Point) seismic profiles along the continental shelf between the deepest part of the Baltimore Canyon

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trough and the Long Island platform. North-northwest-directed compressional forces generated by this right-lateral shear may be the cause of some of the deformation reported by other workers in the Appalachian Plateau regions of New York and Pennsylvania.

Lateral Ramps and the Structure of the Central and Southern Appalachians, with Implications for Thrust Belts Worldwide

Howard A. Pohn

Field mapping combined with side-looking airborne radar (SLAR) and with proprietary seismic reflection data demonstrates that lateral ramps are significant structural elements of the Eastern Overthrust Belt.

Lateral ramps, which are zones where decollements change stratigraphic level along strike, are recognized on SLAR data by abrupt changes in fold wavelength along strike or by zones of fold plunges across strike. Other surface criteria for recognition of lateral ramps include conspicuous changes in frequency of faults, long, linear river courses that cross the Piedmont, Atlantic Coastal Plain, or Appalachian Plateau, abrupt changes in strike or presence of gaps in the Blue Ridge, and interruption of eastern Mesozoic basins by east-west border faults or by blocks of Precambrian rocks.

Examination of more than 150 proprietary seismic reflection profiles in the central and southern Appalachians confirms the presence of lateral ramps and shows their detailed configuration in the subsurface. Strike-line reflection profiles across lateral ramps show a structural complexity closely resembling typical dip lines in areas of complex thrust faulting.

Frontal ramps have long been known to control the presence and orientation of folds that form perpendicular to the direction of transport. Data from my study indicate that the sizes and location of these fold plunges are controlled by the change in stratigraphic level of decollements across lateral ramps.

Lateral ramps have been seen throughout the central and southern Appalachians. SLAR and Landsat data indicate that lateral ramps are also present in the Ouachitas, the Western Overthrust Belt, the Brooks Range, northwest Africa, Papua New Guinea, and southeastern China, in effect everywhere that thin-skinned tectonics dominates the style of deformation.

In the Eastern Overthrust Belt, lateral ramps are coincident with nearly 50 percent of modern earthquakes, although the ramps themselves occupy no more than 15 percent of the geographic area. That this localized seismic activity may have ruptured seals above hydrocarbon reservoirs accords with the observation that lateral ramps and hydrocarbon-producing fields are nearly mutually exclusive.

The generation of lateral ramps is believed by the author to be related to the reactivation of a fundamental Precambrian fracture system, and it is hypothesized that this system produced zones of least resistance that became transform faults as continents separated during episodes of sea-floor spreading.

Carboniferous Petrographic Trends in the Central Appalachian Basin: An Orogenic Interpretation

Joseph T. O'Connor

Carboniferous clastic rocks from the central Appalachian basin show petrographic trends in texture and composition that may relate to Alleghanian orogenic activity. The analysis and interpretation of the Pennsylvanian sandstone petrography presented here follow formal stratigraphic subdivisions, but because of unresolved areal differences in nomenclature, the presentation is divided into northern and southern parts. The study is based on the examination of about 500 thin sections of Carboniferous sandstones and on review of work published by other authors.

Upper Mississippian Sandstones

These sandstones tend to be mineralogically mature and deposited in fluvial and (or) coastal environments. They appear to be derived from tectonically stable terranes possibly including igneous and metamorphic rocks to the southeast and the northwest. The sandstone contains predominantly quartz grains, relatively few rock fragments, and 1 to 2 percent rounded and abraded potassium feldspar grains.

Pennsylvanian Sandstones—Southern Area

All of the Pennsylvanian sandstones examined by the author are quartz-dominated clastics (quartz content between 50 and 100 percent). The quartz content of individual stratigraphic units is quite variable, is dependent upon several provenance-related and depositional factors, and is not generally a reliable indicator of depositional environment. Only some siltstone and finer grained rocks had quartz contents below 50 percent, and very few of the coarser sandstone samples had quartz contents greater than 95 percent.

1. The sandstones of the Pocahontas Formation (earliest Pennsylvanian) of Virginia and West Virginia contain relatively abundant potassium feldspar and plagioclase and also contain broken and angular quartz grains. Rare mafic minerals and the textural immaturity of the sandstones

probably indicate increased tectonic activity in the southeastern source area. These immature sandstone units alternate with more mature sandstone units that are similar to those of the Mississippian.

2. The composition of the sandstones of the Early Pennsylvanian New River Formation of West Virginia is markedly different from those of the Pocahontas Formation, although both derived their sediments from the same general southeastward direction. The sandstones of the upper part of the New River Formation consist of a mixture of reworked quartz grains, micaceous and chloritic rock fragments, and clay minerals (detrital and authigenic) and were derived almost wholly from sedimentary and low-grade metamorphic terranes. The sandstones of the lower part of the New River Formation appear to be transitional in composition and texture between those of the Pocahontas Formation and those of the upper part of the New River Formation. The author suggests that a belt of folded and (or) thrusted Paleozoic sedimentary rocks emerged between the eastern orogen and the basin (east of what is now the West Virginia–Virginia border) to create a source for the new feldspar-impoverished sediments for both parts of the New River Formation. This same belt may have blocked off or overwhelmed the sediment source from the older orogen during the time of deposition of the upper part. To the south, in Kentucky and southeastern Virginia, the petrographic trends are poorly understood, but the paleocurrent directions of the Lee Formation equivalents of the New River Formation suggest that sediment for this unit was supplied from both the eastern and northwestern sources.

3. Sandstones of the Kanawha Formation (Middle Pennsylvanian):

A. The sandstones of the lower part of the Kanawha Formation in West Virginia show an abrupt compositional transition from those of the New River Formation. Untwinned albite and twinned oligoclase-andesine are relatively abundant mineral phases in these clastic rocks along with twinned and untwinned potassium feldspar and microperthite. Biotite or chlorite pseudomorphs of biotite and muscovite are more abundant in the lower part of the Kanawha. Relict sedimentary features (partial quartz overgrowths and broken rounded grains) are not as common in the lower Kanawha sandstones, and relict "granitic" and low- to middle-grade metamorphic rock fragments make up some of the clasts of this unit. These features imply that the sedimentary-rock-dominated source area for the upper part of the New River Formation was replaced by one in which igneous and metamorphic rocks were the main components.

B. The sandstones of the middle part of the Kanawha Formation are compositionally similar to those described for the lower part of the formation. The plagioclase to potassium feldspar ratio is variable in these rocks, possibly decreasing in the upper part of the unit, although the total feldspar increases to greater than 10 percent locally. Biotite (or chlorite pseudomorphs) remains as a scant but ubiquitous mineral phase. The occurrence of many marine and brackish-water zones in this part of the section suggests that these rocks were deposited in lower delta plain or near shore environments. The middle Kanawha sedimentary rocks appear to mark a period of continued erosion of an igneous and metamorphic source area.

C. The sandstones of the upper part of the Kanawha Formation are very immature and contain a relatively high percentage of potassium feldspar (4 to 12 percent) as microcline, cryptoperthites and microperthites, and some zoned orthoclase. The plagioclase to potassium feldspar ratio drops noticeably in the upper part of the Kanawha Formation through the diminution of untwinned albite, which is abundant in the lower and middle parts. The relict rock-fragment fabrics indicate that metamorphic rocks were a major contributor to the sedimentary deposits, but surprisingly, neither igneous nor high-grade metamorphic rock fragments have been observed in these sandstones. The freshness of the rock components, however, implies that a high-grade metamorphic and igneous "basement" was close at hand, perhaps as part of an advancing thrust plate that overwhelmed the provenance supplying sedimentary and low-grade rock fragments to the middle part of the Kanawha Formation.

Pennsylvanian Sandstones—Northern Area

1. In the area of study, the Pottsville Formation is represented by the upper Connoquenessing Sandstone Member, the Mercer Member, and the Homewood Sandstone Member, all of Middle Pennsylvanian age. The Pottsville is, therefore, a partial equivalent of the Kanawha Formation. The arenites of the Pottsville Formation in this area are composed of conglomerate and sandstone derived from an entirely sedimentary or low-grade metamorphic source area. High-grade metamorphic and igneous terranes were apparently not exposed to erosion in the source areas for these units during this time.

2. The Allegheny Formation, in northern West Virginia, Maryland, and Pennsylvania, is a sequence of Middle Pennsylvanian fluvial strata that contain a mixture of feldspar-rich and feldspar-impoverished quartzose sandstones. Diagenetic alteration of the sandstones is very extensive in the strata and greatly impairs mineralogic classification. However, the identified mineral and clast contents indicate derivation from a mixture of source terranes that could include sedimentary, metamorphic, and

igneous rocks. The author suggests that, by the time of Allegheny Formation deposition, the Alleghanian orogeny had largely homogenized the source area.

Interpretations of Sedimentary Patterns in the Pennsylvanian of the Central Appalachian Basin

Charles L. Rice

The Pennsylvanian central Appalachian basin was a foreland basin development that was controlled by the emplacement and western migration of thrust sheets on the North American continental margin. Only the northwestern side of the basin, a southeastward-thickening prism of coal-bearing sandstone and siltstone, is preserved. The lack of easily recognizable regional datums, the rapid facies changes of these largely coastal plain deposits, and the ruggedness of the topography of the thicker (as much as 1,450 m) southeastern part of the prism have hampered development of a comprehensive understanding of depositional patterns during the Pennsylvanian. Whereas the distribution of Middle and Upper Pennsylvanian sediments generally agrees with the predicted sedimentary model, that is, an upward-coarsening clastic sequence reflecting westward migration of the orogen and its deltas, the Lower Pennsylvanian contains as a western facies the anomalously coarse-grained and conglomeratic quartz arenites of the New River and Lee Formations. The latter formations have been interpreted as beach and barrier-bar deposits fringing a northwestward-thinning delta complex. However, evidence of fluvial origin for these sandstones is abundant (they contain unidirectional crossbedding, which parallels their broadly linear geometry, and form persistent upward-fining channel-in-channel units that commonly contain plant fossils and thin coal beds), and they are here interpreted as braided-stream deposits for which the emergent craton was an important source area.

The presence of many thin deposits of epicontinental seas in the upper Middle and Upper Pennsylvanian sections in the northwesternmost part of the Appalachian basin and in the Illinois basin has led to an exaggeration of the importance of that area as a depocenter for clastics derived from the Appalachian orogen and has tended to obscure the fact that the essentially linear central Appalachian basin oriented along the continental margin was closed at its northeastern end and open to the south and southwest during much of the Pennsylvanian. This basin configuration is indicated by many southwest- to southeast-oriented channels and paleovalleys filled with Pennsylvanian clastics that have been identified both in outcrop and in the subsurface of the Mississippian/Pennsylvanian unconformity in areas west of the limits of the Pocahontas Formation. These features appear to be part of a coherent southwest-trending drainage pattern that is corroborated by numerous studies of paleocurrent directions in the basal Pennsylvanian sandstones. Thus, the thick (almost 500 m) Lower Pennsylvanian sequences of conglomerates and conglomeratic quartz arenites near the southeastern margin of the Pennsylvanian outcrop belt in southwestern Virginia and southeastern Kentucky are not the conglomeratic facies of northwest-facing deltas as suggested by some workers but represent deposits of braided streams that flowed toward a major southern depocenter that is now largely eroded away. Studies of the distribution and crossbedding of Middle Pennsylvanian strata in this area also may indicate a strong influence of that depocenter on sedimentation patterns and show major southwest sediment transport during that time.

Depositional Trends in Late Paleozoic Coal-Bearing Strata of the Central Appalachian Basin

Kenneth J. Englund and Roger E. Thomas

The deposition of terrestrial coal-bearing strata in the central Appalachian basin began in Late Devonian time in association with westward-prograding delta lobes situated along the eastern margin of the basin. Most sediments were derived from siliciclastic detritus eroded from tectonic highlands that were elevated to the east by plate collision during the Acadian orogeny. During Mississippian time, terrestrial sediments continued to prograde westward in the slowly subsiding foreland basin, and by Early Pennsylvanian time they extended onto the cratonic shelf. Marine deposition prevailed in a shallow epicontinental sea on the cratonic shelf and periodically encroached eastward over the terrestrial sediments. A transition from marine to terrestrial deposition is recorded by time-equivalent sequences of (1) marine limestone and shale, (2) barrier- and offshore-bar sandstone, (3) lagoonal and bay-fill shale, (4) coal and related swamp deposits, and (5) fluvial and deltaic sandstone. Westward progradation was dominant during periods of increasing rainfall and sufficient subsidence to accommodate a high influx of clastic sediments, whereas marine incursions extended eastward during periods of decreasing rainfall and low clastic input. Periods of equilibrium, as during the change from regression to transgression, were accompanied by stillstands of sea level and the development of widespread peat swamps and longshore bars. In Early Pennsylvanian time, the strandline or wedge-out of terrestrial coal-bearing deposits changed from N. 30° E. to N. 65° E., probably in response to collision with the African plate during the early phase of the Alleghany orogeny. As the Appalachian basin evolved and the plates continued to merge, terrestrial deposits extended farther northwestward and, by Middle Pennsylvanian time, occupied the entire central Appalachian basin. The apparent effects of plate collision on sedimentary patterns are reflected also in a similar change in the strike of deformed strata in the faulted and folded Appalachians.

Eocene Igneous Intrusive Rocks of the Central Appalachian Valley and Ridge Province

C. Scott Southworth and Karen J. Gray

Late Eocene basaltic and rhyolitic dikes, sills, plugs, and diatremes intruded Paleozoic rocks of the Valley and Ridge province of the central Appalachian basin. Two main areas of silicic rocks surrounded by basaltic rocks are found in Pendleton County, W. Va., and Highland County, Va. Major-element and trace-element geochemistry of 46 samples of probable Eocene age suggests a mantle or lower crustal source of rift-related origin. Minimal mixing of the igneous rock with crustal rock, little contact metamorphism, and consistent radiometric dates of late Eocene age suggest that the igneous activity was short lived. No evidence of surface extrusions is preserved after 46 m.y. of erosion.

The proximity of Eocene igneous rocks to the western terminus of Late Jurassic igneous dikes suggests emplacement along possibly reactivated basement faults. A change in the regional strike of Jurassic alkalic igneous dikes across the zone indicates a variation in stress during Mesozoic extension. Both concordant and discordant relationships of Eocene rocks with allochthonous Paleozoic country rock allow only generalizations about the structural trend of the crustal fracture. Insufficient geologic data are available to suggest that the basement fracture zone is the eastward extension of the 38th Parallel lineament or a fault of the Cambrian Rome trough.

A possible tectonic model for the Eocene igneous intrusive rocks in this region is extensional reactivation near the intersection of two basement fracture zones, a growth fault parallel to regional strike that is of Paleozoic age and a cross-strike basement fault. Lateral boundaries of duplexes formed in Cambrian-Ordovician carbonate rocks, tectonic ramps at the lowermost decollement above basement, and tear faults that bound allochthonous blocks on the folded Appalachian Plateau province may reflect the basement faults (fig. 1).

The igneous intrusive rocks provide evidence that basement faulting has taken place in the Appalachian Valley and Ridge province since the Alleghanian orogeny. The role that basement fractures played in the thin-skinned deformation and Cenozoic tectonics can be determined only by detailed mapping and subsurface investigations.

The Geologic Framework of the Continental Shelf and Slope of Virginia, with Emphasis on Petroleum Geology

Kenneth C. Bayer and Robert C. Milici[1]

Stratigraphic intervals selected from publicly available seismic common depth point (CDP) reflection profiles from the Virginia Coastal Plain eastward to the continental rise were used to evaluate the oil and gas potential of the Virginia onshore-offshore area. Our reconnaissance seismic survey consisted of 729 statute miles (1,173 km) of profiling across approximately 15,000 mi^2 (38,850 km^2).

Four identified stratigraphic reflectors (top Upper Cretaceous, top Lower Cretaceous, top Upper Jurassic, and an acoustic basement reflector) were correlated with the COST (Continental Offshore Stratigraphic Test) B–2 well. Depths were calculated from the same traveltimes from which isopach and structure contour maps were constructed. Preliminary results from the Shell B–92–1 well, drilled through Cenozoic and Mesozoic strata, offshore Virginia, and from wells adjacent to our Virginia study area, indicate low source-rock quality and thermal immaturity for Cenozoic and Mesozoic rocks. Therefore, deposition was probably in an oxidizing, open-shelf environment.

On the Continental Shelf, the acoustic "basement" reflector (ABR) is generally the most dominant, continuous band of seismic energy on the seismic profiles. The band suggests a relatively dense, thick sequence of dolomite or limestone. The postrift (probably Early to Middle Jurassic) ABR overlies older Triassic synrift basins, such as the Norfolk basin, offshore Virginia, and may act as a seal or trap.

Offshore Mesozoic basins, the Norfolk for example, and onshore concealed Mesozoic basins, such as the Taylorsville basin, may contain sandstones, shales, and interbedded carbonates analogous to the exposed Triassic basins of eastern Canada and the United States. The depth of burial of the basins is insufficient to create the thermal maturation temperatures necessary for the generation of liquid hydrocarbons. However, the basin's rocks could act as reservoirs if hydrocarbons migrated laterally from offshore strata of equivalent age or vertically from older Paleozoic strata.

Although defined seismically, and as yet untested, stratigraphic traps on the Outer Continental Shelf may be important in future wildcat drilling. Recent offshore drilling indicates Middle to Upper Jurassic rocks as the most favorable hydrocarbon source rocks. Thus, the updip pinch out of the Jurassic, west of seismic CDP line 10 and east of the Virginia coastline, may be a suitable target for hydrocarbon exploration. Offshore from Virginia, additional

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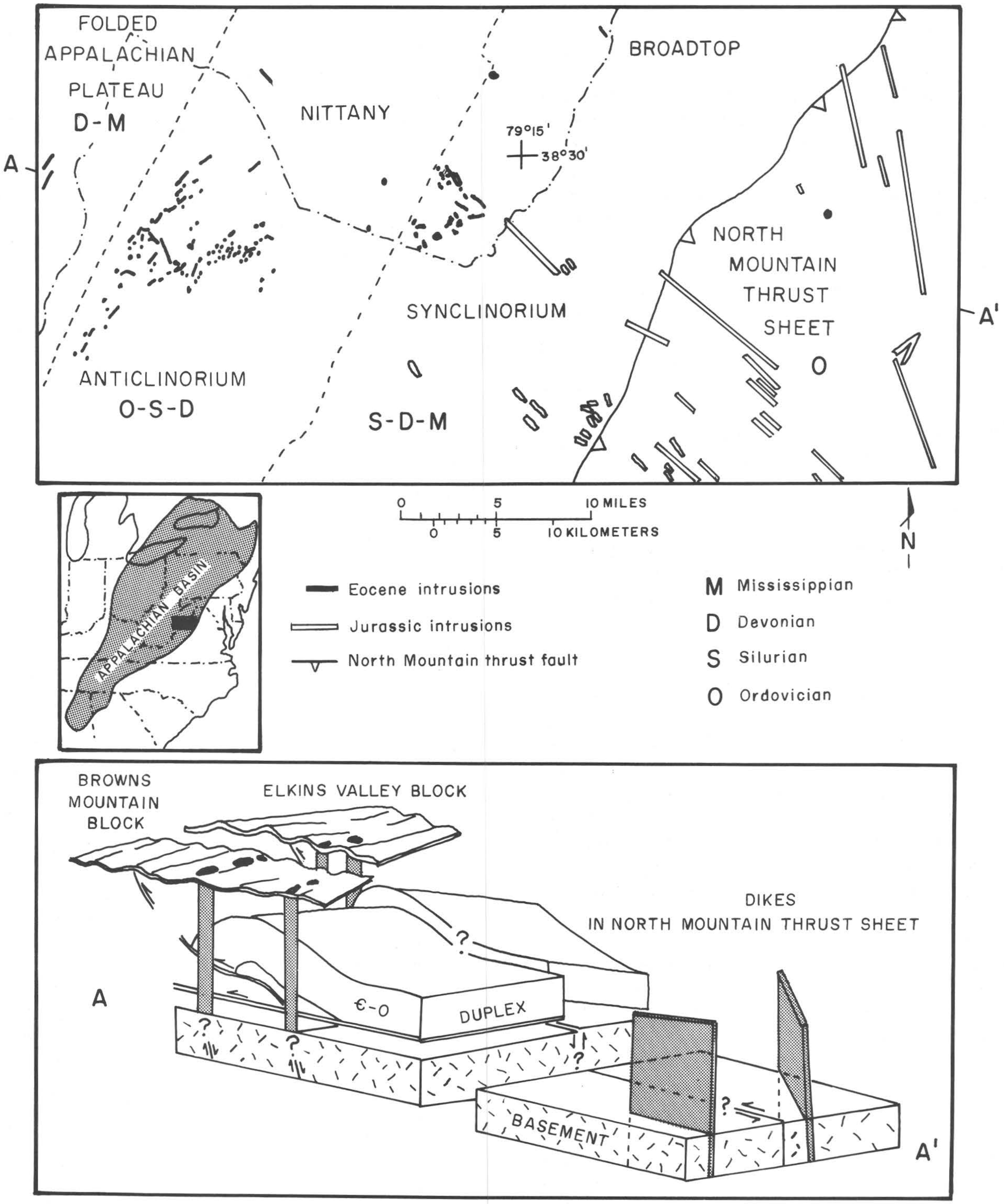

Figure 1. Tectonic model for the Jurassic and Eocene igneous intrusive rocks of the central Appalachian Valley and Ridge province. Extensional reactivation near the intersection of a growth fault and cross-strike fault in basement rocks may relate to Alleghanian cross-strike structures. €, Cambrian. [Southworth and Gray abstract]

stratigraphic, clastic-wedge traps near the shelf edgepinch out against the ABR and Upper Jurassic to Lower Cretaceous rocks, which are reef or carbonate bank deposits on the continental slope. On the Outer Continental Shelf, horsts and grabens in older, prerift Paleozoic strata are identified as possible traps for hydrocarbon accumulations.

We rate the potential of the Virginia continental margin to contain commercially recoverable hydrocarbons as fair (moderate) to poor (low). Structural traps on the continental slope may continue as prime drilling objectives; however, we suggest employing a drilling program to evaluate stratigraphic traps on the Continental Shelf. In shelf waters, drilling at a depth of 20,000 ft (6,100 m) is recommended to explore below the acoustic basement rocks for either locally derived or migrated hydrocarbons.

Petrographic Characteristics of the New River Formation of the Central Appalachian Basin

Joseph T. O'Connor and Nelson L. Hickling

The New River Formation lies stratigraphically between the lowest Pennsylvanian Pocahontas Formation and the lower Middle Pennsylvanian Kanawha Formation of the central Appalachian basin in Virginia, West Virginia, and Kentucky. The Pocahontas and Kanawha Formations contain abundant clastic sedimentary rocks that were derived from igneous and medium- to high-grade metamorphic source rocks; paleocurrent measurements from West Virginia indicate that the source areas for all three formations are to the southeast of the current location of the basin.

Examination of more than 200 thin sections of surface and core samples from sandstones of the New River Formation and perusal of existing petrographic data show that this formation may be separated petrographically into two parts. The upper part of the New River Formation, which is here defined as all units from the top of the Nuttall Sandstone Member down to the top of the Raleigh Sandstone Member, is characterized by a very low (biotite + chlorite)/muscovite ratio and a virtual absence of feldspar. Some sandstone units in the lower part of the New River Formation, which includes all units from the top of the upper Raleigh Sandstone Member to the bottom of the formation, are characterized by a moderate (biotite + chlorite)/muscovite ratio and moderate to abundant quantities of feldspar. A coarse-pebble channel-filling conglomerate in southwestern Virginia has been correlated with the lower part of the New River Formation by Englund and Thomas (USGS Research on Energy Resources–1988 Program and Abstracts, U.S. Geological Survey Circular 1025). This conglomerate contains pebbles of arkosic sandstone and metasandstone, granitic igneous rocks, and high-grade metamorphic rocks. The arkosic sandstone and metasandstone pebbles are mineralogically and texturally similar to Cambrian Chilhowee Group sandstone.

Because the upper part of the New River Formation lacks mineral phases of igneous or high-grade metamorphic derivation and because an effective depositional mechanism for removing such phases from the host rock does not appear to occur in this area, we conclude that the upper part of the New River Formation was derived from a sedimentary and low-grade metamorphic source area. The source rocks were almost certainly the earlier Paleozoic section now exposed in the fold-and-thrust belt of the Appalachian basin. The lower part of the New River Formation exhibits a compositional transition between the Pocahontas Formation provenance, which included igneous and metamorphic rocks from the Late Mississippian orogen, and the mainly sedimentary provenance of the upper part.

Economic Geology of the Big Chimney Quadrangle, Kanawha County, West Virginia

John F. Windolph, Jr.

Recent geologic mapping of Pennsylvanian strata in the Big Chimney quadrangle 2.5 mi (4 km) northeast of Charleston, W.Va., suggests a possible association between syntectonic depositional influences and the occurrences of economically important mineral deposits. Coal and flint clay were deposited in the Middle Pennsylvanian Charleston Sandstone during periods of stillstand. The Mahoning sandstone is disconformable with underlying strata and locally contains Precambrian and Early Paleozoic pebbles. The member is thick in synclinal troughs and thin or absent on the crests of anticlines. These anticlines also have a thinner underlying stratigraphic sequence.

Flint clay deposits reach their maximum quality on the crests of anticlines and in areas adjacent to suspected paleotopographic highs. These deposits are laterally gradational with underclay, ganister, and paleosol. The Elk fire clay (No. 6 Block underclay) may in part have originated as a volcanic ash fall. The No. 5 Block coal bed reaches 60 in (152 cm) in thickness on the Milliken anticline and has minor fault displacement at Big Chimney. The Pittsburgh coal bed is as much as 90 in (229 cm) thick, cropping out in high ridges. It is absent on the northern edge and eastern part of the quadrangle.

More than 260 oil and gas wells have been drilled in the overlapping Elk-Poca, Big Chimney, and Blue Creek gas or oil fields. Natural gas, paraffin-base oil, and (or) minor amounts of condensate are produced from structural and stratigraphic traps in four units: the Weir sand and the Oriskany, Keefer, and Tuscarora Sandstones. The Oriskany Sandstone, however, is used almost exclusively as a gas storage reservoir. Oil is produced largely from repressurized stripper wells.

Table 1. Stratigraphic nomenclature and correlations of the Chilhowee Group in the central and southern Appalachians

[Thickness in meters]

Age		Southern Appalachians				Central Appalachians	
		East-central Tennessee Chilhowee Mountain			Northeasternmost Tenn. to SW. Virginia	NE. Roanoke to Northern Virginia	South Mountain, Maryland and Pennsylvania
Cambrian	Lower Cambrian	Shady Dolomite			Shady Dolomite	Tomstown Dolomite	Tomstown Dolomite
Cambrian	Lower Cambrian	Chilhowee Group	Erwin Formation	Helenmode Member 35–45 Hesse Quartzite Member 203–210 Murray Shale Member 50–110 Nebo Quartzite Member 35–108	Erwin Formation 200–550	Antietam Formation 200–330	Antietam Formation 130–275
Cambrian	Lower Cambrian	Chilhowee Group	Nichols Shale 40–145		Hampton Formation 380–558	Harpers Formation 340–520	Harpers Formation 105–800
Proterozoic to Cambrian (?)	Upper Proterozoic to Lower Cambrian (?)	Chilhowee Group	Cochran Formation* 110–185		Unicoi Formation 300–755	Weverton Formation 120–470	Weverton Formation 490–658
Proterozoic to Cambrian (?)	Upper Proterozoic to Lower Cambrian (?)	Ocoee Supergroup			Mount Rogers Formation	Basement Rocks; Catoctin Formation and Swift Run Formation	Basement Rocks

* Fault truncation

Stratigraphy, Sedimentology, and Economic Potential of the Chilhowee Group in the Central and Southern Appalachians

K.Y. Lee

A detailed stratigraphic and sedimentologic study of the Lower Cambrian Chilhowee Group has been carried out along the outcrops flanking the Blue Ridge anticlinorium in the central and southern Appalachian orogen. The purpose of this study is to clarify the provenance, stratigraphic sequences, depositional framework, and economic potential of sedimentary rocks of the Chilhowee Group.

The outcrops of the Chilhowee Group in the study area occupy a part of the eastern border of the Appalachian basin, and they cover an area of about 46,000 km^2 that include parts of southern Pennsylvania, west-central Maryland, northeastern West Virginia, northern, central, and southwestern Virginia, and northeasternmost and east-central Tennessee. In the southern Appalachians, the Chilhowee Group in the Chilhowee Mountain of east-central Tennessee consists, in ascending order, of the Cochran Formation, Nichols Shale, and Erwin Formation (table 1). The Erwin is, however, divided into the Nebo Quartzite, Murray Shale, Hesse Quartzite, and Helenmode Members. In northeasternmost Tennessee and southwestern Virginia, this group consists of the Unicoi, Hampton, and Erwin Formations. In the central Appalachians, the Chilhowee Group from central Virginia to the South Mountain of Pennsylvania consists, in ascending order, of the Weverton, Harpers, and Antietam Formations (table 1). Generally, the Chilhowee Group is made up of terrestrial and marine, detrital, very fine-grained to pebbly quartz-conglomeratic sedimentary rocks, locally containing thin tholeiitic basalt flows; the Chilhowee Group attains a thickness of 1,863 m in the Washington County, Va., and 1,723 m in the northern part of South Mountain, Pa. Most of the lower Chilhowee Group is characterized by the arkose, arkosic sandstone, and graywacke intercalated with the transverse to linguoid and longitudinal pebbly quartz-conglomeratic sheets and lenses. Planar crossbedding in which the angles of inclination are greater than 10° is common, and trough crossbedding and ripple marks are present locally throughout this clastic sequence. The upper part of the lower Chilhowee Group and the middle and upper Chilhowee Group consist chiefly of thin- to massive-bedded quartzite, arkosic sandstone, mudstone, and shale and are characterized by herringbone cross-stratification, horizontal lamination, and planar crossbedding having angles of inclination less than 10° and locally in the upper part of this sequence have well-developed ripple marks.

During the Late Proterozoic, the initial depositional framework of the Chilhowee Group along the eastern margin of the North American craton consisted of intracratonic rift-faulted depressions in association with plate fragmentation within the Grenville basement rocks. Those rifted depressions were filled with the detrital sedimentary rocks and volcanic flows of the Catoctin and the Mount Rogers Formations and the clastic sedimentary rocks of the Ocoee Supergroup. As the sedimentation proceeded within individual depressions, successive subsidence events subsequently permitted the continuation of the deposition of most of the lower Chilhowee detrital sedimentary rocks on broad flood plains by the braided drainage systems in the southern Appalachians and as a coalescent fan and deltaic system in the central Appalachians. During this time, an aulacogen existed that separated the central Appalachians from the Southern Appalachians near Roanoke, Va. Linear, sheeted arkose and arkosic sandstone within a thick black shale sequence attest to this transition. As subsidence proceeded during extensional tectonics, transgression occurred from the east. Thereafter, detrital sediments of the upper part of Cochran, Unicoi, and Weverton Formations, the Nichols Shale, and the Hampton and Harpers Formations were deposited in a marine shelf environment; the Erwin and Antietam Formations were deposited in a marine coastal environment under a relatively stable tectonic regime. The Chilhowee strata formed a wedge-shaped sedimentary body that thickened seaward toward the shelf edge and thinned out toward the ocean basin at the time of deposition. In places, the Chilhowee sequence is conformable with underlying detrital sedimentary rocks believed to be found within individual depressions. Elsewhere, this sequence unconformably overlies older granitic and metamorphic rocks. Discovery of the trace fossil *Rusophycus* in the upper part of the Unicoi Formation of southwestern Virginia places the age of the Chilhowee Group into the Lower Cambrian. Age of the lower part of Chilhowee would depend on more precise radiometric dating of underlying rocks of the Catoctin Formation that give conflicting dates of U-Pb age (810 m.y.) and Rb-Sr age (570 m.y.).

Framework modes of the Chilhowee sandstones based on the triangle diagrams of quartz and feldspar grains and on lithic fragments with three auxiliary plots suggest that the multicyclic sands of the Chilhowee were derived from the granitic highlands of the North American craton to the west and northwest. Monocyclic sands were derived from the granitic and metamorphic terranes of a nearby magmatic arc along the rifted continental margin. Chemical analysis of seven shale samples from the Nichols Shale, Hampton Formation, and the Murray Shale Member, Tenn., and the Harpers and Antietam Formations, east of Buena Vista, Va., confirms that the mode composition of Chilhowee sandstones was chiefly derived from the granitic terranes. The Chilhowee shales are high in Al_2O_3, K_2O, and TiO_2 and low in SiO_2, Fe_2O_3, MgO, CaO, Na_2O, and P_2O_5. In comparison with younger Paleozoic shales, these data signify a change of shale composition over time. Generally, older shales are more enriched in K_2O and depleted in Na_2O and CaO than younger shales are. A maturity index, $M = Al_2O_3 + K_2O / MgO + Na_2O$, has been used for differentiating Paleozoic stratigraphic sequences and provenance siting. High content of TiO_2 indicates the high concentration of ilmenite minerals in the detrital sediments.

Organic carbon in two black shale samples, one from the Nichols Shale and the other from the Murray Shale at the Chilhowee Mountain in Tennessee, shows less than 0.1 percent organic carbon. Pyrolytic hydrocarbon yields are low, 0.08 and 0.03 mg/g, respectively. It is unlikely these shales warrant consideration as petroleum source rocks (G.E. Claypool, written commun., 1987). Extensive silica sands from the Erwin Formation have been quarried in central Virginia and South Mountain of Pennsylvania. High concentrations of zircon and ilmenite locally from the Hampton, Harpers, Erwin, and Antietam Formations have important resource potential throughout the study area.

Provenance and Depositional History of the Fincastle Conglomerate of Southwestern Virginia

Nelson L. Hickling and Harvey E. Belkin

The Middle Ordovician Fincastle Conglomerate is preserved in a tightly folded, overturned syncline near the town of Fincastle, southwestern Virginia. It crops out for a distance of 2.7 km along the strike of the synclinal axis. The conglomerate conformably overlies the Liberty Hall Shale and is conformably overlain by probable Martinsburg Formation, both marine units. The Fincastle, as much as 55 m thick, is composed of beds and lenses of conglomerate from 0.15 to 12 m thick interbedded with shale and siltstone. Some of the individual conglomerate beds have a siltstone to sandstone matrix, whereas others have a graywacke matrix.

The present study includes detailed sampling (1,656 clasts) of the conglomerate and subsequent chemical, petrographic, X-ray diffraction, dimensional, and scanning electron microscope (SEM) analysis. Table 1 compares previous descriptions of the Fincastle Conglomerate lithologies with the results of the current study.

We have not identified dolostone, dolomitic cement, or high-grade metamorphic clasts. Dimensional analysis

Table 1. Clast lithologies of the Fincastle Conglomerate as previously reported and found in this study

Stow and Bierer, 1937	Butts, 1940	Kellberg and Grant,[1] 1956 (in percent)	Karpa,[2] 1974 (in percent)	This study,[3] (in percent)
"...largely pebbles of diabase"	"...mostly gray quartzite"	limestone 38.6 quartzite 29.0 vein quartz 22.1 sandstone and siltstone 5.7 chert 3.7 other .9	limestone 6.0 dolostone 2.7 vein quartz 13.0 sandstone and siltstone 75.0 chert 2.0	limestone 31.2 quartzite and metasandstone 30.6 vein quartz 17.2 sandstone and siltstone 11.7 chert 5.9 other 3.4

[1] Based on >1,000 clasts.

[2] Data are an unweighted average of three separate collections.

[3] Based on 1,656 clasts identified at Big Gulch and at the new excavated exposure at the Dixon Construction Co. site on U.S. 220, 1.8 km north of Fincastle, Va.

Butts, C., 1940, Geology of the Appalachian Valley in Virginia: Virginia Geological Survey Bulletin, pt. 1, 129 p.

Karpa, J.B., III, 1974, The Middle Ordovician Fincastle Conglomerate north of Roanoke, Virginia and its implications for Blue Ridge tectonics: unpublished M.S. thesis, Virginia Polytechnic Institute and State University.

Kellberg, J.M., and Grant, L.F., 1956, Coarse conglomerates of the Middle Ordovician in the southern Appalachian Valley: Geological Society of America Bulletin: v. 67, p. 697–716.

Stow, M.H., and Bierer, J.C., 1937, The significance of an Athens Conglomerate near Fincastle, Virginia [abs.]: Virginia Academy of Science Proceedings, 1936–1937, p. 71.

indicates that the clasts are subrounded to rounded and range in size (long dimension) from 0.5 to 21 cm (4.5 cm average).

Removal from the matrix has shown that all the clasts are coated by a thin layer of material that resembles desert varnish. The color of this layer ranges from yellow orange and tan to brown and brownish black. The clast/coating bond varies in strength, although most clasts retain some portion of the coating after removal from the matrix and preparation of polished sections. Examination by SEM (energy dispersive analysis) has been used to characterize the coating chemically and mineralogically. All the clasts have a clay coating composed of an iron-bearing potassium clay approximately 10 to 30 m thick. Another coating layer, common on 50 percent of the clasts, is composed mainly of titanium (oxide?) with minor amounts of clay. This titanium-rich layer (10 to 20 m thick) occurs either directly on the clast substrate or on the iron-bearing potassium clay layer. A manganese-rich layer was found on only two clasts.

A model for the depositional history and provenance of the Fincastle Conglomerate must address the following constraints: (1) the conglomerate is within a margin sequence, (2) the clasts are subrounded to rounded, (3) the clasts are composed of a wide variety of lithologies including major amounts of limestone, (4) no high-grade metamorphic clasts were identified in this study, and (5) a coating similar to desert varnish is found on all the studied clasts. We propose that the conglomerate represents material from alluvial fan deposits that was rapidly transported to a marine environment near the source. The alluvial fan(s) formed in an arid or semiarid environment from an upland (high-energy) drainage area to the east or southeast. The uplands were probably associated with a stage of the Taconic orogeny (the Blountian phase; Rodgers, 171, Geological Society of America Bulletin, v. 82, p. 1141–1178). However, the erosion was insufficient to produce clasts of the underlying metamorphic basement. The Fincastle clasts probably represent Lower Cambrian to Middle Ordovician source rocks. The presence of abundant limestone clasts and a "desert varnish" coating strongly suggests rapid transport from the uplands source to form alluvial fans in an arid or semiarid environment. Titanium-rich desert varnish has not been reported to have formed in current desert environments; further study is in progress to characterize this unusual occurrence more completely. Tectonic and (or) climatic changes could have resulted in rapid erosion and subsequent deposition in the proximal marine environment.

Anticlines of the Copper Creek–Narrows Thrust Block, Southwestern Virginia

Robert C. McDowell

The Roanoke reentrant marks the boundary between the southern Appalachians and the more northerly striking central Appalachians. Northeast of the juncture, folds predominate in the foreland fold-and-thrust belt; southwest of Roanoke, thrust faults are more common. In the Tennessee salient of the southern Appalachians, a succession of southeastward-dipping homoclinal sequences are separated

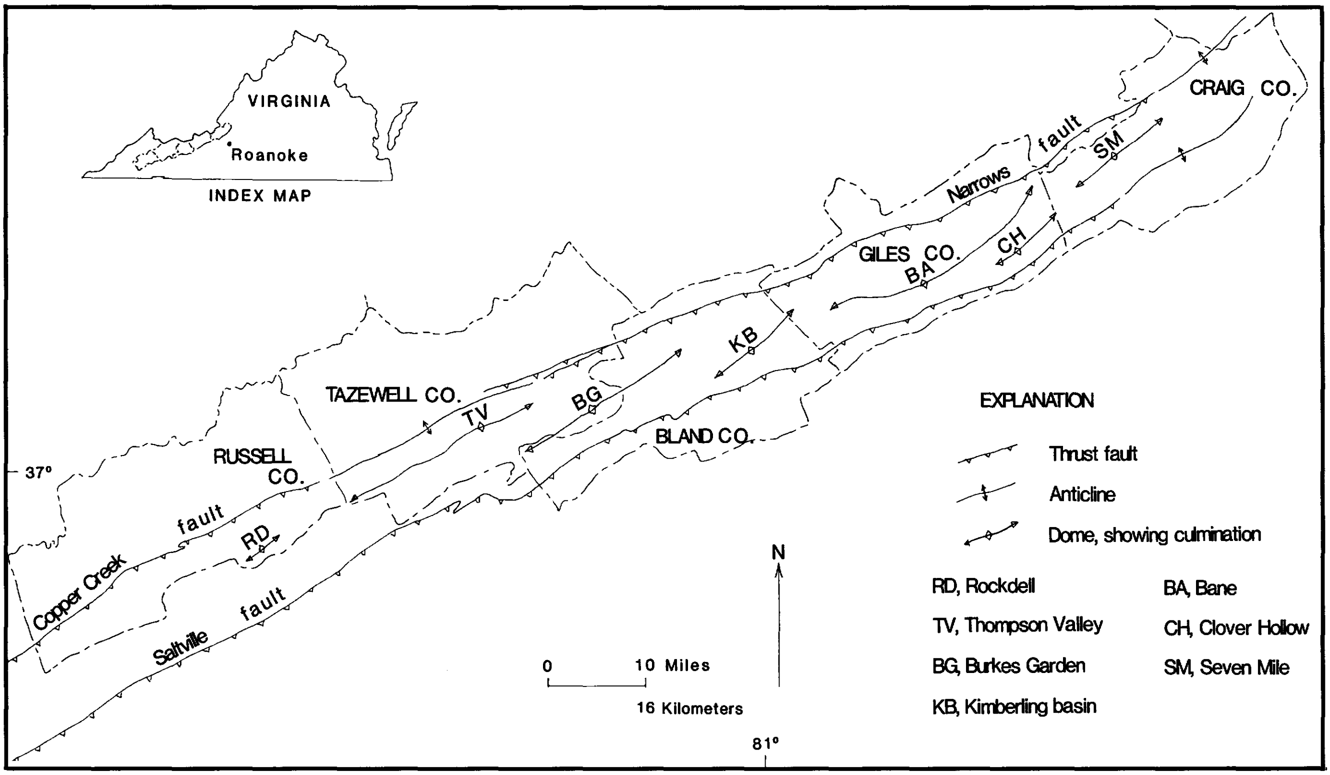

Figure 1. Anticlines and domes of the Copper Creek–Narrows fault block.

by imbricate thrusts. In southwestern Virginia, however, at the northeastern end of the southern Appalachians, thrusts are fewer, and several thrust sheets contain first-order folds. Unlike the relatively long, linear folds of the central Appalachians, folds in southwestern Virginia are relatively short, and anticlines are particularly conspicuous. Many folds have axial trends that are oblique to the regional trends of the thrusts. The most striking examples of these anticlines occur in the Copper Creek–Narrows thrust block (fig. 1).

The Copper Creek–Narrows thrust system extends from the Roanoke reentrant southwestward for about 480 km. It has a gap of about 40 km in Tazewell County, Va., where the thrust shortening is transferred to an anticline (fig. 1). The Copper Creek–Narrows block, bounded on the southeast by the Saltville fault, contains a series of doubly plunging anticlines or domes extending southwestward from the Roanoke juncture for about 200 km (fig. 1). These domes range in length from 3 to 19 km and in structural relief from 300 to several thousand meters. As shown on figure 1, their axial surfaces strike a few degrees more northerly than the bounding thrust faults, the result being in an en-echelon arrangement as first noted by Cooper (1944, p. 197). Recent mapping by McDowell (1988) has shown that a domal structure consistent with this pattern occurs in the Kimberling basin of eastern Bland County, Va. (fig. 1). Although this structure was first noted by Campbell (1896), more recent workers have overlooked it (Butts, 1933; Cooper, 1961, pl. 21), and the Kimberling basin has been described as an example of "contemporaneous downwarp" of a "depositional syncline" containing an abnormally thick section of Devonian clastic rocks (Butts, 1940, p. 460; Cooper, 1964, p. 108–109; Thomas, 1977, p. 1249). The recognition of an anticline in the Kimberling basin obviates the need to consider the section anomalously thick and removes the basis for postulating contemporaneous subsidence.

Origin of the anticlines of the Copper Creek–Narrows block is problematic. Many published interpretations of the Bane dome show a thrust ramp under the anticline. One of these interpretations, based on seismic reflection data, suggests that a subsurface duplex of horse blocks at a ramp is responsible for the dome (Gresko, 1985, p. 49). It is unclear, however, how the ramping of a sole thrust, as commonly suggested, would produce a series of doubly plunging en-echelon anticlines. Two alternative explanations follow. The structures may have been formed during central Appalachian folding and modified by later southern Appalachian thrusting. They would, thus, represent an interference pattern produced by nonsynchronous and nonparallel Alleghanian deformation of the two Appalachian segments at the Roanoke juncture. Or, the folds may have formed in response to a wrench-fault component acting on the Copper Creek–Narrows block.

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Silurian Stratigraphic Changes and Their Effect on the Distribution of Large Bedrock Landslides, Appalachian Valley and Ridge Province

Calvin R. Wiggs and Arthur P. Schultz

Large bedrock landslides have been recognized recently in the Appalachian Valley and Ridge province of eastern North America. Individual failures can be several kilometers in length and involve a hundred meters of stratigraphic section. Most of the landslides involve Silurian rocks that form the dip slopes of the major mountain ridges. Thickness and lithologic changes in the Silurian rocks of the Valley and Ridge may be important factors that control the size, distribution, and frequency of these large slope failures. Silurian formations that make up the landslides compose a three-part lithotectonic unit: an upper part of sandstone and quartzite (Keefer Sandstone), a middle part of shale, siltstone, and sandstone (Rose Hill Formation), and a lower part of sandstone and quartzite (Tuscarora Sandstone). The Keefer Sandstone and the upper part of the Rose Hill Formation are the main rock units in the landslides. The majority of the slope failures occur in a zone approximately 160 km long near Roanoke, Va., where dip slopes of mountain ridges exhibit the three-part lithotectonic unit, characterized by a thick (36–91 m) Keefer Sandstone. Stratigraphic changes in the Keefer Sandstone have the most dramatic effect on modifying the three-part lithotectonic unit. Northeast of Roanoke, in northern Virginia, Maryland, and Pennsylvania, the Keefer thins to 10 m or less. Southwest of Roanoke, in southwest Virginia and Tennessee, the Keefer Sandstone and, locally, the entire lithotectonic unit are missing because unconformities occur in the Silurian and Devonian stratigraphic section. In general, the amount of missing section increases from west to east and from northeast to southwest in the Valley and Ridge of southwest Virginia. These stratigraphic changes are significant because major landslides occur only where a thick Keefer Sandstone is present.

While stratigraphy alone does not control the distribution of the landslides (structural dip, topographic relief, and landslide triggering mechanisms are also important factors), it has a major influence over the distribution of bedrock landslides in the Appalachian Valley and Ridge province. Recognizing the stratigraphic controls on the distribution of the Valley and Ridge bedrock landslides may prove useful in evaluating and predicting future landslides.

Central Appalachian Transect: Geology of the Radford, Virginia, 1° Quadrangle

Mervin J. Bartholomew,[1] Arthur P. Schultz, and Robert C. McDowell

From southeast to northwest, the Radford, Va., 1° quadrangle traverses the Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau physiographic provinces. These physiographic provinces contain rocks that range in age from Middle Proterozoic through Mesozoic and contain a record of the sedimentologic and structural evolution of this part of the central Appalachian basin. Detailed 1:24,000-scale mapping and structural analysis have resulted in a comprehensive synthesis across this part of the fold-and-thrust belt.

Structural domains of the Blue Ridge thrust sheet include 1.1-b.y.-old Grenville basement of the Lovingston and Pedlar Massifs and Lower Cambrian rocks of the Chilhowee Group. Structural analysis indicates multiple folding in the Blue Ridge massifs and transposition of older foliations along the Rockfish Valley ductile deformation zone. The basement and cover rocks that were subjected to metamorphism and ductile deformation during the middle and late Paleozoic subsequently were thrust westward over

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Valley and Ridge sedimentary rocks during the late Paleozoic Alleghanian orogeny.

West of the Blue Ridge fault, the Pulaski fault system consists of a complex series of Alleghanian thrusts that can be distinguished from faults to the east by a thick broken formation in the hanging wall of the fault, ubiquitous tectonic breccias, and numerous fensters and duplexes. The Pulaski fault system, like the Blue Ridge fault, ramps westward from a thrust well below the Cambrian Rome Formation. The Rome is the major lower level decollement of thrust faults west of the Pulaski fault system. Palinspastic reconstructions based on facies analysis combined with balanced cross sections have shown that minimum shortening for the complex Pulaski thrust system is about 80 percent and that shortening for thrusts in the western part of the Valley and Ridge is about 15 percent.

Large-scale folds are in the hanging walls of three major southeast-dipping thrust faults west of the Pulaski thrust system in the western part of the Valley and Ridge province. Decollements are located in the Cambrian Rome Formation, the Ordovician Martinsburg and Moccasin Formations, and the Devonian Millboro and Brallier Formations. Mesoscopic deformation (cleavage, small-scale intense folding, and fracturing) is concentrated in these lithotectonic units. The Saltville and St. Clair thrust faults lose displacement in large anticlines (fault propagation folds) near the central-southern Appalachian junction zone. The Narrows thrust loses displacement in an imbricate fan that apparently continues into the central Appalachian fold belt.

The Alleghany structural front separates thrust-faulted and folded rocks of the Valley and Ridge from gently folded rocks of the Appalachian Plateau. The axis of the Glen Lynn syncline, a subthrust fold in the footwall of the St. Clair fault, is the structural boundary of the two provinces. The gentle folds of the Appalachian Plateau probably formed above minor blind thrusts that propagated westward from a Devonian-level decollement in the Valley and Ridge into the plateau.

Cenozoic Epidermal Gravity Tectonics of the Colorado Front Range and Appalachian Valley and Ridge Province

Arthur P. Schultz

Recently recognized large epidermal gravity slides, some as much as 5 km long, in the Appalachian Valley and Ridge province are found in similar stratigraphic, structural, and geomorphic settings as are previously described large bedrock blockglides of the Colorado Front Range. In both settings, slope failures have occurred over periods of millions of years and involve many single events of up to a billion cubic meters of rock. Epidermal slide sheets have similar cross-sectional geometries and styles of internal deformation. This deformation consists predominantly of folding within the sheet and minor fracturing along the basal shear surface. Comparable emplacement kinematics include slip along bedding on the higher parts of the dip slope and movement across a shear plane lower on the slope. Modification of the gravity slides following emplacement consists of large-scale slumping and colluviation. In areas of massive slope failure, geologic elements common to both the Appalachians and the Front Range are dip slopes in an elevated terrain, a distinctive three-part lithotectonic unit of high anisotropy, a history of climate extremes, and possible paleoseismic activity. These features have been misinterpreted previously as deep-seated compressional structures in both the Front Range and the Valley and Ridge. Thus, recognizing epidermal gravity failures is critical in correctly deciphering both past and more recent structural evolution of these mountain belts. Detailed comparative studies of these features have led to criteria needed to recognize them in similar geologic settings elsewhere.

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