Stratigraphy and Conodont Paleontology of Late Silurian-Early Devonian Strata of Western Virginia

by

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Table of Contents

List of Figures

List of Tables

Introduction

The Helderberg Group and strata immediately above and below it reveal stratigraphic relationships including unconformities, facies changes, wedge-outs, and thickness changes over a relatively small area between the Jackson River and Fagg, Virginia. Facies relationships within the Helderberg Group present an interesting study which indicates increasing terrigenous clastic content within carbonate units as they approach the clastic source area. Sandstone units within the Helderberg Group and the Late Silurian Keyser Formation offer additional information about the location of the source area and the overall facies package. A locally restricted occurrence of the polymictic conglomerate facies of the Ridgeley Sandstone at Fagg, Virginia, is of particular interest. Clasts in the conglomerate have been derived from several of the lower Paleozoic rock units in the surrounding area.

The stratigraphic relationships as presented in a fence diagram (fig. 8) are a complex mosaic of unconformities, wedge-outs, and oversteps. To the northeast, the Late Silurian-Early Devonian section is complete; to the southwest, unconformities and wedge-outs have produced major hiatuses in the section.

Unconformities at the Fagg, Catawba, and Goode quarry sections reveal substantial relief on the unconformity surfaces which occur in the stratigraphic interval between the Silurian Tuscarora and Devonian Ridgeley Sandstones.

Wedge-outs may be in part responsible for the relief found on the unconformities in southwestern exposures of the Late Silurian-Early Devonian section. Within the study area, the Tonoloway Formation is not found southwest of the Johns Creek section although, it may be present as a sandy facies in the upper "Keefer" at Catawba (Tillman, 1963). The Keyser Formation which is represented by more than 100 feet (30.4 m.) of thickness in the New Castle area is reduced to ten feet (3.0 m.) of unconformity bound sandstone at Catawba. At Fagg, the Keyser is entirely absent. The New Creek Limestone has a distribution similar to that of the Keyser Formation. It is present to the northeast, reduced in thickness near New Castle, and absent from sections further southwestward. The Licking Creek Limestone is represented by two limestone members at northeastern exposures; in the New Castle area, only the upper Little Cove Member is present. The Licking Creek Limestone is missing at Catawba, although a sandy facies may be present. At Fagg, the Licking Creek is entirely absent.

The Huntersville Chert can be traced from Fagg to Catawba. At the Goode quarry section, the Huntersville is represented by a thin phosphatic interval lying unconformably on the Licking Creek Limestone. The Needmore Shale is present above the Huntersville at Fagg and Catawba. To the northeast, this interval is occupied only by the Needmore Shale.

The distribution of the Ridgeley Sandstone, which overlies the Helderberg Group, is also quite irregular. The Ridgeley is exposed at the northeastern sections, absent in the New Castle area, and approximately fifteen feet (4.5 m.) thick at Catawba and Fagg. The irregular thickness distribution of the Ridgeley reflects relief on the underlying unconformity surface and post-Ridgeley erosion. The Tonoloway, Keyser, New Creek, Healing Springs, and Licking Creek also exhibit variable thicknesses throughout the study area. Oversteps by the Keyser Formation, Ridgeley Sandstone, and Huntersville Chert occur in the southwest portion of the study area.

The objectives of this study are to examine practical uses for conodont biostratigraphic markers and to review stratigraphic relationships within the Late Silurian-Early Devonian section. Late Silurian-Early Devonian stratigraphy based on measured sections in

Alleghany, Botetourt, Craig, and Roanoke Counties and associated wedge-outs, oversteps, and unconformities reveal a geological setting in which biostratigraphic work may prove quite useful.

Structural Setting

The junction of the central and southern Appalachians is generally considered to be at the conspicuous structural recess at the latitude of Roanoke and New Castle, Virginia (Rodgers, 1949). Northeast and southwest of Roanoke the central and southern Appalachians display two distinctive geologic settings.

The southern Appalachians are structurally characterized by imbricate low angle thrust faults. Large, usually faulted anticlines and synclines form structural belts that in the southern Appalachians strike approximately N60°E. The major structure in the New Castle area is the Sinking Creek anticline which follows the regional strike of the southern Appalachians. The Sinking Creek anticline, which represents the northernmost feature of the southern Appalachians, plunges northeastward to extinction just southwest of New Castle. The trace of the Saltville fault trends along the axis of the Sinking Creek anticline and dies out in the Devonian shale underlying the town of New Castle just north of the anticlinal nose (Bregman, 1967). The Craigs Creek syncline bounds the Sinking Creek anticline to the southeast and is the major synclinal structure in the New Castle area. This syncline is bounded in turn several miles to the east of New Castle by the Pulaski fault which trends in a general northeasterly direction. Strata of Cambrian to Devonian age are exposed on the Sinking Creek anticline.

The central Appalachians are structurally characterized by generally more open anticlinal and synclinal folds and relatively fewer thrust faults at the surface than the southern Appalachians. These folds form structural belts striking approximately N30°E. Locally, in the area northeast of the northeast-plunging nose of the Sinking Creek anticline, are several small anticlines which are the southernmost structures of the central Appalachians as determined by the orientation of their axes parallel to central Appalachian trends. Bregman (1967) referred to these as follows: Nutters Mountain anticline, Peters Hill anticline, Little Mountain anticline, and Pine Top anticline. These structures are more or less surrounded by Devonian Brallier shale and are themselves composed of the stratigraphic units between the Silurian Rose Hill Sandstone and the Devonian Millboro-Needmore shales. It is on these small anticlines as well as the nose of the Sinking Creek anticline that the Late Silurian Tonoloway and Keyser Formations and Early Devonian Helderberg Group are exposed (fig. 1).

The northernmost structure considered in this study is the Fore Mountain anticline (Lesure, 1957) located in the central Appalachians 22 miles (35.4 km.) northeast of New Castle. The Fore Mountain anticline is a small structure located to the east of Low Moor, Alleghany County, Virginia. The Fore Mountain anticline plunges southwest to extinction near Mallow, Alleghany County, Virginia. Strata of Silurian and Devonian age are exposed on the flanks of the anticline.

Location of Sections

Several useful Silurian-Devonian sections are exposed within a five mile (8.0 km.) radius of New Castle, Virginia (figs. 1,2,). The Johns Creek gorge section is located on the southeast flank of the Nutters Mountain anticline and reveals the stratigraphic units from the Silurian "Keefer" Sandstone to the Clifton Forge Member of the Keyser Formation. Along the flanks of

Little Mountain anticline, exposures of the Tonoloway and Keyser Formations are revealed where Mill Creek and Barbours Creek cut across the structure. A small dome just east of the nose of the Sinking Creek anticline exposes Devonian strata including the New Creek Limestone and Little Cove Member of the Licking Creek Limestone.

The northernmost section examined in this study is exposed on the southeast flank of the Pore Mountain anticline near Low Moor, Alleghany County, Virginia. A complete section from the uppermost Keyser Formation to the Needmore Shale is exposed at this section. The section is located along Alleghany County Route 696 which extends along the Jackson River.

Figure 1 : Index map of section locations showing major geologic structures in the study area.

1. Fagg section
2. Catawba section
3. Goode quarry section
4. Johns Creek section
5. Barbours Creek section
6. Mill Creek section
7. Low Moor section
8. Iron Gate section
9. Prices Bluff section

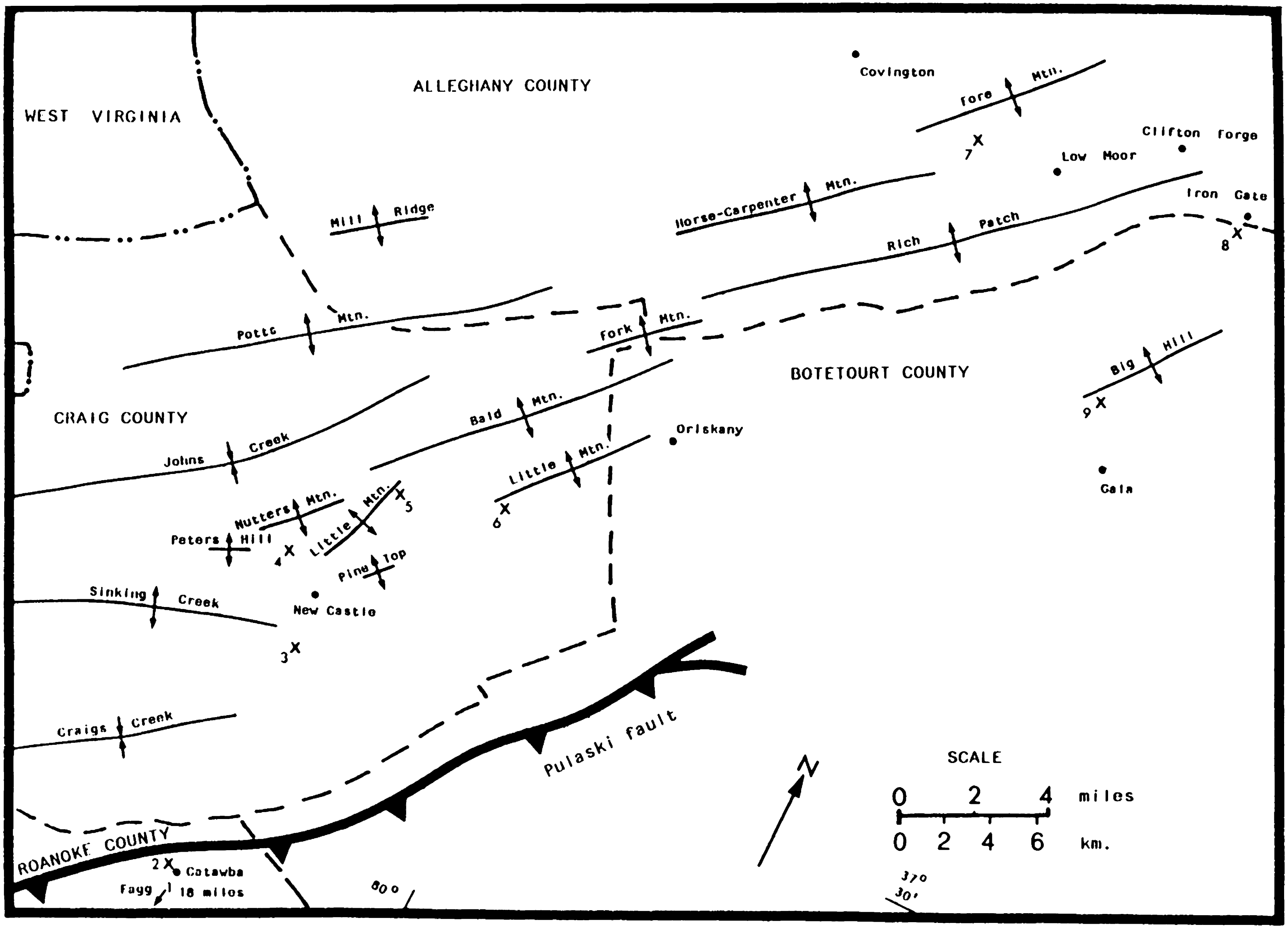
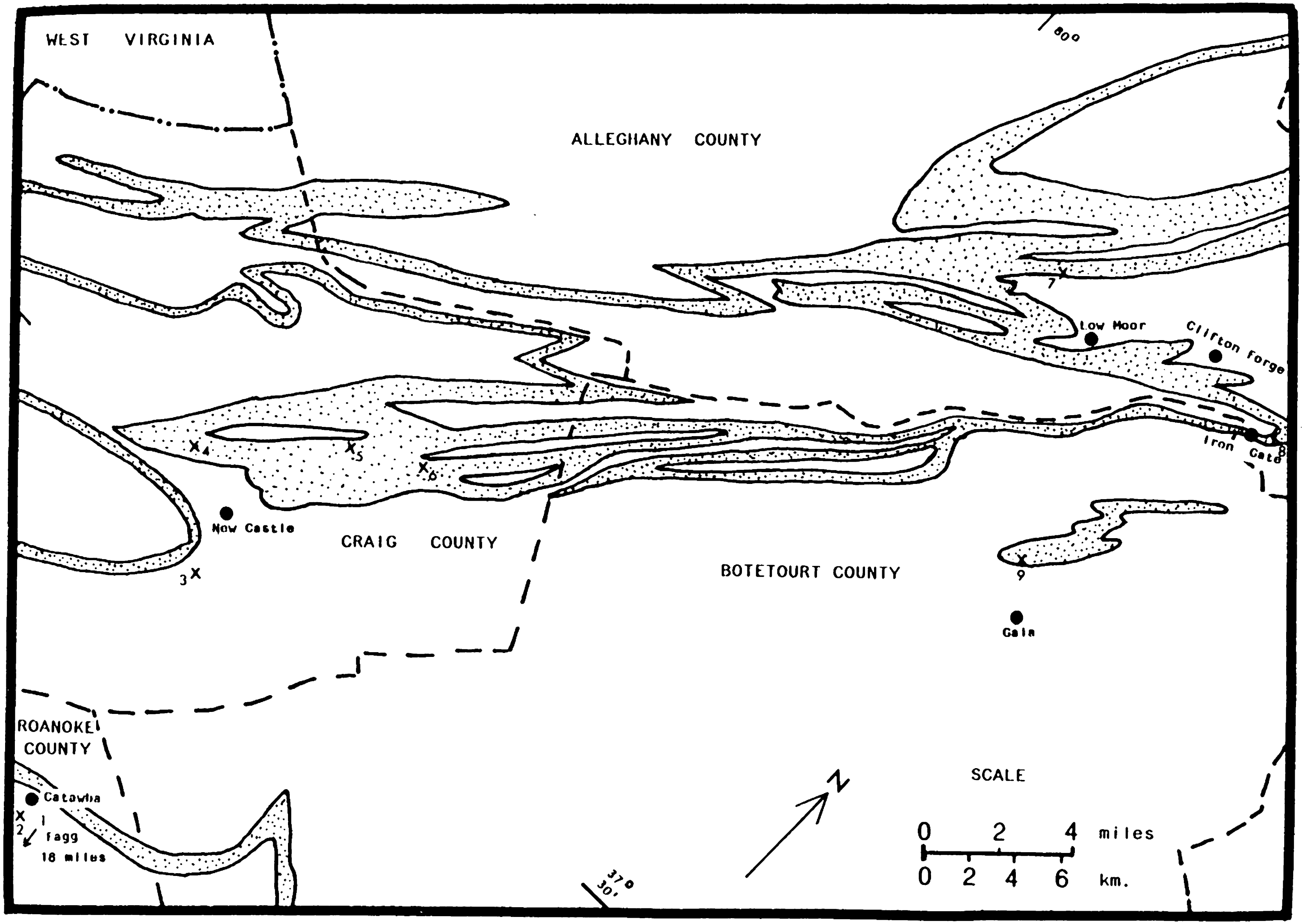

WEST VIRGINIA
ALLEGHANY COUNTY
Covington
Fore Mtn.
7 X
Clifton Forge
Low Moor
Iron Gate
8 X
Hill Ridge
Horse-Carpenter Mtn.
Rich Patch
Potts Mtn.
Fork Mtn.
BOTETOURT COUNTY
Big Hill
9 X
CRAIG COUNTY
Bald Mtn.
Orlskany
Johns Creek
Little Mtn.
6 X
Gala
Nutters Mtn.
Little Mtn.
5 X
Peters Hill
4 X
Pine Top
Sinking Creek
New Castle
3 X
Craigs Creek
Pulaski fault
N
SCALE
0 2 4 miles
0 2 4 6 km.
ROANOKE COUNTY
2 X Catawba
Fagg 1 18 miles
80°
37°
30'

Figure 2 : Map of the Late Silurian-Early Devonian outcrop belt within the study area.

1. Fagg section
2. Catawba section
3. Goode quarry section
4. Johns Creek section
5. Barbours Creek section
6. Mill Creek section
7. Low Moor section
8. Iron Gate section
9. Prices Bluff section


WEST VIRGINIA
ALLEGHANY COUNTY
800
Low Moor
Clifton Forge
Iron Gate
8
7
X4
X5
X6
3X
New Castle
CRAIG COUNTY
BOTETOURT COUNTY
9
Gala
ROANOKE COUNTY
Catawba
X 2
1
Fagg
18 miles
37° 30'
N
SCALE
0 2 4 miles
0 2 4 6 km.

Methods of Investigation

Sampling Interval

Samples were taken at an average interval of approximately eight feet (2.4 m.) in lithologically consistent units of large thickness. Where lithologic changes were frequent, all carbonate beds were sampled resulting in a much smaller average sampling interval.

Attempts were made, in the absence of carbonate units, to process calcareous sandstones and siltstones. In response to the low abundance of identifiable conodonts found in the initial carbonate samples, twice the usual sample weight was collected and processed from conodont-producing sample locations. A total of 1909.4 kilograms of rock were collected and processed. Conodont per kilogram calculations are included in tables 1-5.

Laboratory Techniques

Standard conodont processing techniques were used in this study. Samples were first physically broken to increase surface area, then placed in a ten percent solution of acetic acid which was changed every two days. Disaggregated samples were sieved through mesh sizes 20, 45, and 120; the 45 and 120 mesh fractions were concentrated using the heavy liquid acetylene tetrabromide. The heavy fractions were picked and mounted on slides.

Stratigraphy

Silurian System

"Keefer" Sandstone

Name—The "Keefer" Sandstone was named by Stose and Swartz (1912, p.5) for exposures on Keefer Mountain in Maryland.

Lithology--The "Keefer" Sandstone at Johns Creek is a thick bedded, fine grained, silica cemented, light brown sandstone. The "Keefer" is well sorted and exhibits cross bedding. At Johns Creek, this unit is interbedded with a white to brown, medium grained, friable sandstone.

Distribution and Thickness--The "Keefer" Sandstone is incomplete at the base along Johns Creek where it consists of 158 feet (48.1 m.) of poorly exposed sandstone. The uppermost 36.3 feet (11.0 m.) of the "Keefer" can be measured at the Mill Creeek section. Twenty-three feet (7.0 m.) of flat-lying "Keefer" is exposed near the Barbours Creek section.

Remarks-- Butts (1940) referred to the stratigraphic interval between the "Keefer" Sandstone and the Tonoloway Formation as the Wills Creek Formation. This name was derived from the name given by Uhler (1905, p.20-25) for the shale in Maryland which occupies the same stratigraphic position. In Virginia, north of the James River this formation consists of shale, argillaceous limestone and mudstone.

The names "Keefer" Sandstone and Wills Creek Formation may both be inappropriate for this interval in southwestern Virginia. The "Keefer" Sandstone is believed to be a lateral continuation of the Keefer Sandstone of Maryland, but may be in part younger than the Keefer of the type locality (Lesure, 1957). The Wills Creek Formation in southwestern Virginia is not lithologically similar to the type section near Cumberland, Maryland and for this reason may be inappropriate. The name Keefer is placed in quotation marks to indicate its inappropriate nature.

Lampiris (1975) suggested the name, Eagle Rock Sandstone, to replace the term "Keefer" Sandstone in southwestern Virginia. Lampiris noted the greater thickness and more variable nature of the "Keefer" in southwestern Virginia as compared with the same unit in northern Virginia, Maryland, and Pennsylvania. Lampiris also states that the upper part of the Eagle Rock divides into two discrete sandstone bodies in southwestern Virginia. The Eagle Rock passes by facies change to the west and northwest where it interfingers with the lower

Mifflintown Formation. To the southeast, the top of the Eagle Rock is progressively younger, in this area it passes into the Keyser Formation.

Tonoloway Formation

Name—The name Tonoloway was formally proposed by Stose (Stose and Swartz, 1912, p.7) for beds exposed on Tonoloway Ridge in the Pawpaw and Hancock quadrangles in Maryland. At its type section, the Tonoloway consists of thin bedded, laminated, impure limestone which is characteristically light olive gray in color.

Lithology—The Tonoloway Formation consists of numerous thin beds of varied lithology. These thin units are described below according to lithologic type.

Sandstones in the Tonoloway Formation consist of both silica and calcite cemented types. Calcareous sandstones are fossiliferous containing brachiopods and ostracods. Bedding thicknesses are variable, ranging from massive to thin bedded. Sandstone units are fine to medium grained and frequently exhibit small scale cross-bedding and/or the characteristic planar lamination of the Tonoloway Formation. Silica cemented sandstones are less fossiliferous than calcite cemented units and reveal less cross-bedding. Beds with symmetrical and slightly asymmetrical ripple marks were observed in the lower Tonoloway.

Siltstone units in the Tonoloway Formation consist of light to medium gray, calcareous beds which are fossiliferous. Fossils found in siltstone beds include brachiopods, ostracods, and trilobite fragments. Siltstone units exhibiting small scale cross bedding and planar lamination are common. Bedding ranges from thick to thin bedded.

Lime mudstones are the most abundant type of carbonate rock in the Tonoloway Formation. Lime mudstones found in the Tonoloway Formation are generally silty, dark colored units containing ostracods and fragments of brachiopods and trilobites. Planar lamination is common in the mudstone units. Irregular lamination is found in one lime mudstone bed. A distinctive beige colored lime mudstone containing sparse brachiopods is present in the upper Tonoloway at Johns Creek.

A single bed of wackestone occurs in the Tonoloway Formation at Johns Creek. This intraclast wackestone occurs directly above and contains clasts of the previously described beige mudstone unit. The intraclast wackestone is very thinly bedded and dark gray in color.

Grain-supported carbonate textures in the Tonoloway Formation are present in both packstones and grainstones. Packstone lithologies include ostracod packstone, gastropod packstone, and skeletal packstone. Skeletal packstone contains fragments of bryozoans, brachiopods, trilobites, ostracods, and gastropods. Grain-supported carbonates in the Tonoloway Formation contain quartz grains in various amounts.

Grainstone lithologies in the Tonoloway Formation include crinoidal grainstone, oolitic grainstone, and skeletal grainstone. Skeletal grainstones contain the same types of fossil grains as noted for packstones. Few sedimentary structures are found in the grain-supported units of the Tonoloway Formation.

<u>Distribution and Thickness</u>--The Tonoloway Formation is exposed at the Johns Creek, Barbours Creek, and Mill Creek sections. At Johns Creek, the Tonoloway is complete, but only discontinuously exposed; it is 273 feet (83.2 m.) thick at this location. At Barbours Creek, only the uppermost 10 feet (3.0 m.) of the Tonoloway is revealed in outcrop. The Tonoloway Formation at the Mill Creek section is complete, but poorly exposed. At Mill Creek, the section is 244.3 feet (74.5 m.) thick and consists predominantly of lime mudstone.

Silurian-Devonian Systems

Keyser Formation

Name—The Keyser Formation was named by C.K. Swartz (Schuchert, et. al., 1913) for exposures at Keyser, West Virginia. It was originally considered part of the Lower Devonian Helderberg Group, but was later separated from the group on the basis of faunal and stratigraphic evidence (Swartz, 1939, p.49). At Keyser, West Virginia, the Keyser Formation consists of 281 feet (85.6 m.) of blue limestone which is nodular at its base, massively bedded toward the mid portion of the section and shaly in the upper portion. The lower member of the Keyser Formation, the Clifton Forge Sandstone, was named by F. M. Swartz (1929, p.29) for exposures along the Chesapeake and Ohio Railroad at Clifton Forge, Virginia. In Virginia, the boundary between the Silurian and Devonian Systems is within the Keyser Formation (Berdan, 1964, Bowen, 1967, Boucot and Berry, 1970). Assignment of this boundary is based primarily on brachiopod zonation.

Lithology--The Clifton Forge Sandstone Member of the Keyser Formation is a dark brown to orange, massively bedded, friable, quartz sandstone. The deeply weathered, friable character of the sandstone is believed to be the result of the leaching of carbonate cement. The Clifton Forge Sandstone is medium to coarse grained and generally contains poorly sorted and rounded grains. The Clifton Forge Sandstone is evenly bedded at its base, but reveals uneven bedding and bi-directional cross-bedding higher in the unit. Fossil material in the sandstone is sparse consisting of external molds of crinoid columnals and brachiopods.

Sandstones in the Keyser Formation other than the Clifton Forge Sandstone are white to pink in color, well sorted and silica cemented. These units are frequently cross bedded. Sandstones contain fossils such as brachiopods, trilobites, tabulate corals, and stromatoporoids.

Small amounts of shale are also present in the Keyser Formation. The shales are calcareous and tan to pink in color.

Wackestone in the Keyser Formation consists of light gray, thin to massively bedded units dominated by bryozoans. Packstone lithologies in the Keyser include skeketal packstone, bryozoan packstone, and reefal packstone. Skeletal grains in the packstones include crinoids, brachiopods, ramose and encrusting bryozoa, stromatoporoids, trilobites, and Cladopora corals. Two species of coral, Cladopora rectiliniata and Cladopora multiseriata are considered characteristic of the Keyser Formation (Butts, 1940). These corals provide the skeletal framework for a biostromal reefal packstone found at Barbours Creek. Packstones found in the Keyser are medium to dark gray and medium bedded to massive.

Skeletal grainstones found in the Keyser contain substantial amounts of quartz grains in addition to the skeletal grains mentioned above. Grainstone units are light to dark gray and massively bedded.

Black chert occurs in two grainstone units at Barbours Creek which are 40.75 feet (12.4 m.) and 25.0 feet (7.6 m.) above the Tonoloway Formation contact. Chert also occurs at Barbours Creek in a sandstone unit 22.25 feet (6.8 m.) above the erosional base of the Keyser. Black chert lenses occur in a single sandstone bed at Mill Creek 36.5 feet (11.1 m.) above the Tonoloway contact.

Distribution and Thickness--At the Barbours Creek section, the Keyser Formation is incomplete; 135.25 feet (41.2 m.) of the section is exposed, the upper 33.0 feet (10.0 m.) of which is a partial exposure of the Clifton Forge Sandstone. The uppermost 28 feet (8.5 m.) of the Keyser is exposed at Low Moor, Virginia; this exposure is too high to reveal the Clifton Forge Sandstone. At Johns Creek, the lower 147.0 feet (44.8 m.) of the Clifton Forge Sandstone and shale, which may be a tongue of the Big Mountain Shale (Swartz, 1929), are poorly exposed. At the Mill Creek section, the lower Keyser Formation is 127.2 feet (28.7 m.) thick.

Devonian System

The Lower Devonian Helderberg Group consists of, in ascending stratigraphic order, the New Creek Limestone, the Healing Springs Sandstone, and the Licking Creek Limestone. These units were proposed as the Helderberg Group by F. M. Swartz (1929, p.27). The Helderberg Group includes the stratigraphic units between the Keyser Formation and the Ridgeley Sandstone.

New Creek Limestone

<u>Name</u>—In the Virginias, the stratigraphic interval between the Keyser Formation and the Healing Springs Sandstone has been renamed the New Creek Limestone by Bowen (1967, p.6) for outcrops near the town of New Creek, Mineral County, West Virginia. This interval was previously referred to as the Coeymans Limestone, which was named by Clarke and Schuchert (1899, p.876-877) for

exposures near the town of Coeymans, Albany County, New York.

Lithology--The New Creek Limestone is a coarse grained, medium gray to light brown, crinoidal grainstone. The New Creek is characterized by the presence of large crinoid columnals, articulated crinoid stem fragments, and distinctive grains of pink calcite. Fossil material found in the New Creek, in addition to crinoid columnals, includes brachiopods and ramose bryozoans. The New Creek contains large amounts of quartz sand and lesser amounts of pebble-sized quartz grains. The limestone is massively bedded and exhibits trough cross bed sets which are 3-4 feet (0.9-1.2 m.) in thickness at the Goode section.

Distribution and Thickness--At the Low Moor section, the New Creek Limestone is 49 feet (14.9 m.) in thickness. At the Goode quarry near New Castle, 11 feet (3.2 m.) of exceptionally sandy New Creek Limestone is exposed. An additional seven feet (2.1 m.) of covered New Creek may be present. The New Creek at Goode quarry is deeeply weathered and exhibits a recessive recessive weathering profile, for these reasons this covered interval is included with the New Creek. Another possibility is that this interval contains the Healing

Springs Sandstone. Mapping of the New Castle area (Bregman, 1967) did not reveal the presence of either the Healing Springs or the New Creek.

Healing Springs Sandstone

Name--The Healing Springs Sandstone was named by F. M. Swartz (1929, p.41.) for exposures on Little Mountain, west of Warm Springs, Bath County, Virginia.

Lithology--The Healing Springs Sandstone is a slightly calcareous, medium grained quartz sandstone. The sandstone is light to medium gray in color, massively bedded, and contains quartz pebble lenses. Cross bedding and heavy mineral lamination are common. The Healing Springs contains well sorted and rounded quartz grains and is extremely well indurated. Fossils in the Healing Springs at Low Moor include brachiopods and crinoid fragments. Crinoidal material is previously unreported in the Healing Springs.

Distribution and Thickness--The Healing Springs is found only at the Low Moor section where it is 34.0 feet (10.4 m.) thick.

Licking Creek Limestone

Name--The Licking Creek Limestone was named by F. M.

Swartz (1939, p.69.) for exposures along Licking Creek near Warren Point, Franklin County, Pennsylvania. Swartz extended this name southward to Virginia to replace the New York state term Becraft Formation. In current usage, the Licking Creek Limestone includes both the upper sandy limestone unit named the Little Cove Member and the lower black, cherty limestone called the Cherry Run Member (Head, 1974).

Lithology--The Licking Creek Limestone consists of two limestone members. The Cherry Run Member is the lower of the two members. The Cherry Run Member is a black, argillaceous lime mudstone containing large amounts of black chert. The black chert occurs in nodules and in semi-continuous layers parallel to bedding. Fossil material found in the lower member includes silicified brachiopods, rugose and tabulate corals, gastropods, and trilobites. The lime mudstone is massively bedded and weathers light gray. Beds containing less chert exhibit a shaly weathering pattern.

The Little Cove Member is a gray, fine grained, skeletal grainstone which contains abundant quartz grains. Fossil grains identified in the Little Cove include brachiopods, crinoids, trilobites, bryozoans, and rugose corals. This member of the Licking Creek Limestone is also massively bedded.

Distribution and Thickness--At the Low Moor section, the Cherry Run Member is 60.0 feet (18.3 m.) thick. The Little Cove Member is 41.0 feet (12.5 m.) thick, but is discontinuously exposed. The Cherry Run Member is not present at the Goode section where the Little Cove Member is 43 feet (13.1 m.) thick. At the Goode section the Little Cove Member is disconformably overlain by the Needmore Shale.

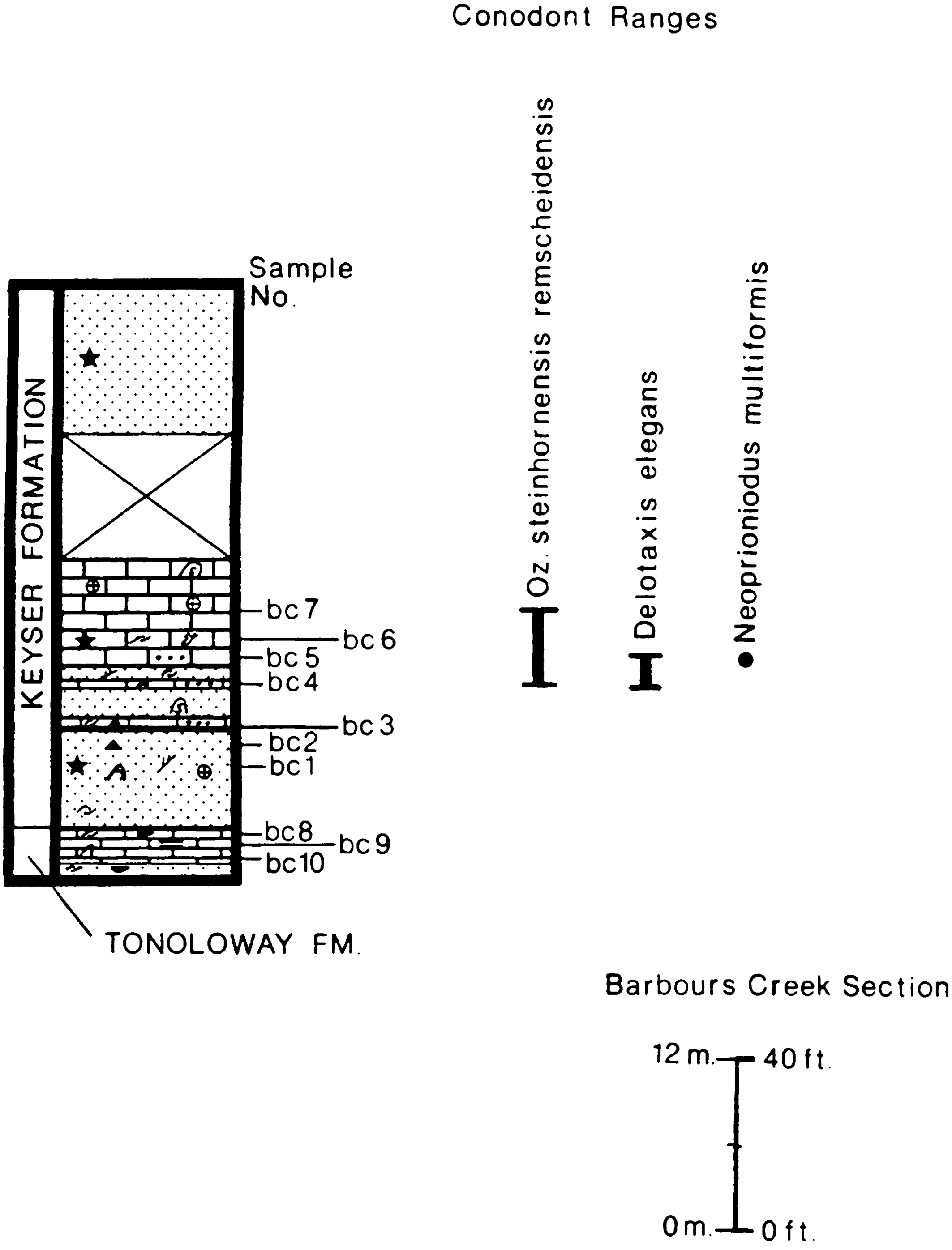
Ridgeley Sandstone

Name--The Ridgeley (or Ridgley) Sandstone was named for exposures near Ridgeley, West Virginia (Schuchert, et al., 1913). Butts (1940) referred to this interval as the Oriskany Sandstone; however, the typical Oriskany is not known to extend south of Pennsylvania (Lesure, 1957). The two units are considered correlative. The Ridgeley can be traced from its type locality into Virginia.

Lithology--The Ridgeley Sandstone is a brown, medium to coarse grained, quartz sandstone. The Ridgeley examined was deeply weathered and friable. The Ridgeley is medium bedded and contains external molds of the brachiopod Costispirifer.

Distribution and Thickness--The Ridgeley Sandstone crops out only at the Low Moor section. It is poorly exposed at this location where it is 25.0 feet thick.

Figure 3 : Barbours Creek Section. See Figure 6 for explanation of lithologic symbols.



Barbours Creek Section

Figure 4 : Goode Quarry Section. This section has also been described by Tillman (1963) and Bregman (1967). See Figure 6 for explanation of lithologic symbols.

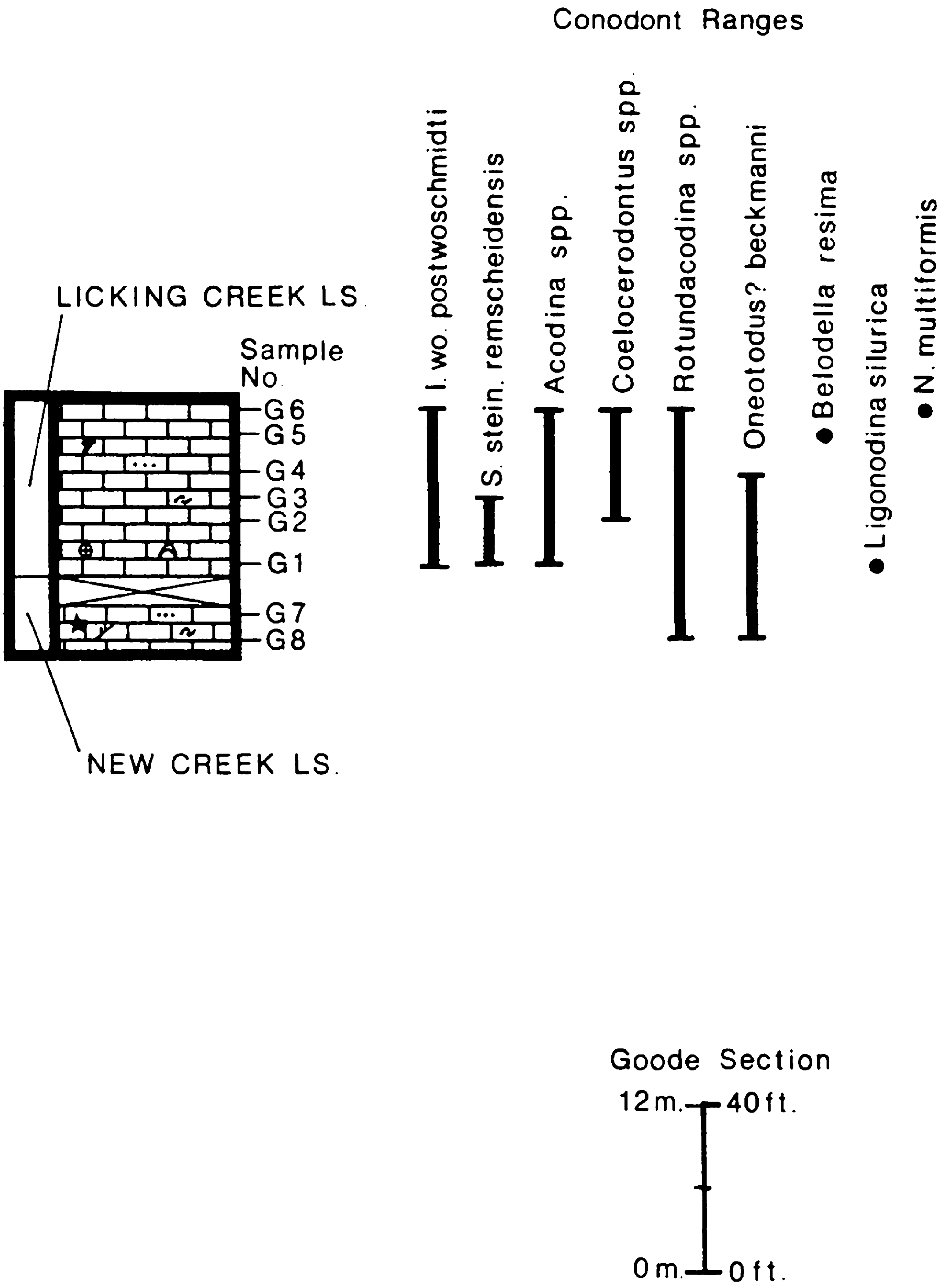
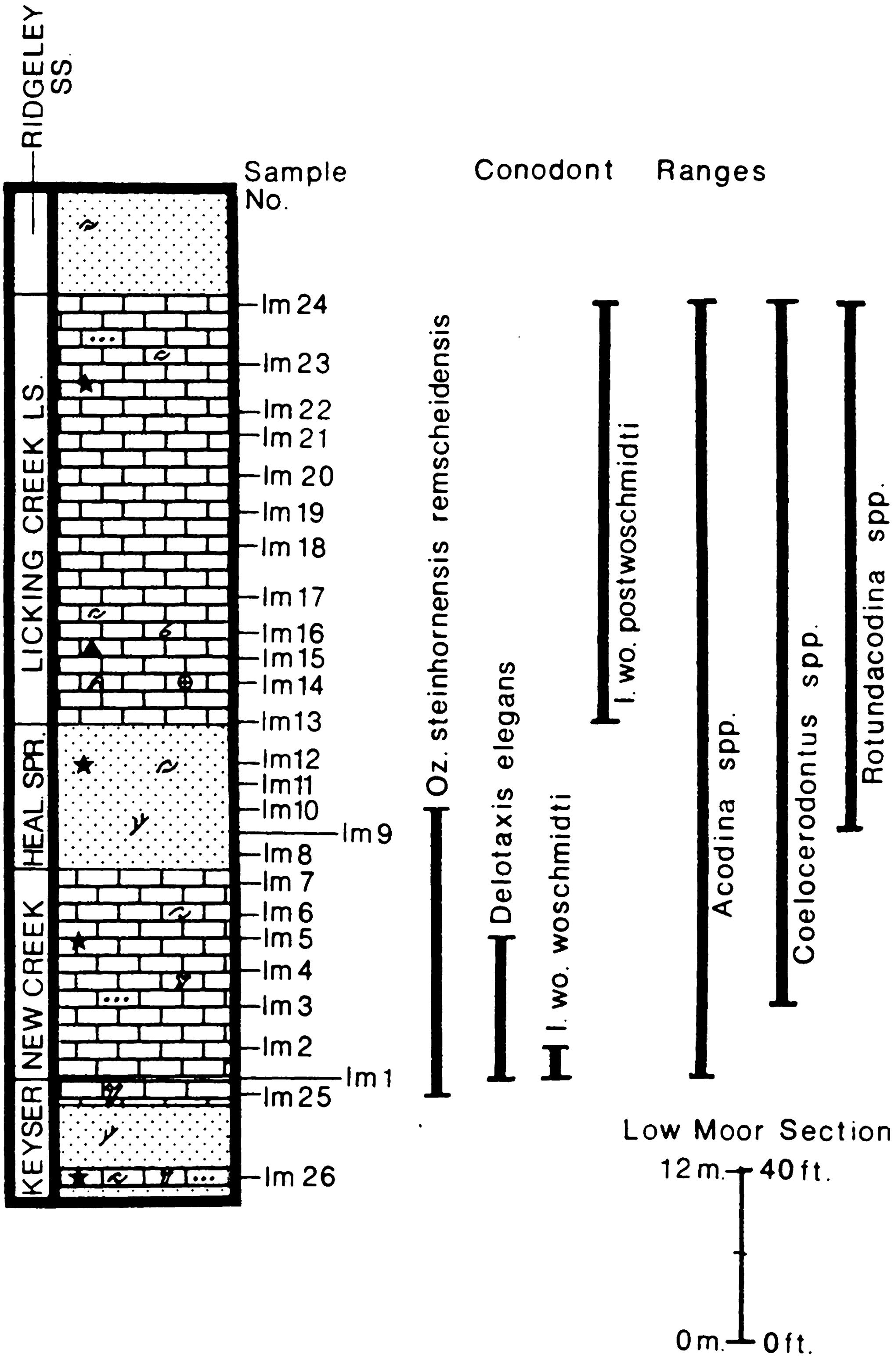

Conodont Ranges
I. wo. postwoschmidti
S. stein. remscheidensis
Acodina spp.
Coelocerodontus spp.
Rotundacodina spp.
Oneotodus? beckmanni
● Belodella resima
● Ligonodina silurica
● N. multiformis
LICKING CREEK LS.
Sample No.
G6
G5
G4
G3
G2
G1
G7
G8
NEW CREEK LS.
Goode Section
12 m.
40 ft.
0 m.
0 ft.

Figure 5 : Low Moor Section. See Figure 6 for explanation of lithologic symbols.


RIDGELEY SS.
LICKING CREEK LS.
HEAL. SPR.
NEW CREEK
KEYSER
Sample No.
lm 24
lm 23
lm 22
lm 21
lm 20
lm 19
lm 18
lm 17
lm 16
lm 15
lm 14
lm 13
lm 12
lm 11
lm 10
lm 9
lm 8
lm 7
lm 6
lm 5
lm 4
lm 3
lm 2
lm 1
lm 25
lm 26
Conodont Ranges
Oz. steinhornensis remscheidensis
Delotaxis elegans
I. wo. woschmidti
I. wo. postwoschmidti
Acodina spp.
Coelocerodontus spp.
Rotundacodina spp.
Low Moor Section
12 m.
40 ft.
0 m.
0 ft.

Facies and Depositional Environment

Introduction

The Late Silurian-Early Devonian package examined in this study is comprised of the stratigraphic units between and including the Silurian "Keefer" Sandstone and the Devonian Ridgeley Sandstone. The oldest unit examined in this study is the "Keefer" Sandstone of Niagaran age (Oliver, et al., 1969). Progressively younger Silurian strata include the Tonoloway Formation and the Silurian portion of the Keyser Formation which consists of the lower limestone member and the Clifton Forge Sandstone. These units are considered Cayugan in age. The upper portion of the Keyser Formation, the Helderberg Group, and Ridgeley Sandstone belong to the Ulsterian Series (Oliver, et al., 1969).

The Helderberg Stage is the oldest of the three stages in the Ulsterian Series. The Helderberg Stage includes the upper limestone member of the Keyser Formation, the New Creek Limestone, Healing Springs Sandstone, and Licking Creek Limestone (Dennison, 1980). The Ridgeley Sandstone is the sole stratigraphic unit in the Deerpark Stage of the Ulsterian Series. The Needmore Shale and Huntersville Chert belong to Onesquethaw Stage, which has been studied in detail in Virginia and West

Virginia by Dennison (1961). These units will be discussed in relationship to unconformities in the section.

Geologic Setting

During Late Silurian-Early Devonian time, the Appalachian basin was a northeast trending, elliptical trough extending from Alabama to New York (Dennison and Head, 1975). The basin was contained by reef banks to the northwest and by low land areas to the northeast and southeast (Head, 1969). The geologic setting at this time is one of relative tectonic quiescence following the activity of the Taconic orogeny. The steady deposition of carbonates, interrupted only by clastic influxes represented by the Clifton Forge Sandstone and the Healing Springs Sandstone, is typical of these "quiet" periods. An isopach map of the Helderberg Stage (Oliver, et al., 1967) reveals the widespread extent of the Helderberg carbonate package. Many depositional environments are represented within this sequence of marine sediments. Regional depositional models for Silurian-Devonian time have been proposed by Dennison (1961), Oliver, et al., (1967), Head (1969), Laporte (1971), Dennison and Head (1975), Mackurath (1977), and Smosna and Patchen (1978). Studies of the Early Devonian in Virginia have been conducted by Swartz (1929), Montgomery (1967), Travis (1971), Smosna and Warshauer (1979), and Cook (in prep.).

Paleogeographic reconstructions of the Middle Silurian (Scotese, et al., 1979) place the Appalachian Basin approximately twenty degrees south of the equator. By Late Early Devonian time, the basin was within ten degrees of the equator.

A fence diagram (fig. 8) is presented to display the relationship of the Tuscarora Sandstone, "Keefer" Sandstone, Tonoloway Formation, Keyser Formation, Helderberg Group, and Ridgeley Sandstone in Alleghany, Botetourt, Craig, Montgomery, and Roanoke Counties, Virginia. Data for the fence diagram was compiled from published sections (Swartz, 1929, Tillman, 1963, Dennison, 1970) and sections measured in the course of this study (figs. 3-7). A discussion of the facies and depositional environments of the units will follow in stratigraphic order. Source areas for the clastic units will also be discussed.

"Keefer" Sandstone

The "Keefer" Sandstone is exposed throughout the study area included in the fence diagram (fig. 8). At Iron Gate 218 feet (66.4 m.) of "Keefer" was recorded (Dennison 1970); at Low Moor and Prices Bluff the "Keefer" is not exposed. In the New Castle area, the "Keefer" is partially exposed at Johns Creek and Mill Creek where it is 158 feet (48.2 m.) and 36 feet (11.0 m.) thick, respectively. Near the Barbours Creek section, 23 feet (7.0 m.) of flat-lying "Keefer" Sandstone is exposed; a map measurement of the covered interval between the top of this outcrop of "Keefer" and the uppermost ten feet (3.0 m.) of Tonoloway exposed at the Barbours Creek section revealed a thickness for the combined "Keefer"-Tonoloway interval of 445 feet (135.6 m.). This interval includes the majority of the Tonoloway Formation plus "Keefer" higher in the section than the 23 feet (7.0 m.) of flat-lying rock which is exposed.

To the southwest between Catawba and Fagg, the "Keefer" thins drastically. At Catawba the "Keefer" is 184 feet (56.1 m.) thick; at Fagg the entire Silurian sandstone sequence is represented by five feet (1.5 m.) of Tuscarora Sandstone (Tillman, 1963, Eubank, 1967, Amato, 1968, Seal, 1980). Seal (1980) has traced the "Keefer" from the Catawba section to Fagg and reports that the "Keefer" wedges out before it reaches the Fagg section. The relatively thin unit of Tuscarora Sandstone at Fagg is the product of a major Late Silurian-Early Devonian unconformity. This unconformity is believed to be the result of a recurring positive area at the site of the Salem syncline (Tillman, 1963, Amato, 1968). Tillman (1963) states that the unconformity gains relief to the southwest and cites oversteps by the Huntersville Chert, Ridgeley Sandstone, and Keyser Formation to substantiate a positive area at this location.

A considerable difference in structural relief can be measured between the Fagg and Iron Gate sections. Calculation of the interval between the base of the Tuscarora Sandstone and the base of the Ridgeley Sandstone at Iron Gate (Dennison, 1970) reveals 994 feet (302.9 m.) of structural relief. The same interval at Fagg (Eubank, 1967) reveals only 11 feet (3.3 m.) of relief. Silurian and Devonian age units are missing above the unconformity at Fagg.

The "Keefer" Sandstone has been interpreted by Dennison and Head (1975) and Smosna and Patchen (1978) as a high energy shelf sand deposited in a littoral or sublittoral environment during a period of lowered sea level. Lampiris (1975) suggested that the Late Siluran clastic package represents an onlap-offlap sequence and that the Eagle Rock Sandstone ("Keefer") represents a return to a strand-line environment after the normal marine conditions interpreted from the middle Rose Hill Sandstone. Lampiris interpreted the Eagle Rock Sandstone as being a delta-top sand deposit. Mudcracks and ripple marks have been reported from the Eagle Rock ("Keefer") at Catawba Mountain (Lampiris, 1975).

Dennison's suggestion that the "Keefer" was entirely deposited during a period of lowered sea level is perhaps a generalization. Throughout much of Virginia, the "Keefer" is underlain by the Rose Hill Sandstone and overlain by the Wills Creek or Tonoloway Formation. These bounding units are deeper marine facies than the "Keefer". The vertical succession of environments from marine Rose Hill to near-shore "Keefer" to marine Tonoloway suggests that the upper part of the "Keefer" may have been reworked as sea level rose following deposition of the lower "Keefer".

Dennison (1970) suggests that "Keefer" deposition centered around Roanoke, Virginia, and that "Keefer" deposits initiated the development of the Giles Peninsula. The Giles Peninsula, named for its location in Giles County, Virginia, refers to both the area covered by "Keefer" deposition and to the land area which was later exposed and eroded supplying clastics for re-working and deposition in Clifton Forge Sandstone and Healing Springs time. The source area for "Keefer" sands is to the south and east of the depositional basin (Dennison and Head, 1975), more specifically located by Dennison (1970) as in the vicinity of Roanoke County, Virginia, and east of Massanutten Mountain. These points of clastic influx are interpreted as either major river drainages or promontories of land extending westward into the basin (Dennison, 1970).

During mid-Cayugan Wills Creek Formation time, the sea covered the Giles Peninsula. Southwestern Virginia and land east to the Massanutten syncline were also flooded (Dennison, 1970).

Tonoloway Formation

The Tonoloway Formation is exposed at Iron Gate and Prices Bluff in the northern section of the study area (Alleghany and Botetourt Counties) and at Johns Creek (fig. 6), Mill Creek (fig. 7), and Barbours Creek (fig. 3) in Craig County near New Castle. The Tonoloway Formation is 140 feet (42.7 m.) thick at Iron Gate (Dennison, 1970), approximately 250 feet (76.2 m.) thick in the New Castle area, and is missing from the Salem synclinorium (Tillman, 1963, Eubank, 1967, Amato, 1968). The uppermost 100 feet (30.1 m.) of the Tonoloway Formation is exposed at Prices Bluff (Lesure, 1957). The absence of the Tonoloway Formation in the Salem synclinorium near Mason Cove and farther south at Fagg in the trough of the Salem syncline (Tillman, 1963) is part of a major unconformity between the youngest Silurian and Early Devonian strata.

A change in facies from sandy limestone to sandstone may also be a reason for the Tonoloway's absence in the southwestern portion of the study area. At Iron Gate and Prices Bluff, the Tonoloway consists of argillaceous, laminated limestone (Swartz, 1929, Dennison, 1970); southern exposures of the Tonoloway reveal a sandier facies. Laminated limestones examined in the New Castle area contain abundant quartz grains. Tonoloway outcrops in this area also contain greater thicknesses of sandstone than the Iron Gate and Prices Bluff sections. Tillman (1963) has suggested that some calcareous units of Late Silurian-Early Devonian age may pass to sandy facies to the southeast in the Catawba syncline. Tillman (1963) and Tillman and Lowry (1968, 1971) allow that the Tonoloway Formation may be present in the Salem synclinorium section as a sandstone facies in the upper part of the "Keefer" Sandstone or in the thin fossiliferous ten foot (3.0 m.) clay beneath the Keyser sandstone at Mason Cove.

The Tonoloway Formation was deposited under tidal flat and shallow subtidal conditions (Head, 1969, Laporte, 1972, Smosna and Patchen, 1978). Head (1969) states that the Tonoloway was deposited along the eastern edge of the basin in tidal flat areas marginal to areas where streams were delivering quartz clastics to the basin. In the New Castle area, the Tonoloway Formation does not exhibit characteristics of a tidal flat facies. Mudcracks, salt crystal impressions, and other evidences of subaerial exposure which have been reported from the Tonoloway in West Virginia (Ludlum, 1959) were not found in the Tonoloway in this vicinity. The fauna of the Tonoloway includes brachiopods, crinoids, and bryozoans which are usually not associated with tidal flat environments. The fairly diverse fauna and symmetrically rippled bed tops suggest a shallow subtidal environment for the Tonoloway in this area.

Keyser Formation

The Keyser Formation crops out at Low Moor (fig. 5), Iron Gate, Prices Bluff, Johns Creek (fig. 6), Mill Creek (fig. 7), Barbours Creek (fig. 3), and Catawba sections. The Clifton Forge Sandstone Member of the Keyser Formation is 69 feet (21.0 m.) thick at Prices Bluff and 65 feet (19.8 m.) thick at Iron Gate. Southern exposures of the Clifton Forge Sandstone are incomplete. The Clifton Forge Sandstone is 67 feet (20.4 m.) thick at Mill Creek, 147 feet (44.8 m.) thick at Johns Creek, and 33 feet (10.0 m.) thick at Barbours Creek. The total thickness of the Keyser at Barbours Creek is 135.3 feet (41.2 m.). At Johns Creek, 13 feet (3.9 m.) of shale within the Clifton Forge Sandstone is also exposed. This could be a tongue of the Big Mountain Shale; however, greater stratigraphic control is necessary for confirmation. The Clifton Forge Sandstone is correlative with the Big Mountain Shale (Swartz, 1929) to the northeast.

Between New Castle and Catawba the Keyser thins drastically. Ten feet (3.0 m.) of Keyser sandstone has been reported by Tillman (1963) at Catawba Mountain. The Keyser sandstone at this section is thought to be bounded by unconformities. At Fagg, the Keyser is absent except for the fossilferous clast discussed below. An excellent extensive exposure of nearly flat-lying Clifton Forge Sandstone which was not measured in this study is located in the quarries of the Castle Sand Company just outside of the town of New Castle.

Montgomery (1967) studied the distribution of the Clifton Forge Sandstone in Virginia. Isopachs of the Clifton Forge Sandstone by Montgomery reveal that the unit forms a wedge within the Keyser Formation which thickens to the south and east and thins to the north and northwest. Paleocurrent measurements (Montgomery, 1967) indicate a major current flow to the north and northeast. This evidence suggests a southeastern source area for the Clifton Forge Sandstone. Montgomery (1967) states that the source area was probably located in the vicinity of present-day Roanoke and southern Botetourt Counties. Clastics were derived from previously deposited Silurian age sandstones. Dennison (1970) proposes a source area in Giles, Montgomery, and Roanoke Counties where exposed "Keefer" clastics were being eroded. The "Keefer" source area may in fact extend further to the south and southeast of the area suggested by Dennison. Unconformities which bound the unusually thin Silurian sandstone sequences at Fagg and Catawba Mountain

(Tillman, 1963) may be interpreted as evidence for partial erosion of these units providing sand to be re-worked and deposited as the Clifton Forge Sandstone. However, a large fossiliferous clast from the Ridgeley-age conglomerate at Fagg is tentatively identified as Keyser (Eubank, 1967) so despite the thinness of the Silurian at Fagg, the main Keyser source area may have been still farther to the south or southeast and not necessarily in the Catawba syncline.

Barwis and Mackurath (1978) interpret the Clifton Forge Sandstone as a tidal inlet-back barrier lagoonal complex based on lithologic, faunal, and stratigraphic evidence. Regional implications drawn by Barwis and Mackurath are in conflict with Head's carbonate basin depositional model for the Clifton Forge Sandstone time interval. Barwis and Mackurath argue that the Appalachian Basin was not open to the southwest at this time as suggested by Head, but rather was an emergent area supplying clastic material to the southern portion of the basin.

Sandstones other than the Clifton Forge Sandstone occur in the Keyser Formation at Barbours Creek and Low Moor. Calcareous sandstone may be found at Barbours Creek within the lower limestone member of the Keyser.

Sandstone at Low Moor occurs 6.5 feet (1.9 m.) below the base of the New Creek Limestone, within the upper limestone member of the Keyser Formation. The position of these sandstone beds is determined by their stratigraphic relationship to the Clifton Forge Sandstone, which is bounded by limestone members in the outcrop area (Swartz, 1929).

An unbedded reef facies within the lower Keyser Formation is present at Barbours Creek. This is a biostromal reef packstone 20.5 feet (6.2 m.) thick which has as the major constituent of its framework two species of the coral genus Cladopora. Cladopora corals were also found in a grainstone unit 50 feet (15.2 m.) above the base of the Keyser Formation at Mill Creek and were used for local correlation of the sections. Swartz (1929) previously reported Cladopora in the Keyser Formation at the Bolar, Island Ford, Monterey, and Little Mountain sections in Virginia. The occurrence of the coral Cladopora is considered diagnostic of the Keyser Formation (Butts, 1940). Stromatoporoids were observed near the top of the Cladopora biostrome at Barbours Creek. Reef build-ups in the Keyser Formation containing Favosites and stromatoporoids have been reported by Smosna and Warshauer (1979) at Mustoe, Virginia, and by

Swartz (1929) and Cook (in prep.) at Prices Bluff near Gala, Virginia. An overview of Silurian and Devonian reef trends is presented by Mesolella (1978).

At the Barbours Creek outcrop, the base of the Keyser Formation is an erosional unconformity. This unconformity was not observed at other outcrops in the vicinity due to poor exposure of the contact between the Keyser and underlying Tonoloway Formation. Because of the incomplete exposure of the Tonoloway at Barbours Creek, it is impossible to estimate the thickness of rock missing due to this hiatus relative to other sections in the New Creek area.

New Creek Limestone

The New Creek Limestone is 25 feet (7.6 m.) thick at Prices Bluff, 18 feet (5.4 m.) thick at Iron Gate, and 49 feet (14.9 m.) thick at Low Moor. The New Creek is absent from the sections at Catawba and Fagg due to erosional unconformities. The New Creek is a lithologically consistent unit throughout most of the Appalachians consisting of coarse grained crinoidal grainstone. At the Goode section, the southernmost exposure of the New Creek in this study, it is an exceptionally sandy limestone facies which suggests proximity to a clastic source. This sandy limestone is considered to be the New Creek in this study. Another possibility may be that this is an exceptionally calcareous facies of the Healing Springs Sandstone. Neither unit has been reported in a detailed mapping project of the New Castle area (Bregman, 1967). The New Creek is missing from the sections at Catawba and Fagg.

At the Goode section, the New Creek may be unconformably overlain by the Little Cove Member of the Licking Creek Limestone, but this interval is mostly concealed by a highway along this section. Units missing from this interval include the Healing Springs Sandstone and the Cherry Run Member of the Licking Creek Limestone. These units occur in northern sections, but wedge-out before they reach New Castle. The base of the New Creek is not exposed at the Goode section. Bregman (1967), who previously described the Goode section, considered the lithology identified as New Creek in this study, part of the overlying Licking Creek Limestone. This unit is believed to be New Creek on the basis of its lithologic similarity to the New Creek at other localities. The New Creek at the Goode quarry section contains abundant quartz grains and long sections of articulated crinoid stems which are characteristic of the New Creek at other localities.

Head (1969) states that the New Creek in Virginia is partially correlative to the Coeymans Limestone of New York state. However, the relationship between the two cannot be traced in surface outcrop from New York to Virginia. In light of this, Head suggests that the New Creek is a facies analog of the Coeymans because their depositional settings are similar. Laporte (1969) interprets the Coeymans Limestone as having been deposited in a wide belt of shallow subtidal crinoid mounds and banks which served as a barrier for quieter shoreward environments. Head (1969) applies the same interpretation to the Licking Creek Limestone.

Healing Springs Sandstone

The Healing Springs Sandstone is the southern sandy facies of the northern New Scotland Limestone (Swartz, 1929). The Healing Springs Sandstone is also correlative with the Corriganville Limestone in Pennsylvania and West Virginia (Head, 1969, 1974). The Healing Springs is 20 feet (6.0 m.) thick at its type locality near Healing Springs, Virginia (Swartz, 1929). In northern outcrops included in the fence diagram, the Healing Springs is between 15.5 feet (4.7 m.) and 34 feet (10.3 m.) thick. The latter thickness was measured at the Low Moor outcrop where the Healing Springs Sandstone has a gradational contact with the underlying New Creek Limestone. The former thickness is from the Prices Bluff section (Swartz, 1929). The Healing Springs seems to be missing from outcrops in the New Castle area, most notably from the Goode section where the New Creek is directly overlain by the Licking Creek Limestone. The interval between the Licking Creek and New Creek is obscured at this section therefore, the absence of the Healing Springs is tentatively suggested. At Catawba and Fagg, the Healing Springs is absent due to major unconformities in the sections.

Montgomery (1967) suggests that the Healing Springs, like the Clifton Forge Sandstone, represents an influx of clastic material into the Helderberg sea. Healing Springs clastics were derived from the Giles Peninsula during a period of lowered sea level (Dennison, 1970).

However, relatively thin Silurian sandstone sections which are bounded by unconformities at the Fagg and Catawba sections are evidence that this area supplied clastic material at this time. Broad tectonic uplifting of the Giles Peninsula and surrounding area may have provided the structural relief necessary for widespread erosion of Silurian clastic units.

Licking Creek Limestone

The Licking Creek Limestone is 119 feet (36.2 m.) thick at Prices Bluff (Swartz, 1929), 108 feet (32.9 m.) thick at Iron Gate (Dennison, 1970), and 101 feet (30.7 m.) thick at the Low Moor section. Southwest of these sections, Licking Creek is exposed at the Goode section where only the upper member is present. The Little Cove Member at this section is 43 feet (13.1 m.) thick. The absence of the Cherry Run Member at the Goode quarry may result from a wedge-out or an unconformity. The consistent thickness of the Little Cove Member from northern sections to New Castle suggests an erosional hiatus. The base of the Little Cove is not exposed at the Goode section.

At the Goode section, the top of the Little Cove Member is bounded by an unconformity. It is overlain by the Needmore Shale which occurs stratigraphically above the Ridgeley Sandstone. The Ridgeley is missing at this section. Dennison (1961) and Bregman (1967) report the occurrence of several inches of phosphatic chert immediately above the Licking Creek Limestone and below the Needmore Shale. Dennison believes this phosphatic interval represents the Huntersville Chert which is equivalent to the Needmore Shale in southwestern outcrops, but underlies the Needmore in the vicinity of New Castle (Tillman and Lowry, 1971). McGugan (1965) suggests that phosphatic layers commonly represent condensed deposits above unconformities. Phosphatic nodules occur immediately above the Huntersville Chert at the Fagg section.

There appears also to be an unconformity below the Little Cove Member at the Goode quarry. The Little Cove is underlain by the New Creek Limestone at this section. Missing from this interval is the Cherry Run Member of the Licking Creek Limestone and the Healing Springs Sandstone which is also absent in the Catawba and Fagg sections. The Healing Springs, which is believed to have a southeastern source area, occurs in sections in the northern portion of the study area. Its absence at the Goode quarry suggests an unconformity rather than a stratigraphic pinch out.

Farther south at Catawba and Fagg, the entire Licking Creek Limestone is missing. At the Catawba section, ten feet of Clifton Forge Sandstone is unconformably overlain by the Ridgeley Sandstone (Tillman, 1963, Eubank, 1967, Tillman and Lowry, 1971). Missing from this interval are, in ascending stratigraphic order, the upper part of the Keyser

Formation, New Creek Limestone, Healing Springs Sandstone, and the Licking Creek Limestone. At Fagg, greater relief on the unconformity is exhibited by the absence of the "Keefer" Sandstone, Tonoloway Formation, and Keyser Formation, in addition to the units named above (Tillman, 1963, Eubank, 1967).

The Licking Creek Limestone is correlative with the Rocky Gap Sandstone to the southwest of the study area and with the Shriver Chert to the northwest (Head, 1974). The Little Cove Member of the Licking Creek Limestone was deposited in a shallow shelf environment along the basin margins (Head, 1974). The Little Cove consists of skeletal grainstone containing fairly abundant quartz grains at both exposures examined in this study.

The Cherry Run Member of the Licking Creek Limestone is a black, cherty, lime mudstone interpreted by Head (1974) as indicating a depositional environment intermediate between the Little Cove Member and the correlative Shriver Chert. The Shriver Chert is believed to be a deeper water, below wave base deposit which formed in the center of the basin where fine grained carbonate and quartz debris accumulated. The Cherry Run Member exhibits characteristics of both shallow shelf and deeper water environments; therefore, Head (1974) suggests that it was deposited in a transitional basin-shelf edge environment.

Travis (1971) discusses the origin of the Shriver Chert and cherts in the Helderberg Group and concludes that the chert is of replacement origin and thus cannot be used as an environmental clue in the interpretation of the depositional setting of the Cherry Run Member or the Shriver Chert. However, it may be stated in defense of Head's (1974) proposed depositional model that while replacement may have played a prominent part in its origin the amount of chert to be accounted for is considerable. Futhermore, Travis' study did not involve a detailed paleogeographic model as did Head's (1969, 1974) studies which allow an overview of co-existing environments to be sketched based on regional outcrop patterns.

Ridgeley Sandstone

The Ridgeley Sandstone is exposed within the study area at Iron Gate, Low Moor, Prices Bluff, Catawba, and Fagg. The distribution of the Ridgeley is quite irregular. Two of the northern sections, Iron Gate and Low Moor, have a consistent thickness of 25 feet (7.6 m.) of Ridgeley Sandstone. The third northern section, Prices Bluff, is reported by Swartz (1929) and Lesure (1957) as containing only 1.5 feet (0.4 m.) of Ridgeley, which is overlain by the Romney Shale. Southwest of these outcrops, near New Castle, the Ridgeley is absent. At the Goode quarry, the Licking Creek Limestone is directly overlain by the Huntersville Chert and Needmore Shale.

Within the Salem synclinorium, 30 feet (9.1 m.) of sandstone occupies the interval between the "Keefer" Sandstone and Huntersville Chert. The upper 20 feet (6.0 m.) of this sandstone is the Ridgeley; the lower ten feet (3.0 m.) is tentatively identified as the Clifton Forge Sandstone based on lithology and fossil associations (Tillman and Lowry, 1971).

At Fagg, 18 feet (5.4 m.) of Ridgeley is reported (Tillman, 1963). The basal part of the Ridgeley exposure at this location is an interesting polymictic conglomerate which contains clasts from several stratigraphic units. Eubank (1967) identified several clasts from this outcrop. In addition to the previously mentioned fossiliferous clast of Keyser Sandstone, clasts from the Ordovician Martinsburg Formation and Bays Sandstone, and the Cambrian Chilhowee Group have been identified. Vein quartz clasts which range in size up to five inches (10.1 cm.) in diameter are common in the conglomerate. Eubank (1967) believes the vein quartz clasts were originally deposited as part of the Tuscarora Sandstone.

The source of chert clasts in the Ridgeley conglomerate is open to conjecture. Sources for the chert may have been the Elbrook, Knox, and Middle Ordovician carbonates or Upper Silurian and Lower Devonian carbonates which occur in strike belts to the northwest (Eubank, 1967). The chert clasts are subrounded to rounded and are as large as four inches in diameter. The origin of shale clasts in the conglomerate is also unknown.

The Fagg outcrop contains numerous small faults. Abundant slickensides and displacement of beds can be seen. Repetition of approximately 1.5 feet (0.4 m.) of the section, including the polymictic conglomerate, appears to result from faults trending sub-parallel to bedding. Large lenses of Ridgeley Sandstone suggest considerable relief must have existed on the unconformity surface.

The polymictic conglomerate facies of the Ridgeley has been reported only at the Fagg section. Quartz pebble conglomerates have been reported in the Ridgeley at other localities. The restricted occurrence of the polymictic conglomerate facies indicates a localized depositional setting. Eubank (1967) suggests that the conglomerate was deposited in a shallow depression in the erosion surface developed on the underlying Tuscarora Sandstone which received a veneer of clasts some of which were transported a long distance. Distance of transport was determined by the relative degree of rounding of the clasts. The clasts indicate that the Catawba syncline and the land area farther southeast were subaerially exposed and eroded before or during the deposition of the Ridgeley conglomerate (Eubank, 1967).

The typical facies of the Ridgeley is a brown, medium to coarse grained, friable quartz sandstone. The Ridgeley is a transgressive sheet sand deposit which was distributed throughout the shallow sea within the basin during mid-Deerpark time (Dennison, 1961, Wheeler, 1963, Dennison and Head, 1975).

Thinning of the Ridgeley is due to relief on the underlying erosional surface. Outcrop thicknesses of the Ridgeley Sandstone may also reflect a period of post-Ridgeley erosion. Isopachs by Dennison (1961) show an abrupt thinning of the Ridgeley in western Virginia. Dennison (1961) and Oliver (1967) note the occurrence of isolated remnants of Ridgeley in southwestern Virginia suggesting post-Ridgeley erosion along the basin margins.

Conclusions

The source area for the "Keefer" Sandstone, Clifton Forge Sandstone, Healing Springs Sandstone, and abundant quartz grains in the carbonate units of the Helderberg Group is believed to be to the south and southeast of the study area. Dennison and Head (1975) have interpreted several sea level variations from their study of the Silurian and Devonian of the Appalachian Basin. They suggest lower sea level was reflected in the basin by the deposition of the "Keefer", Clifton Forge, and Healing Springs Sandstones.

Head (1969) has suggested that episodes of clastic influx are likely to occur during minor regressive pulses within major transgressive phases. The Helderberg Group was deposited during a major transgressive phase (Head, 1969). Dennison and Head (1975) suggest isostatic causes, tectonic causes, eustatic sea level changes, and variation in sediment source and progradation patterns as possible causes for basin-wide changes in sea level, hence, for transgressions and regressions within the basin. Head (1969) suggests that clastic influx into the basin occurred during stable periods in the transgression allowing transport of clastic material out into the basin where it temporarily masks carbonate deposition. This line of reasoning would explain the quartzose carbonates in the Helderberg Group.

The deposition of "Keefer" Sandstone occurred in a regressive period during which clastics were derived from the south and southeast and delivered to the basin (Dennison and Head, 1975, Smosna and Patchen, 1978). The Late Silurian Clifton Forge Sandstone and Early Devonian Healing Springs Sandstone contain re-worked "Keefer" sands from the Giles Peninsula area (Dennison, 1970).

However, based on the extent of the erosional unconformity at the top of the "Keefer" and the underlying Tuscarora Sandstone, the clastic source area may extend further south and southeastward than previously suggested by Dennison (1970). In the southern Appalachian Basin, clastic supply from the south and southeast may have been due to broad upwarp caused by tectonic activity. Intermittent emergence of the Salem synclinorium has been suggested by Tillman (1963). This does not imply that the source area was limited to that specific area. Dennison (1970) has suggested that tilting of Late Silurian strata in southwestern Virginia may have resulted from activity associated with the Salinic disturbance.

Several unconformities may be recognized in southwestern Virginia. Dennison (1970) has reported four regional unconformitites in the Late Silurian-Early Devonian section. These are the pre-Clifton Forge, pre-Rocky Gap-Licking Creek, pre-Ridgeley, and pre-Huntersville-Needmore unconformities. An example of each of these unconformities can be found in the study area. The location, within the study area (fig. 8), of these unconformities serves as further evidence, along with facies changes previously discussed, for a southern source area.

The stratigraphic relationships revealed in the fence diagram (fig. 8) reflect several episodes of emergence throughout Late Silurian-Early Devonian time. Unconformities in the stratigraphic column are most prevalent in the southwestern portion of the study area. Most notable are the Fagg, Catawba, and Goode sections which contain stratigraphic breaks involving the absence of Late Silurian and Helderberg age units. Sections in the northern portion of the study area are without major pre-Ridgeley hiatuses. The thickness distribution, facies, and stratigraphic breaks revealed by the sections in this study suggest that the southwestern portion of the study area was intermittently emergent and served as a source area for clastics during Late Silurian-Early Devonian time. The clastic material derived from this area was deposited in Clifton Forge and Healing Springs time. Limestones units are quite quartzose throughout the study area, but even more so to the southwest suggesting proximity to a source area.

Conodont Biostratigraphy

Late Silurian Zonation

Walliser (1964, 1971) established a conodont zonation for the Silurian and lowermost Devonian strata of Europe based on his study of the section at Cellon, Austria (fig. 9). Walliser's zones are based on the first appearance of various diagnostic index species. Zonation of the Late Silurian-Early Devonian portion of the section is based specifically on first appearances of several form species of Spathognathodus and Icriodus. Walliser's conodont zones (fig. 9) for the Late Silurian-Early Devonian interval are as follows:

woschmidti Zone
eosteinhornensis Zone
crispus Zone
latialatus Zone

The woschmidti Zone is Gedinnian in age; the lower three zones are upper Ludlovian (Walliser, 1964).

Several modifications of Walliser's original zonation have been made. Bultynck and Pelhate (1971) extended the base of the uppermost Silurian eosteinhornensis Zone downward to incorporate the crispus and latialatus Zones of Walliser based on their work in

Bohemia and the Armorican massif. Schonlaub (1971) has suggested that the early Llandovery is missing from Walliser's section at Cellon. Unconformities in the section have been inferred by Barrick and Klapper (1976) and Jeppsson (1974).

Klapper and Murphy (1975) have reported a conodont zone from the Pridolian of Nevada which is believed to be correlative with the lower portion of the Walliser's *eosteinhornensis* Zone. The *eosteinhornensis* Zone is reduced in Nevada relative to the same interval at Walliser's Cellon sequence. The *Pelekysgnathus* fauna, which is characteristic of this zone, has not been recognized in the Silurian-Devonian boundary beds in the Appalachians.

Helfrich (1975) suggested a new zonation for the Appalachian Silurian based on two distinct lineages within what is now called the genus *Ozarkodina*. These zones have subsequently been modified by Cooper (1980) and are as follows: (oldest at bottom)

Ozarkodina steinhornensis eosteinhornensis Zone
Ozarkodina crispa Zone
Ozarkodina tillmani Zone
Ozarkodina snajdri Zone
Ozarkodina bicornuta Zone
Ozarkodina sagitta bohemica Zone

Helfrich's Silurian zonation was originally set forth as a series of concurrent range zones. Cooper (1980) has grouped the diagnostic form species of the zones into apparatuses, thus suggesting that they be used as lineage zones.

The uppermost Silurian *eosteinhornensis* Zone of Walliser is recognizable in the Appalachians. Helfrich (1972, 1975) reported the occurrence of *Spathognathodus crispus* and *Spathognathodus steinhornensis eosteinhornensis* from the Tonoloway Formation of the Wills Mountain anticline. In the present study, all conodont-bearing samples taken from the Tonoloway (table 3,4) contain *Spathognathodus steinhornensis eosteinhornensis* and elements with which the spathognathodiform element is associated in a multielement apparatus. *Spathognathous crispus*, which was found by Helfrich (1975) in the lower Tonoloway, was not present in samples from the Tonoloway Formation in this study. The absence of *S. crispus* may be due to the lower Tonoloway being a sandy facies indistinguishable from the "Keefer" in the New Castle area. The Tonoloway Formation based on its conodont fauna is considered to be Late Ludlovian-Early Pridolian in age (Berry and Boucot, 1970).

The form species, Spathognathodus primus highlandensis, was first reported by Helfrich (1975) from the upper Wills Creek and lowest Tonoloway Formation. In the present study, the range of S. p. highlandensis is extended higher in the Tonoloway on the basis of samples from Johns Creek (table 3). Helfrich (1975) proposed a six element apparatus containing S. p. highlandensis from his collection from the Wills Creek Formation. This apparatus includes Plectospathodus extensus, which occurred in samples with S. p. highlandensis from Johns Creek. The other elements of the apparatus were not present in these samples.

Silurian-Devonian Boundary

By agreement the Silurian-Devonian boundary has been designated at the first appearance of the graptolite Monograptus uniformis (Walliser, 1966, Jaeger, 1967, Berdan, 1969, Chlupac, et al., 1972, McLaren, 1977). The stratotype section containing the Silurian-Devonian boundary is located at Klonk, Czechoslovokia. The first appearance of the conodont form species Icriodus woschmidti woschmidti occurs 6.5 feet (2 m.) below the first occurrence of Monograptus uniformis at the stratotype section (Chlupac, et al., 1972). The first appearance of Monograptus uniformis has been reported 6 feet (1.8 m.) below the first appearance of the Icriodus woschmidti fauna in central Nevada (Klapper and Murphy, 1975).

In the Appalachians, the base of the woschmidti Zone (fig. 9), as marked by the first appearance of the I. woschmidti, has been identified by Helfrich (1978) in the topmost Keyser Formation and lowermost New Creek Limestone. In the present study, Icriodus woschmidti woschmidti has been found in the lowermost New Creek Limestone at Low Moor (table 4). The findings of Helfrich (1978), Cook (in prep.), and the present study imply that in the Appalachians Icriodus woschmidti woschmidti may have a more restricted range than in Europe. The New Creek Limestone is considered to be Gedinnian in age (Oliver, et al., 1969).

Due to the lack of graptolites and the widespread distribution of conodonts in the Appalachians, the appearance of Icriodus woschmidti woschmidti may be a more practical indicator of the base of the Devonian System than the first appearance of Monograptus uniformis. Walliser (1971) suggests the use of Spathognathodus steinhornensis remscheidensis as an indicator of the woschmidti Zone in areas where Icriodus woschmidti woschmidti is not present. However, due to the overlapping ranges and transitional relationship of Spathognathodus steinhornensis remscheidensis and its predecessor Spathognathodus steinhornensis eosteinhornensis, a large collection is needed to identify each species. Even with large collections, species intergradation makes recognition of either species difficult.

In the present study, S. s. eosteinhornensis was found in the Tonoloway Formation at Johns Creek (table 3) and Mill Creek (table 5). S. s. remscheidensis was found in the lower Keyser Formation at Barbours Creek (table 3), the uppermost Keyser, New Creek, and Healing Springs at Low Moor (table 4), and in the Licking Creek at Goode quarry (table 2). Transitional forms between Spathognathodus steinhornensis eosteinhornensis and S. s. remscheidensis were observed in samples taken from the Tonoloway Formation. Further transition between the two forms must occur within the Keyser Formation. A complete exposure of the Keyser Formation was not available in the area studied.

The multielement species, Delotaxis elegans, was found in the lower Keyser at Barbours Creek and in the New Creek Limestone at Low Moor. A single specimen of the ligonodiniform element of this species was found in the upper Tonoloway Formation at Johns Creek and at Mill Creek. This species appears to span the Silurian-Devonian boundary in this area.

Early Devonian Zonation

In the Appalachians, relatively little conodont biostratigraphic work has been attempted on the lower Devonian strata. Cook (in prep.) and the present study have examined the Helderberg Group of Virginia. Epstein (1970) has studied the biostratigraphy of the Coeymans Formation in New York. In western North America, Klapper (1979) has recognized a lower Devonian conodont fauna characterized by *Icriodus woschmidti hesperius*, which to date has not been identified in eastern North America.

Mashkova (1979) defined the Gedinnian *postwoschmidti* and *eolatericrescens* Zones on the basis of index species of the genus *Icriodus*. These zones occur above Walliser's *woschmidti* Zone. The *eolatericrescens* Zone is younger than the *postwoschmidti* Zone. Mashkova's zones are based on sections from the Tiver Superhorizon in Podolia.

The form species *Icriodus woschmidti postwoschmidti*, upon which Mashkova (1979) based the *postwoschmidti* Zone, has been recognized in this study from the Licking Creek interval at Low Moor (table 4) and Goode quarry (table 2). The collection is similar to Mashkova's (1968) illustrated type material with differences noted in the systematic paleontology section of this paper. This subspecies was identified by Cook (in prep.) as _Icriodus helderbergensis_ n. sp.

The first appearance of _I. w. postwoschmidti_ at Low Moor occurs 77 feet (23.4 m.) above the two samples containing _I. w. woschmidti_. Ziegler (1971) suggested that _I. w. woschmidti_ is the ancestor of _I. w. postwoschmidti_. Ziegler also states that gradational forms between the two subspecies have been found. The absence of these transitional forms at the Low Moor section may be facies controlled as the Healing Springs Sandstone occurs in the interval between the appearances of the two subspecies. _I. eolatericrescens_ was not found in the present study.

Species of the genera _Acodina_ and _Rotundacodina_ were found in the New Creek, Healing Springs, and Licking Creek units at Low Moor (table 4), and in the New Creek and Licking Creek at Goode quarry (table 2). Species of these two genera were absent from Silurian age strata in this study. Particularily high abundances of

Rotundacodina were found in the Little Cove Member of the Licking Creek Limestone at Low Moor.

Further conodont biostratigraphic studies will be helpful in clearing up the stratigraphic relationships on a regional scale. Conodont-bearing samples are needed from the Ridgeley Sandstone and Needmore Shale to explain the absence of conodont zones in the central Appalachians (Cook, in prep.) which have been reported from western North America. The base of the _Icriodus woschmidti woschmidti_ zone, which marks the base of the Devonian System, needs further substantiation throughout the Appalachians. If the first appearance of _Icriodus woschmidti woschmidti_ proves impractical, a method will be needed to define a boundary between the occurrence of _Ozarkodina steinhornensis eosteinhornensis_ and _Ozarkodina steinhornensis remscheidensis_. The latter has been suggested as an alternative indicator of the base of the Devonian (Walliser, 1971). However, as previously discussed, the relationship between _O. s. eosteinhornensis_ and _O. s. remscheidensis_ is transitonal.

Figure 9 : Standard conodont zonation chart. (after Walliser, 1964, Mashkova, 1968, Helfrich, 1975)

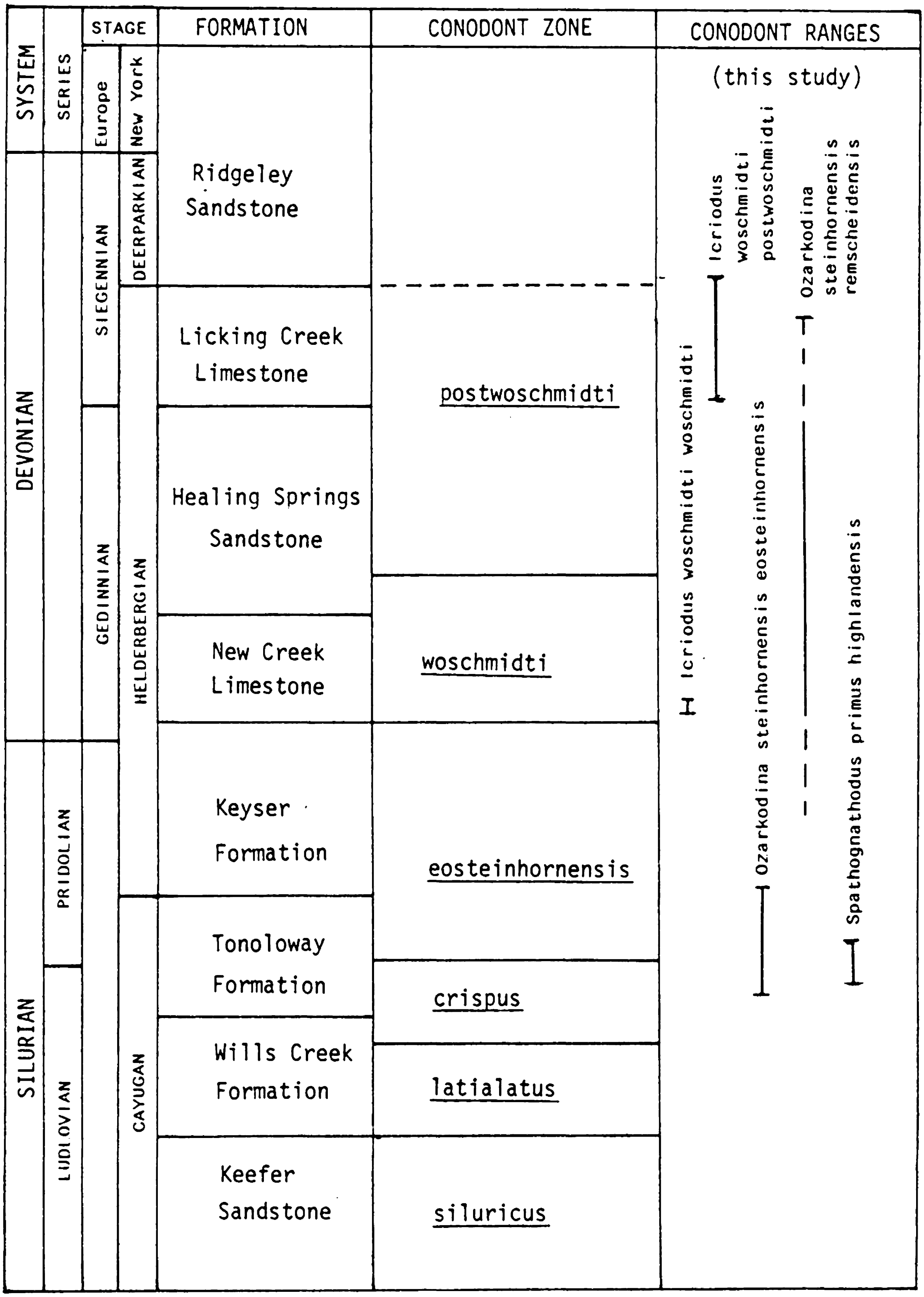

SYSTEM
SERIES
STAGE
Europe
New York
FORMATION
CONODONT ZONE
CONODONT RANGES
(this study)
DEVONIAN
SILURIAN
PRIDOLIAN
LUDLOVIAN
SIEGENNIAN
GEDINNIAN
DEERPARKIAN
HELDERBERGIAN
CAYUGAN
Ridgeley Sandstone
Licking Creek Limestone
Healing Springs Sandstone
New Creek Limestone
Keyser Formation
Tonoloway Formation
Wills Creek Formation
Keefer Sandstone
postwoschmidti
woschmidti
eosteinhornensis
crispus
latialatus
siluricus
Icriodus woschmidti postwoschmidti
Ozarkodina steinhornensis remscheidensis
Icriodus woschmidti woschmidti
Ozarkodina steinhornensis eosteinhornensis
Spathognathodus primus highlandensis

Table 1. Barbours Creek Data

BARBOURS CREEK SECTION

SPECIES	SAMPLES									
	KEYSER FM.							TONOLOWAY FM.		
	1	2	3	4	5	6	7	8	9	10
Ozarkodina steinhornensis remscheidensis apparatus										
Spathognathodus steinhornensis remscheidensis	-	-	-	11	9	-	2	-	-	-
Ozarkodina typica denckmanni	-	-	-	-	-	-	1	-	-	-
Plectospathodus alternatus	-	-	-	2	-	-	-	-	-	-
Hindeodella priscilla	-	-	-	-	-	-	2	-	-	-
Delotaxis elegans apparatus										
Ligonodina elegans	-	-	-	-	1	-	-	-	-	-
Lonchodina detorta	-	-	-	1	-	-	-	-	-	-
Lonchodina greilingi	-	2	-	-	-	-	-	-	-	-
Neoprioniodus multiformis	-	-	-	-	1	-	-	-	-	-
Sample weight (kg)	7.7	7.7	7.0	7.9	7.1	7.7	1.1	4.5	4.5	1.9
Conodonts/kg	0.0	0.3	0.0	1.8	1.5	0.0	4.5	0.0	0.0	0.0

Table 2. Goode Quarry Data

GOODE QUARRY SECTION

SPECIES	SAMPLES LICKING CREEK LST.						NEW CREEK LST.	
	1	2	3	4	5	6	7	8
Icriodus woschmidti postwoschmidti	2	4	1	2	10	75	-	-
Icriodus juvenile specimens	-	-	-	-	-	33	-	-
Spathognathodus steinhornensis remscheidensis	6	2	1	-	-	-	-	-
Ligonodina silurica	1	-	-	-	-	-	-	-
Neoprioniodus multiformis	-	-	-	-	-	1	-	-
Belodella resima	-	-	-	-	1	-	-	-
Coelocerodontus biconvexus	-	-	-	-	8	2	-	-
Coelocerodontus reduncta	-	1	1	-	4	6	-	-
Oneotodus? beckmanni	-	-	-	26	-	-	-	1
Acodina aragonica	2	-	-	-	-	7	-	-
Acodina curvata	-	6	11	1	-	5	-	-
Acodina plicata	-	2	-	3	-	9	-	-
Rotundacodina noguerensis								
lenticular	-	4	2	-	-	6	-	-
quadricostate	-	-	-	1	-	1	-	1
triangular	-	-	-	1	-	1	-	-
tricostate	-	-	-	-	-	6	-	-
Sample weight (kg)	10.3	9.2	6.1	8.5	7.3	7.0	4.5	8.7
Conodonts/kg	1.0	2.1	2.6	4.0	3.4	7.4	0.0	0.2

Table 3. Johns Creek Data

JOHNS CREEK SECTION

SPECIES

SAMPLES

TONOLOWAY FM.

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Ozarkodina steinhornensis eosteinhornensis apparatus																							
Spathognathodus steinhornensis eosteinhornensis	-	-	-	-	-	-	11	6	-	7	-	46	10	32	53	17	3	21	41	64	-	54	10
Spathognathodus primus primus	-	-	-	-	-	-	2	-	-	-	-	26	5	4	11	6	-	3	1	7	-	3	1
Ozarkodina typica denckmanni	-	-	-	-	-	-	-	5	-	-	-	34	2	18	7	-	-	7	11	13	-	15	2
Synprioniodina bicurvata	-	-	-	-	-	-	1	3	-	-	-	30	-	10	-	1	-	2	4	8	-	3	-
Hindeodella priscilla	-	-	-	-	-	-	1	6	-	1	-	23	3	15	3	5	1	1	10	5	-	6	-
Plectospathodus alternatus	-	-	-	-	-	-	-	5	-	2	-	5	-	6	3	-	-	-	5	1	-	6	-
Trichonodella symmetrica	-	-	-	-	-	-	-	3	-	1	-	12	-	4	2	-	1	2	3	4	-	7	-
Spathognathodus primus highlandensis	-	-	-	-	-	-	-	-	-	-	-	5	-	1	1	-	-	-	-	-	-	-	-
Plectospathodus extensus	-	-	-	-	-	-	-	1	-	-	-	4	-	2	-	-	-	1	-	4	-	-	-
Plectospathodus flexuosus	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichonodella inconstans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-
Ligonodina elegans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Ligonodina silurica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Gen. & Sp. indet. B Helfrich	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sample weight (kg).................................	4.5	9.2	4.5	9.3	4.5	4.4	6.5	9.2	4.5	4.5	4.5	7.9	4.5	7.0	8.2	8.2	2.8	1.6	7.7	8.2	1.9	7.7	8.7
Conodonts/kg	0.0	0.0	0.0	0.4	0.0	0.0	2.3	3.2	0.0	2.4	0.0	23.4	4.4	13.1	9.7	3.5	1.8	23.1	9.7	13.2	0.0	12.6	1.5

Table 4. Low Moor Data

LOW MOOR SECTION

SPECIES	SAMPLES																									
	NEW CREEK LST.							HEALING SPRINGS SS.					LICKING CREEK LST.												KEYSER LM.	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Ozarkodina steinhornensis remscheidensis apparatus																										
Spathognathodus steinhornensis remscheidensis	2	19	-	-	-	-	-	1	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Ozarkodina typica denckmanni	3	2	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Hindeodella priscilla	-	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plectospathodus alternatus	-	-	-	-	-	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Trichonodella symmetrica	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Delotaxis elegans apparatus																										
Ligonodina elegans	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lonchonodina detorta	3	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lonchonodina walliseri	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichonodella inconstans	-	3	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Icriodus woschmidti woschmidti	4	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Icriodus woschmidti postwoschmidti	-	-	-	-	-	-	-	-	-	-	-	-	5	10	-	2	1	-	-	6	39	13	20	8	-	-
Juvenile *Icriodus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44	-	-	-
Ligonodina salopia	-	2	-	3	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ligonodina silurica	-	1	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Neoprioniodus excavatus	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Neoprioniodus multiformis	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Plectospathodus extensus	-	2	-	3	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Belodella resima	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	3	3	-	-	-	-	-
Coelocerodontus biconvexus	-	-	-	-	1	-	-	-	-	-	-	-	-	3	-	4	-	-	-	13	26	-	23	-	-	-
Coelocerodontus reductus	-	-	2	-	-	-	-	-	-	1	-	-	2	5	-	1	-	-	-	9	56	17	14	4	-	-
Acodina curvata	2	5	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	7	9	5	1	-	-
Acodina aragonica	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	43	7	3	4	-	-
Acodina plicata	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	8	11	7	-	-
Oneotodus? beckmanni	-	-	7	4	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	21	1	-	-
Rotundacodina dubia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Rotundacodina noguerensis																										
lenticular	-	-	-	-	-	-	-	-	1	-	-	-	-	6	-	1	-	-	-	1	182	43	14	9	-	-
tricostate	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	6	106	22	9	9	-	-
quadricostate	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	63	10	3	-	-	-
triangular	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
plano-convex	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Sample weight (kg)	11.8	7.7	10.9	9.2	8.8	8.2	8.9	8.4	7.8	7.8	8.4	4.8	13.6	13.7	9.5	10.4	4.5	12.2	4.5	9.1	7.7	8.8	6.4	9.2	8.6	4.5
Conodonts/kg	1.4	5.0	0.9	1.5	7.0	0.1	0.3	0.1	0.4	0.4	0.0	0.0	0.7	2.0	0.0	0.9	0.2	0.0	0.0	4.3	69.6	15.8	26.4	4.8	0.5	0.0

Table 5. Mill Creek Data

MILL CREEK SECTION

SPECIES	SAMPLES						
	TONOLOWAY FM.						
	1	2	3	4	5	6	7
Ozarkodina steinhornensis eosteinhornensis apparatus							
Spathognathodus steinhornensis eosteinhornensis	-	23	-	-	-	-	-
Spathognathodus primus primus	-	3	-	1	-	-	-
Ozarkodina typica denckmanni	1	4	-	-	-	-	-
Synprioniodina bicurvata	-	5	-	-	-	-	-
Hindeodella priscilla	-	2	-	-	-	-	-
Plectospathodus alternatus	-	2	-	-	-	-	-
Trichonodella symmetrica	-	1	-	-	-	-	-
Ligonodina elegans	-	1	-	-	-	-	-
Coelocerodontus biconvexus	-	-	-	1	-	-	-
Sample weight (kg)	4.5	8.2	4.5	4.5	4.5	4.9	4.5
Conodonts/kg	0.0	5.0	0.0	0.2	0.0	0.0	0.0

Systematic Paleontology

Introduction

Conodont samples were processed from the Silurian Tonoloway Formation, the Silurian-Devonian Keyser Formation, and the Early Devonian Helderberg Group. A total of 1909.4 kilograms of rock yielded 2006 identifiable conodont specimens. The average number of conodonts per kilogram was quite low (1.05 conodonts/kg.) due to low abundances and poor preservation in the quartzose carbonates typical of the Late Silurian-Early Devonian strata within the study area.

A total of twelve genera were identified. Three multielement species, *Ozarkodina steinhornensis eosteinhornensis*, *Ozarkodina steinhornensis remscheidensis*, and *Delotaxis elegans* were recognized. Elements belonging to a fourth multielement species, *Delotaxis salopia*, were also found. Twenty-two form species, not counting those included in the previously mentioned multielement apparatuses, were identified. Practical uses of biostratigraphic markers within the Late Silurian-Early Devonian section are discussed in the chapter on conodont biostratigraphy.

Multi-element Apparatuses

Multielement apparatuses are recognized by the following criteria suggested by Klapper and Philip (1971).

1. "constant numerical ratios of constituent elements in collections numbered in hundreds of thousands"
2. "similarity of stratigraphic ranges of the elements"
3. "similarity of identity of size, denticulation, character of basal cavity, distribution of white matter, and other morphologic features."

Another criterion suggested by Sweet and Bergstrom (1966) recommends "a survey of the literature and of reference collections to ascertain whether most faunas from other localities that contain one of the form elements of the multielement group also contain the others." The following text will discuss the multielement apparatuses identified from the Late Silurian-Early Devonian units included in this study. Form taxa will also be discussed under their generic heading when appropriate.

Taxa are morphologically consistent with Cook (in prep.) unless otherwise stated; for updated synonomies and illustration of the Helderberg fauna that work should be consulted. Illustrations and updated synonomies for the conodont fauna of the Silurian Tonoloway Formation are available in recent studies by Helfrich (1972, 1975).

Genus DELOTAXIS Klapper and Philip, 1971

Delotaxis elegans (Walliser, 1964)

Remarks--The multielement species *Delotaxis elegans* was initially recognized by Jeppsson (1969). Jeppsson applied the name *Ligonodina elegans* to the apparatus. Included in this apparatus are an ozarkodiniform, neoprioniodiniform, ligonodiniform, lonchodiniform (=detortiform), and trichonodelliform element. In form taxonomic terms the original elements assigned to the *Ligonodina elegans* apparatus are as follows:

Ozarkodina ortuformis Walliser, 1964
Neoprioniodus bicurvatus (Branson and Mehl, 1933)
Ligonodina elegans Walliser, 1964
Lonchodina detorta Walliser, 1964
Trichonodella inconstans Walliser, 1957

Klapper and Philip (1971) transferred the multielement apparatus *Ligonodina elegans* to a new genus called *Delotaxis*. Klapper and Philip (1971) included *Lonchodina walliseri* in the apparatus on the basis of associated occurrences in an effort to make the apparatus conform to their Type 3 grouping. Jeppsson (1974) disagreed with the inclusion of *Lonchodina walliseri* citing his collection, as well as the collection of Legault (1968) and other smaller published collections, which do not reveal a consistent association between elements belonging to *Delotaxis elegans* and the form species *Lonchodina walliseri*. In the present study, *Lonchodina walliseri* does not show a strong similarity of stratigraphic range with other elements of *Delotaxis elegans*. The sole occurrence of *Lonchodina walliseri* in the writer s collection is within a sample which contains only the trichonodelliform element of the *Delotaxis elegans* apparatus.

Jeppsson (1972, 1974) suggested that variation within the neoprioniodiform and detortiform elements of the *Delotaxis elegans* apparatus is rather large. *Neoprioniodus bicurvatus*, the neoprioniodiform element of *Delotaxis elegans*, was not present in the writer s collection. However, samples from the New Creek

Limestone contained the form species Neoprioniodus multiformis, which exhibits the same stratigraphic range as that of Delotaxis elegans and may be the neoprioniodiform element in this species.

All previous occurrences of Delotaxis elegans have been confined to strata older than Walliser s woschmidti Zone from the Cellon sequence (Jeppsson, 1969). The apparatus has been reported in the lower eosteinhornensis Zone, but is more commonly found in the upper eosteinhornensis Zone (Jeppsson, 1972). Helfrich (1978) has reported the occurrence of Delotaxis elegans from the Keyser Formation in Virginia and West Virginia. Helfrich s samples also contained the multielement species Ozarkodina steinhornensis eosteinhornensis. In this study, elements of the Delotaxis elegans apparatus have been identified from the upper Tonoloway, Keyser, and lowest New Creek units. In the New Creek at Low Moor, Delotaxis elegans occurs in samples with Icriodus woschmidt woschmidti, which indicates that these beds are in Walliser s woschmidti Zone. In the Keyser Formation at Barbours Creek, Delotaxis elegans occurs in samples which also contain the multielement apparatus Ozarkodina steinhornensis remscheidensis.

Delotaxis salopia Savage, 1976

Remarks--A multielement apparatus containing five elements has been proposed by Savage (1976) from the Gedinnian strata of the Klamath Mountains, California. The apparatus consists of an ozarkodiniform, neoprioniodiform, ligonodiniform, plectospathodiform, and trichonodelliform element. In form taxonomy these elements are as follows:

Ligonodina salopia Rhodes, 1953
Lonchodina walliseri Ziegler, 1960
Neoprioniodus excavatus (Branson and Mehl, 1933)
Lonchodina greilingi Walliser, 1957

The plectospathodiform element is illustrated for the first time by Savage and is not named. The ozarkodiniform and trichonodelliform elements are regarded by Savage as having affinities with Lonchodina walliseri and Lonchodina greilingi, respectively. Savage based this apparatus on a total of 55 specimens from two localities.

Ligonodina salopia and Neoprioniodus excavatus occur together in the New Creek Limestone at Low Moor. However, other elements included in the apparatus were not found. The overall yield of identifiable conodonts from the New Creek at Low Moor was too low to eliminate or substantiate the possibilty of the entire apparatus being present in the New Creek interval. Intensive sampling at the section or another locality may turn up the missing elements.

Genus ICRIODUS, Branson and Mehl, 1938

Icriodus woschmidti postwoschmidti Mashkova, 1968

Remarks--Specimens of the genus *Icriodus* recovered from the Licking Creek Limestone are placed in the form taxon *Icriodus woschmidti postwoschmidti* with reservations discussed in the following paragraphs. Ziegler (1971) suggested placing *Icriodus eolatericrescens* Mashkova (1968), and *Icriodus woschmidti transiens* Carls and Gandl (1969) in synonomy with *Icriodus woschmidti postwoschmidti* Mashkova (1968). Ziegler stated that *I. w. postwoschmidti* differs from *I. w. transiens* only in that the latter has a larger cusp. *I. eolatericrescens* is considered by Ziegler to be younger ontogenetic stages of *I. w. postwoschmidti*. It was further suggested by Ziegler that the name *I. w. postwoschmidti* be used for the entire subspecies. This name was suggested, although in violation of page priority, because it effectively reveals the subspecies' relationship to its ancestral stock, *Icriodus woschmidti woschmidti* Ziegler (1960). Later work by Ziegler (et al., 1973) and Klapper and Murphy (1975) placed *I. w. transiens* in synonomy with *I. w. postwoschmidti* and regarded *I. eolatericrescens* as a separate taxon. Mashkova (1979) constructed a conodont zone based on the occurrence of *I. eolatericrescens* with diagnostic species of graptolites and trilobites. The *eolatericrescens* Zone lies above the *woschmidti* and *postwoschmidti* Zones.

Specimens from the Licking Creek Limestone interval are similar to both *I. w. postwoschmidti* and *I. w. transiens* in all major morphologic characteristics. These morphologic similarities include the number of transverse ridges on the main platform (5-8), the number of lateral processes, the number of longitudinal denticle rows on the main platform, and the spacing of transverse ridges. The transverse ridges are widely spaced at the anterior end and become more closely spaced with increasing proximity to the posterior end of the platform.

Further similarities include the presence of two median denticles posterior to the last transverse ridge.

The relative height of these two median denticles, termed the principal tubercle and the corner tubercle by Mashkova (1968) is a point of dissimilarity between I. w. postwoschmidti, I. w. transiens, and the collection from the Licking Creek Limestone. The principal tubercle, which is the anteriormost of the two, is considered to be at the apex of the basal cavity. The corner tubercle is directly posterior to the principal and is the final denticle on the main platform proper. The Licking Creek interval collection is similar to the type material of I. w. postwoschmidti in that the corner tubercle is greater in height and more robust than the principal tubercle. The original description of I. w. transiens Carls and Gandl, (1969) states the opposite relationship to be the case with the principal tubercle being of greater height, although the illustrated specimens poorly reveal this relationship.

The denticles of the median longitudinal row of the main platform are connected by a longitudinal ridge. This relatively sharp edged ridge is found in both I. w. postwoschmidti and I. w. transiens, but is thinner and better developed in the Licking Creek collection. The denticles in both taxa and in the Licking Creek collection rise slightly above the longitudinal ridge at its junction with the transverse rows. Although the three longitudinal rows of denticles are fused into transverse rows, the transverse row thins in the area between each denticle allowing for distinction of the individual denticles. The degree of fusion between the denticles is much less than in *Icriodus woschmidti woschmidti* Ziegler (1960).

The junction point of the postero-lateral process with the main platform occurs at the corner tubercle in both taxa and in this collection; however, differences in the point of junction of the antero-lateral process with the main platform are apparent. On *I. w. postwoschmidti* the antero-lateral process joins the main platform at the location of the most posterior transverse row. On *I. w. transiens* and specimens of the Licking Creek collection the antero-lateral process joins the main platform at the location of the principal tubercle.

Dentition on the postero-lateral process consists of a maximum of five denticles or five transverse ridges with single denticles raised slightly above the ridge. The development of transverse ridges and a maximum of five denticles on the postero-lateral process are common to both the Licking Creek interval collection and *I. w. postwoschmidti*. *I. w. transiens* was originally described as having only two or three denticles on the postero-lateral process. The development of transverse ridges was not mentioned nor is it obvious on illustrated material.

Immature specimens from the Licking Creek interval collection reveal characteristics which are within the range of species ontogenetic variation and therefore are not separated into another taxon. These immature forms display narrower basal cavities, weak development of the antero-lateral process and median longitudinal ridge, poorly defined transverse rows on the main body of the platform, and less contrast between the lobes and embayments of the basal cavity outline. A few specimens also display a slight posterior displacement of the median row of denticles.

The proposal of Ziegler (et al., 1973) and Klapper and Philip (1975) to place *Icriodus woschmidti transiens* in synonomy with *Icriodus woschmidti postwoschmidti* is followed herein. Having noted the minor differences between specimens of the collection herein and the taxa of Mashkova (1968) and Carls and Gandl (1969), this collection can be regarded as belonging to *I. w. postwoschmidti*. Specimens examined in this study are essentially identical to those identified by Cook (in prep.) as *Icriodus helderbergensis* n. sp.

The placement of members of the genus *Icriodus* in multielement species is still in a state of controversy. Lange (1968) first recognized a multielement apparatus containing members of the form genera *Icriodus* (Branson and Mehl, 1938) and *Acodina* (Stauffer, 1940). Lange reported an assemblage preserved within a coprolite to contain one pair of *Icriodus* elements and fifteen pairs of *Acodina* elements. Due to the mode of preservation, the position of the elements did not reveal any pertinent information regarding the life position of these elements within the conodont animal. Lange suggested that all thirty-two conodonts belong to a single individual.

Klapper and Philip (1971) assigned the *Icriodus-Acodina* assemblage to their Type 4 apparatus which consists of an icriodontan (I) and a sagittodontan (S2) element. The sagittodontan element in this apparatus is acodinan in form. Klapper and Philip, however, dispute Lange's (1968) ratio of cone elements to icriodontan elements stating that their data shows the icriodontan element to be numerically more abundant than the acodinan element.

The collection of icriodontan and acodinan elements from samples taken from the Licking Creek Limestone interval was not large enough to statistically assess the ratio between the I and S2 elements. The relatively small number of specimens which were identifiable is a function not solely of population density, but also of poor preservation and sorting which would have the net effect of increasing the number of more robust icriodontan forms while decreasing the number of less stout cone forms.

Genus ONEOTODUS Lindström, 1955

Remarks--Lindström (1955) erected the genus *Oneotodus* with the following generic description: "Simple teeth with a well-defined basal cavity and the cusp un-keeled and subcircular in cross section." Due to the generalized nature of the generic diagnosis many different form species have been assigned to this genus. Ethington and Brand (1981) have reviewed the genus *Oneotodus* and suggest a stricter definition which would exclude from the genus many of the form species attributed to it in the twenty-five years since Lindström's original diagnosis.

Specimens identical to those illustrated by Bischoff and Sannemann (1958) and Lane and Ormiston (1979) have been recovered from the New Creek Limestone and the

Little Cove Member of the Licking Creek Limestone. Ethington and Brand suggest reassignment of *Oneotodus*? *beckmanni* Bischoff and Sannemann (1958), but do not offer an alternative generic assignment for the species. Lane and Ormiston (1979) used the name *Pseudooneotodus beckmanni* for specimens which appear identical to Bischoff and Sannemann s type material of *Oneotodus*? *beckmanni*. The name *Pseudooneotodus beckmanni* has not been formally proposed and is probably illegal. This name is not included in Ethington and Brand's review of the genus, but because of its similarity to Bischoff and Sannemann's illustrated material, it should also be reassigned. For the purposes of the present study, these simple cone cone forms will be assigned to the form species *Oneotodus*? *beckmanni*.

Genus OZARKODINA Branson and Mehl, 1933

Ozarkodina steinhornensis eosteinhornensis (Walliser, 1964)

Remarks--Walliser (1964) in his study of Silurian conodonts in Europe grouped six form species to which he applied the title apparatus "J". The six elements originally included in Walliser's apparatus "J" are:

Spathognathodus steinhornensis, Ziegler, 1956
Ozarkodina typica, Branson and Mehl, 1933
Hindeodella priscilla, Stauffer, 1938
Plectospathodus flexuosus, Branson and Mehl, 1933
Neoprioniodus bicurvatus, (Branson and Mehl, 1933)
Trichonodella symmetrica, (Branson and Mehl, 1933)

Helfrich (1972, 1975), in his study of conodonts from Silurian strata in Virginia, West Virginia, and Maryland, followed the basic grouping as presented by Walliser, but replaced *Plectospathodus flexuosus* with the form species *Plectospathodus alternatus* (Walliser, 1964). Helfrich (1975) called this emended assemblage Group XI. Fåhraeus (1971, 1974) suggested that *P. alternatus* is distinguished from *P. flexuosus* by the alternating height of the blade denticles. The characteristic alternation of denticles is also present in the hindeodelliform element of Walliser's apparatus "J" and thus, the substitution of *P. alternatus* for *P. flexuosus* is probaby correct. Fåhraeus (1971, 1974) suggested that *P. alternatus* is transitional to *Plectospathodus extensus*

Rhodes (1953). Specimens of Plectospathodus alternatus, Plectospathodus flexuosus, and Plectospathodus extensus were found in samples from the Tonoloway Formation of the New Castle area. Specimens of Plectospathodus alternatus dominated the collection of plectospathodiform elements found in the Tonoloway Formation. Two specimens of Plectospathodus flexuosus were identified, whereas twelve specimens of Plectospathodus extensus were recovered.

Walliser's (1964) apparatus "J" has subsequently been renamed Ozarkodina steinhornensis eosteinhornensis (Mashkova, 1972). Ozarkodina steinhornensis eosteinhornensis as defined by Mashkova (1972) consists of the following form species:

Spathognathodus steinhornensis eosteinhornensis, Walliser, 1964
Ozarkodina typica denckmanni, Ziegler, 1956
Hindeodella priscilla, Stauffer, 1938
Plectospathodus flexuosus, Branson and Mehl, 1933
Neoprioniodus bicurvatus, (Branson and Mehl, 1933)
Trichonodella symmetrica, (Branson and Mehl, 1933)

The above apparatus, with the substitution of Plectospathodus alternatus for Plectospathodus flexuosus, has been reported by Helfrich (1971, 1975) from the Silurian Tonoloway Formation. Helfrich (1972, 1975) also reported the _Ozarkodina steinhornensis eosteinhornensis_ apparatus from the Keyser Formation.

In the present study, a multielement apparatus identical to Helfrich's Group XI (_Ozarkodina steinhornensis eosteinhornensis_) was recognized from the Tonoloway interval. Elements of the _Ozarkodina steinhornensis eosteinhornensis_ apparatus were found in all conodont-bearing samples taken from the Tonoloway Formation. Samples from the lower Keyser Formation in this study were barren; samples higher in the Keyser Formation taken from the Barbours Creek and Low Moor sections yielded elements of the _Ozarkodina steinhornensis remscheidensis_ apparatus.

Several specimens of _Spathognathodus steinhornensis eosteinhornensis_, the platform element of the _Ozarkodina steinhornensis eosteinhornensis_ apparatus, vary slightly from those illustrated by Walliser (1964) and Helfrich (1972, 1975). A prominent apical denticle above the central basal cavity is present on some specimens disrupting the characteristically even oral margin of the spathognathodiform element. This is perhaps a transitional stage between _Spathognathodus steinhornensis_ eosteinhornensis and Spathognathodus steinhornensis remscheidensis which is characterized by a prominent apical denticle and 1-3 raised denticles on the anterior end of the blade. Spathognathodus steinhornensis remscheidensis Ziegler (1960) is considered to be evolutionarily linked to S. s. eosteinhornensis (Walliser, 1964, Bultynck, 1971, Mashkova, 1972) and is typically found in the lowermost Gedinnian.

Ozarkodina steinhornensis eosteinhornensis is currently considered to be the main stock of an evolutionary lineage (Mashkova, 1972, Fåhraeus, 1974) which begins with Ozarkodina steinhornensis eosteinhornensis in Pridolian time and evolves into the Lower Gedinnian multielement species Ozarkodina steinhornensis remscheidensis Ziegler. This evolutionary lineage is based on morphologic change within the spathognathodiform element of the Ozarkodina apparatuses (Walliser, 1964, Bultynck, 1971, Mashkova, 1972). Evidence has been presented suggesting an overlap of the stratigraphic ranges of Spathognathodus steinhornensis eosteinhornensis and Spathognathodus steinhornensis remscheidensis, the spathognathodiform elements of Ozarkodina steinhornensis eosteinhornensis and Ozarkodina steinhornensis remscheidensis, respectively (Bultynck, 1971, Klapper and Murphy, 1975). Bultynck (1971) and Klapper and Murphy (1975) have reported conodont faunas containing specimens of both _S. s. eosteinhornensis_ and _S. s. remscheidensis_ suggesting a transitional relationship between the two. Walliser (1964) considered the form species _Spathognathodus steinhornensis eosteinhornensis_ to have its first appearance in upper Ludlow time and to extend through the Pridolian until replaced by _Spathognathodus remscheidensis_ Ziegler (1960). The evolutionary relationship between the form species _S. s. eosteinhornensis_ and _S. remscheidensis_ has been well documented (Walliser, 1964, Bultynck, 1971, Mashkova, 1968).

Ozarkodina steinhornensis remscheidensis, (Ziegler, 1960)

Remarks--The multielement species _Ozarkodina steinhornensis remscheidensis_ is distinguished from _Ozarkodina steinhornensis eosteinhornensis_ by its spathognathodiform element. The spathognathodiform element of _Ozarkodina steinhornensis remscheidensis_ is the form species _Spathognathodus remscheidensis_ Ziegler (1960). As in _O. s. eosteinhornensis_, the plectospathodiform element of _O. s. remscheidensis_ was originally thought to be the form species *Plectospathodus flexuosus* (Mashkova, 1972). Påhraeus (1974) has replaced *P. flexuosus* with *P. alternatus* in the multielement species. This substitution is consistent with the findings of this study from samples in the Keyser and New Creek intervals.

Both *Ozarkodina steinhornensis remscheidensis* and *Ozarkodina steinhornensis eosteinhornensis* contain a platform element (P), an ozarkodinan (O1), a neoprioniodontan (N), and a symmetry series consisting of a hindeodellan (A1), plectospathodan (A2), and a trichonodellan (A3). These apparatuses are therefore considered to belong to Klapper and Philip's (1971) Type 1 grouping. The shorthand abbreviation for each of the elements was suggested by Klapper and Philip (1971).

The *Ozarkodina steinhornensis remscheidensis* apparatus has been reported from the Upper Silurian-Lower Devonian boundary beds in Italy (Serpagli and Mastandrea, 1980), Central Nevada (Klapper and Murphy, 1975), Alaska (Lane and Ormiston, 1979), the U.S.S.R. (Mashkova, 1972), and in Virginia by Cook (in prep.) and the present study. Elements of *Ozarkodina steinhornensis remscheidensis* were found in the lower Keyser Formation at Barbours Creek and in the uppermost Keyser at Low Moor suggesting that it ranges through the entire Keyser interval. *Ozarkodina steinhornensis remscheidensis* was also found in the New Creek Limestone and Healing Springs Sandstone at Low Moor and in the Licking Creek Limestone at Goode quarry. An updated synonomy of the apparatus is given by Klapper and Murphy (1975).

Genus SPATHOGNATHODUS Branson and Mehl, 1933

Spathognathodus primus highlandensis Helfrich, 1975

Remarks--Helfrich (1975) proposed a new subspecies of *Spathognathodus primus* (Branson and Mehl) from the upper Wills Creek and lower Tonoloway Formations at Wills Creek anticline in Virginia, West Virginia, and Maryland. This distinctive subspecies is characterized by denticles which decrease anteriorly and posteriorly of a nearly medial cusp-like denticle (Helfrich, 1972). Helfrich (1975) recognized a multielement apparatus from the upper Wills Creek Formation which contains *S. p. highlandensis* and four other elements. This apparatus, called Group IX, consists of the following:

Spathognathodus primus highlandensis Helfrich, 1975
Ozarkodina typica intermedia Helfrich, 1975
Plectospathodus extensus Rhodes, 1953

Neoprioniodus excavatus (Branson and Mehl, 1933)

Trichonodella excavata (Branson and Mehl, 1933)

In the present study, *S. p. highlandensis* was found in the middle Tonoloway Formation at Johns Creek. This occurrence may extend the previously reported range of this subspecies. However, Helfrich s (1972, 1975) Tonoloway sections are thicker than the exposure at Johns Creek and it is possible that the Keyser Formation is occupying part of the interval included in Helfrich s Tonoloway sections. Of the five elements grouped with *S. p. highlandensis* by Helfrich (1975), only *Plectospathodus extensus* occurred in samples with *S. p. highlandensis* taken from Johns Creek.

Spathognathodus primus primus, Branson and Mehl, 1933

Remarks--Samples from the Tonoloway Formation contain, in addition to members of *Ozarkodina steinhornensis eosteinhornensis*, the form species *Spathognathodus primus primus* Branson and Mehl (1933). *Spathognathodus primus primus* was found to range through the entire Tonoloway interval in this study. However, in samples containing both *S. s. eosteinhornensis* and *S. p.*

primus, the form species *S. p. primus* consistently occurred in lesser numbers than *S. s. eosteinhornensis*. Helfrich (1972, 1975) suggested that *S. p. primus* was the central stock for a spathognathodid lineage which includes *S. p. primus* and three subspecies. Helfrich considered *S. p. primus* to be the spathognathodid element in his Group IV species which also includes an ozarkodiniform, ligonodiniform, plectospathodiform, neoprioniodiform, and trichonodelliform elements. In this study, only the spathognathodiform element was found in significant numbers throughout the Tonoloway interval.

It is not evident exactly where *Spathognathodus primus primus* should be placed taxonomically since its range extends concurrently with several of Helfrich's groups and *Ozarkodina steinhornensis eosteinhornensis*. It is conceivable that *S. p. primus* may belong to one or more of these multielement groupings rather than to a separate species. Within the limits of this study, *Spathognathodus primus primus* will be considered part of the *Ozarkodina steinhornensis eosteinhornensis* apparatus based on the absence of other elements with which to associate the spathognathodiform element and the morphologic similarity of *S. p. primus* to *S. s.*

eosteinhornensis. *Spathognathodus primus primus* has been suggested as the possible antecedent of *S*. *s*. *eosteinhornensis* (Rexroad and Craig, 1971, Helfrich, 1975).

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Appendix A

Barbours Creek Section

Location--This section is exposed along Barbours Creek, Craig County, Virginia, where it cuts the southeast flank of Little Mountain. The section is located 1.9 miles (3.0 km.) east along County Route 611 from its intersection with County Route 609 near New Castle, Craig County, Virginia.

Unit Name	(total thickness)		Unit Thickness		Cumulative Thickness	
	(ft.)	(m.)	(ft.)	(m.)	(ft.)	(m.)
Keyser Formation	(135.3)	(41.3)				
15. Sandstone, dark brown-gray, medium-coarse grained, thick bedded, moderately sorted, friable, with molds of crinoid columnals.			33.0	10.1	135.3	41.3
14. Covered interval.			31.0	9.5	102.3	31.2
13. Reefal packstone, medium-light gray, massive, reef framework			20.5	6.2	71.3	21.7

	consists of *Cladopora rectiliniata* and *Cladopora multiliniata*, also contains brachiopods, trilobites, crinoids, and stromatoporoids, BC7, BC6,				
12.	Crinoidal-bryozoan grainstone, dark gray, coarse grained, medium bedded, with pink calcite grains, quartzose, black chert lenses, ramose and fenestrate bryozoans, crinoids, brachiopods, sample BC5.	4.5	1.4	50.8	15.5
11.	Sandstone, medium brown, fine grained, medium bedded, cross bedded, (3 inch sets), rusty specks throughout, thin hematitic seams, calcareous, with crinoids, brachiopods.	2.8	0.8	46.3	14.1
10.	Skeletal packstone, medium gray, medium grained, thin bedded, argillaceous weathering, quartzose, with ramose and	1.5	0.5	43.5	13.3

	fenestrate bryozoans, crinoids, and trilobites, sample BC4.				
9.	Sandstone, medium brown, fine grained, massive, same as unit 11, with stromatoporoids.	7.0	2.1	42.0	12.8
8.	Skeletal packstone, medium gray, medium bedded, nodular, quartzose, black chert grains, brachiopods, bryozoans, sample BC3.	2.8	0.8	35.0	10.7
7.	Sandstone, dark gray, medium grained, thin bedded, nodular, well sorted, calcareous, well indurated, chert lenses, rusty specks, brachiopods, bryozoans, trilobites, sample BC2.	2.5	0.8	32.3	9.8
6.	Sandstone, light gray, fine grained, thin-medium bedded, well sorted and rounded, cross bedded, rusty specks, brachiopods, favositid corals.	2.3	0.7	29.8	9.0

5.	Shale, light gray, calcareous, alternating with very fine grained, calcareous, sandstone, light gray; layers show pinch and swell.	2.3	0.7	27.5	8.4
4.	Sandstone, medium gray, fine grained, thin-medium bedded, nodular, calcareous, with crinoids, brachiopods, craggy weathering, sample BC1.	4.0	1.2	25.3	7.7
3.	Sandstone, dark gray, fine grained, thin bedded, blocky, well indurated, well sorted and rounded.	8.5	2.6	21.3	6.5
2.	Sandstone, white-gray, medium grained, medium bedded, rusty specks, calcareous.	1.8	0.5	12.8	3.9
1.	Sandstone, light gray, medium-coarse grained, thin bedded, calcareous, poorly sorted and	1.0	0.3	11.0	3.3

rounded, with lime mudstone rip-ups, brachiopods, encrusting bryozoans; base of unit is an erosional unconformity between the Keyser and Tonoloway Formaions.				
Tonoloway Formation (10.0) (3.0)				
4. Lime mudstone, black, thin bedded, irregular laminations, with trilobites, brachiopods, samples BC10, BC9.	6.0	1.8	10.0	3.0
3. Lime mudstone-siltstone, dark gray, thin bedded, blocky, with brachiopods.	1.8	0.5	4.0	1.2
2. Lime mudstone-siltstone, black, thin bedded, abundant ostracods, samples BC8.	0.3	0.1	2.3	0.7
1. Sandstone, light gray, very fine grained, medium bedded,	2.0	0.6	2.0	0.6

platy, with brachiopods, ostracods, covered below.

Goode Section

Location--This section is in an abandoned quarry located on the property of Ralph Goode. The Goode property is located 3.7 miles (5.9 km.) south along State Route 311 from its intersection with Route 42 near New Castle, Craig County, Virginia.

Unit Name	(total thickness) (ft.)	(total thickness) (m.)	Unit Thickness (ft.)	Unit Thickness (m.)	Cumulative Thickness (ft.)	Cumulative Thickness (m.)
Needmore Shale	(not measured)					
Huntersville Chert	(not measured)					
Licking Creek Limestone	(43.0)	(13.1)				
Little Cove member	(43.0)	(13.1)				
1. Skeletal-quartzose grainstone, medium gray, fine grained, massive, abundant fine and coarse ribbed brachiopods,			43.0	13.1	61.0	18.6

rare rugose corals, trilobites,
byrozoans, samples G1,G2,G3,G4,
G5,G6.

New Creek Limestone (18.0) (5.5)

2. Covered interval. 7.0 2.1 18.0 5.5
May be Healing Springs Sandstone.

1. Crinoidal-quartzose grainstone, 11.0 3.3 11.0 3.3
light brown, coarse grained,
massive, with brachiopods,
large crinoid columnals, and stem
segments, large (3 feet) and
and small (3-4 inches) scale
cross beds, with pink calcite
grains, abundant quartz pebbles,
friable, deeply weathered,
samples G7,G8.

Johns Creek Section

Location--The section is located along Johns Creek on the southeast flank of Nutters Mountain, 2.5 miles (4.0 km.) along a jeep trail from County Route 678 along the property of Mrs. Anne Willis Taylor of Roanoke, Virginia. The Taylor property is located at the end of County Route 678, northwest of the town of New Castle, Craig County, Virginia.

Unit Name	(total thickness) (ft.)	(total thickness) (m.)	Unit Thickness (ft.)	Unit Thickness (m.)	Cumulative Thickness (ft.)	Cumulative Thickness (m.)
Keyser Formation	(147)	(44.8)				
5. Sandstone, white-tan, medium grained, massive, well sorted, iron oxidized color, forms low cliff, strike N70E, dip 70SE.			17.0	5.2	578.0	176.1
4. Covered interval.			82.5	25.1	561.0	170.9
3. Sandstone, white-pink, medium grained, massive, friable, well sorted, cross bedded, silica			9.5	2.9	478.5	145.7

	cemented, forms massive cliff.				
2.	Shale, dark tan-pink, Big Mountain Shale(?).	13.0	4.0	469.0	142.8
1.	Sandstone, white-pink, medium grained, massive, well sorted, cross bedded, forms cliff.	25.0	7.6	456.0	138.0
Tonoloway Formation (273.0) (83.2)					
45.	Covered interval.	82.0	25.0	431.0	131.2
44.	Lime mudstone, dark gray, thin bedded.	0.5	0.1	348.5	106.1
43.	Sandstone, light gray, fine grained, thin bedded, calcareous, with brachiopods.	0.5	0.1	348.5	106.1
42.	Siltstone, light gray, thin bedded, calcareous, rare ostracods.	0.5	0.1	348.0	106.0

41.	Gastropod grainstone, medium gray, thin bedded, trilobites, brachiopods, and bryozoans, sample JC23.	1.5 0.5	347.5	105.8
40.	Quartzose grainstone, dark gray, medium grained, thin bedded, platy, brachiopod and trilobite fragments, sample JC22.	4.5 1.4	346.0	105.4
39.	Lime mudstone, dark gray, thin bedded, sample JC21.	6.0 1.8	341.5	104.0
38.	Sandstone, light gray, medium bedded, moderately sorted and rounded, calcareous, brachiopod fragments.	5.5 1.7	335.5	102.1
37.	Siltstone, medium gray, thin bedded, calcareous, brachiopod and trilobite fragments, sample JC20.	2.0 0.6	330.0	100.5
36.	Siltstone, medium gray, thin	5.5 1.7	328.0	99.9

	bedded, calcareous, cross bedded.				
35.	Gastropod packstone, dark gray, thin bedded, silty, sample JC19.	2.0	0.6	322.5	98.3
34.	Intraclast wackestone, dark gray, very thinly bedded, clasts 0.5-3.0 mm diameter, with rounded outline, sample JC18.	0.5	0.1	320.5	97.6
33.	Lime mudstone, beige, thin bedded, with rare brachiopod fragments, sample JC17,	1.5	0.5	320.0	97.4
32.	Siltstone, light gray, thin bedded, cross bedded, laminated, calcareous.	1.5	0.5	318.5	97.0
31.	Oolitic grainstone, medium gray, thin bedded, brachiopod fragments, sample JC16.	5.0	1.5	317.0	96.5
30.	Siltstone, medium gray, thin	7.0	2.1	312.0	95.0

bedded, calcareous, cross bedded, laminated.				
29. Brachiopod packstone, medium gray, medium bedded, trilobite fragments, sample JC15.	3.0	0.9	305.0	92.9
28. Siltstone, medium gray, calcareous.	2.0	0.6	302.0	91.9
27. Covered interval.	18.0	5.5	300.0	91.3
26. Sandstone, medium gray, very fine grained, medium bedded, well sorted, laminated, calcareous, brachiopods and ostracods.	5.0	1.5	282.0	85.8
25. Sandstone, dark gray, medium-fine grained, laminated, brachiopods.	1.0	0.3	277.0	84.3
24. Covered interval.	17.0	5.2	276.0	84.0
23. Sandstone, medium gray, very	10.0	3.0	259.0	78.8

	fine grained, thin bedded, laminated, platy, calcareous, with brachiopods and crinoids.				
22.	Covered interval.	5.0	1.5	249.0	75.8
21.	Sandstone/siltstone, brown, fine grained, thin bedded, calcareous, well indurated, cross bedded, slightly asymmetric, ripple marks.	11.0	3.3	244.0	74.3
20.	Crinoidal grainstone, dark gray, medium grained, vuggy, with ostracods, brachiopods, and trilobites, sample JC13, JC14.	6.0	1.8	233.0	70.9
19.	Quartzose grainstone, dark gray, medium grained, thick-thin bedded, with brachiopods, trilobites, and ostracods, vuggy, ripple marks, sample JC12.	2.5	0.8	227.0	69.1
18.	Sandstone/siltstone, medium	2.0	0.6	224.5	68.3

	gray, very fine grained, thinly laminated, rare brachiopods and ostracods.				
17.	Quartzose grainstone, medium gray, coarse grained, thin bedded, with crinoids, ostracods, brachiopods, sample JC11.	0.5	0.1	222.5	67.7
16.	Lime mudstone, medium gray, thick bedded, rare brachiopods, symmetrical and interference ripples on bed top.	6.0	1.8	222.0	67.6
15.	Skeletal packstone, medium gray, fine grained, thin bedded, with brachiopods, crinoids, trilobites, and bryozoans, vuggy, sample JC10,	1.0	0.3	216.0	65.7
14.	Sandstone, medium gray, very fine grained, massive, moderately sorted, cross bedded, thinly laminated, calcareous, brachiopods rare, sample JC9.	4.0	1.2	215.0	65.4

13.	Quartzose grainstone, medium gray, fine grained, with abundant brachiopod, trilobite, and crinoid fragments, ostracods, sample JC8.	3.0	0.9	211.0	64.2
12.	Covered interval.	2.5	0.8	208.0	63.3
11.	Skeletal packstone, brown-gray, thin bedded, quartzose, with brachiopods, trilobites, and ostracods, vuggy, sample JC7.	1.5	0.5	205.5	62.5
10.	Sandstone, light gray, fine grained, massive, with brachiopods and ostracods, calcareous, partially covered, sample JC6.	7.5	2.3	204.0	62.1
9.	Sandstone, tan, fine grained, thin bedded, friable, silica cemented; forms ledge.	1.5	0.5	196.5	59.8
8.	Covered interval.	4.0	1.2	195.0	59.3

7. Sandstone, white-light brown, very fine-fine grained, medium bedded, with rusty specks; forms low ledge.	2.0	0.6	191.0	58.1
6. Sandstone, brown, fine grained, thin bedded, nodular, with drab olive clay partings, calcareous, sample JC5.	3.0	0.9	189.0	57.5
5. Covered interval.	11.0	3.3	186.0	56.6
4. Sandstone, medium gray-light brown, fine grained, medium bedded, well sorted, well indurated, calcareous, rare ostracods, w/drab olive clay partings, sample JC3.	1.5	0.5	175.0	53.2
3. Ostracod packstone, black, medium bedded, quartzose, with brachiopods, trilobites, crinoids, and gastropods, sample JC4.	3.5	1.0	173.5	52.9

2. Covered interval.	7.0	2.1	170.0	51.8
1. Ostracod packstone, same as unit 3., sample JC2.	5.0	1.5	163.0	49.7

Keefer Sandstone (158) (48.2)

11. Covered interval.	17.5	5.3	158.0	48.2
10. Sandstone, light brown, medium fine grained, thin bedded, friable; forms small ledge.	0.5	0.1	140.5	42.8
9. Covered interval.	23.0	7.0	140.0	42.7
8. Sandstone, white-brown, fine grained, thin bedded, well sorted and rounded, well indurated.	2.0	0.6	117.0	35.7
7. Covered interval.	3.0	0.9	115.0	35.0
6. Sandstone, chocolate brown,	2.0	0.6	112.0	34.1

fine grained, well sorted, well indurated, calcareous; forms low ledge, sample JC1.				
5. Covered interval.	20.5	6.2	110.0	33.5
4. Sandstone, interbedded units as described in unit 2.	2.5	0.8	89.5	27.3
3. Covered interval.	67.0	20.4	87.0	26.5
2. Sandstone, white with brown specks, medium grained, medium bedded, friable, interbedded with sandstone, chocolate brown, fine grained, medium bedded, well sorted and rounded.	15.0	4.6	20.0	6.1
1. Sandstone, light brown, fine grained, thick bedded, well sorted, cross bedded; forms low ledges over which creek flows. Axis of anticline. Lower units of Keefer in subsurface.	5.0	1.5	5.0	1.5

Low Moor Section

Location—The Low Moor section is exposed on the southeast flank of Pore Mountain where it is cut by the Jackson River. The section is located on the east limb of the eastern of two small anticlines about 4 miles west of the Route 696-Low Moor exit from Interstate 64 along Alleghany County Route 1104.

Unit Name	(total thickness)		Unit Thickness		Cumulative Thickness	
	(ft.)	(m.)	(ft.)	(m.)	(ft.)	(m.)
Needmore Shale (not measured)						
Ridgeley Sandstone	(25.0)	(7.6)	25.0	7.6	237.0	72.3
1. Sandstone, orange-brown, medium-coarse grained, medium bedded, friable, brachiopods: *Costispirifer* produces yellow sandy soil, poorly exposed.			25.0	7.6	237.0	72.3

Licking Creek Limestone (101.0) (30.8)

Little Cove Member (41.0) (12.5)

2. Skeletal grainstone, medium gray, fine grained, massive, quartzose, abundant brachiopods and crinoids, discontinuously exposed, samples LM21-LM24.	32.5	9.9	212.0	64.6
1. Covered interval.	8.5	2.6	179.5	54.7

Cherry Run Member (60.0) (18.3)

1. Lime mudstone, black, very fine grained, massive, abundant black chert in nodules and semi-continuous layers parallel to bedding, weathers light gray, shaly weathering in beds with less chert, brachiopods, trilobites, tabulate and rugose corals, gastropods, samples LM13-LM20.	60.0	18.3	171.0	52.1

Healing Springs Sandstone (34.0) (10.4)

1. Sandstone, white-gray, fine grained, massive, well sorted and rounded, calcareous, cross bedded, brachiopods and crinoid fragments, heavy mineral lamination, clean, pink calcite, well indurated, contains pebble horizons, gradational contact with underlying New Creek Ls., samples LM8-LM12.	34.0	10.4	111.0	33.8

New Creek Limestone (49.0) (14.9)

1. Crinoidal grainstone, light gray, very coarse-coarse grained, massive, quartzose, pink calcite, large crinoid columnals and articulated stem sections, brachiopods, ramose bryozoans, stylolitic seams, occasional pebbles, rusty	49.0	14.9	77.0	23.5

specks, samples LM1-LM7.

Keyser Formation (28.0) (8.5)

4. Bryozoan wackestone, dark gray, thick bedded, light gray weathering, ramose bryozoans, sample LM25.	6.5	1.9	28.0	8.5
3. Sandstone, white-gray, fine grained, thick bedded, calcareous, cross bedded, well sorted and rounded, well indurated, rusty specks throughout.	15.0	4.6	21.5	6.5
2. Quartzose-skeletal grainstone, medium gray, with bands of purple hematitic sandstone, medium grained, medium bedded, with crinoids, brachiopods, and bryozoans, pink calcite grains, friable, poorly sorted and rounded, sample LM26.	4.0	1.2	6.5	2.0

1. Sandstone, calcareous, same as unit 3.	2.5	0.8	2.5	0.8

Mill Creek Section

Location--This section is exposed on the flank of Little Mountain where it is cut by Mill Creek north of New Castle, Virginia. The section is located 2.0 miles (3.2 km.) north along Fenwick Mine Road from its intersection with County Route 611 in Craig County, Virginia.

Unit Name	(total thickness) (ft.)	(total thickness) (m.)	Unit Thickness (ft.)	Unit Thickness (m.)	Cumulative Thickness (ft.)	Cumulative Thickness (m.)
Keyser Formation	(127.2)	(38.8)				
9. Sandstone, rust orange, coarse grained, medium bedded, poorly sorted and rounded, friable, deeply weathered, cavities formed by disolved brachiopods.			21.0	6.4	407.8	124.3
8. Covered interval.			55.6	16.9	386.8	117.9
7. Shale, tan-olive, thin bedded, calcareous.			0.5	0.2	331.2	100.9

6.	Bryozoan packstone, dark gray, medium-coarse grained, medium bedded, with ramose and encrusting, bryozoans, brachiopods, *Cladopora*, stromatoporoids, sample MC7.	1.4	0.4	330.7	100.8
5.	Bryozoan wackestone, olive-gray, thin bedded, shaly, ramose bryozoans, sample MC6.	1.7	0.5	329.3	100.4
4.	Sandstone, white-light brown, medium grained, medium bedded, silica cemented, poorly sorted, moderately rounded, cross bedded.	0.5	0.2	327.6	99.8
3.	Covered interval.	10.0	3.0	327.1	99.7
2.	Sandstone, white-gray, medium grained, thin bedded, with crinoid fragments, black chert lenses, samples MC5.	5.5	1.7	317.1	96.6
1.	Sandstone, light brown-rust	31.0	9.4	311.6	95.0

orange, fine-medium grained, thick bedded, well sorted and rounded, calcareous, deeply weathered.

Tonoloway Formation (244.3) (74.5)

26. Covered interval.	12.5	3.8	280.6	85.5
25. Lime mudstone, dark gray, thick bedded, calcareous, same as unit 21.	4.1	1.2	268.1	81.7
24. Covered interval.	36.3	1.1	264.0	80.5
23. Sandstone, light tan-pink, fine grained, medium bedded, moderately sorted, poorly rounded, well indurated.	5.1	1.5	227.7	69.4
22. Covered interval.	20.6	6.1	222.6	67.8
21. Lime mudstone, dark brown, thin-medium bedded, silty lam-	10.6	3.2	202.6	61.8

	inae, slightly calcareous.				
20.	Covered interval.	12.6	3.8	192.0	58.5
19.	Lime mudstone, medium gray, thick-thin bedded, shaly, silty laminae, rare ostracods, sample MC4.	15.4	4.7	179.4	54.7
18.	Covered interval.	44.8	13.6	164.0	50.1
17.	Siltstone, black, very fine grained, thick bedded, calcareous, rare brachiopods.	5.0	1.5	119.2	36.3
16.	Sandstone, light brown, very fine grained, thinly bedded, bedding uneven, with shaly intervals, well rounded grains.	3.0	0.9	114.2	34.8
15.	Lime mudstone-siltstone, medium gray, very fine grained, medium bedded, slightly calcareous.	4.8	1.5	111.2	33.9

14.	Covered interval.	23.5	7.2	106.4	32.4
13.	Siltstone, light gray, medium bedded, calcareous, with trilobite fragments, rare ostracods.	1.5	0.5	82.9	25.3
12.	Lime mudstone, light brown, thin bedded, calcareous.	2.4	0.7	81.4	24.8
11.	Covered interval.	7.0	2.1	79.0	21.9
10.	Lime mudstone, dark brown, medium bedded, capped by dark brown skeletal grainstone, two inches thick, sample MC3.	2.0	0.6	72.0	21.3
9.	Covered interval.	7.5	2.3	70.0	19.0
8.	Skeletal grainstone, brown, medium-coarse grained, thin bedded, with brachiopods.	0.5	0.2	62.5	19.0
7.	Lime mudstone, dark brown, thin bedded.	0.4	0.1	62.0	18.9

6. Sandstone, light brown-drab olive, very fine-fine grained, thin bedded, calcareous.	6.3	1.9	61.6	18.8
5. Skeletal grainstone, medium gray, medium-coarse grained, thin bedded, quartzose, abundant coarse and fine ribbed brachiopods, sample MC2.	0.8	0.2	55.3	16.9
4. Sandstone, light brown-white, fine grained, thin bedded, silica cemented, cross bedded, thicker beds with climbing ripples, shaly beds with planar lamination, well indurated.	4.2	1.3	54.5	16.6
3. Lime mudstone, dark brown, same as unit 1.	1.5	0.5	50.3	15.3
2. Covered interval.	9.5	2.9	48.8	14.9
1. Lime mudstone, dark brown, medium bedded, unfossiliferous, sample MC1.	3.0	0.9	39.3	12.0

Keefer Sandstone (36.3) (11.1)

2. Covered interval.	29.0	8.8	36.3	11.1
1. Sandstone, light tan, fine-medium grained, thick bedded, moderately sorted, subrounded, silica cemented, well indurated, with iron reduction spots, gash veins. Beds flat. Base not exposed.	7.3	2.2	7.3	2.2

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STRATIGRAPHY AND CONODONT PALEONTOLOGY
OF LATE SILURIAN-EARLY DEVONIAN STRATA
OF WESTERN VIRGINIA

by

Robert R. Sartain

(ABSTRACT)

Biostratigraphic study of the Late Silurian-Early Devonian strata of western Virginia reveals the presence of at least three potentially useful multielement conodont apparatuses. Two multielement species of the genus _Ozarkodina_ may prove to be useful in determining the boundary between the Silurian and Devonian Systems in the Appalachian Basin. Currently, a single form species, _Icriodus_ _woschmidti_ _woschmidti_, which was found in the lowermost New Creek Limestone at Low Moor, Virginia, is used by previous agreement to denote the base of the Devonian System. In the absence of this standard paleontologic indicator, multielement species of the genus _Ozarkodina_ may be useful. _Ozarkodina_ _steinhornensis_ _eosteinhornensis_ is identified from the Silurian Tonoloway Formation in the area of New Castle, Virginia. _Ozarkodina_ _steinhornensis_ _remscheidensis_, which is transitional to _Oz_.

s. eosteinhornensis, has been identified in the overlying Late Silurian-Early Devonian Keyser Formation and Early Devonian New Creek Limestone near New Castle and Low Moor. *Oz. s. remscheidensis*, which is reported to occur first in the Gedinnian, has been suggested as a possible alternative indicator of lowest Devonian strata (Walliser, 1971). However, because of the transitional relationship of these two multielement species, abundant yields of conodonts are necessary to determine the first appearance of *Oz. s. remscheidensis*.

Elements belonging to a third conodont apparatus, *Delotaxis elegans*, have been recovered from the Keyser and New Creek intervals at the same locations. *Delotaxis elegans* may ultimately prove to be a significant biostratigraphic marker with further study of these units.

An overview of the Late Silurian-Early Devonian strata in Alleghany, Botetourt, Craig, and Roanoke Counties is developed to provide a regional perspective of this stratigraphic package and to illustrate significant biostratigraphic markers. Unconformities, wedge-outs, facies changes, and thickness variations are examined within the study area based on nine measured sections and a review of pertinent literature. Clastic units and quartzose carbonates within the Helderberg Group are discussed with regard to source area.

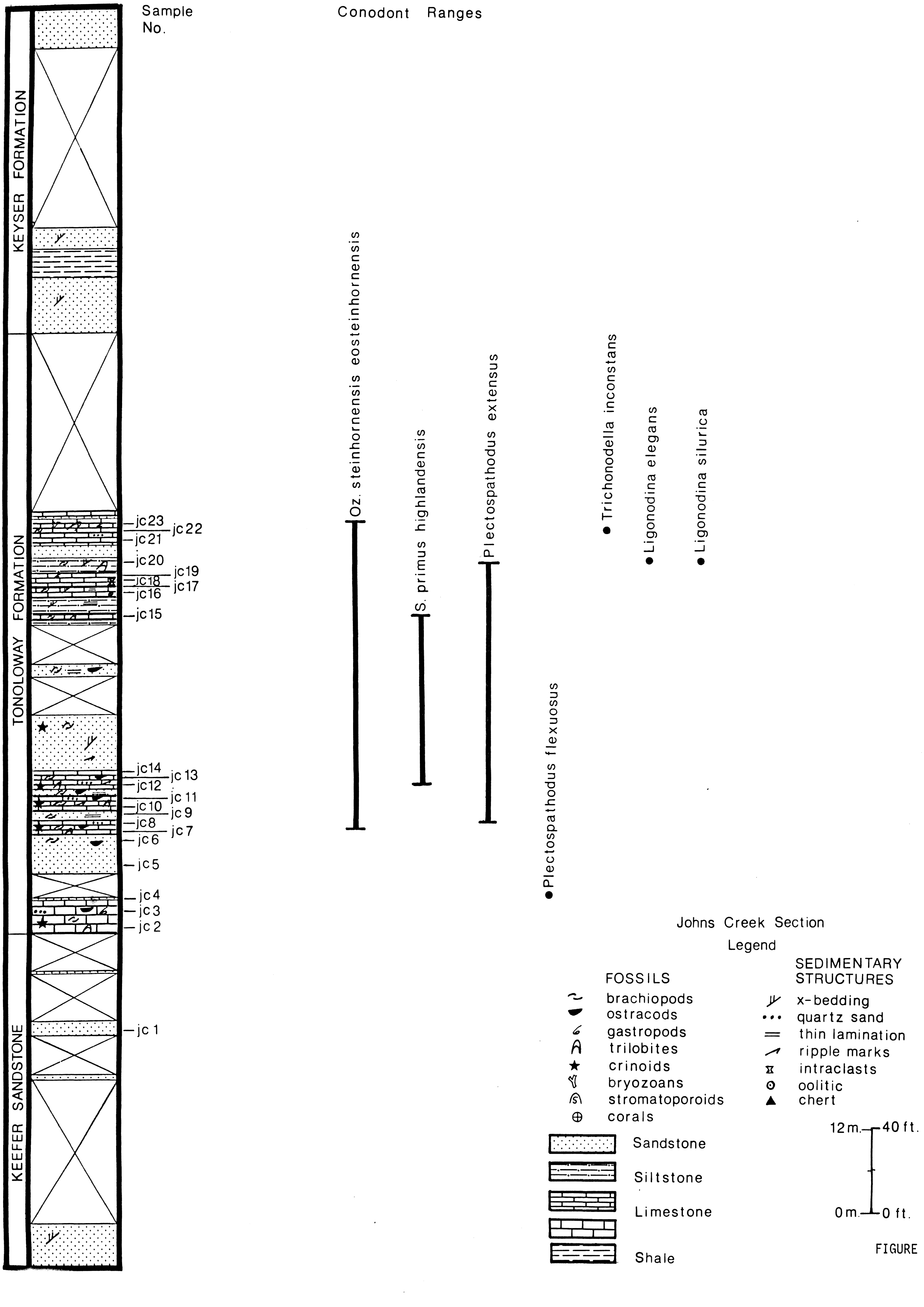

Sample No.
Conodont Ranges
KEYSER FORMATION
TONOLOWAY FORMATION
KEEFER SANDSTONE
jc23
jc22
jc21
jc20
jc19
jc18
jc17
jc16
jc15
jc14
jc13
jc12
jc11
jc10
jc9
jc8
jc7
jc6
jc5
jc4
jc3
jc2
jc1
Oz. steinhornensis eosteinhornensis
S. primus highlandensis
Plectospathodus extensus
Plectospathodus flexuosus
Trichonodella inconstans
Ligonodina elegans
Ligonodina silurica
Johns Creek Section
Legend
FOSSILS
brachiopods
ostracods
gastropods
trilobites
crinoids
bryozoans
stromatoporoids
corals
SEDIMENTARY STRUCTURES
x-bedding
quartz sand
thin lamination
ripple marks
intraclasts
oolitic
chert
Sandstone
Siltstone
Limestone
Shale
12m.
40 ft.
0m.
0 ft.

FIGURE 6

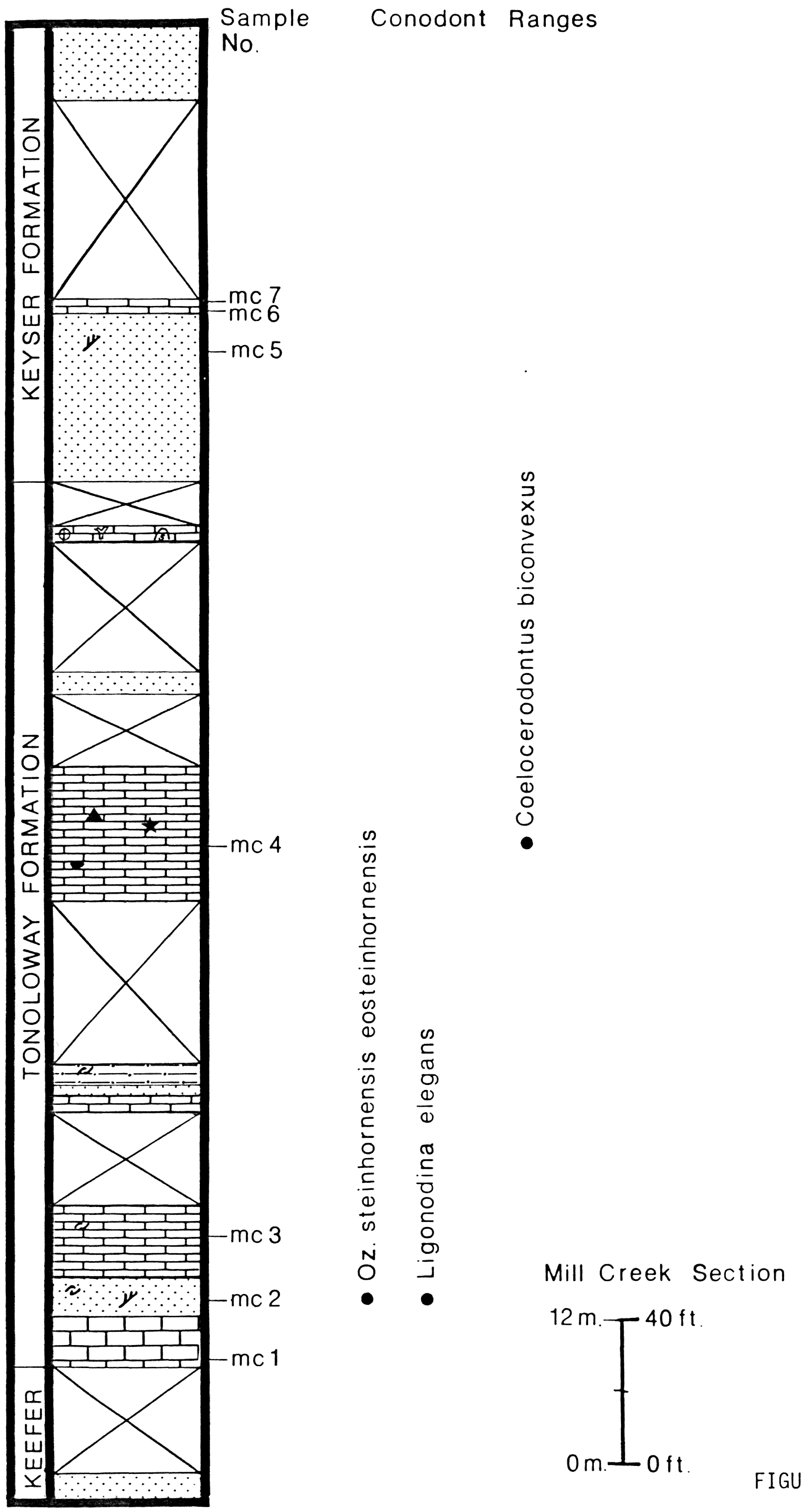
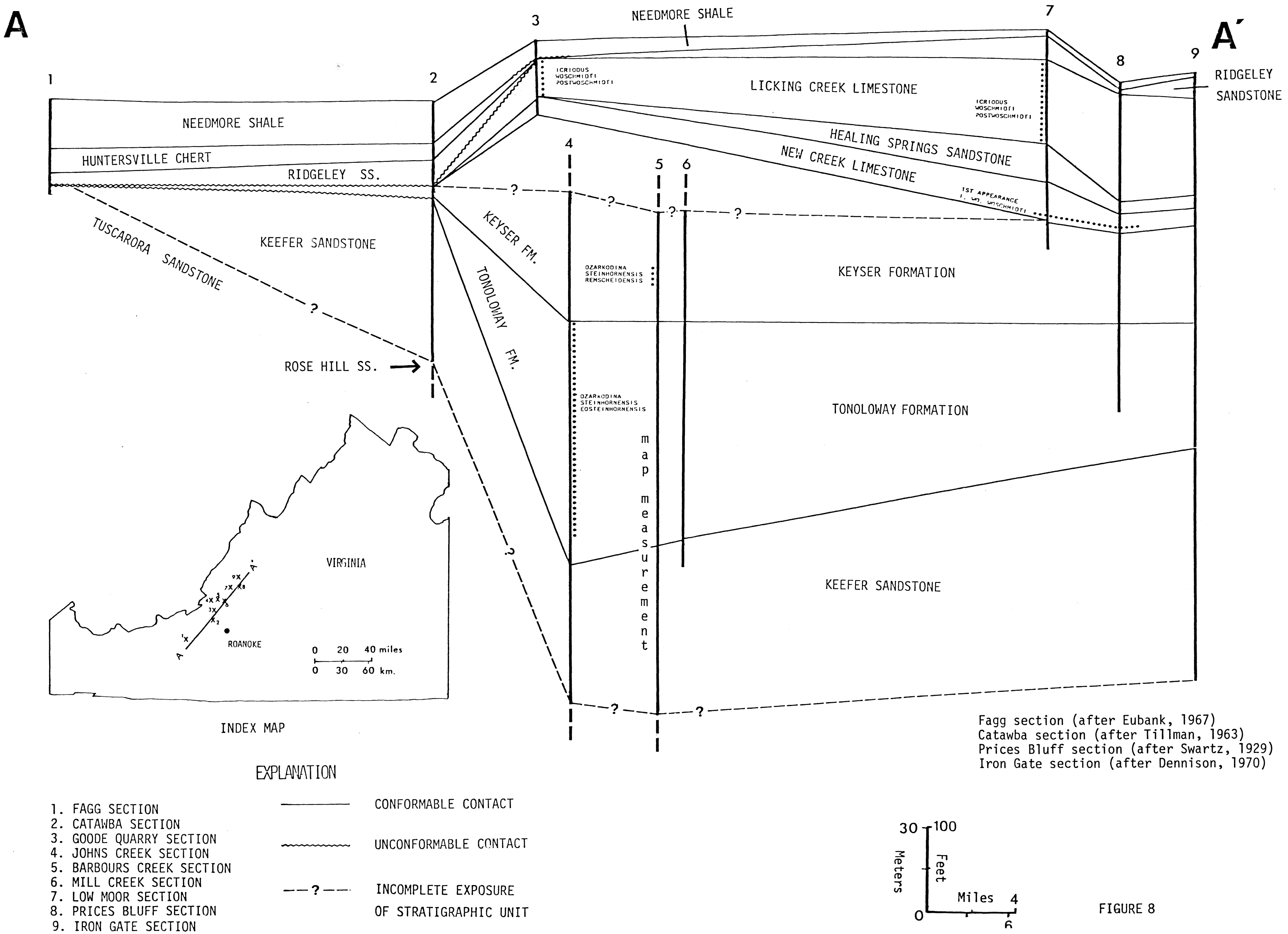

Sample No.
Conodont Ranges
KEYSER FORMATION
TONOLOWAY FORMATION
KEEFER
mc 7
mc 6
mc 5
mc 4
mc 3
mc 2
mc 1
Oz. steinhornensis eosteinhornensis
Ligonodina elegans
Coelocerodontus biconvexus
Mill Creek Section
12 m.
40 ft.
0 m.
0 ft.

FIGURE 7

FENCE DIAGRAM OF LATE SILURIAN-EARLY DEVONIAN STRATA IN ALLEGHANY, BOTETOURT, CRAIG, AND ROANOKE COUNTIES, VIRGINIA



1. FAGG SECTION
2. CATAWBA SECTION
3. GOODE QUARRY SECTION
4. JOHNS CREEK SECTION
5. BARBOURS CREEK SECTION
6. MILL CREEK SECTION
7. LOW MOOR SECTION
8. PRICES BLUFF SECTION
9. IRON GATE SECTION

Fagg section (after Eubank, 1967)
Catawba section (after Tillman, 1963)
Prices Bluff section (after Swartz, 1929)
Iron Gate section (after Dennison, 1970)

FIGURE 8