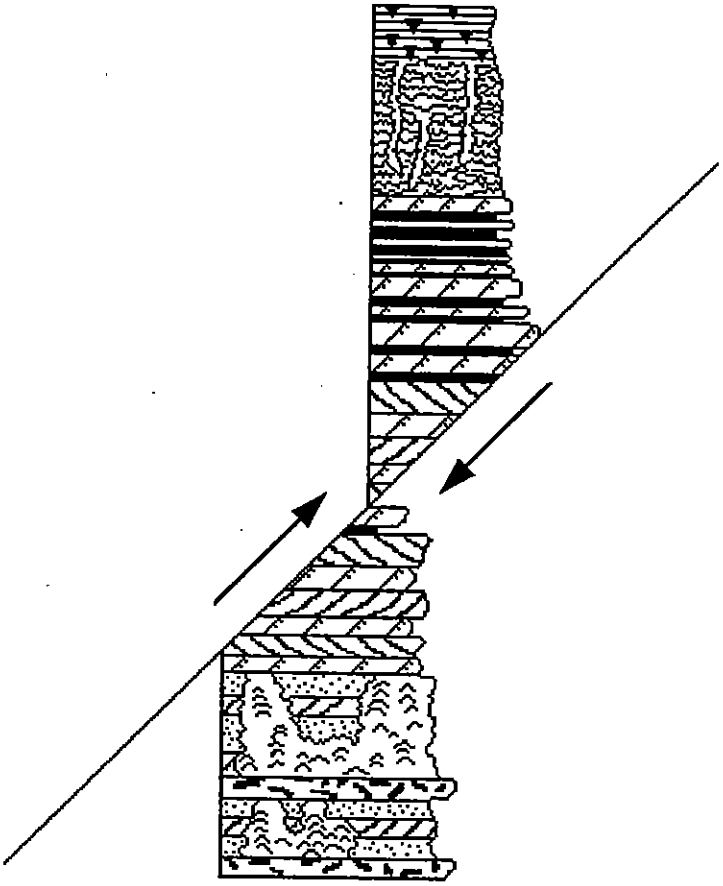
# CAMBRIAN AND ORDOVICIAN ROCKS OF THE BIRMINGHAM AREA

## BLAIR AND HUNTINGDON COUNTIES, PENNSYLVANIA



**Guidebook for the**

# Pittsburgh Geological Society Field Trip

**May 4, 1996**

Guidebook for the

PITTSBURGH GEOLOGICAL SOCIETY

Field Trip

Saturday, May 4, 1996

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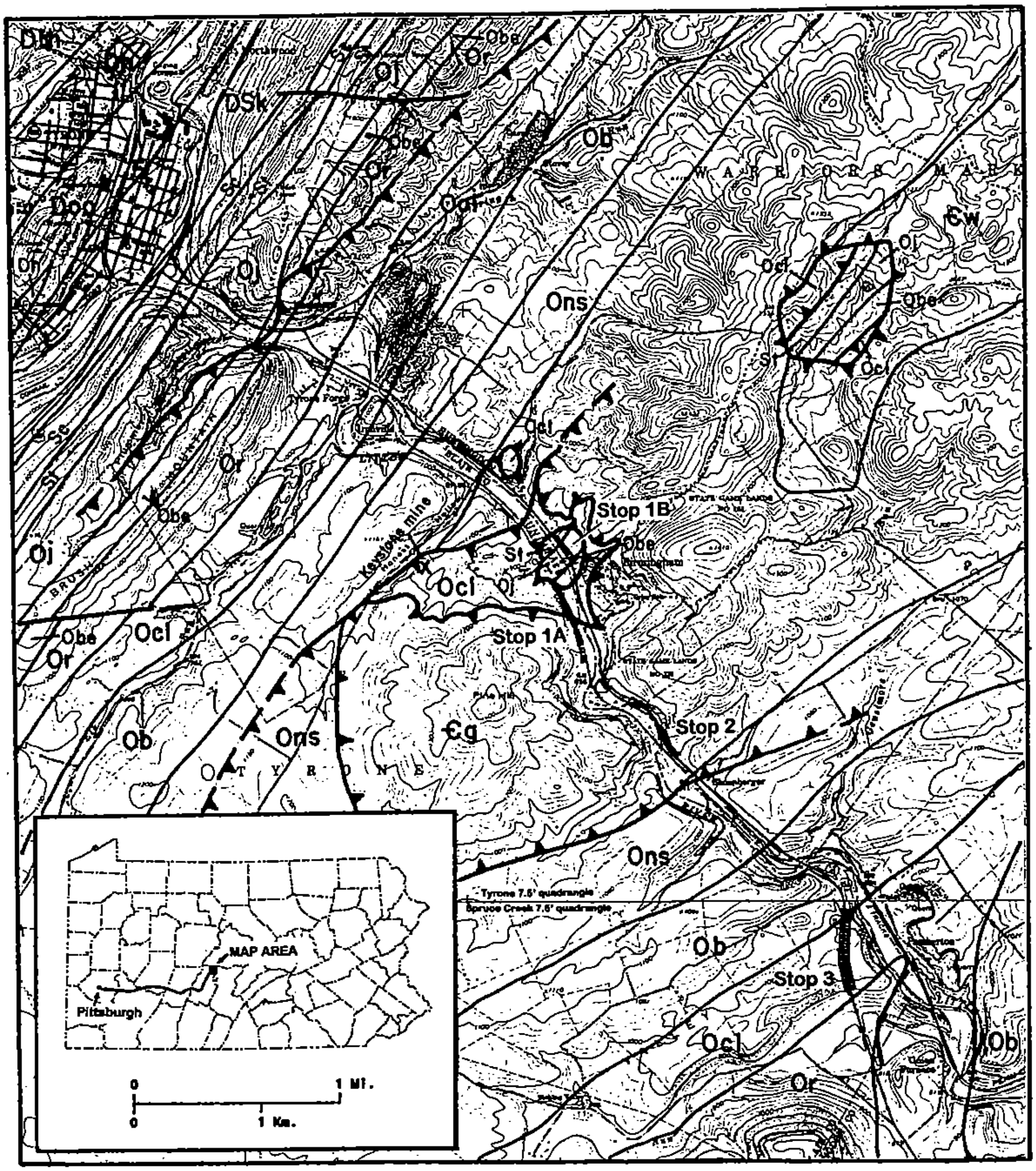


Figure 1. Geologic map of the Tyrone area showing the locations of field stops. Formation abbreviations are as follows: Dbh - Brallier and Harrell formations; Dh - Hamilton Group; Doo - Onondaga through Old Port formations; Dsk - Keyser through Mifflintown formations; Sc - Clinton Group; St - Tuscarora Formation; Oj - Juniata Formation; Obe - Bald Eagle Formation; Or - Reedsville Formation; Ocl - Coburn through Loysburg formations; Ob - Bellefonte Formation; Ons - Nittany through Stonehenge formations; Cg - Gatesburg Formation; and Cw - Warrior Formation.

# CAMBRIAN AND ORDOVICIAN ROCKS OF THE BIRMINGHAM AREA, BLAIR AND HUNTINGDON COUNTIES, PENNSYLVANIA

**John A. Harper and Christopher D. Laughrey**
**Pennsylvania Geological Survey**

## INTRODUCTION

Welcome to the Pittsburgh Geological Society's 1996 field trip, a journey back into the distant recesses of time. This year's trip will enable the attendee to examine many of the aspects of the Upper Cambrian through Upper Ordovician stratigraphic sequence that will show how unique these rocks are to Pennsylvania and to the Appalachians as a whole. In addition, we will have the opportunity to examine some outstanding Alleghanian structures that occur in that sequence. The best and most continuous outcrop of these rocks lies within a small area of Blair and Huntingdon Counties in central Pennsylvania where the Little Juniata River cut a watergap through the Nittany anticline. The juxtaposition of older Paleozoic strata, complex structures, and convenient exposures is no mere coincidence, however. The Little Juniata River watergap is one of the more highly visible surface expressions of a major cross-strike structural discontinuity called the Tyrone-Mt. Union lineament.

During the trip we will be able to observe numerous roadcuts that expose a wide variety of carbonate rocks. Three field stops (Figure 1) will demonstrate the nature of many of these rocks, including specific lithologic characteristics and their interpreted depositional environments. We will also examine the structural geology of the Birmingham overthrust fault, one of the classic structures of Appalachian geology. These three exposures were included as part of a DNAG (GSA's Decade of North American Geology) centennial field site (Faill, 1987).

A bit of historical trivia: the little village of Birmingham (Figure 1) at one time vied with Harrisburg as the potential capital of Pennsylvania. Had Birmingham won the honors, the state capital would be much more centrally located than it is now. That's the good news. The bad new is: you can imagine the mess PennDOT, the politicians, and the land developers would have made of the picturesque and geologically unique Little Juniata River watergap (just picture the area with a plethora of six-lane expressways, state office buildings, and malls)!

## STRUCTURAL GEOLOGY

The folds and faults of central Pennsylvania resulted from the Alleghanian orogeny near the end of the Paleozoic Era. At the surface the folds appear to be relatively simple, but in reality are cored by complexes of thrust faults splaying off decollements buried 5 to 10 km (3 to 5 mi) beneath the surface. The major structure in this area is the overturned (to the northwest) Nittany anticline, the westernmost and structurally largest anticline in

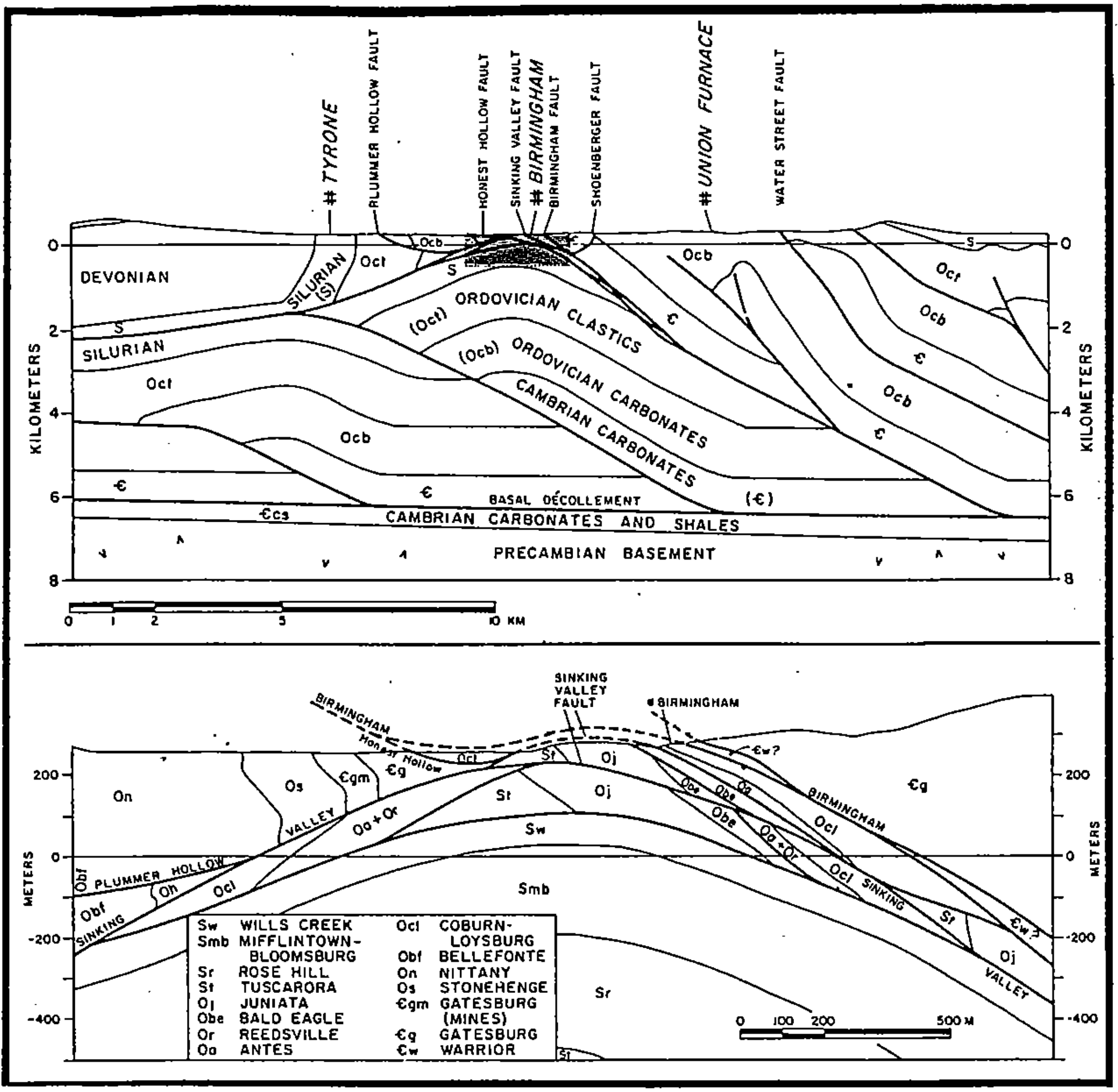


**Figure 2.** Cross sections of the Nittany anticline in the vicinity of Birmingham (modified from Faill, 1987, figs. 2 & 3). Top - Thrust faults splay off a basal decollement, probably in Lower Cambrian shales, creating a series of stacked duplexes of Cambrian, Ordovician, and Silurian strata. The lower figure is a blow-up of the shaded rectangle. Bottom - The Birmingham fault is the roof of the uppermost complex splay fault system (shown in the upper figure), whereas the Sinking Valley fault locally is the floor. Where the Little Juniata River traversed the anticline, Upper Cambrian through Upper Ordovician carbonate rocks were breached, exposing the faults and Upper Ordovician through Lower Silurian clastic rocks lying beneath the overthrusts.

the Valley and Ridge province. It is 15 km (9 mi) wide by 180 km (112 mi) long, with structural relief up to 6.5 km (4 mi). One of the more interesting features of the anticline is the Birmingham window, a view of distorted Upper Ordovician and Lower Silurian clastic rocks through overthrust Lower Paleozoic carbonates that resulted from exposure of a secondary decollement, the Sinking Valley fault duplex (Faill, 1987) (Figure 2). The Birmingham fault, a subsidiary splay of the Sinking Valley fault, thrust Upper Cambrian dolostones over a slice of Middle Ordovician limestone. This fault is well exposed along the main line of the Conrail Railroad tracks on the south side of the Little Juniata River opposite Birmingham (Figure 1), and will be the central feature of Stop 1 on this field trip.

The Little Juniata River watergap through the Nittany anticline presents us with the opportunity to view some of the complex structure associated with "thin-skinned", or detachment, tectonics. Beneath the relatively simple structure of the Nittany anticline lies a complex of decollements and duplexes, and, near the surface, an interweaving series of faults that includes the major thrust faults exposed in the area. Faill (1987, p. 37) gives a good description of this structural complexity:

> "The Nittany anticline probably consists of two splay slices that have been stacked, one above the other. The upper slice, to which most of the present surface exposures belong, rode on the Sinking Valley fault, up and over the back of the lower slice... The Sinking Valley fault is a large, anastomotic, duplex fault [Figure 2] containing numerous horses of Silurian-Ordovician clastic rocks and Ordovician limestones that have been scooped mostly from the footwall, although one or more horses of Warrior Formation [Cambrian] from the hanging wall may have been carried along as well."

In addition, the rocks of the area reveal mesoscopic structures such as cleavage, kink band folding, disharmonic folding, and wrench, normal, and thrust faults, among others, that can be used to describe the progression of deformation as the anticline grew. Faill (1987) points out that the presence of a particular structure is dependent on lithology, position within the anticline, and inclination of bedding to the deformational stresses. The steep, overturned northwestern flank of the anticline contains most types of observed mesoscopic structures whereas the most common structures in the relatively gently dipping rocks on the southeastern flank are wrench and thrust faults.

## Tyrone-Mt. Union Lineament

The alignment of streams, watergaps, and mineralization phenomena extending from northwest of Tyrone in Blair County to southeast of Mt. Union in Huntingdon County has been recognized for many years. Because there were no major faults in the area, however, the alignment was relegated basically to the status of coincidence. It was not until the introduction of LANDSAT-1 imagery and remote sensing studies in the early 1970s that the full extent of the alignment became appreciated. This is no ordinary coincidence, but rather represents the surface expression of a linear feature extending for many kilometers from the Blue Ridge, across the Great Valley, Ridge and Valley, and through the Appalachian Plateau at least as far as Lake Erie. Gold and others (1973) named this feature the Tyrone-Mt. Union lineament. Still, the lack of major faults remained puzzling, and no one was sure just what the lineament represented. Gold and Canich (1986) applied studies of the stratigraphic and structural characteristics along and

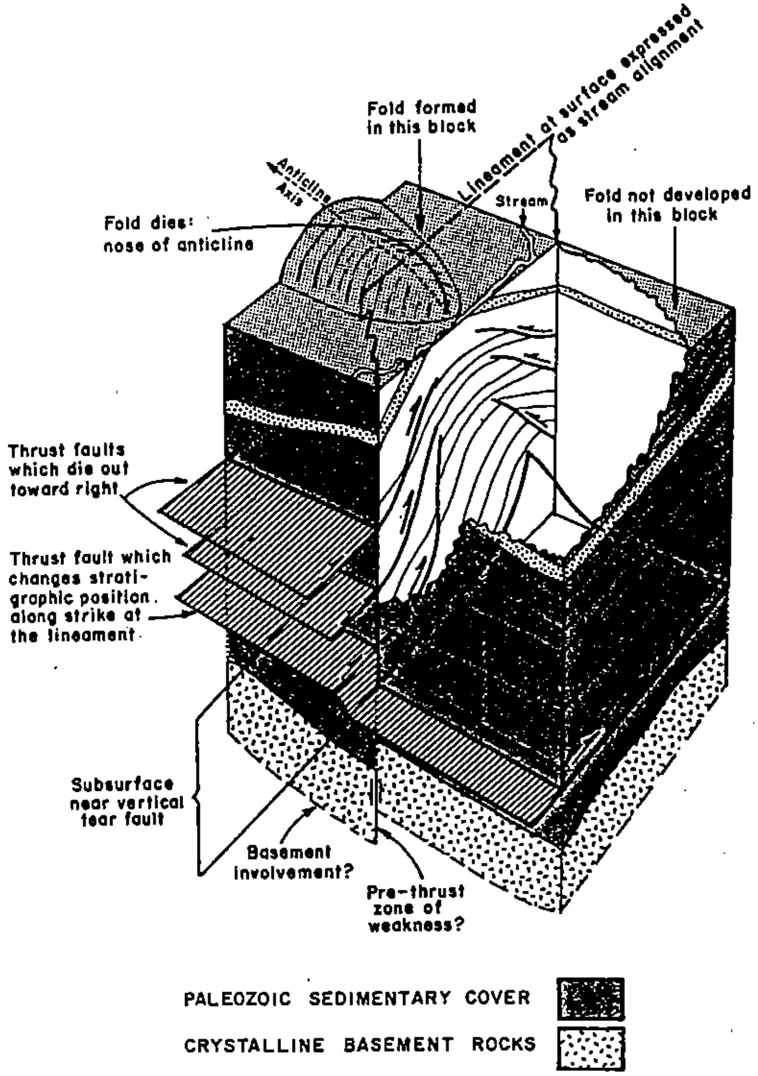


**Figure 3. Idealized block diagram showing three-dimensional structure of a CSD such as the Tyrone-Mt. Union lineament (modified slightly from Kowalik and Gold, 1976, fig. 7).**

adjacent to the lineament and concluded that it represents a zone of intense fracture concentration and disturbed structural trends 2-3 km (1.2-1.8 mi) wide. The genesis of this disturbed zone remained in doubt until the late 1970s and early 1980s when faculty and students at Penn State University used Bouguer gravity and aeromagnetic studies to show the Tyrone-Mt. Union lineament is a deep crustal fracture possibly more than 600 km (360 mi) long (Lavin and others, 1982). Several other large lineaments lie to the northeast and southwest, dividing the crust into blocks or even slivers, but the Tyrone-Mt. Union lineament appears to be the most prominent. In the Phanerozoic cover, surface and subsurface structural trends often end, form distinct saddles, or are offset where they cross lineaments of this sort (Rodgers and Anderson, 1984). The lineaments apparently acted as boundaries between semi-independent thrust blocks (Kowalik and Gold, 1976) during Alleghanian deformation. Decollement surfaces, rather than being single regional-scale fault planes, were fragmented into sets of splay faults (Figure 3). This allowed each block

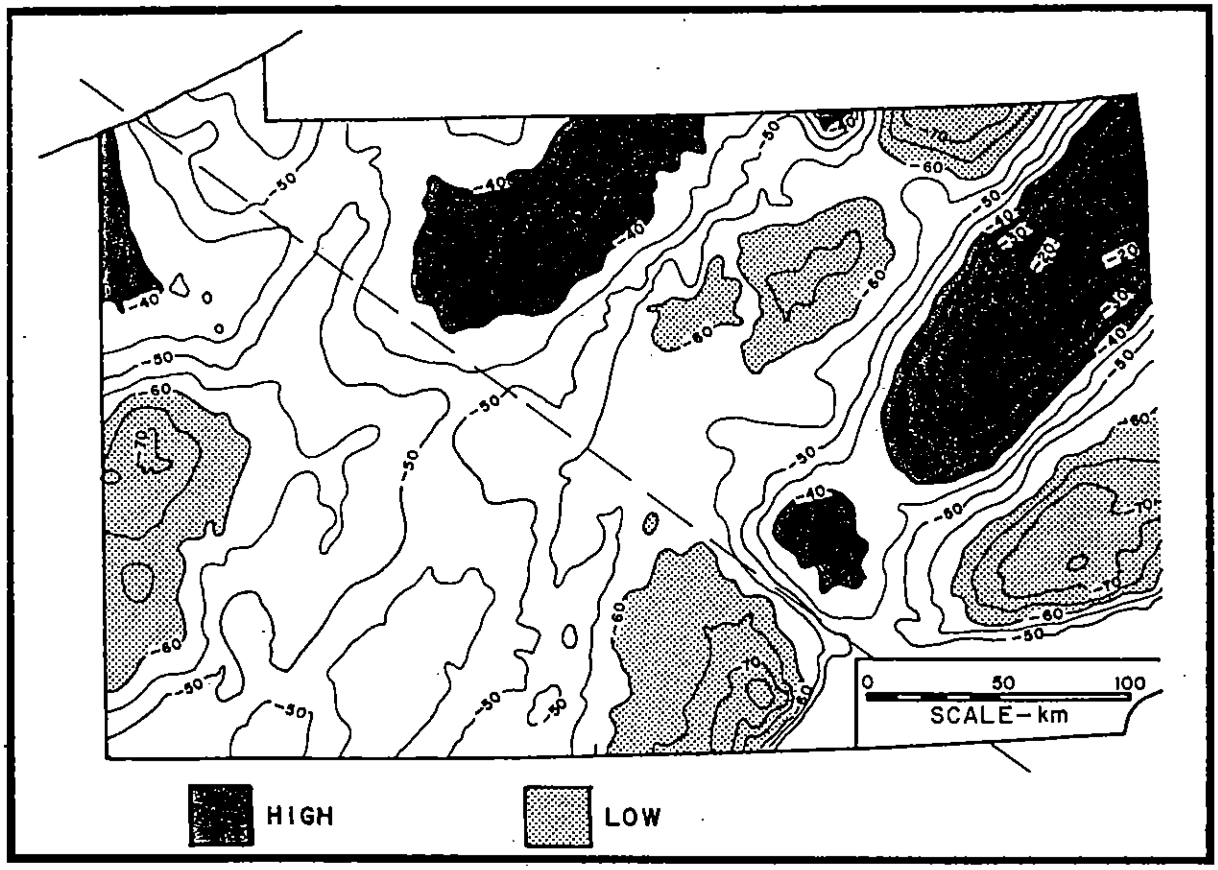
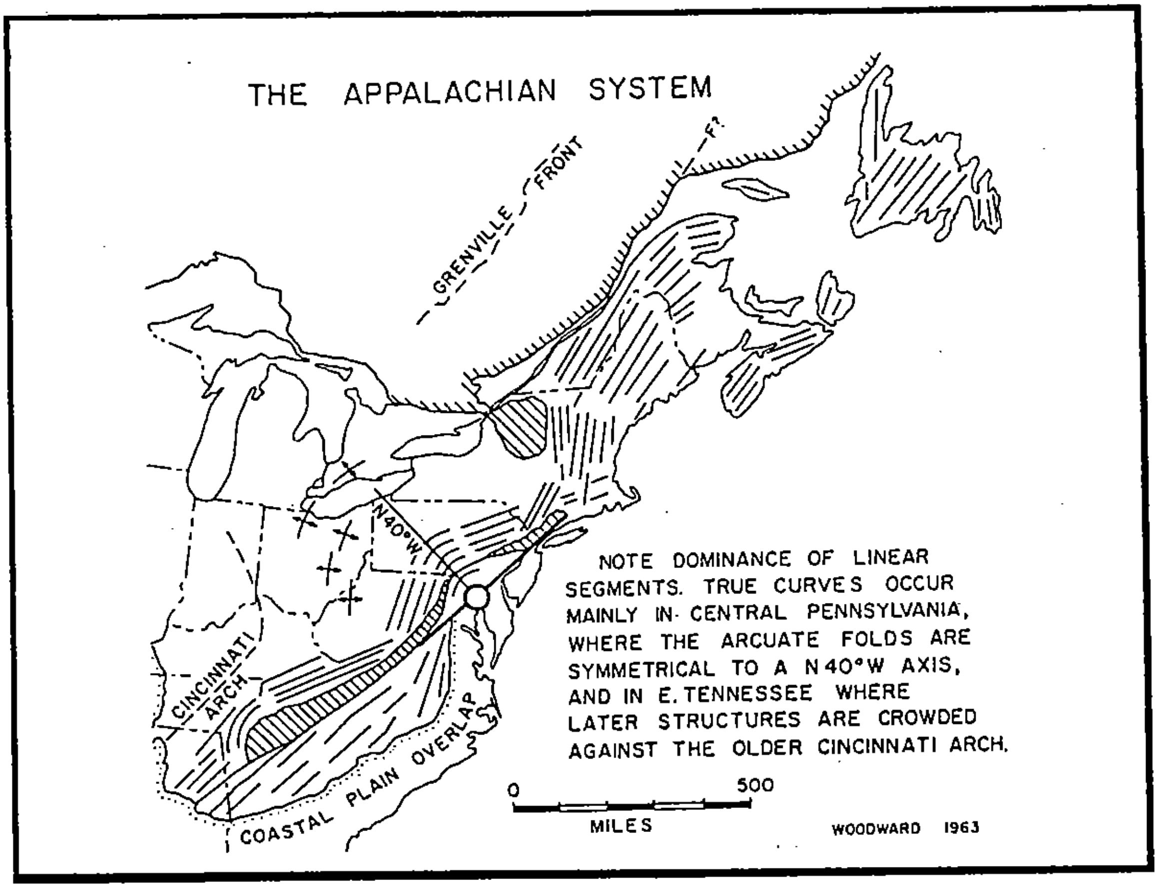


**Figure 4. Simple Bouguer gravity anomaly map of Pennsylvania. The dashed line represents the trace of the Tyrone-Mt. Union lineament. High and low gravity anomalies have been shaded to show the amount of offset across the lineament.**

to form its own set of anticlines and synclines with little regard to, or help from, its neighbors. Because the lineaments trend across the regional strike of surface structure, they have been termed cross-strike structural discontinuities, or CSD's (Wheeler, 1980).

So, what is the origin of these lineaments, these CSDs? Gravity data, especially, indicate a right-lateral offset in anomalies of some 60 km (36 mi) across the Tyrone-Mt. Union lineament in western and southcentral Pennsylvania (Figure 4), suggesting a basement wrench fault or shear zone. Other CSDs, such as the Pittsburgh-Washington lineament to the south, can be observed as aeromagnetic anomalies, also indicating a probable basement fault. Basement wrench faults and fault assemblages probably originated as transform faults during Late Precambrian/Early Cambrian rifting associated with the opening of the Iapetus Ocean (Thomas, 1977), and later became zones of crustal instability between adjacent crustal blocks (Lavin and others, 1982). It has become apparent through several studies (for example, Rodgers and Anderson, 1984, Harper and Laughrey, 1987, and Riley and others, 1993) that most of the CSDs, most notably the Tyrone-Mt. Union and Pittsburgh-Washington lineaments, have influenced structure and deposition in the Appalachians throughout geologic time (Harper, 1989), and still might be



NOTE DOMINANCE OF LINEAR SEGMENTS. TRUE CURVES OCCUR MAINLY IN CENTRAL PENNSYLVANIA, WHERE THE ARCUATE FOLDS ARE SYMMETRICAL TO A N40°W AXIS, AND IN E. TENNESSEE WHERE LATER STRUCTURES ARE CROWDED AGAINST THE OLDER CINCINNATI ARCH.

WOODWARD 1963

**Figure 5. Map of the Appalachians showing the Baltimore dome (circle) and N40°W- trending axis that bisects the reentrant in central Pennsylvania (from Woodward, 1964, fig. 1).**

seismically active (Canich and Gold, 1985). It is interesting that, although geophysical log data in Ohio strongly suggest strike-slip movement along some of the more prominent lineaments (Baranoski, 1989), Rodgers and Anderson (1984) found no evidence of a strike-slip component in the shallower (i.e. Lower Devonian through Pennsylvanian) rocks associated with the Tyrone-Mt. Union lineament. They suggested instead that, after the Early Ordovician, the rocks northeast of the lineament were uplifted relative to those southwest.

In an interesting paper addressing the problem of the origin of the Pennsylvania reentrant, that strange curve in the regional strike that occurs between Altoona and Lock Haven, Woodward (1964) proposed that the rocks fit a geometric pattern bilaterally symmetrical about an axis striking N40°W from the Baltimore dome (Figure 5). He conjectured that this axis was a wrench fault with a dextral offset of 128 km (80 mi) or more, and that it extended out into the Atlantic continental shelf. This axis, of course, coincides almost exactly with the Tyrone-Mt. Union lineament. What makes this paper interesting is that Woodward's study commenced more than 25 years before publication of the paper, or about 35 years before LANDSAT-1 satellite imagery was even a remote possibility.

# CAMBRIAN AND ORDOVICIAN STRATIGRAPHY

Figure 6 shows the outcrop patterns of Cambrian and Ordovician rocks in Pennsylvania, and Figure 7 is a correlation chart of the Cambrian/Ordovician carbonate-dominated strata of the northern Appalachians as it is currently understood.

Much of the Cambrian and Ordovician stratigraphic section comprises a thick sequence of predominantly shallow-water carbonates formed on what Ginsburg (1982) called the "Great American Bank". The "Great American Bank" extended more than 3,000 km (1,875 mi) along the length of the southern seaboard of Laurentia from Early Cambrian through early Late Ordovician (Hardie, 1986). This bank contained a complex mosaic of interdependent subenvironments in which depositional processes imprinted distinctive physical, diagenetic, and biogenic features on the sediments. Read (1989), Hardie (1986), and Osleger and Read (1991) interpreted the vertical stacking of various peritidal carbonate facies in this sequence to be the result of cyclical sea-level fluctuations; these cycles were shelf-wide features (Borer and Harris, 1991). Subtidal carbonate facies in the section occur within shallowing-upward sequence deposited in a shelf lagoon environment. These facies might be cyclical or non-cyclical (Demicco, 1985; Read, 1989), and therefore might be either shelf-wide phenomenon or localized sedimentary accumulations. Finally, lowstand deposits of siliciclastic sediments (mostly Late Cambrian), related to both third-order sea-level falls and short-term sea-level falls were transported onto the peritidal platform and mixed with subtidal facies as well. These clastics were transported across the shelf during sea-level lowstands and reworked during subsequent sea-level rises (Read, 1989). Mixtures of siliciclastic and carbonate lithologies encountered in outcrop or in cores are the result of both spatial and temporal variability. Lithologic heterogeneity is acute and complex.

Several important diagenetic events affected the Cambro-Ordovician carbonate rocks of the central Appalachians (Hardie, 1989). Compactional deformation and dolomitization are the most significant of these diagenetic events. The following succession of diagenetic events that affected the rocks was developed by Hardie (1989, p.77 -78) and is based on the work of various workers with whom he collaborated at Johns Hopkins University.

Petrographic studies reveal that *early marine cementation*, evidenced by isopachous pore-lining cements, micritization, and submarine hardgrounds, was the first apparent diagenetic event in the sediments. This cementation was followed by *mechanical compaction* during which carbonate mudstone layers bent and flowed ductily around non-ductile features. Fossils in the mudstones are oriented along flow paths or are crushed, while burrows and mudcracks are flattened and folded. Short, dark "wispy seams" (organic layers ?) wrap around hard grains. The brittle grainstone layers in the sequence cracked and broke. Mudstone interbeds were squeezed into the cracks and between and around broken fragments of the grainstones producing "pseudo-breccias" and even boudinage structures. The fossils and burrows in these grainstones are not deformed.

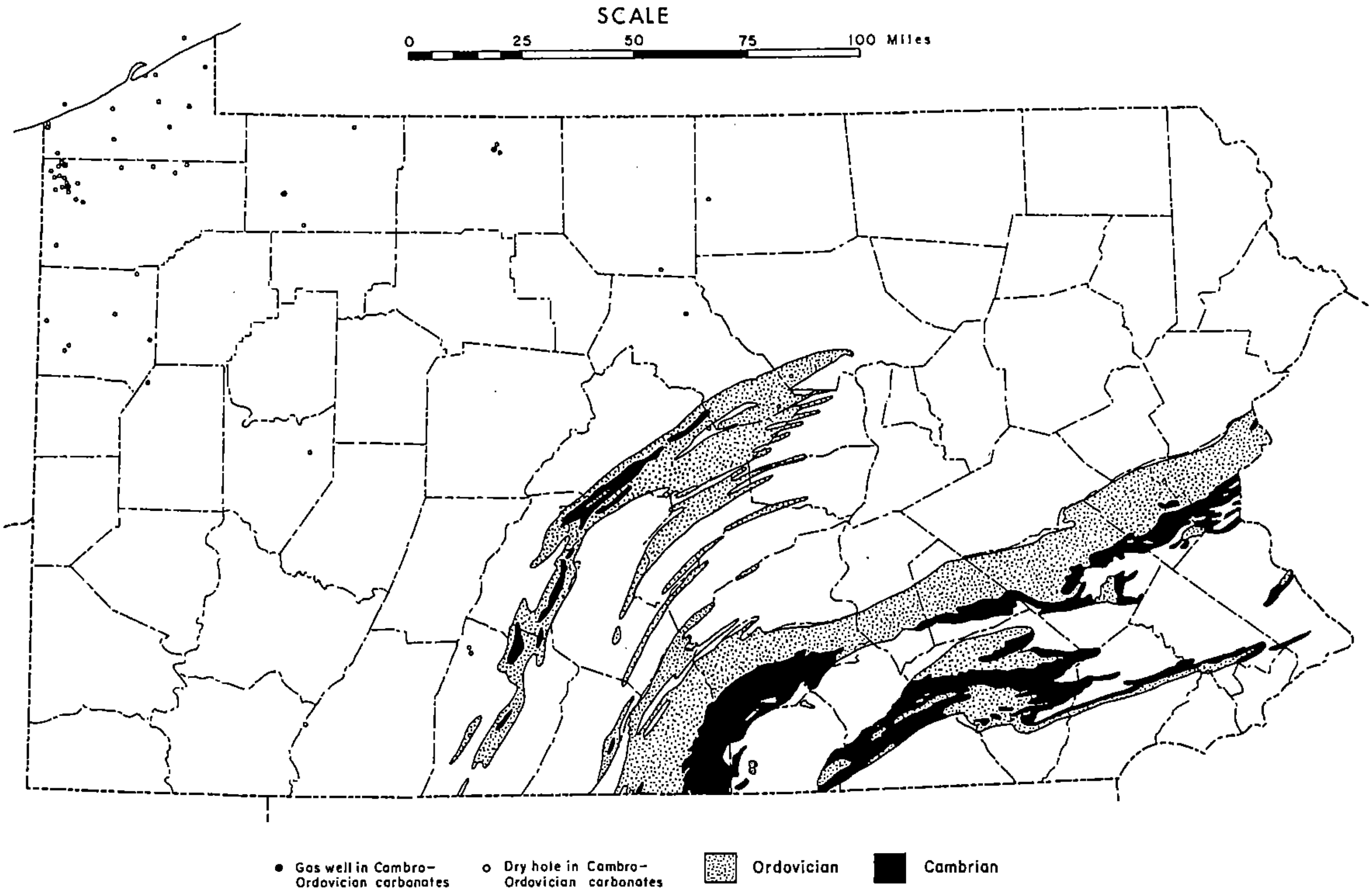


Figure 6. Map of Pennsylvania showing generalized outcrop patterns of Cambrian and Ordovician rocks, and locations of wells penetrating the Cambrian and/or Ordovician carbonate section.

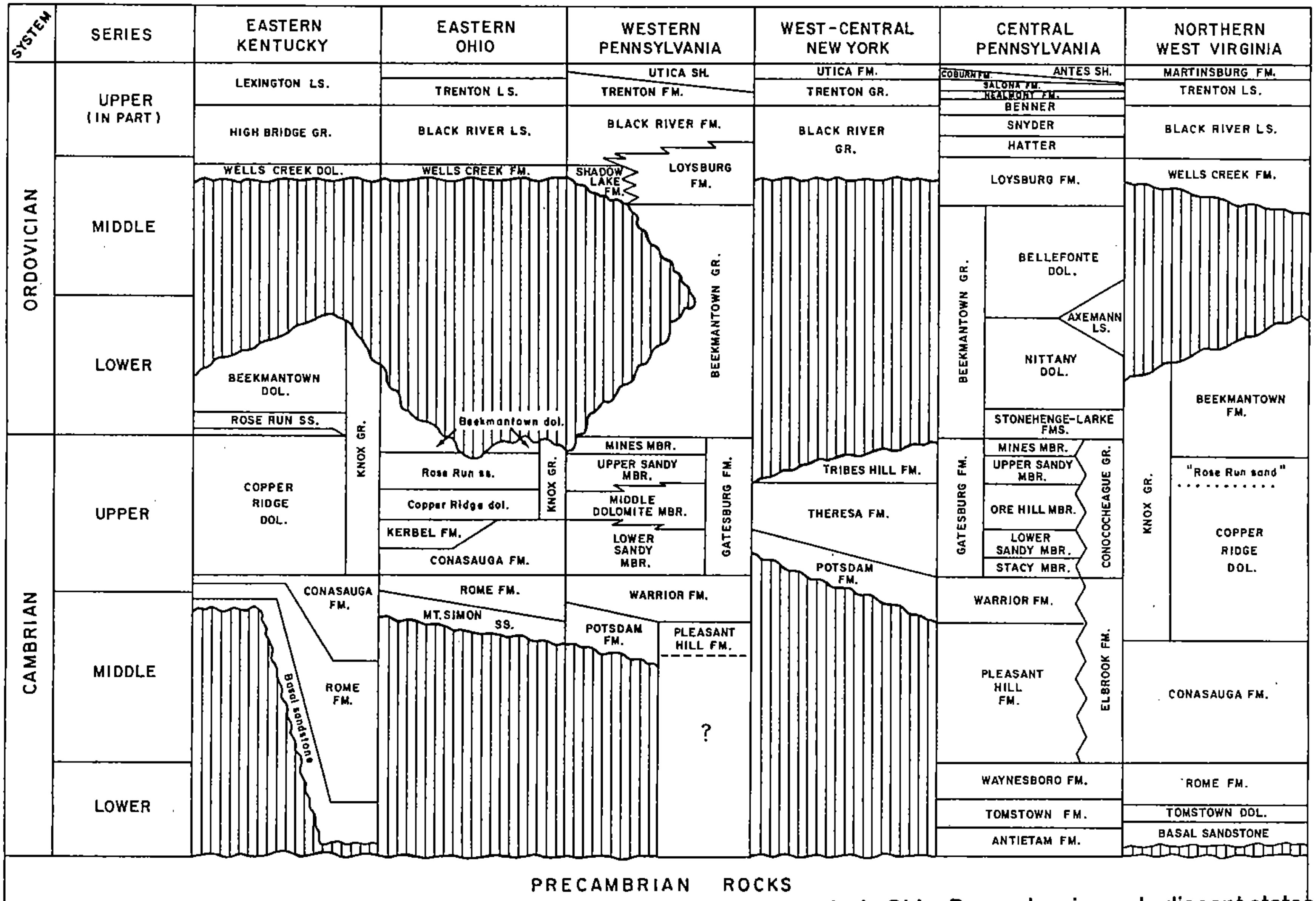


Figure 7. Generalized correlation diagram for Cambrian and Ordovician rocks in Ohio, Pennsylvania, and adjacent states (from Riley and others, 1993, fig. 3).

*Early burial cementation* features are superimposed on the compactional deformational features. Evidence for early burial cementation includes ferroan calcite spar, minor saddle dolomite, and minor low-amplitude stylolites. *Selective dolomitization of mudstones* followed the episode of early burial cementation; sucrosic and mosaic dolomite pereferentially replaced peloidal carbonate mudstones in all lithofacies.

*Major stylolitization* was the next significant diagenetic event. Hardie (1989) estimates that stratigraphic thinning by chemical compaction occurred on the order of 10 to 40 percent!

*Features related to tectonic deformation* comprise the next diagenetic episode. Examination of the rocks reveals stretching and folding of all previous features. Epigenetic quartz and calcite fill these tectonic features and joints. We have also noted epigenetic evaporite minerals filling fractures in core of these rocks from central Pennsylvania.

*Late burial dolomitization* was the last of the diagenetic events recorded in the Cambro-Ordovician rocks of the Central Appalachians. Massive, coarse-grained dolomite mosaics completely replace all of the previously described diagenetic features in the Nittany Arch and Reading areas of Pennsylvania and in the Fredrick Valley of Maryland. This replacement cuts across stratigraphic boundaries and appears to have occurred at structural highs where warm, upwelling brines might have focused.

The Cambrian section exposed in central Pennsylvania consists of approximately 1,065-1,220 m (3,500-4,000 ft) of predominant dolostone with subsidiary sandstone, shale, and limestone strata at varying intervals (Figure 8). Carbonates comprise more than 1,370-1,675 m (4,500-5,500 ft) of Lower, Middle, and Upper Ordovician strata in this area (Figures 9 and 10). About 75% of these carbonates consist of dolostones of varying texture, color, constituents, etc.

Included here, by way of an introduction to the outcrops we will be seeing andvisiting on this field trip, are brief descriptions of the Cambrian and Ordovician carbonates in central Pennsylvania. Lithologic (as well as nomenclatural) variations occur laterally within Pennsylvania. For example, the rocks named Gatesburg Formation in the Ridge and Valley become Conococheague Formation strata in the Great Valley (Figure 7). Other than the fact that limestones dominate the Conococheague, whereas dolostones dominate the Gatesburg, the two are virtually identical in thickness, (noncarbonate) composition, fossil content, depositional environments, and cyclicity of strata. Thus, we see just how important a secondary mineralization phenomenon (dolomitization) is to lithostratigraphy.

## Cambrian Strata

Throughout much of the Appalachians, the Cambrian System consists of basal sandstones, siltstones, and shales overlain by shallow continental shelf carbonates. As Early Cambrian seas transgressed across the continental edges of Laurentia (pre-

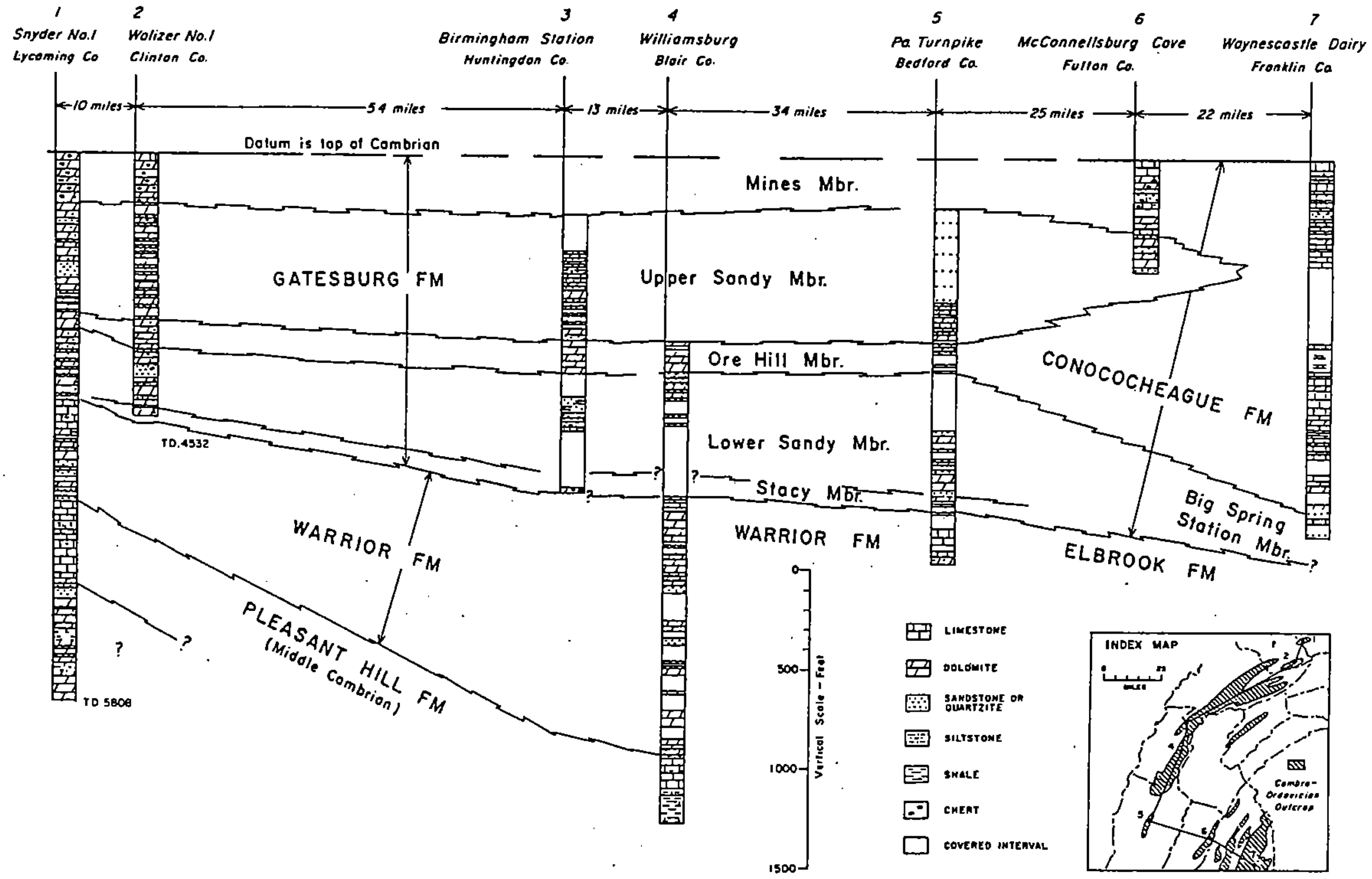


Figure 8. Stratigraphic cross section of Upper Cambrian in central and south-central Pennsylvania (modified slightly from Wagner, 1963, fig. 1).

Alleghanian North America), they mixed and winnowed large amounts of sand derived from, and deposited on, metamorphosed and eroded Grenville rocks (Late Precambrian). These sands spread progressively westward through time, onlapping the exposed continent, and resulting in basal sandstones that range in age from Earliest Cambrian (Antietam) in the Great Valley and Valley and Ridge provinces to late Middle Cambrian (Potsdam in New York and Pennsylvania, Mt. Simon in Ohio) on the fringes of the Canadian Shield. These sandstones formed the basis of a vast, shallow continental shelf hundreds of kilometers wide and thousands of kilometers long (from the Caledonides to the Ouachitas). Throughout the remainder of the Cambrian, and well into the Upper Ordovician, the shelf developed into, and remained, a relatively stable carbonate factory where thousands of feet of limestones and subordinate evaporites formed. Depositional patterns are distinctly cyclical on numerous hierarchical levels, the largest being the "grand cycles" of Aitken (1966).

***Antietam, Tomstown, and Waynesboro Formations.***-Most of the Lower Cambrian, including the entire Antietam and Tomstown formations and the lower 2/3 to 3/4 of the Waynesboro Formation, remains unexposed in the Ridge and Valley of central Pennsylvania. These rocks crop out only in the Great Valley and farther southeast, and have not been penetrated by drilling anywhere in the Appalachian Plateau. Only the upper 60-90 m (200-300 ft) of the Waynesboro, consisting mostly of sandstones and red and green shales, is exposed in central Pennsylvania.

***Pleasant Hill Formation.***-The Middle Cambrian in central Pennsylvania consists of the upper portion of the Waynesboro Formation, the entire Pleasant Hill Formation, and the lower portion of the Warrior. The Pleasant Hill in the Huntingdon-Hollidaysburg area is about 180 m (600 ft) thick. It consists of a lower 120 m (400 ft) of thin-bedded, argillaceous and arenaceous limestones and calcareous shales, and an upper 60 m (200 ft) of thick-bedded, fine-grained, dark-gray limestones (Butts, 1945). Wilson (1952) noted that the Pleasant Hill limestones exposed in the Juniata River watergap at Williamsburg, Blair County weather to brownish-yellow, thin-bedded, platy layers up to 15 cm (6 in) thick. Some sandstone and siltstone occurs within the section at this locality. The Pleasant Hill and overlying Warrior are thought to be equivalent with the Elbrook Formation of the Great Valley (Figure 7). In the area of the field trip, the Pleasant Hill Formation crops out only in a narrow, 2.5 km (1.5 mi) long strip about 6.5 km (4 mi) east-northeast of Birmingham.

***Warrior Formation.***-The Upper Cambrian in central Pennsylvania consists of the upper part of the Warrior Formation and the entire Gatesburg Formation. The Warrior Formation consists of approximately 410 m (1,340 ft) of carbonate, both limestone and dolostone, with minor (about 5%) sandstones. The most common lithology, according to Wilson (1952), is platy to medium-bedded, fine-grained to microcrystalline, oolitic and fossiliferous limestone. At Williamsburg, the formation is mostly massive, fine to microcrystalline dolostone containing some quartzose sandstone in the middle and upper portions, and minor medium- to coarse-grained dolostone in the lower portion of the formation (Wilson, 1952; Wagner, 1966). The Warrior is exposed along the Nittany

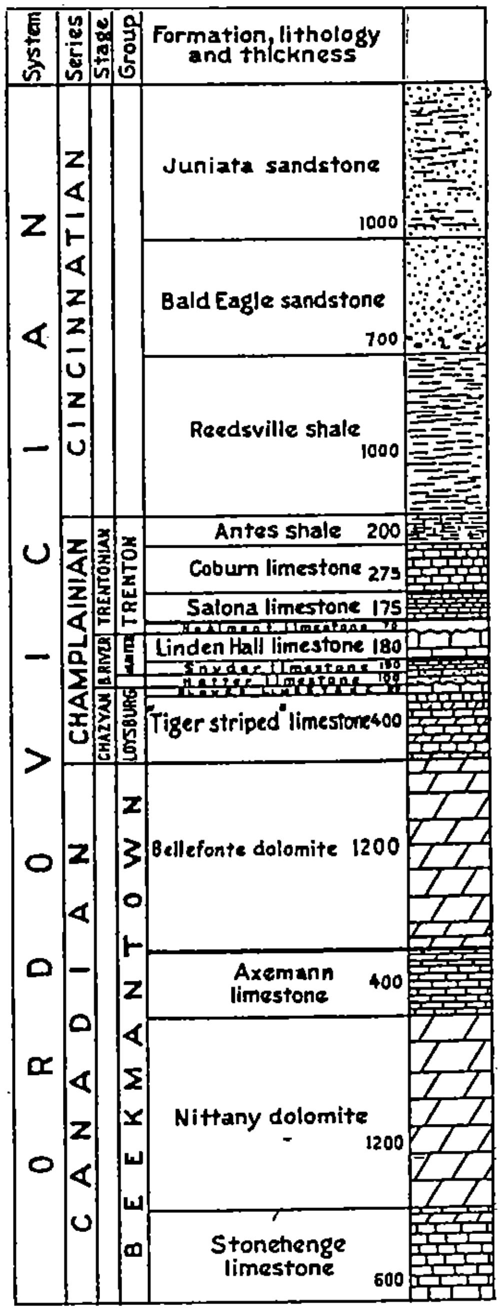


**Figure 9. Stratigraphic column of the Ordovician for central Pennsylvania (from Rones, 1969, fig.7).**

anticline northeast of Birmingham, but it is uncertain whether or not it crops out in the Birmingham window area. The rock in the hanging wall of the Birmingham thrust fault at Stop 1 consists of carbonates containing quartz grains, but it's detailed character has been obscured by shearing. No obvious bedding occurs, and it is uncertain if this rock is upper Warrior or lower Gatesburg.

***Gatesburg Formation.***-The uppermost Cambrian unit, the Gatesburg Formation, has been divided into five members, in ascending order the Stacy, Lower Sandy, Ore Hill, Upper Sandy, and Mines. The Stacy, Ore Hill, and Mines members consist of, by definition, massive dolostones lacking any arenaceous strata, whereas the Upper and Lower Sandy members consist of interbedded dolostones and sandstones. Limestones commonly replace dolostones in various portions of the formation. The Gatesburg typically is 490 to 550 m (1,600-1,800 ft) thick in central Pennsylvania (Wagner, 1966). Except for within the Birmingham window, the Gatesburg occupies the axis of the Nittany anticline. The best exposures include Stacy and Lower Sandy outcrops along the Conrail railroad tracks on the southwest side of Little Juniata River, opposite Birmingham, and Lower Sandy through Upper Sandy on both sides of Route 453 between Birmingham and Shoenberger (Figure 1). In fact, these constitute the most complete exposure of Gatesburg anywhere in Pennsylvania (Wilson, 1952).

## Lower and Middle Ordovician Carbonates

The Beekmantown Group occupies the entire Lower Ordovician and most of the Middle Ordovician section of central Pennsylvania. Dolostones dominate the lithology, but limestones are common, especially at the base and middle of the section. The Beekmantown has been divided into five formations in central Pennsylvania. In ascending order they include the equivalent Stonehenge Formation, Larke Formation, Nittany Formation, Axemann Formation, and Bellefonte Formation. As many as all five or as few as three of these formations might occur at any given locality.

***Stonehenge and Larke Formations.***-The Stonehenge consists of about 150 m (500 ft) of thin- to thick-bedded, blue limestone containing minor beds of magnesian limestone and dolostone. The Larke, on the other hand, consists of about 150 m (500 ft) of thick-bedded, medium- to coarse-crystalline, dark blue dolostone with very minor beds of sandstone, chert, and limestone (Donaldson, 1959). The two formations actually are one, divided simply on the basis of the presence or lack of secondary mineralization (dolomitization). Lateral and vertical intergradations of the two lithologies are quite common. The Stonehenge crops out to the north, in Centre County, and to the southeast, in Franklin County. In addition, Wagner (1966) used the name Stonehenge for rock samples collected from this interval in a well drilled in Hampshire County, West Virginia. In contrast, the equivalent rocks in much of the Blair-Huntingdon County area must be called Larke owing to the preferential dolomitization of the Lower Ordovician limestones in this area. Strangely enough, the Stonehenge is the lower Beekmantown formation of preference within the Birmingham area where intense fracturing along the Tyrone-Mt. Union lineament channeled mineral-rich fluids through the rocks, depositing lead and zinc minerals along the way. The Stonehenge can be seen in the roadcut on the northeast side of Route 453 opposite Honest Hollow (Figure 1). Faill (1987, p. 40) states that a kink band occurs here "within which the vertical enclosing bedding has been rotated back to subhorizontal and right-side-up."

***Nittany Formation.***-The Nittany comprises up to 600 m (2,000 ft) of fine- to coarse-crystalline dolostone sandwiched between the limestones of the Stonehenge and Axemann formations. Spelman (1966) divided the Nittany into three members, based primarily on the presence or absence of sand- or silt-size quartz grains in the dolostone (the middle member contains no quartz). The upper and lower boundaries of the Nittany become obvious where the Stonehenge and Axemann limestones occur; where the limestones have been dolomitized, however, the boundaries become obscure. Spelman indicated that the sandy dolostones of his lower Forge Union Member are more abundant toward the top. As a result, he had great difficulty picking the Larke/Nittany boundary, necessitating the use of fossils to distinguish one formation from the other(!!!). Where the Axemann was missing, he placed the Nittany/Bellefonte boundary at the top of the highest sandy dolostones of his upper Etna Furnace Member. Neither of these boundary definitions conveys much confidence, particularly in light of Wagner's (1966) work showing the Bellefonte is more likely to contain sandy beds than the Nittany. The lower boundary is even worse - the Code of Stratigraphic Nomeclature strictly forbids the use of

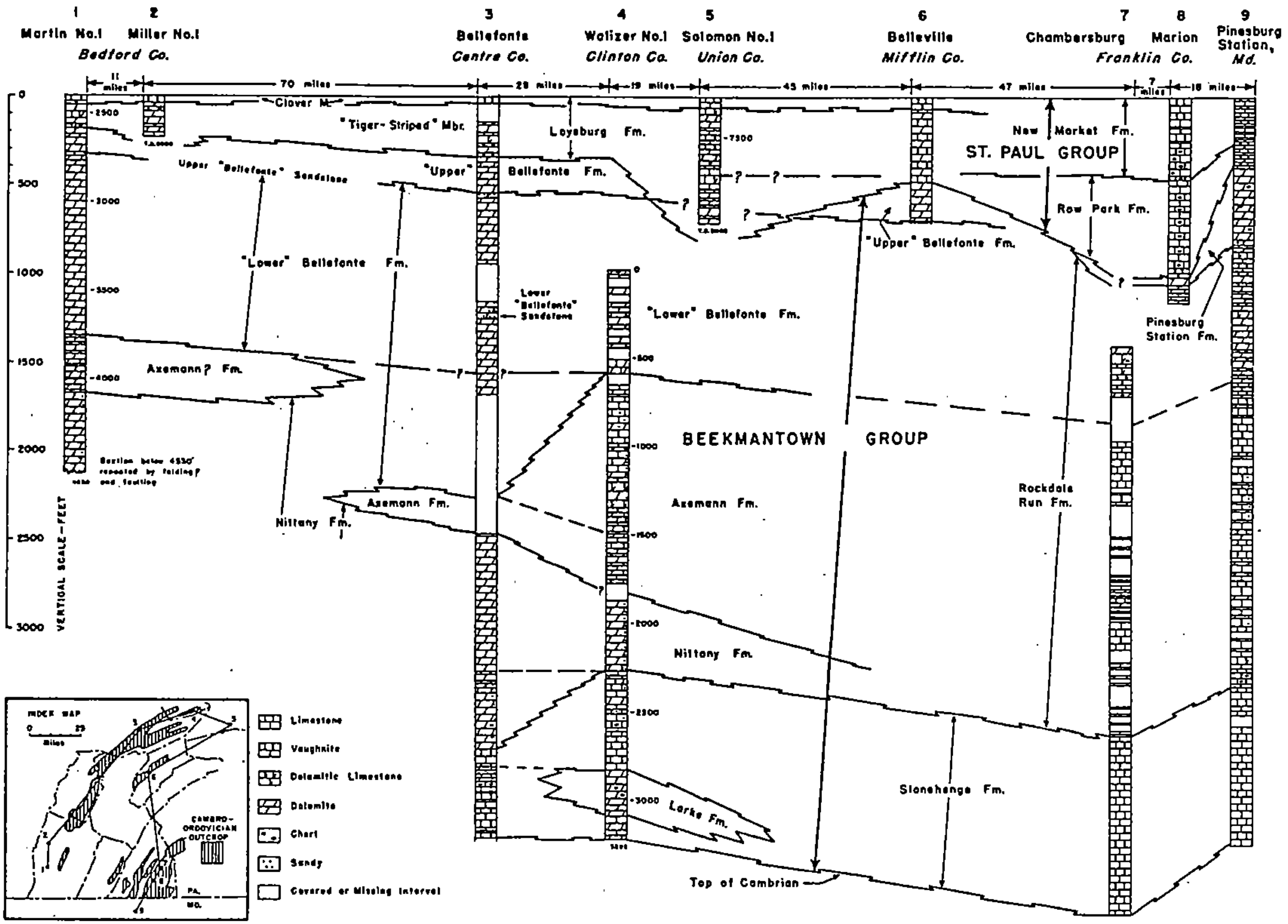


Figure 10. Stratigraphic cross section of Lower and Middle Ordovician rocks in central and south-central Pennsylvania (modified slightly from Wagner, 1963, fig. 2).

biostratigraphy to define lithostratigraphic units. This could lead one to believe that, perhaps, the Beekmantown has been overly split in certain areas. The Nittany is exposed in roadcuts on both sides of Route 453 between Ironville and Honest Hollow on the northwest flank of the Nittany anticline, and on the northeast side of Route 453 between Shoenberger and the bridge of the river on the southwest flank of the anticline (Figure 1).

***Axemann Formation.-***The Axemann Formation may be as thick as 365 m (1,200 ft) in a well in north-central Pennsylvania (Wagner, 1966), but apparently rarely exceeds 150 m (500 ft) in the area between Centre and Bedford counties in central Pennsylvania. It typically consists of interbedded limestones, dolomitic limestones, and dolostones of varying texture, with minor amounts of sandstone and chert. Lees (1967) divided the formation into two members, the upper predominantly micritic and the lower calcarenitic and fossiliferous. The formation (actually, facies) appears to be absent (dolomitized) in this area.

***Bellefonte Formation.-***The Bellefonte Formation, at 600 m (2,000 ft) thick, is composed mostly of dolostones lying between the limestones of the Axemann and Loysburg formations. Where the Axemann limestones have been dolomitized, the Nittany and Bellefonte are extremely difficult to distinguish. Although Bellefonte rocks, supposedly, are finer grained than those of the Nittany, Wagner (1966) acknowledged that lower Bellefonte dolostones tend to be medium- to coarse-crystalline. The upper part, called the Tea Creek Member, commonly is very finely crystalline (Chafetz, 1969) (this member is the only portion of the Beekmantown Group that is Middle Ordovician in age). In addition, the Nittany contains little or no chert, especially in the upper member, whereas a zone of chert occurs near the base of the Bellefonte throughout central Pennsylvania at least from Bedford (Knowles, 1966) to State College (Butts and Moore, 1936) (see Butts and others, 1939, p. 16 and 17 for a different viewpoint). This chert zone occurs along Route 320 on the northwest side of the Nittany anticline (Riley and others, 1993). Ryder and others (1992; also Riley and others; 1993) speculated that this chert zone might be a remnant of a widespread unconformable surface that is unidentifiable in this area by other means (the Knox unconformity). Where significant amounts of limestone occur within the Bellefonte section, Wagner (1966) used the name Rockdale Run Formation (Figure 10). The Bellefonte Formation in the Birmingham area is exposed in the same roadcuts as the Nittany (see above).

***Loysburg Formation.-*** Above the Beekmantown dolostones lie approximately 460 m (1,200 ft) of limestones with minor dolostone layers. The lower of these, the Loysburg Formation, is Middle Ordovician in age, whereas the remaining units are (mostly) Late Ordovician. The Loysburg ranges in thickness from as little as 15 to as much as 150 m (50-500 ft) in central Pennsylvania. This vast difference is due to the variable thickness of the lower Milroy (or "tiger-striped") Member, which is present in outcrop only as inferred lens-shaped masses (Chavetz, 1969). The upper Clover Member maintains a relatively constant thickness in central Pennsylvania. The Milroy consists of thin, ribbon-like alternating bands of cryptalgal dolostone and limestone less than 2.5 cm (1 in) thick in beds 0.3-0.6 m (1-2 ft) thick. The differential weathering of the limestone and more resistant dolostone accounts for the name "tiger-striped" member. The Clover Member is a thick-bedded, relatively pure, micritic and fossiliferous limestone, quite different from anything below it. This formation is well exposed at the Union Furnace roadcut along Route 453 adjacent to the Union Furnace quarries (Stop 3).

## Upper Ordovician Strata

The Upper Ordovician section in central Pennsylvania consists of carbonates progressively contaminated with fine clastic sediments, overlain by a coarsening-upward sequence of clastics derived from tectonic deformation of the eastern (present cardinal directions) margin of the Laurentian continent. In western Pennsylvania, as in adjacent parts of Ohio and West Virginia, the Upper Ordovician carbonates fall within the Black River and Trenton formations. Over the last 77 years these two units have been relegated to "stage" status and divided into numerous formations and members in New York and central and eastern Pennsylvania. The stratigraphic succession of central Pennsylvania has been based on minute details of bedding, texture, and detrital and fossil content (see Kay, 1944a and 1944b, Chavetz, 1969, Rones, 1969, and Thompson, 1963 for details). Many of these characteristics seem to be quite indiscernable outside local or limited regional areas, representing depositional facies variations on the "Great American Bank"concept of Ginsburg (1982). The Union Furnace roadcut along Route 453 (Figure 1) is the best exposed and most complete section of Upper Ordovician carbonate rocks in central Pennsylvania. Upper Ordovician clastics comprise a classic flysch and molasse sequence deposited during the Taconic orogeny (the Ordovician portion of the Taconic clastic wedge).

***Hatter Formation.***-At the Union Furnace roadcut (Stop 3) the Hatter Formation consists of about 30 m (100 ft) of argillaceous dark-gray laminated micrites and calcarenites (skeletal wackestones and packstones). Kay (1944a) divided the formation into three member, but according to Rones (1969) the lower Eyer Member is absent over much of the outcrop area of the formation. Wagner (1966) did not recognize any of the members in the subsurface of western Pennsylvania. There presumeably is an unconformity between the Hatter and the underlying Loysburg, according to Rones (1969), who described the boundary at Union Furnace as a "knife-edge break". Berkheiser and Cullen-Lollis (1986), however, interpreted the rocks at the Loysburg/Hatter boundary to be representative of a low-energy, lagoonal-type environment. That knife-edge boundary could be nothing more than a diastem. Only intensive biostratigraphic analysis of the situation will resolve the question.

***Snyder Formation.***-The Snyder Formation, stratigraphically the lowest of the Upper Ordovician carbonates to definitely contain altered volcanic ash beds, consists of about 29 m (95 ft) of dark-colored, faintly laminated, bioturbated micrites and calcarenites. Wagner (1966) characterized the Snyder as being coarser textured than adjacent formations. At least three ash beds, 1.3-2.3 cm (0.5-0.9 in) thick, and a brownish or orangish color very distinctive from the surrounding rock, occur at the Union Furnace roadcut (Berkheiser and

Cullen-Lollis, 1986). Rones (1969) recognized only one ash bed in Centre County, but it was found in five separate outcrops.

***Linden Hall Formation.***-Approximately 46 m (151 ft) of light- to dark-gray micritic limestones with some dolomitic streaks and a few discontinuous intraclastic calcarenites characterize the Linden Hall Formation (Rones, 1969; Berkheiser and Cullen-Lollis, 1986). Rones recognized four members irregularly distributed over central Pennsylvania. This formation, particularly near its center, contains numerous ash beds. Berkheiser and Cullen-Lollis listed four. Three of these were less than 2.5 cm (1 in) in thickness and the fourth was more than 7.6 cm (3 in) thick. Rones recognize five ash beds within a 12 m (40 ft) zone of the Linden Hall in Centre County. Both the uppermost and lowermost of these were traceable over large areas of the outcrop.

***Nealmont Formation.***-The Nealmont Formation is divided into two members, a lower Centre Hall characterized by dark-colored, thin- to thick-bedded impure limestone, and an upper Rodman consisting mostly of highly fossiliferous calcarenites. Kay (1944b) described the formation at Union Furnace as 41 m (135 ft) thick, but Berkheiser and Cullen-Lollis (1986) recognized only 23 m (76 ft) at that locality. Rones (1969) recognized two ash beds within this formation, whereas Berkheiser and Cullen-Lollis listed six, one of which was 4 cm (1.6 in) thick. Wagner (1966) indicated that the calcarenites of the Rodman Member could be recognized in drill cuttings in western Pennsylvania. He postulated that, over time, this facies transgressed westward across what Ginsburg (1982) called the "Great American Bank", replacing the darker colored, finer grained facies typical of the overlying Salona and Coburn formations. This becomes very evident when one uses the ash beds for correlation.

***Salona Formation.***-The Salona Formation consists of 53-73 m (175-240 ft) of black, argillaceous limestones that Thompson (1963) separated into two members. Numerous altered volcanic ash beds (K-bentonites) occur throughout the formation. Two of them probably correspond with the Millbrig and Dieke ash beds (Haynes, 1994) that have been recognized throughout eastern North America and the Mississippi valley. The Millbrig has even been correlated with the "Big Bentonite" ash bed of Scandinavia (Huff and others, 1992 ). Berkheiser and Cullen-Lollis (1986) suggested that the relative paucity of fossils in the Salona might be related to chemical changes and variables related to volcanic ash in Ordovician sea water.

***Coburn Formation.***-The Coburn Formation grades upwards from dark-colored skeletal calcarenites and calcirudites to black argillaceous limestones interbedded with calcareous shales. The Coburn is about 120 m (400 ft) thick at Bellefonte, Centre County,but only the lower 60 m (200 ft) is exposed at Union Furnace. The top of the Coburn is gradational with the overlying black shales of the Antes Formation (or Utica Shale in western Pennsylvania). Berkheiser and Cullen-Lollis (1986) suggested that the Salona-Coburn interval was deposited by storms on a deep ramp or continental slope. These rock grade eastward into classic

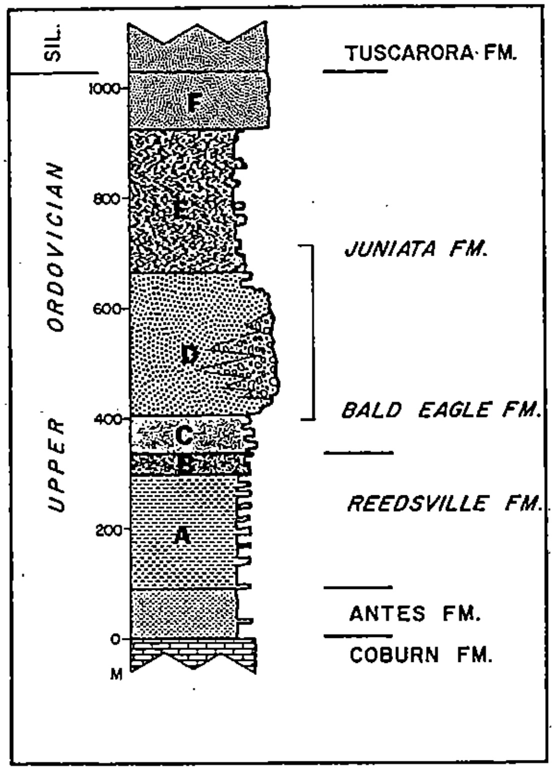


**Figure 11. Comparison of formal stratigraphic and Thompson' (1970) lithostratigraphic nomenclature in Upper Ordovician rocks of central Pennsylvania (from Thomp son, 1986, fig. 11). The bracket indicates the interval in which the boundary between red and gray coloration occurs.**

***Post-Coburn Ordovician Strata.***-With the Taconic orogeny under full steam, the 60 Ma-old "Great American Bank" was rapidly buried under the thick deposits of the first of the two great superdeltaic systems of the Appalachian Phanerozoic, the Queenston deltaic system[1]. The standard stratigraphic sequence in central Pennsylvania (Figure 11) is as follows: 1) Antes Formation, consisting of black shales deposited in an anoxic water column (often termed a "deep-basin black shale" regardless of the actual water depth); 2) Reedsville Formation, relatively non-descript gray shales and siltstones; 3) Bald Eagle Formation, interbedded sandstones and shales, with sandstone dominant; 4) Juniata Formation, red sandstone and shale, generally considered to be of fluvial-deltaic origin; 5) Tuscarora Sandstone, generally well-sorted quartzose sandstones. The Tuscarora, although part of the Taconic clastic sequence, is Earliest Silurian in age. Allan Thompson has spent considerable time examining the Upper Ordovician clastic sequence. He argued that the standard central Pennsylvania stratigraphic nomenclature is inadequate and confusing owing to the lack of inconsistent criteria for defining these formations (Thompson, 1970). He suggested, instead, the use of six lithofacies (Figure 11) that are independent of the classic names but which can be recognized and correlated regionally. Lithofacies A, which is typical of the Reedsville Formation, consists of gray interbedded shale, thin sandstone, and minor limestone. Lithofacies B is a gray, fossiliferous, quartz wacke and siltstone unit traditionally assigned to the top of the Reedsville. Lithofacies C consists of several types of sandstones with minor shales and red beds. Although this lithofacies typically belongs to the Bald Eagle Formation, the upper parts commonly are red in color and so are relegated to the Juniata Formation. Lithofacies D contains coarse-grained, cross-bedded

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[1] The second is the Catskill. These two systems, although separated by 40 million years, retain many similarities of depositional facies and lithotypes. For anyone interested in investigating these similarities, Thompson and Sevon (1982) offer a marvelous comparison of the two through both descriptive text and field examination.

sandstones and conglomerates typical of the Oswego Sandstone of New York (which is equivalent to the Bald Eagle across the New York/Pennsylvania "state line fault"). The gray Bald Eagle/red Juniata color transition commonly occurs within this lithofacies. Lithofacies E, interbedded lithic wackes, siltstones, and mudstones that are characteristically red in color, most commonly are assigned to the Juniata Formation. Lithofacies F consists of well-sorted red and gray quartz arenites and interbedded shales. Although lithologically characteristic of the Tuscarora, the red units typically are placed in the Juniata just because of their coloration. Piotrowski (1981) recognized this problem in the subsurface of western Pennsylvania where geophysical logs indicated a good clean sandstone but sample descriptions indicated red coloration. His solution was to place these rocks in a "Juniata/Tuscarora transition zone". On this trip, the Reedsville, Bald Eagle, and Juniata formations (or their lithofacies, if you prefer) are best seen in Tyrone Gap just east of Tyrone and in the Birmingham window at Birmingham (Stop 1B).

## LEAD AND ZINC DEPOSITS

Although Blair County is well known for its Colonial Period iron ore mines and furnaces, including Union Furnace near Stop 3 of this field trip, the Birmingham area itself is better known for its Mississippia Valley-type[2] lead and zinc deposits. Tectonic deformation of the Upper Cambrian and Lower Ordovician carbonates of Sinking Valley (the breached center of the Nittany anticline) included a high degree of fracturing where mineral-rich fluids deposited sphalerite and galena with calcite, dolomite, barite, pyrite, and minor to trace amounts of hydrozincite, smithsonite, calamine, cerussite, jordanite, and anglesite. Perhaps the best known deposit is the old Keystone mine in Honest Hollow, approximately 1.3 km (0.8 mi) due west of Birmingham (Figure 1).

The following narrative, from Miller (1924, p. 13-14), explains the history of mining for lead and zinc in Blair County:

> "The first lead and zinc mines of Pennsylvania were operated in the Sinking Valley, Blair County, during the Revolutionary War. The Continental Army being in great need of lead for bullets, a party was sent to investigate some lead deposits said to be in the Wilderness near Frankstown. As a result of the examination General Daniel Roberdeau opened and worked some shallow mines in the southern end of Sinking Valley during 1778 and 1779... At one time 1,000 pounds of lead was sold to the State at $6.00 a pound in the depreciated currency of that period. It is not known when the mines closed but probably the operations were short-lived because of the expense of transporting materials for mining and smelting the ore, the maintenance of the laborers in the Wilderness, as it was called, and the guards that were necessary on account of hostile Indians.

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[2] The Glossary of Geology (Bates and Jackson, 1987) define Mississippi Valley-type deposit as, "A strata-bound deposit of lead and/or zinc minerals in carbonate rocks, together with associated fluorite and barite. These deposits characteristically have relatively simple mineralogy, occur as veins and replacement bodies, are at moderate to shallow depth, show little post-ore deformation, are marginal to sedimentary basins, and are without an obvious source of the mineralization."

"The next period of active mining was in 1795 when John Musser was employed by Robert Morris to drive a drainage tunnel into the side of the hill near Birmingham to connect with a shaft previously sunk. No further information is available concerning this undertaking.

"It seems that there was little if any more work done until 1864 when the Keystone Zinc Company was organized and with abundant capital started operations on a large scale. Most of the work was done in the northern part of the valley near Birmingham but investigations by this company and others were made in a number of places in the southern part of the valley. New shafts and tunnels were driven and a larege reducing plant for the manufacture of zinc oxide was built near Birmingham for the treatment of ores from this and other regions. In this attempt the principal anttention was given to zinc while in the previous operations only lead was sought and the zinc minerals present were regarded as worthless or as part of the gangue. After six years, during which several thousand tons of ore were mined, the company became financially involved and the plant was closed in 1870. Since that time there have been sporadic efforts to discover workable ore beds in various parts of the valley but with indifferent success. In 1875 some diamond drill boring was done in the southern part of the valley and in 1876 a small quantity of ore from another property was mined and shipped to the Bamford reduction plant near Lancaster.

"The latest known attempt to reopen the mines was in 1901 when a certain company issued a prospectus and endeavored to interest capital in the project. This is said to have been merely a stock-selling scheme.

"At present the mines are in bad condition although the writer was able to go down one of the old shafts near Birmingham in the summer of 1921 and to see something of the old drifts and stopes that are above water level."

In examining the Keystone mine deposits Moebs and Hoy (1959) determined that they occur in limestones, rather than dolostones, and assigned the host rock to the Black River-Chazy Groups (Loysburg through Linden Hall formations). The mine occurs close to, if not in association with, the Honest Hollow fault (Figure 1), and although it is likely the rock is Loysburg-Linden Hall, Smith (1977) stated that he would not rule out the Stonehenge or Warrior as possible host rock. Other occurrences in the Birmingham are found in the Mines Member of the Gatesburg Formation, and the Stonehenge, Nittany, and Bellefonte formations.

In discussing the origins of the Birmingham lead and zinc deposits, Smith (1977, p. 99-100) stated that the occurrence of these minerals in the local rocks suggested some post-deformational emplacement:

"In order to mineralize all these hosts, one possibility is that the Sinking Valley thrust was a primary conduit for hydrothermal solutions localized by secondary splays. However, movement of solutions through a major thrust should be difficult. Problems also arise in thoroughly brecciating the incompetent limestone in the mine and in accounting for mineralization on both sides of the crest of the Sinking Valley fault. Hydrothermal solution movement toward the crest of the fault from two directions seems unlikely.

"A. W. Rose (personal commun., 1974) offers an alternative path or primary conduit for hydrothermal solutions. He believes that steeply dipping, highly fractured Silurian Tuscarora quartzite and Ordovician Bald Eagle (Oswego) sandstone present beneath the Sinking Valley thrust would serve as excellent conduits as they apparently have in the Milesburg Gap and Mapleton areas. Moebs and Hoy (1959) encountered Reedsville and Juniata Formations in drilling and these as well as the Tuscarora and Bald Eagle Formations are exposed in nearby windows. According to Rose's model, metals would be precipitated upon passing through the Sinking Valley thrust and encountering suitable carbonate rocks. The report of sphalerite, galena, and pyrite in Tuscarora quartzite nearby teds to suport this theory."

A large hole about 1.8 to 2.4 m (6-8 ft) deep in the railroad cut at Stop 1A of this field trip might be lead/zinc mineral "farm bank" mine. Although previous trips to this locality have not resulted in any obvious sphalerite or galena, field trip participants will have the opportunity to examine the hole and see for themselves if any lead or zinc deposits occur there.

# ROAD LOG

Although this particular field trip begins in Pittsburgh, the road log begins in downtown Tyrone at the intersection where SR 453 becomes Pennsylvania Avenue (at the Burger King restaurant). This is in order to avoid confusion (and major gas mileage) for potential future participants who might not want to go all the way to Pittsburgh to begin their trip.

| MILEAGE | | ROAD LOG AND REMARKS ON ROADSIDE GEOLOGY |
|---|---|---|
| Int | Cum | |
| 0.00 | 0.00 | **START:** Intersection of Pennsylvania Avenue and SR 453. Drive SE on SR 453, passing under the I-99/US 220 overpass. |
| 0.35 | 0.35 | Tyrone Borough limits. Entering Tyrone water gap. The roadcut on the left (northeast) exposes the red shales, siltstones, and sandstones of the Juniata Formation, the uppermost Ordovician portion of the Taconic clastic wedge. From northwest to southeast these change from Juniata red rocks to the basic green and gray sandstones of the Bald Eagle Formation, and gray shales of the Reedsville Formation. Numerous mesoscopic structures occur here, including kink bands, kink faults, northwest-dipping normal and reverse faults in conjugatge pairs, cleavage, and wedge faults (Faill, 1987). |
| 0.20 | 0.55 | End of the outcrop. The vegetated slope from here to the intersection with SR 550 is underlain by the Bald Eagle and Reedsville formations. |
| 0.05 | 0.60 | The bridge to the right leads to Plummer Hollow. |
| 0.35 | 0.90 | Intersection with SR 550. Stay on SR 453 and cross the Little Juniata River. |
| 0.20 | 1.10 | Tyrone Regional Water Pollution Control facility on the left. |
| 0.25 | 1.35 | Note the large quarry on the left. This is the Narehood quarry operated by New Enterprise Stone and Lime Co. Bellefonte dolostones through Coburn limestones are overturned to the northwest. The company produces PennDOT-approved coarse and fine aggregate and pulverized agricultural limestone (Berkheiser, 1986). |
| 0.05 | 1.40 | The roadcut on the left exposes the beginning of 365 m (1,200 ft) of cyclically bedded dolostones of the Bellefonte Formation. |
| 0.20 | 1.60 | This roadcut, which continues on the left over the next 0.5 mi, exposes Bellefonte, Nittany, and Stonehenge formations. Smith (1977) indicates all three of these formations contain mineralized zones of lead and/or zinc in association with fractures. A chert zone within the Bellefonte formation near the crest of the hill might represent the Knox unconformity in central Pennsylvania. |
| 0.40 | 2.00 | The bridge across the Little Juniata River on the right leads to Honest Hollow where the old Keystone Zinc Company mine is located about 915 m (3,000 ft) SW of the river. Rocks in outcrop on the left include Stonehenge limestones and Mines (uppermost Gatesburg) dolostones. |
| 0.60 | 2.60 | The bridge across the Little Juniata River on the right leads to the Conrail railroad and our first stop. Notice the red rock on the left. This is the Upper Ordovician Juniata Formation. How did this get here (in Cambrian and Lower Ordovician carbonates)? |
| 0.05 | 2.65 | Pull onto the dirt area on the left side of the highway at the entrance to the village of Birmingham. From here we will walk across the bridge, following the dirt road to the Conrail railroad tracks. |

## STOP 1: BIRMINGHAM WINDOW AND FAULT LOCALITY

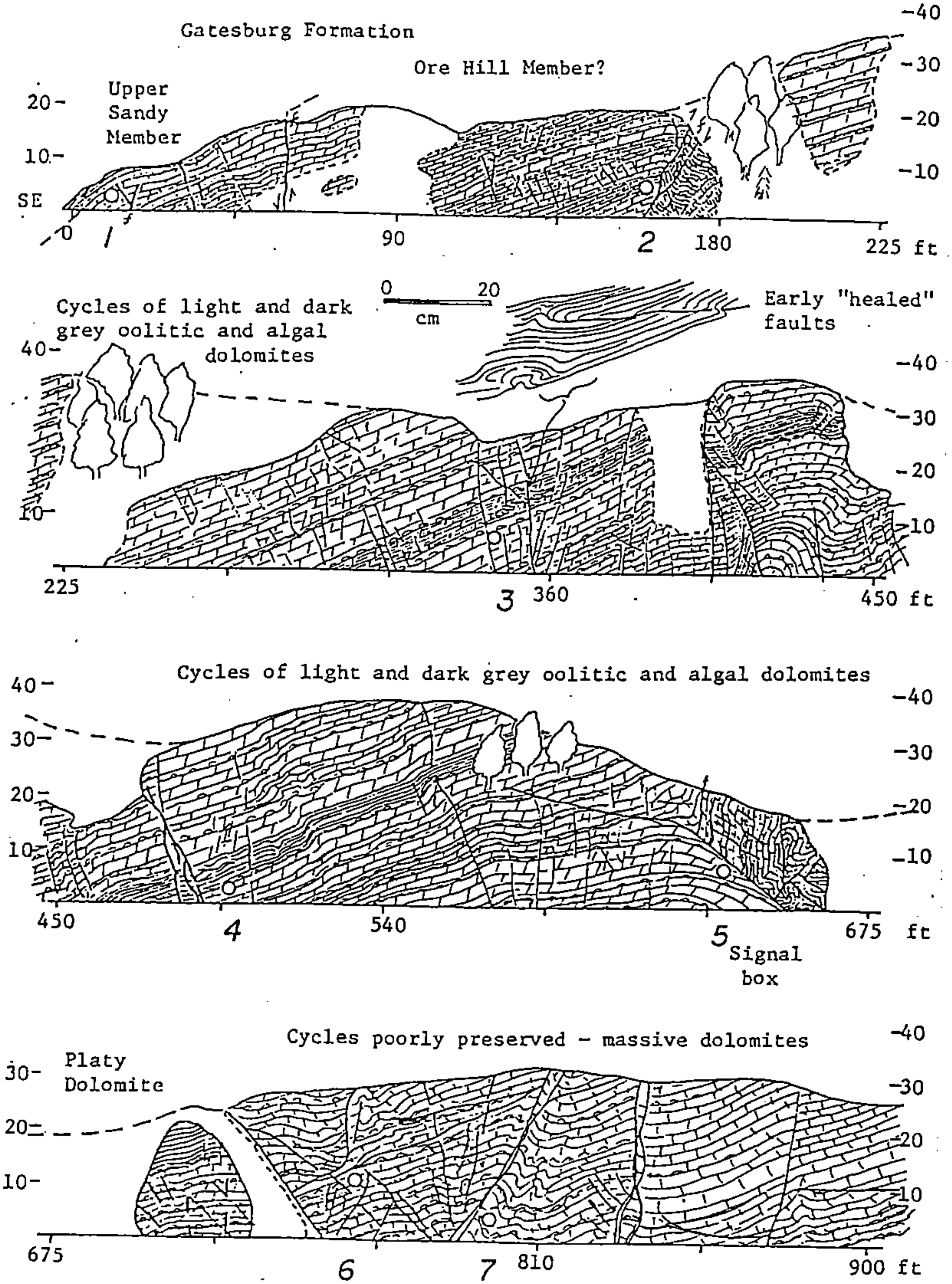
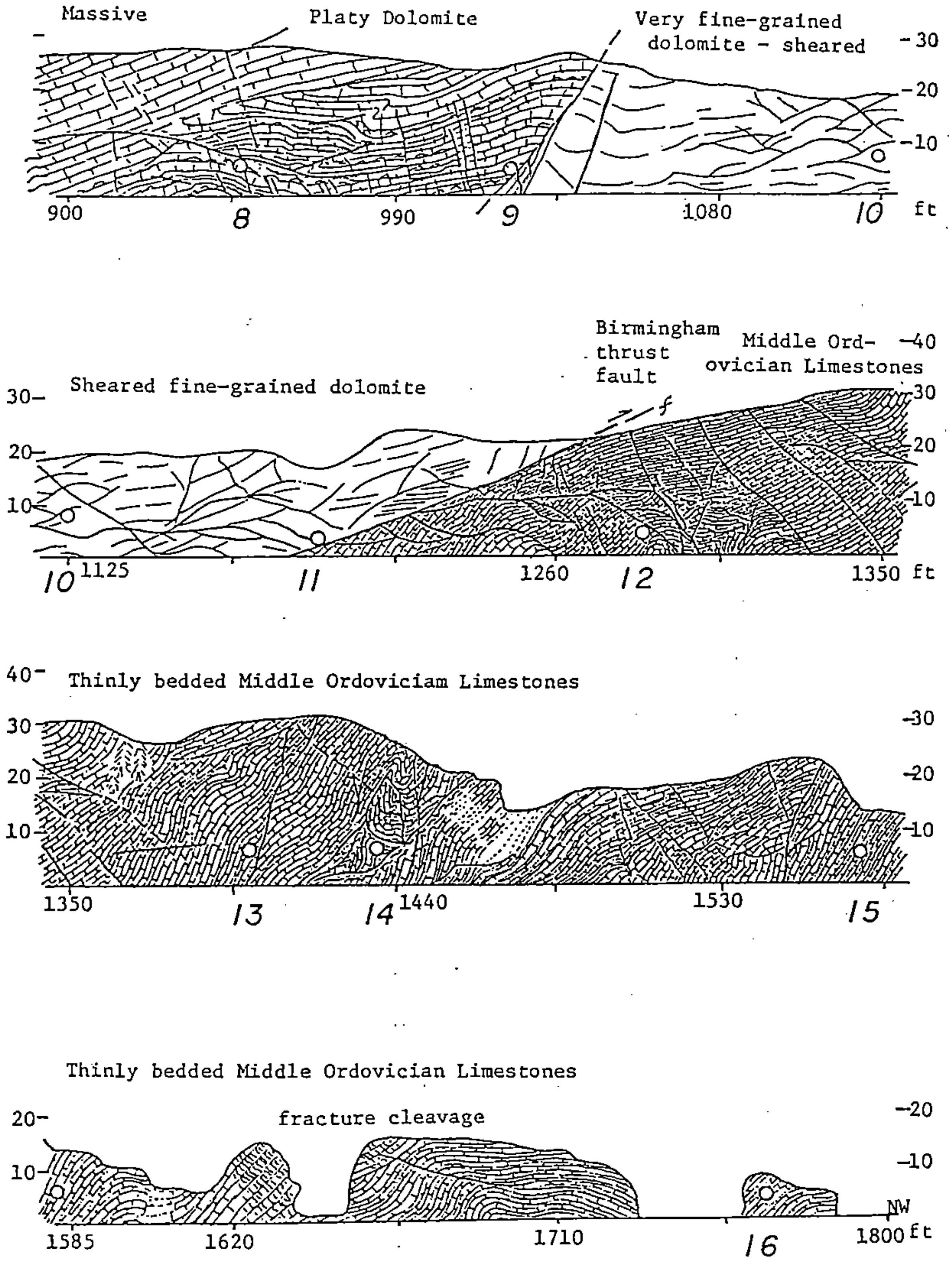


**Figure 12.** Schematic cross section of the Conrail railroad cut south of is to the top left and northwest at the bottom right. Stratigraphic at station 2.



**Birmingham (Stop 1A) (from Gold and others, 1995, p. 172-173, fig. 3). Southeast corrections include the Lower Sandy member at station 1 and the Stacy Member**

We will walk approximately 1 km (0.6 mi) southeast along the Conrail railroad tracks, observing the structure and stratigraphy as we go. The railroad cut exposes the Birmingham thrust fault where Upper Cambrian dolostones lie directly on Middle Ordovician limestones along a well defined low angle thrust plane. **CAUTION:** This is the main Conrail line between Pittsburgh and parts east. It carries both freight and ***very*** fast Amtrak traffic. When someone yells, "**TRAIN!**", be prepared to get out of the way quickly.

## A. THE BIRMINGHAM THRUST FAULT

### Structure

The Birmingham thrust fault is just the surface expression of a highly complex set of anastomosing splay faults ultimately derived from a basal decollement in Lower Cambrian shales and carbonates at an estimated depth of 6.5 km (3.9 mi) (Figure 2). The fault is actually a zone of faulting consisting of several planar and lensoid fault planes in both the hanging wall and the foot wall. At this locality the fault is a discrete thrust plane where sheared Upper Cambrian carbonates and sandstones lie directly on Middle or Upper Ordovician limestones (see below for discussion of the stratigraphy). Gold and others (1985, p. 174) were uncertain as to whether or not the Birmingham fault is the major thrust fault in the region or just a minor splay off the Sinking Valley fault:

"Unfortunately the simple anticlinal form. . . of the southern end of Sinking Valley is complicated here by faults, some of which are inferred from drill cores... The Sinking Valley fault and its splays are arched along an axis plunging southwest, which is nearly coincident with the axis of the Sinking Valley anticline. The northwest limb is displace about 2 miles. This thrust fault has no apparent surface expression except at the two fensters (windows) near Birmingham, where Ordovician and Silurian rocks are exposed beneath Cambrian dolomites and sandstones. The Sinking Valley fault dips northwestward from the fensters at Birmingham under Brush Mountain, and presumably continues under the Allegheny Plateau.

"If the Honest Hollow and Birmingham faults [Figures 1 and 2] are splay faults off the Sinking Valley thrust fault, then they represent the bounding faults of the Birmingham "window" slice... More drill-holes are needed to determine the relationship of the Shoenberger fault to the Sinking Valley fault system."

Faill (1987) appears to have no doubt about these relationships. He describes the Birmingham fault as a single fault within the uppermost duplex above the basal decollement (Figure 2). Locally it forms the roof thrust. Northwest of the anticlinal crest it conceivably splayed upward into the overturned rocks of the northwest limb of the anticline, cutting off the Honest Hollow fault. Faill also shows (Figure 2) the Middle and Upper Ordovician limestones of the large fenster at Birmingham unequivocally bounded by the Birmingham and Honest Hollow faults, respectively, on the southeast and northwest. The famous Birmingham "window" itself, which exposes Bald Eagle through

Tuscarora sandstones, siltstones, and shales within the Ordovician limestones (see Stop 1B), is a slice of rock carried into position by the Honest Hollow and Sinking Valley faults.

Figure 12 illustrates the exposures of Cambrian and Ordovician rocks along the Conrail railroad tracks at this locality. The numbered stations refer to locations discussed by Gold and others (1985). There are numerous intraformational antithetic and synthetic thrust faults of unknown displacement throughout the Cambrian dolostones southeast of the Birmingham fault. In addition, several extensional faults with small displacements can be seen. A number of "healed" fault planes in these rocks probably indicates an earlier deformational event. Northwest of the fault, the Ordovician limestones occupy horse blocks at a scale of meters to tens of meters. Most of the faults in these rocks are synthetic, but small antithetic faults can be observed. A block of limestone, located about 75 m (240 ft) northwest of the main exposure of the Birmingham fault, represents what might be the most complex structure at this stop. The block is bound by a folded fault and has been rotated nearly 180° clockwise from the normal 40° dip of the surrounding beds.

Some of the things to look for at this stop (from Gold and others, 1985) (see Figure 12) include:

- quartz arenites and sandy, conglomeratic dolostones of the Lower Sandy member of the Gatesburg Formation at station 1.
- thinly bedded, cyclically deposited dolostones of the Stacy Member of the Gatesburg Formation between stations 2 and 7.
- healed faults, representing early layer parallel shortening on a scale of decimeters, near station 3.
- well developed thromboid algae at station 4.
- antithetic splay fault and complex defored zone behind the signal box near station 5.
- the Birmingham fault at station 11. Lensoid and curviplanar splay faults can be seen in the hanging wall rocks between stations 9 and 11, and curved "under-splay" faults occur in the footwall between stations 11 and 12.
- folded faults in the disturbed zone near station 14. Clockwise rotation of the beds is apparent.

## Cambro-Ordovician Stratigraphy

The Birmingham thrust fault places Cambrian dolostones on Middle or Upper Ordovician limestones, a displacement of some 1,525 m (5,000 ft) (Butts and others, 1939). Under normal circumstances, the stratigraphy of this area would be relatively straight-forward. The problems here occur as a result of shear metamorphism - the rocks associated with the Birmingham thrust fault are so deranged that their precise identification is impossible. Therefore, speculation will have to do.

The hanging wall must be either Warrior Formation or Lower Sandy member of the Gatesburg because they contain numerous quartzose sand grains and even some small masses of quartz arenite. Also included are lenses of fine-grained dolostone and cherty limestone. This mish-mosh of rock ends approximately 45 m (150 ft) to the southeast where a high-angle fault separates it from normal Gatesburg dolostones ("typical Ore Hill Member lithologies" according to Gold and others, 1985) dipping about 15°SE. Faill (1987) shows this fault as a secondary thrust splaying off the main Birmingham fault (Figure 2). Although this discussion suggests that the hanging wall is composed of Gatesburg, two key points show it is more likely to be Warrior. First, the unmistakeable Gatesburg lithologies to the southeast of the high-angle fault can be traced through outcrop almost continuously from the Mines Member (near Shoenberger - Stop 2) to the uppermost beds of the Stacy Member (the "typical Ore Hill Member lithologies" of Gold and others, 1985). The Stacy is, by definition, lacking in quartz arenites, so the disturbed beds cannot be Stacy as suggested by Wilson (1952). Second, the presence of cherty limestone lenses suggest Warrior. The Gatesburg rarely contains limestones in outcrop, and those generally occur close to the areas where the name Conococheague Formation is used for Gatesburg-equivalent limestones.

The foot-wall formations have not been firmly established, either. Although it seems possible that the formation in contact with the fault is Loysburg Formation, the limestones are so distorted by folding, faulting, and fracturing as to be nearly impossible to distinguish individual formations and members. Creating an even worse problem is the fact that these beds are overturned and dipping about 40°SE. Therefore, it is difficult to determine if the rocks in contact with the fault are at the top, in the middle, or at the bottom of the Middle-Upper Ordovician limestone sequence. Perhaps some enterprising Masters or Doctoral candidate can help straighten out the mess.

## B. THE BIRMINGHAM WINDOW

Upon returning from the Conrail railroad locality, you will have the opportunity to take a few minutes to examine the outcrops along the north side of SR 453 where the bus will be parked. As you walk northwest along the birm of the road you will notice that the rocks at this locality are very different from the rocks you just observed along the railroad tracks. Gone are the grayish limestones and dolostones, replaced within 300 m (1,000 ft) by sandstones, siltstones, and shales ranging in color from light gray to brick red. Welcome to the famous Birmingham "window", a classic exposure of younger rocks beneath a thrust sheet.

Figure 13 is a schematic cross section of the rocks exposed in the roadcut between Birmingham and the next valley to the northwest. Butts (1918) was the first to report on the anomalous outlier, but the section was not mapped and interpreted until much later (Butts and others, 1939). As Gold and others (1985, p. 177) explained, "The outcrops of overturned Tuscarora Quartzite (Lower Silurian) Upper and Middle Ordovician Juniata, Bald Eagle and Reedsville Formations, and sheared carbonates of Middle Ordovician age in the road-cuts along Rte 453 (see Figure [13]) and for a

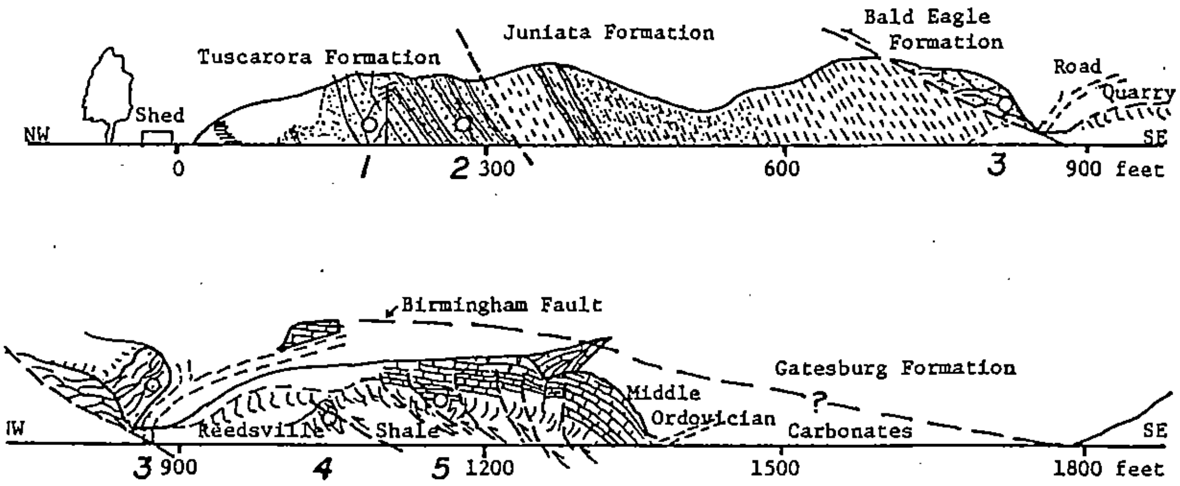


**Figure 13. Schematic cross section of the roadcut on SR 453 below Birmingham (Stop 1B) (from Gold and others, 1985, p. 176, fig. 4).**

restricted area around Birmingham, probably has challenged more minds over the past 50 years than any other structure in central Pennsylvania. . . While the mapped configuration of windows (fensters) exposed in this area have changed but little through the past 50 years, there has been a considerable variation in the interpretation of the sub-surface geology." Much of the trouble probably owed to the old "thick-skinned" concept of tectonics in which the sedimentary cover was deformed in imitation of the crystalline basement. Under this concept, Nittany anticline was simply draped over a basement fold. But then what did you do with the windows that exposed younger rocks beneath older ones? The answer is, you conceived some rather implausible explanations.

Within the same publication (Butts and others, 1939) there appeared two alternate concepts for the origin of the Birmingham "window". Butts' interpretation (pl. 3) used an overthrust truncated overturned syncline to account for this feature, with the Gatesburg thrust to the northwest over an inverted sequence of Loysburg through Tuscarora formations that were "strangely preserved and faulted downward on the northwest side" (Butts and others, 1939, p. 77). Butts included Stose's illustration (p. 78, fig. 4) as an alternative explanation. It required three southeasterly dipping thrust faults with their corresponding thrust sheets. Other authors proposed different concepts, but many of them required the younger rocks to be outliers thrust from the overturned limb of an anticline 6 to 8 km (4-5 mi) to the southeast. This distance is difficult to reconcile with the limited 3 km (2 mi) southward extension of the Birmingham fault.

Gold and others (1985) compared the thicknesses of the Ordovician and Silurian clastics at Birmingham with those at Tyrone Gap and found 65% reduction for the Juniata, and more than 90% for the Bald Eagle and Reedsville. Despite this, there appears to be relatively little internal deformation, at least in the Tuscarora and Juniata (the Bald Eagle and Reedsville are highly sheared). The reasons for these reductions is uncertain. Gold and others (1985) suggest it is due in part to splay faults beneath the Birmingham fault (i.e. the faults shown in Figure 13).

Some of the things to look for at this locality (Figure 13) include:

- overturned beds of Tuscarora and Juniata sandstones between stations 1 and 3.
- sheared and fractured Bald Eagle Formation sandstones exposed along the road into Birmingham at station 3.
- if time permits, look for cleaved and folded black shales of the Antes Formation in the overgrown barrow pit between the road to Birmingham and station 5.

Return to vehicles and continue southeast on SR 453.

| MILEAGE | | |
|---|---|---|
| **Int** | **Cum** | **ROAD LOG AND REMARKS ON ROADSIDE GEOLOGY** |
| 0.30 | 2.95 | Grier School on the left. |
| 0.30 | 3.25 | This roadcut exposes cyclical bedding in the Lower Sandy member of the Gatesburg Formation. Wilson (1952) measured 45 m (150 ft) of section in this exposure. |
| 0.25 | 3.50 | The outcrop on the left exposes dolostones of the Ore Hill Member of Gatesburg Formation. |
| 0.05 | 3.55 | Park on the right shoulder of the highway. We will walk southeast along SR 453 to the beginning of the next roadcut on the left side of the highway. |

## STOP 2: SHOENBERGER ROADCUT LOCALITY

At this locality, we will have the opportunity to study a classic exposure of the cyclical nature of deposition on Ginsburg's (1982) "Great American Bank". The rocks here constitute much of the Upper Sandy member of the Gatesburg Formation, including some very well developed shallow marine sandstones and dolostones. **CAUTION:** Route 453 is a well-used road with relatively high-speed traffic, particulary 18-wheelers traveling between US 22 at Waterstreet and I-99/US 220 at Tyrone . Take extreme care in crossing the road and in standing on the shoulders. Do not stand in the road to "get a better look". A "better look" can be gotten from across the road, behind the guide rail.

## DEPOSITIONAL FACIES AND CYCLES IN THE GATESBURG FORMATION, UPPER SANDY MEMBER

### Introduction

This well-known locality has been discussed several times over the course of the last 57 years (Butts and others, 1939; Pelto, 1942; Wilson, 1952; Frost, 1963; Faill, 1987). Pelto (1942) and Wilson (1952) give the best descriptions of the rocks, whereas Faill (1987) concentrated on the structures evident in the outcrop.

This outcrop consists of about 130 m (435 ft) of cyclically deposited dolostones and sandstones of the Upper Sandy member, Gatesburg Formation. The boundary between the Upper Sandy and the underlying Ore Hill Member is poorly exposed to the north, but Wilson (1952) managed to measure an additional 63 m (205 ft) of Upper Sandy on the wooded hillside. Wilson measured 430 m (1,410 ft) of Gatesburg Formation exposed on the southeastern flank of the Nittany anticline in the outcrops, roadcuts, and railroad cuts along or adjacent to Route 453 between Birmingham and Shoenberger (Figure 1). With the exception of the Mines Member, this represents most of a complete section of the formation.

## Depositional Setting

The probable configuration of the Late Cambrian-Early Ordovician crustal plates is shown in Figure 14. During the Early Paleozoic, eastern North America occupied the southwestern continental shelf of Laurentia. The major land mass of Laurentia included what is now called the Canadian Shield and, according to some reconstructions, the Transcontinental Arch. Because the southwestern coast lay between 0° and 30° south latitude, the dominant wind pattern in this area would have been southeasterly trade winds carrying warm maritime air and pushing warm ocean currents from the moist western side of the high pressure center in the Iapetus Ocean (Figure 15). Along the eastern coast of Laurentia this airmovement would have provided abundant rainfall between 15° and 30° south latitude. Although at least part of Laurentia's east coast would have been

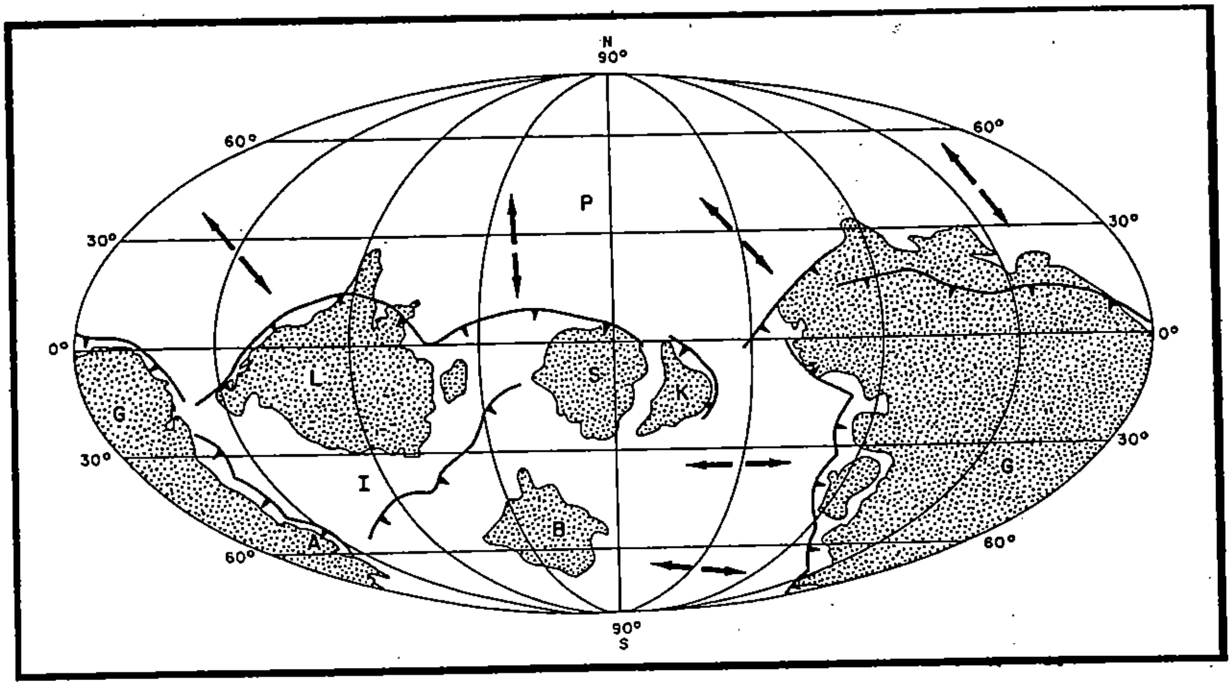


**Figure 14. Global Late Cambrian plate tectonic reconstructions (modified from Scotese and McKerrow, 1991). Continents include Baltica (B), Gondwana (G), Kazakhstan (K), Laurentia (L), and Siberia (S). Seas include the Iapetus (I) and Paleotethys (P) oceans.**

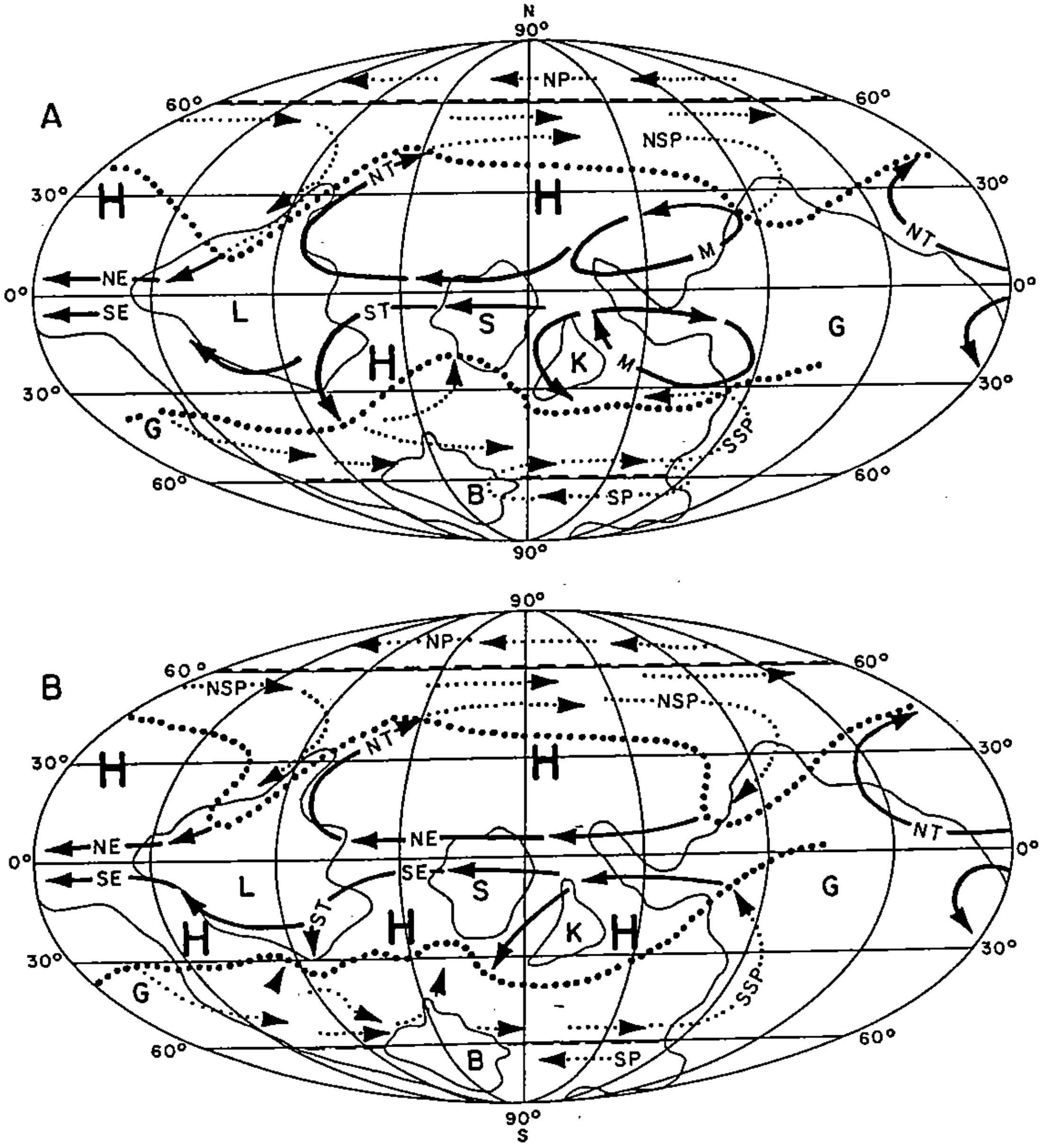


Figure 15. Paleoceanography of Earth during the Late Cambrian (modified from Wilde, 1991). A - Southern hemisphere summer and northern hemisphere winter. B - Southern hemisphere winter and northern hemisphere summer. Continents and seas are the same as those in Figure 14. Surface currents include north and south polar (NP and SP), north and south subpolar (NSP and SSP), north and south tropical (NT and ST), north and south equatorial (NE and SE), and monsoonal counter (M) currents. Oceanic and atmospheric high pressure cells are designated H.

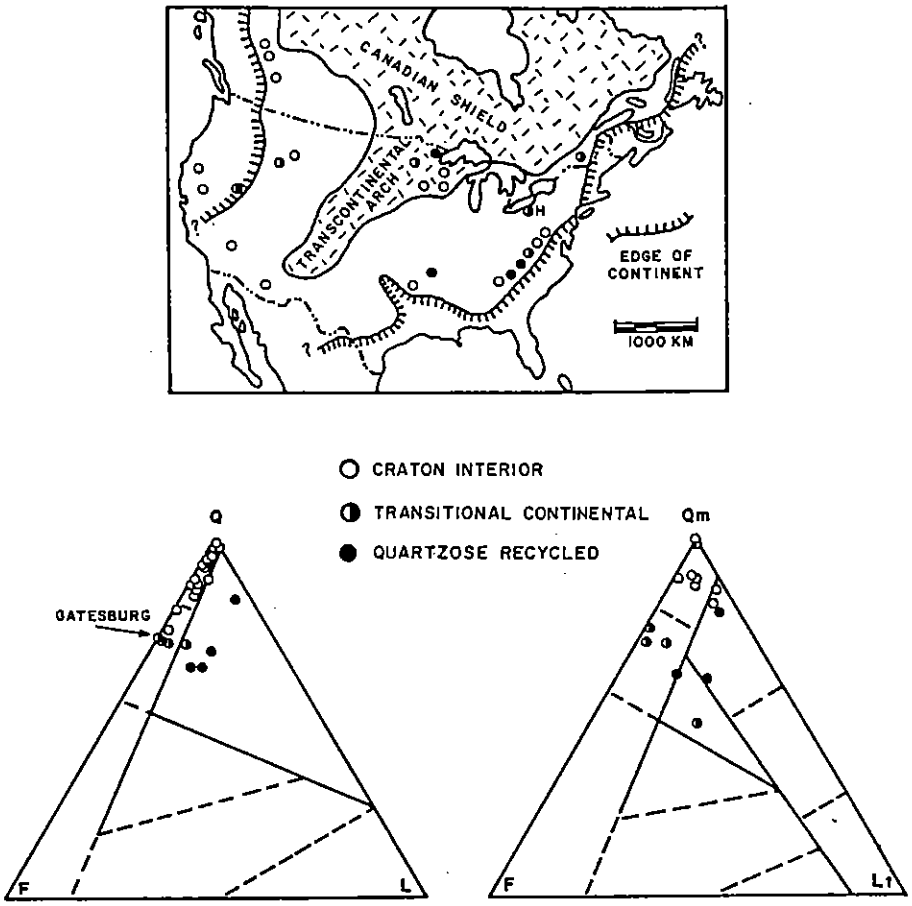


**Figure 16.** **Paleotectonics and sandstone provenance in North America (modified from Dickinson and others, 1983). Top - Paleotectonic map showing locations of sandstone suites for Late Precambrian to Middle Ordovician time. (The H on Lake Erie indicates the Hammermill Paper Co. #2 Fee well in Erie County, which is discussed in the text). Bottom left - QFL (quartz-feldspar-lithic fragments) ternary sandstone composition diagram. Bottom right - QmFLt (monocrystalline quartz-feldspar-total lithic fragments) ternary sandstone composition diagram. The two ternary diagrams indicate that most North American sandstone suites contain quartzose frameworks derived from the stable craton. Some suites in different areas have more feldspathic frameworks indicating a continental block provenance transitional between basement uplift and cratonic sediment sources. Gatesburg sandstones fall into this latter category.**

abundantly wet during the summer, the southwestern coast would have had very different conditions. Continental west coasts in latitudes 15° to 30° (north or south) are extremely dry (for example, those of Recent Morocco, Baja California, and Western Australia), generally with less than 10 inches of rainfall annually. Such conditions are termed West Coast Desert Climates. West coast deserts tend to be relatively cool, with a mean annual temperature of 18°C (65°F) due to oceanic upwelling along the coast. Upwelling along the southwestern coast of Laurentia (Wilde, 1991), coupled with a high pressure system in the Iapetus to the west or southwest, suggests that this region experienced cool wet summers and warm dry winters.

During the Cambrian the cratonic interior of Laurentia remained exposed to erosion. Sedimentary and metasedimentary rocks lithified from Precambrian clastic sediments provided ideal sources for the basal Cambrian sandstones of eastern North America (Potsdam, Mt. Simon, Antietam). Recycled orogenic sands continued to be deposited throughout much of the Late Cambrian, but by that time they were mixed with the shelf carbonates that eventually dominated sedimentation on the continental shelf. Sandstone suites from the central and eastern United States are mostly quartzose, reflecting their origin from tectonically stable portions of the craton (Dickinson and others, 1983; Figure 16). Some of the Gatesburg Lower Sandy member sandstones in Ohio and northwestern Pennsylvania are quite feldspathic, indicating a continental block provenance. These feldspathic sandstones suggest that some basement uplift with greater relief than land areas of the craton also supplied sediments to the passive margin of southern Laurentia. Much of the sand apparently accumulated around the land mass, whereas most of the carbonates accumulated in the shallow waters of the shelf. Mixing of these sediments occurred during cyclical sea level changes. By the end of the Cambrian deposition of quartz sands had almost ceased, whereas the deposition of carbonates continued unabated.

Upper Cambrian rocks in eastern North America represent deposition on or adjacent to a rimmed shelf (Figure 17), a broad, continental shelf of low relief that was subject to periodic eustatic sea level changes. Although most documented sea level changes resulted from glacio-eustasy forced by Milankovitch astronomical cycles, Osleger and Read (1991) found no evidence to suggest that glaciation occurred in the Late Cambrian. At present, there is no documentable reason for the eustatic fluctuations, but the evidence for such fluctuations in the rock record is indisputable. This record consists of complex mixed carbonate-siliciclastic sequences, typically dominated by carbonates. Because of the low relief of the rimmed shelf, periodically raising and lowering sea level a few tens of feet was probably sufficient to drown or expose this surface nearly completely at various times. As a result, deposition during the Late Cambrian was cyclical, with fine-grained quartz sands or lime muds and sands alternating with carbonates exhibiting cryptalgal laminae and hemispheroids, ooids, and other features.

Late Cambrian depostional sequences commonly are cyclical at several scales, from the 90-610 m (300-2,000 ft) thick "grand cycles" of Aitken (1966), to bed-scale cycles described by Pelto (1942), Krynine (1946), Wilson (1952), and Root (1964), among others. Grand cycles frequently constitute large portions of formations to entire groups of formations characterized by fine-grained terrigenous mudstones, carbonates, and sandstones that grade upward into sequences consisting predominantly of carbonates. The Upper Sandy member of the Gatesburg Formation represents a portion of a grand cycle that correlates with Read's Late Cambrian cyclic carbonate sequence 4 (Read, 1989, p. 152-153). This sequence includes the Conococheague Formation of Virginia,

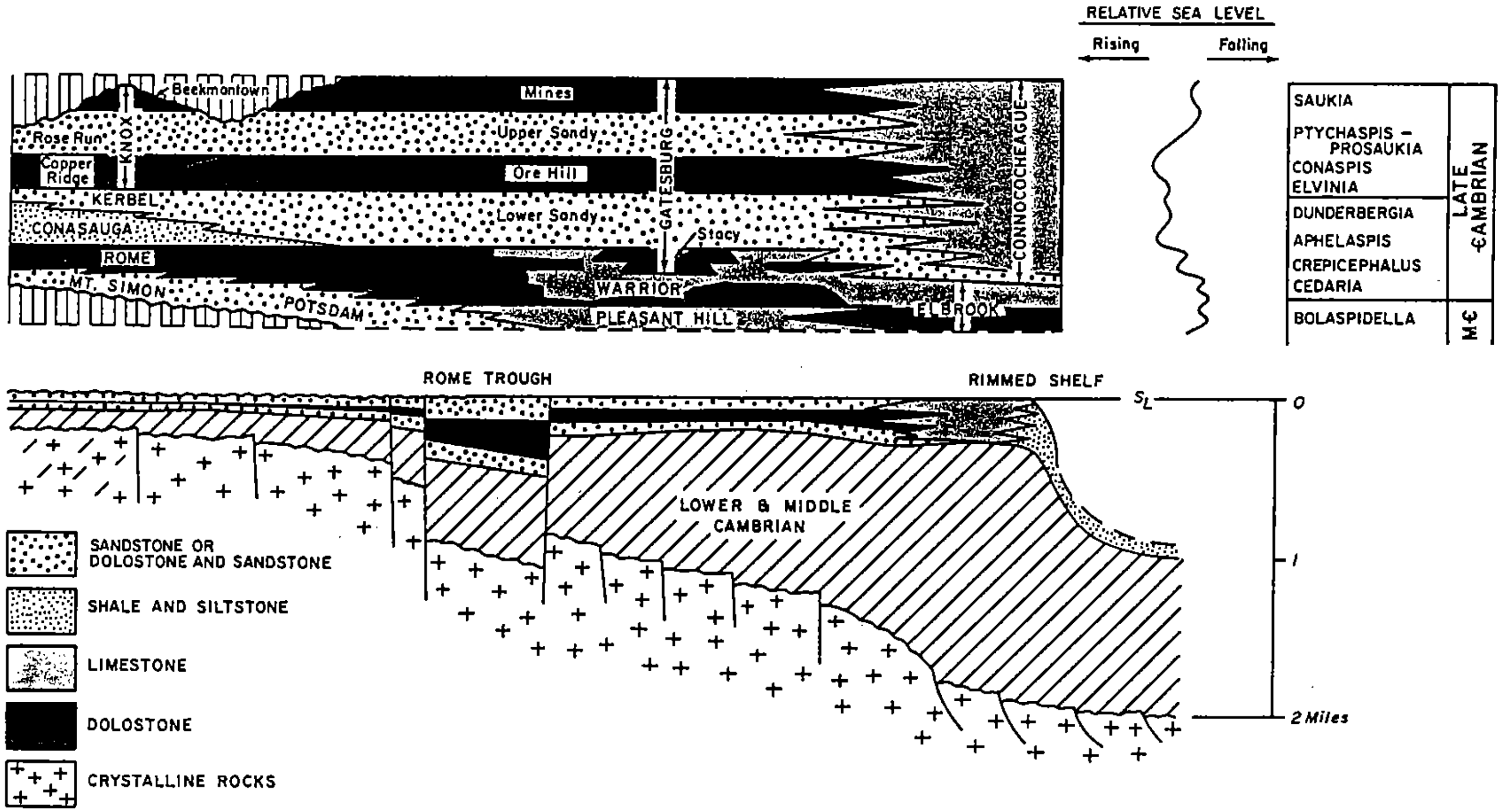


Figure 17. Late Cambrian depositional and stratigraphic relationships (modified from Read, 1989, figs. 8 and 12). Top - Chronostratigraphic relationships of the Late Cambrian rocks of Ohio and Pennsylvania. Names on the right are trilobite index genera. Bottom - Cross section of the Late Cambrian continental shelf of eastern North America illustrating the concept of the rimmed shelf with platform morphology.

Gatesburg Formation of Pennsylvania and lower Knox Dolomite of Ohio (Figure 7). Peritidal carbonates dominate this sequence, but subtidal carbonates and peritidal sandstones also occur. Smaller scale cycles tend to be only a 0.8-3 m (2.5-10 ft) thick, and mimic the grand cycles in composition. Within the Upper Sandy member and adjacent units, cyclical peritidal and subtidal carbonate and sandstone sequences dominate the lithofacies, but sandstones interpreted as fluvial and eolian occur in cores from Erie County, Pennsylvania. This suggests that continental facies may be more common than suspected, and just have not been recognized. Small-scale cycles are mostly asymmetrical and are genetically linked by shared lithofacies (Osleger and Read, 1991).

## Depositional Environments and Lithofacies

Gatesburg rocks are generally interpreted as paralic to shallow marine in origin (Wagner, 1966; Lytle and others, 1971); however, there are very few detailed environmental interpretations in the literature. The repeated cycles of algal dolomite, oolitic dolostones, and quartzose to dolomitic sandstones (Figure 18) certainly testify to a close association of shifting peritidal and adjacent shallow subtidal deposits. Read (1989) included the Upper Sandy interval within one of his stratigraphic sequences of the Cambro-Ordovician passive margin succession in the Appalachians, his Sequence 4. He recognized cyclic peritidal carbonates, non-cyclic subtidal carbonates, and marine-reworked siliciclastics. Smith (1969) suggested that an eolian, as well as coastal, siliciclastic component mixed with the inner and outer shelf carbonates of the Upper Sandy sequence.

We have divided the Upper Sandy member into sandstone or dolostone lithofacies and mixed sandstone and dolostone associations (Figure 19). Several geologists have defined mixed associations of shallow marine siliciclastic lithofacies and interpreted them as part of a continuum of physical energy condition (Johnson, 1978). The single and mixed lithofacies associations used here, however, represent both lateral facies mixing and vertical variations in lithologic sequences induced by cyclic sea level changes and/or changes in sediment supply. These facies associations represent both spatial variability and temporal variability in a carbonate-siliciclastic mixed sequence (Lomando and Harris, 1991).

Three principal facies occur in the Upper Sandy member at both Stop 2 and in the subsurface of western Pennsylvania: 1) a sandstone facies ***S***; 2) mixed sandstone and dolostone associations ***M***; and 3) a dolostone facies ***D***. The mixed facies ***M*** is subdivided into sandstone-dominated (***Ms***), dolostone-dominated (***Md***), and equally mixed sandstone-dolostone (***Me***) associations. The equally mixed sandstone-dolostone association ***Me*** can be further subdivided into medium-bedded (***Mem***) and thick-bedded (***Met***) categories.

***Sandstone Facies.***- In outcrop, the sandstone facies **S** are thick to very thick bedded. Some cross-bedding occurs, including excellently displayed herringbone cross-stratification. The sandstone is light-gray, fine-grained, well-sorted quartz arenite, but

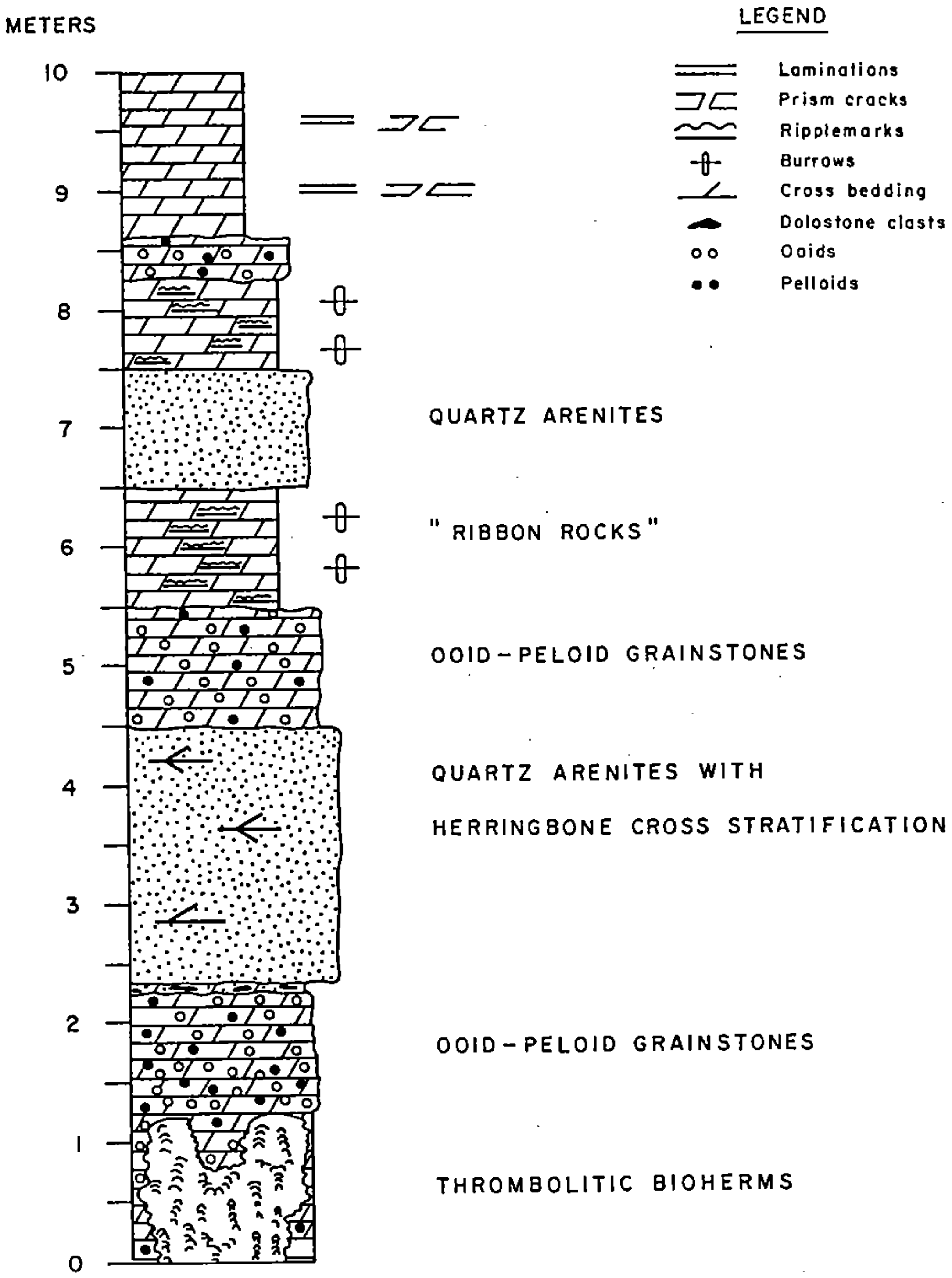


Figure 18. Graphical description of a portion of the Upper Sandy member of the Gatesburg Formation at Stop 2, the Shoenberger locality, Huntingdon County, Pennsylvania.

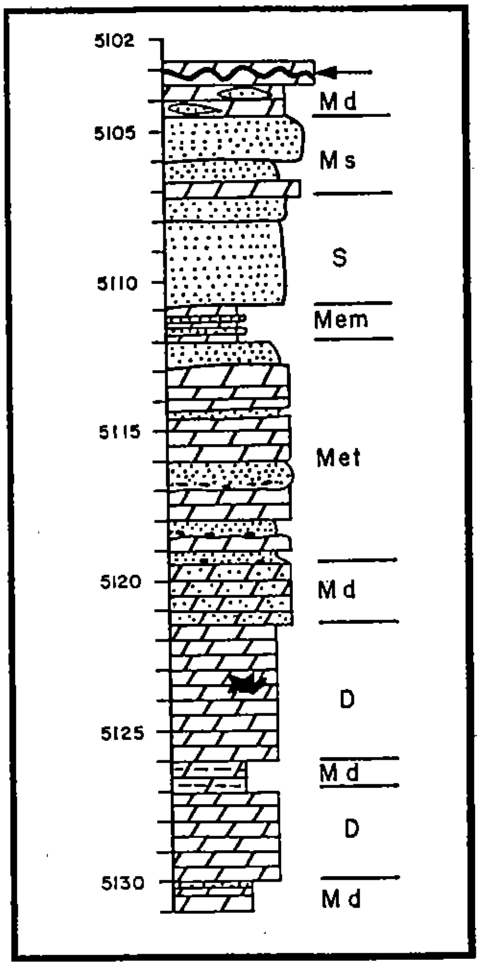


**Figure 19.** **Graphical description of a portion of the core recovered from the Upper Sandy member of the Gatesburg Formation in the Hammermill Paper Co. #2 Fee well in Erie County, Pennsylvania, showing the distribution of lithofacies (based on Riley and others, 1993, fig. 39). The arrow indicates the position of the Knox unconformity.**

basal lags of dolostone and shaly dolostone clasts are common. Cements are variable, but consist chiefly of quartz and dolomite, with lesser amounts of feldspar and illite cements. Although porosities and permeabilities vary, in cores from northwestern Pennsylvania they typically are low.

***Mixed Sandstone and Dolostone Facies.***-All three subdivisions of the mixed sandstone and dolostone facies ***M*** occur at Stop 1. Facies ***Ms*** comprises mixed sandstone-dolostone lithologies, but is dominated by sandstone. The sandstones consist of fine- to medium-grained, moderately well-sorted quartz arenites. The principal cement is dolomite. Dolomite cements are polymodal, with planar-e to planar-s textures, and contain ghosts of former peloids and ooids when viewed under the microscope in diffused plane-polarized light. Many of the ooid ghosts have detrital quartz nuclei. The sandstones are medium bedded and porous. Dolostones in facies ***Ms*** are medium-bedded rocks with unimodal, planar-s textures. They contain up to 40% detrital quartz and feldspar. The dolostones contain some visible ooid and peloid ghosts.

Dolostones dominate facies ***Md***. The dolostones are polymodal, planar-s to nonplanar. Polymodal, planar-s dolomites contain nonmimically replaced ooids, peloids, and void-filling dolomite. Crystals are decimicron to centimicron-sized. Original matrix, if ever present, cannot be distinguished from void-filling dolomite. Some ooid nuclei consist of detrital sand- and silt-sized quartz and feldspar. The dolostones are bioturbated and mottled; burrows contain large amounts of detrital siliciclastic silt. The polymodal nonplanar dolomites are wavy, flaser, and lenticular cross-laminated, with minor lenses of quartz silt detritus. Micron- and decimicron-size crystals occur within discrete laminae. Sandstones in facies ***Md*** occur as lenses and laminations of fine-grained,well-sorted quartz arenite within dolostone. Laminated sandstones are interlaminated with dolomitic siltstone and dolostone. Porosities generally are low in both rock types.

Rocks within facies ***Me*** contain approximately equal amounts of sandstone and dolostone. The distinction between ***Mem*** and ***Met*** is one of bed thickness. ***Mem*** consists of thinly interstratified, medium-thick (~ 15 cm) beds of fine-grained, well-sorted quartz arenite and dolostone. Dolostones in this facies consist of medium-gray, unimodal, planar-s dolomite, with both medium- to fine-grained quartz and occasional feldspar floating in the carbonate groundmass. Dolomite crystals are decimicron-sized. Mudcrack, actually prism-cracked wavy laminites do occur, but these are indistinct in most samples. Some dolostone beds consist of medium dark-gray, polymodal, nonplanar dolostone. Dolomite laminae are graded, i.e. crystal size decreases upward from decimicron-size to smaller decimicron-size and micron-size dolomite. Dolomite laminae contain silt-size quartz, muscovite, feldspar, and pyrite. The dolostones contain wavy and flaser cross laminations. Porosity in both sandstones and dolostones of facies ***Mem*** is very low. Facies ***Met*** consists of thick (> 30 cm) beds of sandstone interstratified with thick beds of dolostone. The sandstones are moderately well- to very well-sorted, fine- to medium-grained quartz arenites. Sandstone porosity varies from poor to good. Pervasive dolomite cementation obliterated porosity in some samples, but most sandstones have porosities between six and twelve percent. Some examples from Stop 2 exhibit true herringbone cross-stratification with sharp set boundaries, i.e. opposite-dipping sets of avalanche cross-stratification (see Klein, 1977, p. 20-21). Prism-cracked wavy laminite s are preserved at the tops of some herringbone cross-stratified co-sets. Dolostones in facies ***Met*** are medium dark-gray, unimodal, planar-s dolomites with nonmimically replaced allochems. The latter consist of ooids, probable peloids, and possible shell fragments - all visible in diffused plane polarized light. Some of the dolostone groundmass supports very fine- to coarse-grained quartz and feldspar detritus. The rocks display nodular bedding, prism-cracked wavy laminite s, and bioturbation.

***Dolostone Facies (D).***-Rocks of the dolostone facies ***D*** consist mostly of light olive-gray to greenish-gray ooid dolograinstones at Stop 2. They consist of polymodal, planar-s dolomite with replaced ooid allochems, partial to complete ooid molds, and void-filling dolomite. Most allochems are mimically replaced by dolomite, but some nonmimic replacement also took place.unimodal to polymodal planar-s dolomite. Ooid allochems exhibit uniform isopachous fringes of mimically replaced marine cement that originally had a radial-fibrous fabric. Centimicron-sized planar-s dolomite fills intergranular voids; although this dolomite texture resembles equant, pore-filling sparite of meteoric or deep connate origin, it is difficult to tell if this is a mimic of earlier cements now replace by dolomite or strictly a dolomite cement texture. This facies also contains "ribbon rocks", thin-bedded, wave-rippled and burrowed dolostone, as well as wavy dololaminite, flat pebble conglomerates, and thrombolitic algal mounds (Figure 20). In cores from northwestern Pennsylvania, the facies is dominated by light-gray to light olive-gray, nodular bedded, and strongly bioturbated dolostones. Quartz and feldspar silt lines and partially fills some burrows, and calcite nodules, some pyritic, occur.

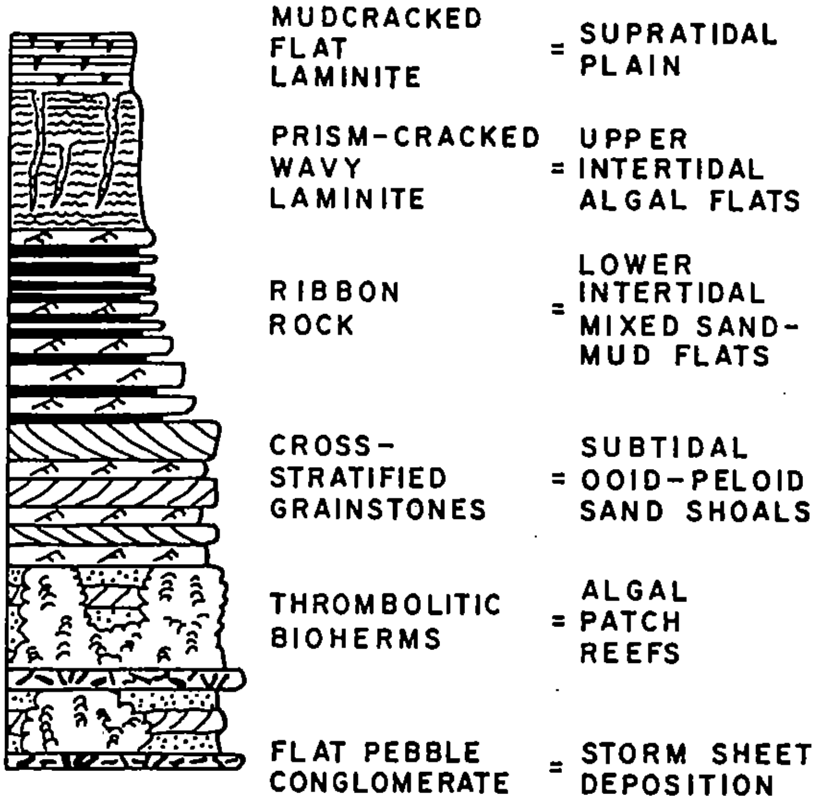


**Figure 20. Subfacies of the dolostone lithofacies, with depositional environmental enterpretations (based on Hardie, 1986).**

nodular bedded, and strongly bioturbated dolostones. Quartz and feldspar silt lines and partially fills some burrows, and calcite nodules, some pyritic, occur.

Upper Sandy strata record, in part, deposition in peritidal to shallow subtidal marine environments. Mussman and Read (1986), Anderson (1991), and Enterline (1991), among others, interpreted the depositional environment of the Gatesburg and equivalent strata as tidal-flat. Although much of the Gatesburg does represent tidal-flat deposition, such a singular designation clearly is not appropriate for the entire interval. A number of sedimentary features in the lithofacies described above support a broader interpretation of peritidal deposition. These include:

- Wavy, flaser, and lenticular cross-laminations indicate alternation of bedload and suspension deposition during variable phases of high to low, or non-existent, subaqueous current flow (Klein, 1977). Reinech and Wunderlich (1968) attribute flaser-bedding to an intertidal environment where incomplete mud laminae are trapped in ripple troughs during periods of slack water.
- Prism-cracked wavy laminites, i.e. layered algal deposits featuring dessication cracks, indicate exposure of the sediments to the atmosphere in the supratidal environment, or during particularly arid conditions in the intertidal environment.

- Herringbone cross-stratification represents sandwave migration in response to reversing current flow. For example, one small sequence of rocks at Stop 2 exhibit herringbone cross-stratification and prism-cracked wavy laminites that reveal a flood-to-ebb tide sequence followed by exposure to the atmosphere.
- Ooids and peloids indicate proximity to the littoral and shallow marine realm, whereas burrows and bioturbation suggest organic activity, although fossils are rare in the rocks. Mottling as a result of bioturbation is common within the intertidal zone (Shinn, 1983; Wilson, 1983).
- Nodular chert, possibly a secondary replacement feature after nodular evaporites (Folk and Pittman, 1971), might signify the presence of an arid supratidal environment (Shinn, 1983; Hardie, 1986).
- Basal lags of dolostone and shaly dolostone in the sandstones indicate scour, possibly due to erosion along tidal channel thalwegs.
- Algal laminae and hemispheroids indicate deposition in the upper intertidal to lower supratidal zone. According to Shinn (1983), horizontal laminations and absence of mottling in tidal flat deposits are limited to the upper intertidal to supratidal zone (see also detailed discussions by Logan and others, 1964, and Bathurst, 1971).

The ooid grainstones, which are abundant at Stop 2 (Figure 18), represent subtidal, shallow marine deposition. Ooids form in agitated marine waters in carbonate sand shoals and in tidal deltas associated with tidal inlets (Ball, 1967; Hine, 1977). Ooids also form on tidal flats and beaches, in lagoons, and in some non-marine and hypersaline environments (Tucker, 1981), but these are not nearly so common as subtidal sand shoals. We interpret the ooid grainstones of the Gatesburg Formation as subtidal, shallow marine deposits because of their thickness and extent, and because they reveal a vestige of former submarine carbonate cementation, i.e. mimically replaced isopachous fibrous cement on ooids. At Stop 2 these dolostones are associated with thrombolitic bioherms that Hardie (1986) interpreted as algal patch reefs.

The facies **S** sandstones in both outcrop and core from northwestern Pennsylvania and eastern Ohio reveal very little. They lack apparent sedimentary structures, grain size trends, or fossils. Although some herringbone cross-bedding and cross-lamination occurs in quantity in some beds, these rocks generally consist of nearly pure, featureless quartz arenites that coarsen upwards. Herringbone cross-stratification, where it occurs, is evidence for some aspect of tidal deposition. However, the thickness of the **S** sandstone in a core from Erie County, Pennsylvania, its lack of erosional clasts and scour features, and the coarsening-upwards grain size trends should preclude a tidal channel origin. These sandstones might be eolian coastal dunes (Smith, 1969), marine-reworked subtidal sands, or some combination of both (Shinn, 1980).

Return to vehicles and continue southeast on SR 453.

| MILEAGE | | ROAD LOG AND REMARKS ON ROADSIDE GEOLOGY |
|---|---|---|
| **Int** | **Cum** | |
| 0.40 | 3.95 | The dirt road on the right leads to Shoenberger, a former station on the Pennsylvania Railroad (now Conrail). It currently appears to be used by fishing enthusiasts as an access road to the Little Juniata River. |
| 0.05 | 4.00 | SR 453 crosses the Shoenberger fault, an antithetic thrust fault splaying off the Sinking Valley thrust (Faill, 1987). This fault marks the southeastern limit of Cambrian rocks exposed on this portion of the Nittany anticline. |
| 0.05 | 4.05 | The roadcut on the left exposes Beekmantown rocks. Alternating light and dark Nittany dolostones define, respectively, cyclical supratidal and subtidal deposition over the next 0.3 mi (Gold and others, 1985). |
| 0.35 | 4.40 | Limestone Road on the right leads to the Union Furnace quarries in Middle and Upper Ordovician limestones. The contact between the Nittany and Bellefonte formations is near here. |
| 0.20 | 4.60 | Cross the bridge over the Little Juniata River. The outcrop on the southeastern side of the bridge is the Tea Creek Member of Bellefonte Formation. |
| 0.25 | 4.85 | Pull the vehicles onto the broad parking area on the left side of the road. We will walk southeast along the berm of SR 453. Take extreme caution. |

## STOP 3. UNION FURNACE ROADCUT

**CAUTION:** SR 453 is a relatively high-speed highway here, as it was at Stop 2, and the roadcut is comparatively very narrow. Stay on the berm and keep your noses to the rock wall. Also, loose, overhanging rocks make dangerous playmates. ***DO NOT HAMMER ON THE OUTCROP***!!! If you want a sample, pick up some float material. Leave the fossils, minerals, and other items in the outcrop for future generations.

### Stratigraphy

This roadcut exposes about 260 m (850 ft) of Middle and Upper Ordovician carbonates, probably the most complete and best exposed section of these rocks in Pennsylvania. Exposed formations include the Loysburg, Hatter, Snyder, Linden Hall, Nealmont, Salona, and Coburn. These are economically significant formations in that the settlers who came to this area in the early to mid 1800s found them to be most useful for agricultural lime, building stone, mortar, whitewash, and plaster. They probably also supplied flux for the colonial and post-colonial iron furnaces scattered throughout the area. Later uses included crushed stone, fillers, rock dust for coal mines, railroad ballast and PennDOT-approved coarse and fine aggregate (Berkheiser, 1986).

The stratigraphy of the Middle and Upper Ordovician carbonate section in central Pennsylvania has undergone much examination in the past 160 years. Names have been changed, formations have been shuffled from group to formation to member and back again, and stage boundaries have migrated up and down section. Much of the finely tuned nomenclature used today in central Pennsylvania cannot be recognized outside of a two- or three-county area. In fact, in western Pennsylvania we feel lucky if we can recognized three discrete formations (Loysburg, Black River, and Trenton).

The depositional sequence of these rocks suggests a gradual deepening of a storm-dominated shelf (Berkheiser and Cullen-Lollis, 1986). In succession these are (Figure 21): 1) Loysburg carbonates represent tidal-flat deposits of the tidal to supratidal regime; 2) Hatter limestones were deposited in intertidal to shallow subtidal environments, possibly lagoonal; 3) Snyder limestones also originated in the intertidal to subtidal regime, probably as a combination of Bahamian-type oolite shoals, washover islands, and more open marine conditions; 4) limestones of the Linden Hall Formation appear to be primarily open marine carbonates of the shallow shelf; 5) Nealmont rocks indicate somewhat deeper shelf environments; and 6) the Salona and Coburn formations represent deep ramp to basin margin deposits. These latter formations are interesting in that they show a progressive increase in clastic influx related to the beginnings of the Taconic orogeny.

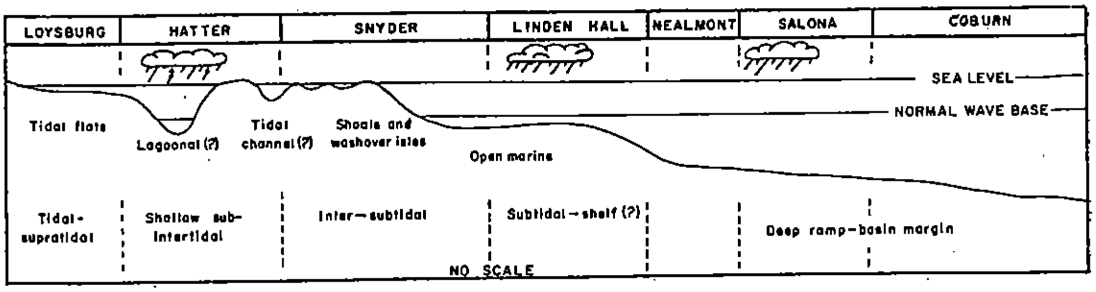


**Figure 21. Suggested depositional environments for the Loysburg through Coburn formations at Union Furnace (modified from Berkheiser and Cullen-Lollis, 1986, p. 113, fig. 49).**

Twenty (possibly 25) K-bentonite (altered volcanic ash beds) have been identified between the base of the Hatter Formation and the middle of the Coburn Formation. These K-bentonites have been used, with relatively good success, since 1924 for stratigraphic correlations in central Pennsylvania and elsewhere. The problem has been in tracing these beds over long distances. Numerous errors in identification owing to splits, unrecognized small paraconformities, and intervening minor beds had kept the success of K-bentonite correlations at a disappointingly low level (Haynes, 1992) until the use of trace-element geochemistry and fine-tuned petrology began to take affect in the 1980s. Cullen-Lollis and Huff (1987) showed that five of the K-bentonites in the Salona Formation, including those at the Union Furnace locality, can be discriminated on the basis of chemical "fingerprints". Using trace-element geochemistry, a serious stratigrapher can now correlate K-bentonites throughout Pennsylvania, indeed throughout the Appalachians, with a high degree of confidence.

Some of the things to look for at this roadcut include:

- Rip-up clasts of algal mats, horizontal burrows and burrow mottling, mudcracks, and thrombolitic algal stromatolites in the Loysburg Formation.

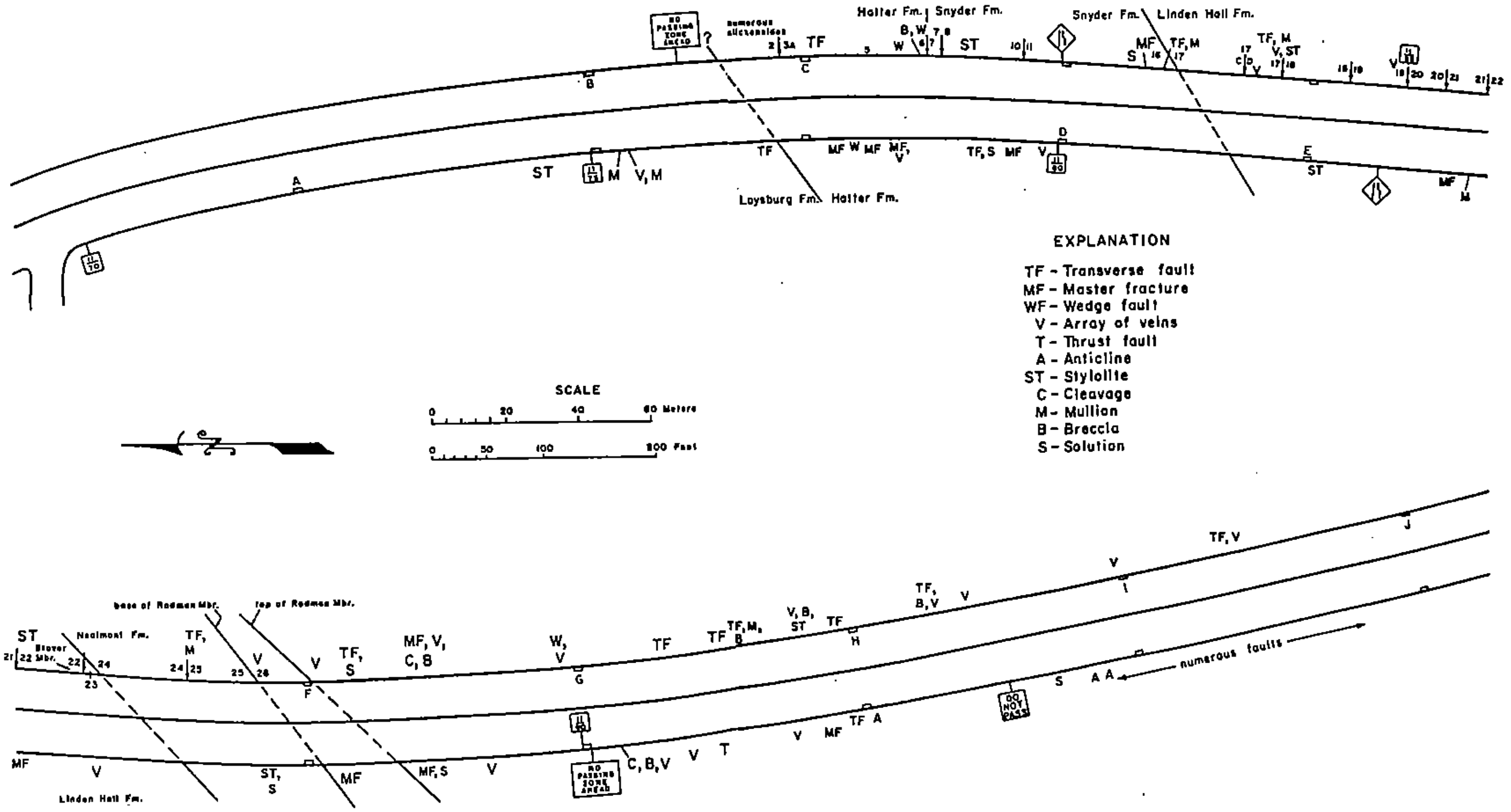


Figure 22. Schematic map of the Union Furnace roadcut section along SR 453, showing locations of formation boundaries, some of the mesostructures, highway signs, and drainage culverts (labeled A through J from northwest to southeast) (modified from Faill, 1986, p. 120-121, fig. 50).

- Cross bedded quartz-rich intervals, hardgrounds, lenses and pods of skeletal packstones and wackestones, and fossils in the Hatter Formation.
- Ooliths, flat-pebble conglomerates, mudcracks, cross bedding, horizontal and vertical burrows, and fossil bryozoans, brachiopods, gastropods, crinoids, and corals(?) in the Snyder Formation.
- Hardgrounds, irregular chert nodules, fossils, numerous preserved K-bentonites, and possible hummocky cross-stratification (an indication of storm deposition) in the Linden Hall Formation.
- Anoxic black shales, carbonate nodules (due to pressure solution?), and K-bentonites up to 4 cm (1.6 in) thick in the Nealmont Formation.
- Cyclical fining-upward, alternating beds of black carbonaceous limestone and black calcareous shale (390 feet of "rhythmites") and K-bentonites up to 25 cm (10 in) thick in the combined Salona and Coburn formations.

## Structures

The following discussion is paraphrased from Faill (1986).

This roadcut occurs on the southeastern limb of the Nittany anticline, so the strata dip generally to the southeast (from 27° to 43°). The beds exhibit numerous geologic structures, typically small and localized. Faill (1986) found no large mappable faults in the exposure, but lots of small faults of various kinds. Many of these are transverse faults striking northwestward across bedding. Additional structures, typically more in line with the strike of bedding, include wedge faults, duplexes, and conjugate extension faults. Figure 22 illustrates the locations of the various types of structures found at the Union Furnace roadcut. Use this as a guide as you walk along the road berm.

Although the strata dip relatively uniformly to the southeast (modal attitude of 155-30 - see Figure 23A), rare folds plunging gently to the west and southwest do occur. These occur only on the southwest wall near the southeastern end of the roadcut. Faill (1986) described this area as a distinct structural domain, separated from the remainder of the outcrop by a subvertical north-trending transverse fault (near the "H" on the left side of the lowest section of the highway on Figure 22).

The most immediately recognizable structures include vertical planar fractures (called "master fractures" on Figure 22) that penetrate the outcrop from top to bottom. These are much larger than the other fractures evident in the roadcut. Faill (1986) speculated that the extent of these fractures might mean that they have a more fundamental significance than the typical fractures associated with only one, or a few, beds. The majority of these have an azimuth of 157° (Figure 23B), almost perpendicular to bedding; a secondary set trends 137°, close to the strike of the Tyrone-Mt. Union lineament. Slickensides associated with most of these master fractures indicate some

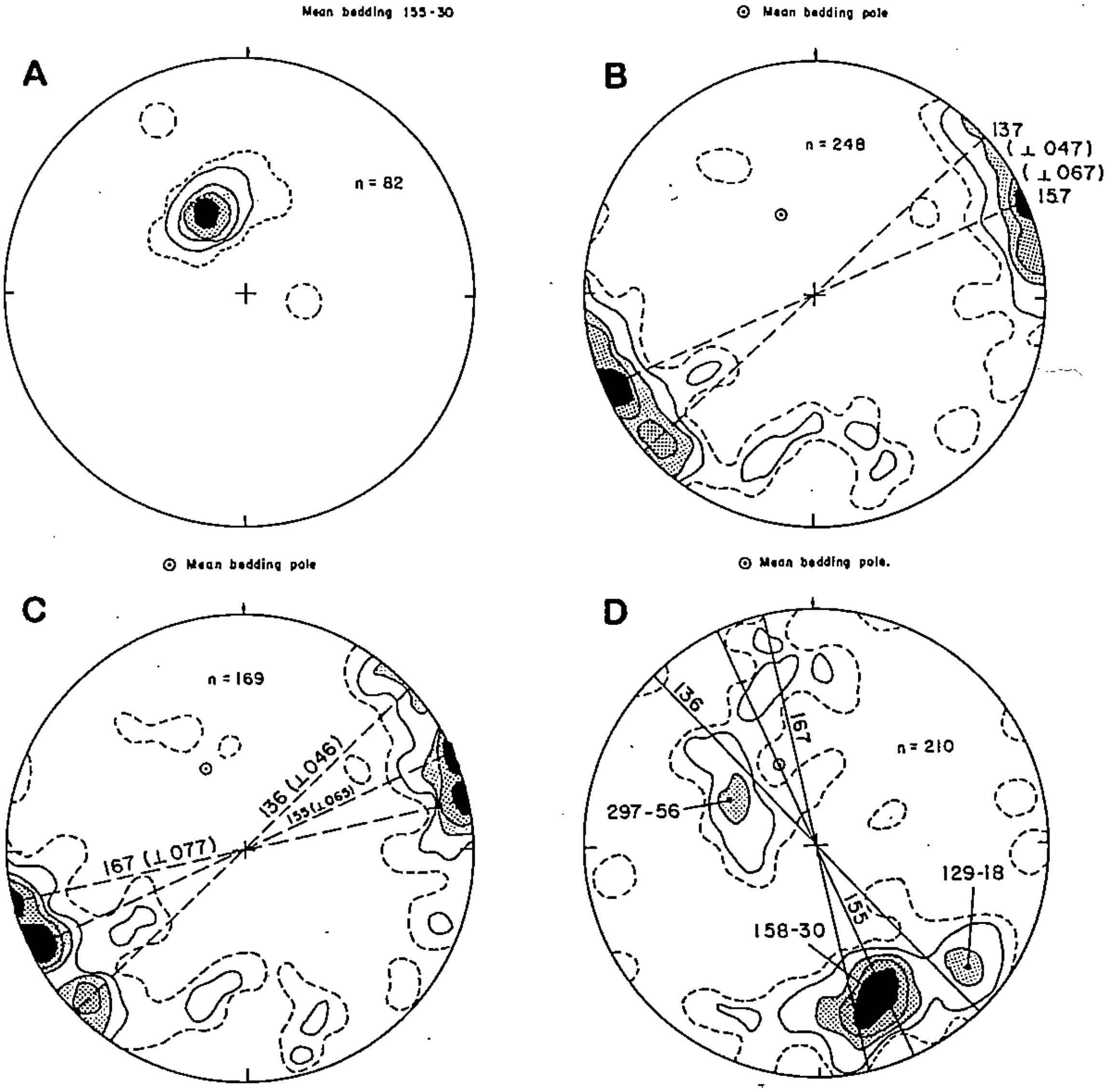


**Figure 23. Stereograms of various measured structural elements (from Faill, 1986, p.123-124, figs. 51-54. A. Bedding poles (CIs = 1, 5, 20, 40, and 60%). B. All measured fractures (CIs = 1, 2, 4, 6, and 10%). The two maxima define two principal sets (137° and 157° azimuth) within a broad range of dip fractures. No set of strike fractures are defined. C. All fractures on which slickensides were measured (CIs = 1, 2, 4, 6, and 10%). Notice that two of the three maxima are nearly identical with those in B. D. All measured slickenlines on fractures (CIs = 1, 2, 4, 6, and 8%). Solid diameters represent the three trends in C.**

component of movement, making the fractures wrench faults. Slickensides on these faults plunge gently to the southeast at about 27° (Figure 23D), which is close to the dip of the bedding. This indicates that substantial horizontal movement occurred prior to Alleghanian folding. Other slickensides (Figure 23D) include: 1) a set that is basically parallel to the bedding-fracture intersection, trending eastward at 129°, that might represent a pre-folding movement along the secondary master fracture (136°) set, early in the decollement tectonic phase of Alleghanian deformation; and 2) a steeply plunging northwesterly set that probably indicate late movement, either near the end of folding or sometime after the Alleghany orogeny.

Transverse faults include fractures along which discernible movement has taken place, offsetting the bedding. Movement generally ranged from a few centimeters to several meters. These faults appear to be similar to the master fractures, sharing similarities in slickenside trends, but they differ in other ways. First of all, many of them are not as planar as the master fractures, and a few are not even vertical. Secondly, a considerable amount of dissolution has taken place along them. Thirdly, based on information from the slickensides, actual displacement on the faults exceeds the stratigraphic offset. Movement generally was left-lateral.

Other commonly observed structures include wedge faults, mullions, stylolites, and veins. Wedge faults, where they occur, parallel the strike of bedding and form 20° to 30° angles. These faults developed early in Alleghanian folding. Mullions, which are undulatory structures that vary in attitude by tens of degrees, are not common in central Pennsylvania. Some good examples of mullions occur at this locality (Figure 22). Stylolites occur both parallel and perpendicular to bedding. The bedding-parallel stylolites probably represent standard pressure-solution phenomena unrelated to tectonic deformation, whereas the bedding-perpendicular stylolites are good indicators of Alleghanian deformation. Because they are perpendicular to bedding, rather than perpendicular to folding, these structures probably represent dissolution related to early horizontal stresses incurred during Alleghanian decollement development.

Veins, which are quite common at this roadcut, almost always are filled with calcite. Although they vary greatly in width and shape, their lengths generally fall within a range of 10 to 30 cm (4-12 in). Near faults, the number, and variety of orientations, seem to increase, whereas in many places they are arranged in *en echelon* arrays in zones 5 to 10 cm (2-4 in) wide and 1 to 2 m (3-7 ft) long. These latter veins make angles of 20° to 40° to the zone boundaries, indicating that they are fault shear zones. Individual veins formed as extension fractures, parallel to the maximum principal stress, yet the arrays are oriented 30° to 40° to maximum stress. They are, in effect, ductile faults.

Faill (1986) summed up the tectonic significance of these structures as follows:

"The primary tectonic indicators at Union Furnace are the slickensides. These represent the direction of movement on the surface between 2 contiguous rock masses and thus provide a record of the movement directions, sequences of events, and relative times of the various structures. The primary assumption is that all the deformation was a product of the Alleghanian orogeny that produced the Valley and Ridge and other provinces of the central Appalachians. The fundamental tectonics was a decollement tectonics involving a horizontal transport of the Paleozoic section over the basement.

Because bedding was initially horizontal, it is assumed, as a working hypothesis, that any movement (as shown by slickenlines) parallel to bedding probably occurred early in the deformation, before any significant regional folding developed. The larger the angle a slickenline makes with bedding, the later during folding that event occurred. With these premises, the variety of structure present at Union Furnace show a reasonable pattern.

"The regional folding is the fundamental structure that can be seen at the surface in Pennsylvania. The folding process was flexural slip, with shape change occurring by slippage between adjacent beds. The slickensides on the bedding surfaces, and the fold geometries (orientation of the fold axes) indicate the primary tectonic and transport direction. All other structures were ancillary to the folding, developed before the folding commenced, or were late features that developed after the folds were largely in their present form. The few slickenlines on bedding here and nearby (Faill and others, [1989]) indicate that the principal transport direction was to the north-northwest."

Turn the vehicles around and retrace the route back to Tyrone.

| MILEAGE | | ROAD LOG AND REMARKS ON ROADSIDE GEOLOGY |
|---|---|---|
| **Int** | **Cum** | |
| 2.25 | 7.10 | Village of Birmingham. Stay on SR 453. |
| 1.70 | 8.80 | Intersection with SR 550. Stay on SR 453. |
| 0.20 | 9.00 | Enter the Tyrone water gap |
| 0.40 | 9.40 | Enter the Borough of Tyrone. |
| 0.35 | 9.75 | Intersection with Pennsylvania Avenue. **END OF FIELD TRIP.** |

# REFERENCES

Aitken, J.D., 1966, Middle Cambrian to Middle Ordovician cyclic sedimentation, southern Rocky Mountains of Alberta. Canadian Petroleum Geology Bulletin, v.14, p. 405-441.

Anderson, W.H., 1991, Mineralization and hydrocarbon emplacement in the Cambrian-Ordovician Mascot Dolomite of the Knox Group in south-central Kentucky. Kentucky Geological Survey Report of Investigation no. 4, 31 p.

Ball, M.M., 1967, Carbonate sand bodies of Florida and the Bahamas. Journal of Sedimentary Petrology, v. 43, p. 812-821.

Baranoski, M.T., 1989, Another opinion about the origin of the Cambridge Arch of southeastern Ohio (abs.). Ohio Geological Society, November, 1989 Geogram.

Bates, R.L., and Jackson, J.A., eds., 1987, Glossary of Geology, 3rd ed. American Geological Institute, Alexamdria, VA, 788 p.

Bathurst, R.G., 1975, Carbonate Sediments and Their Diagenesis, 2d ed. Elsevier Scientific Publishing Co., Amsterdam, Developments in Sedimentology 12, 658 p.

Berkheiser, S. W., 1986, Union Furnace Ordovician carbonates: Past, present, and future, *in* Sevon, W. D., ed., Selected geology of Bedford and Huntingdon Counties. Guidebook, 51st Annual Field Conference of Pennsylvania Geologists, Huntingdon, PA, p. 7-11.

Berkheiser, S. W., and Cullen-Lollis, J., 1986, Stop 1. Union Furnace section: Stratigraphy and sedimentology, *in* Sevon, W. D., ed., Selected geology of Bedford and Huntingdon Counties. Guidebook, 51st Annual Field Conference of Pennsylvania Geologists, Huntingdon, PA, p. 111-119.

Borer, J.M., and Harris, P.M., 1991, Depositional facies and model for mixed siliciclastics and carbonates of the Yates Formation, Permian Basin, *in* Lomando, A.J., and Harris, P.M., eds, Mixed carbonate-sliliciclastic sequences. SEPM Core Workshop 15, Dallas, TX, April 7, 1991, p. 1-134.

Butts, C., 1918, Geologic section of Blair and Huntington Counties, central counties, central Pennsylvania. American Journal of Science, 4th ser., v. 46, p. 523-537.

Butts, C., 1945, Hollidaysburg-Huntington, Pennsylvania. U.S. Geological Survey Folio 227, 20 p.

Butts, C., and Moore, E.S., 1936, Geology and mineral resources of the Bellefonte quadrangle, Pennsylvania. U.S. Geological Survey Bulletin 855, 111 p.

Butts, C., Swartz, F.M., and Willard, B., 1939, Tyrone quadrangle: Geology and mineral resources. Pennsylvania Geological Survey, 4th ser., Atlas 96, 118 p.

Canich, M.R., and Gold, D.P., 1985, Structural features in the Tyrone-Mt. Union lineament, across the Nittany Anticlinorium in central Pennsylvania, in Gold, D.P., and others, Central Pennsylvania Revisited. Guidebook, 50th Annual Field Conference of Pennsylvania Geologists, State College, PA, p. 120-137.

Chavetz, H.S., 1969, Carbonates of the Lower and Middle Ordovician in central Pennsylvania. Pennsylvania Geological Survey, 4th ser., General Geology Report 58, 39 p.

Cullen-Lollis, J., and Huff, W.D., 1987, Correlation of Champlainian (Middle Ordovician) K-bentonite beds in central Pennsylvania based on chemical fingerprinting. Journal of Geology, v. 94, p. 865-874.

Demicco, R.V., 1985, Patterns of platform and off-platform carbonates of the Upper Cambrian of western Maryland. Sedimentology, v. 32, p. 1-22.

Dickinson, W.R., Beard, L.S., Brakenridge, G. R., Erjavec, J.L, Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindberg, F.A., and Ryberg, P.T., 1983, Provenance of North American Phanerozoic sandstones in relation to tectonic setting. Geological Society of America Bulletin, v. 94, p. 222-235.

Donaldson, A.C., 1959, Stratigraphy of Lower Ordovician Stonehenge and Larke formations in central Pennsylvania. Unpublished Ph.D. thesis, Pennsylvania State University.

Enterline, D.S., 1991, Depositional environments of the Cambro-Ordovician Upper Sandy formation in N.E. Ohio and equivalent, Gatesburg Formation in N.W. Pennsylvania. Unpublished M.S. thesis, University of Akron, 163 p.

Faill, R.T., 1986, Stop 1. Union Furnace section. Structure, *in* Sevon, W.D., ed., Selected geology of Bedford and Huntingdon counties. Guidebook, 51st Annual Field Conference of Pennsylvania Geologists, Huntingdon, PA, p. 119-126.

Faill, R.T., 1987, The Birmingham window; Alleghanian decollement tectonics in the Cambrian-Ordovician succession of the Appalachian Valley and Ridge Province, Birmingham, Pennsylvania, *in* Roy, D.C., ed., Northeastern Section of the Geological Society of America. Geological Society of America Centennial Field Guide, v. 5, p. 37-42.

Faill, R.T., Glover, A.D., and Way, J.H., 1989, Geology and mineral resources of the Altoona 15-minute quadrangle, Blair, Cambria, Centre, and Clearfield counties, Pennsylvania. Pennsylvania Geological Survey, 4th ser., Atlas 86, 209 p.

Folk, R.L., and Pittman, J.S., 1971, Length-slow chelcedony: A new testament for vanished evaporites. Journal of Sedimentary Petrology, v. 41, p. 1045-1058.

Frost, D., 1963, Stop IV, *in* Cate, A., ed., Tectonics and Cambrian-Ordovician stratigraphy, central Appalachians of Pennsylvania. Guidebook, 1963 Field Conference of the Pittsburgh Geological Society, p. 57-58.

Ginsburg, R.N., 1982, Actualistic depositional models for the Great American Bank (Cambro-Ordovician) (abs.). International Association of Sedimentologists, 11th International Congress on Sedimentology, Abstracts, Hamilton, Ontario, p. 114.

Gold, D.P., and Canich, M.R., 1986, The anatomy of the Tyrone-Mount Union lineament, central Pennsylvania (abs.). Proceedings, Fifth International Conference on Basement Tectonics, Cairo, Egypt, October , 1983, p. 301-302.

Gold, D.P., Guber, A.L., Voight, B., Pohn, H., and Canich, M.R., 1986, Field trip #4: Field guide - Cross-strike and strike-parallel deformation zones in central Pennsylvania, *in* Gold, D. P. and others, Central Pennsylvania revisited. Guidebook, 50th Annual Field Conference of Pennsylvania Geologists, State College, PA, p. 165-203.

Gold, D.P., Parizek, R. R., and Alexander, S.S., 1973, Analysis and application of ERTS-1 data for regional geological mapping, *in* Symposium on Significant

Results Obtained from the Earth Resources Technology Satellite-1. National Aeronautics and Space Administration, Special Publication 327, p. 231-246.

Hardie, L.A., 1986, Ancient carbonate tidal-flat deposits, in Hardie, L.A., and Shinn, E.A., Carbonate Depositional Environments, Modern and Ancient, Part 3: Tidal Flats. Colorado School of Mines Quarterly, v. 81, no. 1, p. 37-57.

Hardie, L.A., 1989, Cyclic platform carbonates in the Cambro-Ordovician of the Central Appalachians, *in* Walker, K.R., and others, Sedimentation and stratigraphy of carbonate rock sequences. Cambro-Ordovician carbonate banks and siliciclastic basins of the United States Appalachians. Guidebook for Field Trip T161, 28th International Geological Congress, Volume 1, Washington D.C., p.51-78.

Harper, J.A., 1989, Effects of recurrent tectonic patterns on the occurrence and development of oil and gas resources in western Pennsylvania. Northeastern Geology, v. 11, p. 225- 245.

Harper, J.A., and Laughrey, C.D., 1987, Geology of the oil and gas fields of southwestern Pennsylvania. Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 87, 166 p.

Haynes, J.T., 1994, The Ordovician Deicke and Millbrig K-bentonite beds of the Cincinnati Arch and the southern Valley and Ridge Province. Geological Society of America Special Paper 290, 80 p.

Hine, A.C., 1977, Lily Bank, Bahamas: History of an active oolite sand shoal. Journal of Sedimentary Petrology, v. 47, p. 1554-1582.

Huff, W.D., Bergstrom, S.M., and Kolata, D.R., 1992, Gigantic Ordovician volcanic ash fall in North America and Europe: Biological, tectonomagmatic, and event-stratigraphic significance. Geology, v. 20, p. 875-878.

Johnson, H.D., 1978, Shallow siliclastic seas, in Reading, H.G., ed., Sedimentary Environments and Facies. Elsevier, New York, p. 207-258.

Kay, G. M., 1944a, Middle Ordovician of central Pennsylvania. Journal of Geology, v. 52, p. 1-23.

Kay, G. M., 1944b, Middle Ordovician of central Pennsylvania: Part II. Later Mohawkian (Trenton) formations. Journal of Geology, v. 52, p. 97-116.

Klein, G.de V., 1977, Clastic Tidal Facies. Continuing Education Publishing Co., Inc., Champaign, IL, 149 p.

Knowles, R.R., 1966, Geology of a portion of the Everett 15-minute quadrangle, Bedford County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Progress Report 170, 90 p.

Kowalik, W.S., and Gold, D.P., 1976, The use of LANDSAT-1 imagery in mapping lineaments in Pennsylvania. Proceedings, First International Conference on the New Basement Tectonics, Utah Geological Association Publication 5, p. 236-249.

Krynine, P.D., 1946, From the Cambrian to the Silurian near State College and Tyrone. 12th Annual Field Conference of Pennsylvania Geologists, State College, PA, 32 p.

Lavin, P.M., Chaffin, D.L., and Davis, W.F., 1982, Major lineaments and the Lake Erie-Maryland crustal block. Tectonics, v. 1, p. 431-440.

Lees, J.A., 1967, Stratigraphy of the Lower Ordovician Axemann Limestone in central Pennsylvania. Pennsylvania Geological Survey, 4th ser., General Geology Report 52, 79 p.

Logan, B.W., Rezak, R., and Ginsburg, R.N., 1964, Classification and significance of algal stromatolites. Journal Geology, V. 72, p. 1-83.

Lomando, A.J., and Harris, P.M, 1991, Preface, in Lomando, A.J., and Harris, P.M., eds, Mixed carbonate-siliciclastic sequences. SEPM Core Workshop 15, Dallas, TX, April 7, 1991, 569 p.

Lytle, W.S., Heyman, L., Kelley, D.R., and Wagner, W.R., 1971, Future Petroleum potential of western and central Pennsylvania, in Cram, I.H., ed., Future petroleum provinces of the United States - their geology and potential. American Association of Petroleum Geologists Memoir 15, v. 2, p. 1232-1242.

Miller, B.L., 1924, Lead and zinc ores of Pennsylvania. Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 5, 91 p.

Moebs, N.N., and Hoy, R.B., 1959, Thrust faulting in Sinking Valley, Blair and Huntingdon counties, Pennsylvania. Geological Society of America Bulletin, v. 70, p. 1079-1088.

Mussman, W.J., and Read, J.F., 1986, Sedimentology and development of a passive- to convergent-margin unconformity: Middle Ordovician Knox unconformity, Virginia Appalachians. Geological Society of America Bulletin, v. 97, p. 282-295.

Osleger, D., and Read, J.F., 1991, Relation of eustasy to stacking patterns of meter-scale carbonate cycles, Late Cambrian, U.S.A. Journal of Sedimentary Petrology, v. 61, p. 1225-1252.

Pelto, C.R., 1942, Petrology of the Gatesburg Formation of central Pennsylvania. Unpublished M.S. thesis, Pennsylvania State University, 60 p.

Piotrowski, R.G., 1981, Geology and natural gas production of the Lower Silurian Medina Group and equivalent rock units in Pennsylvania. Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 82, 21 p.

Read, J.F., 1989, Controls on evolution of Cambrian-Ordovician passive margin passive margin, U.S. Appalachians, in Crevello, P.D., and others, eds., Controls on carbonate platform and basin development. Society of Economic Paleontologists and Mineralogists Special Publication 44, p. 147-165.

Reinech, H.E., and Wunderlich, F., 1968, Classification and origin of flaser and lenticular bedding. Sedimentology, v. 11, p. 99-104.

Riley, R.A., Harper, J.A., Baranoski, M.T., Laughrey, C.D., and Carlton, R.W., 1993, Measuring and predicting reservoir heterogeneity in complex deposystems: The Late Cambrian Rose Run sandstone of eastern Ohio and western Pennsylvania. Appalachian Oil and Natural Gas Research Consortium, West Virginia University, Morgantown, WV, 257 p.

Rodgers, M.R., and Anderson, T.H., 1984, Tyrone-Mt. Union cross-strike lineament of Pennsylvania: A major Paleozoic basement fracture and uplift boundary. American Association of Petroleum Geologists Bulletin, v. 68, p. 92-105.

Rones, M., 1969, A lithostratigraphic, petrographic and chemical investigation of the lower Middle Ordovician carbonate rocks in central Pennsylvania. Pennsylvania Geological Survey, 4th ser., General Geology Reporet 53, 224 p.

Root, S.I., 1964, Cyclicity of the Conococheague Formation. Pennsylvania Academy of Science Proceedings, v. 38, p. 157-160.

Ryder, R.T., Harris, A.G., and Repetski, J.E., 1992, Stratigraphic framework of Cambrian and Ordovician rocks in central Appalachian basin from Medina County, Ohio - through southwestern and south-central Pennsylvania - to Hampshire County, West Virginia. U.S. Geological Survey Bulletin 1839-K, 32 p.

Scotese, C.R., and McKerrow, W.S., 1991, Ordovician plate tectonic reconstructions, in Barnes, C.R.,and Williams, S.H., eds., Advances in Ordovician Geology. Geological Survey of Canada, Paper 90-9, p. 271-282.

Shinn, E.A., 1980, (talk summary by Horowitz, D.H., 1981), *in* Byers, C.W., and Dott, R.H., SEPM Research Conference on modern shelf and ancient cratonic sedimentation - the orthoquartzite-carbonate suite revisited. Journal of Sedimentary Petrology, v. 51, p. 329-397.

Shinn, E.A., 1983, Tidal flat environment, *in* Scholle, P.A. and others, eds, Carbonate epositional environments. American Association of Petroleum Geologists Memoir 33 p. 171-211.

Smith, R.C., 1977, Zinc and lead occurrences in Pennsylvania. Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 72, 318 p.

Smith, R.E., 1969, Petrography-porosity relations in carbonate-quartz system, Gatesburg Formation (Late Cambrian), Pennsylvania. American Association of Petroleum Geologists Bulletin, v. 57, p. 261-278.

Spelman, A.R., 1966, Stratigraphy of Lower Ordovician Nittany Dolomite in central Pennsylvania. Pennsylvania Geological Survey, 4th ser., General Geology Report 47, 186 p.

Thomas, W.A., 1977, Evolution of the Appalachian-Ouachita salients and recesses from reentrants and promentories in the continental margin. American Journal of Science, v. 277, p. 1233-1278.

Thompson, A.M., 1970, Lithofacies and formation nomenclature in Upper Ordovician stratigraphy, central Appalachians. Geological Society of America Bulletin, v. 81, p. 1255-1260.

Thompson, A.M., 1986, Stratigraphy of Upper Ordovician clastic rocks in south-central Pennsylvania, *in* Sevon, W. D., ed., Selected geology of Bedford and Huntingdon Counties. Guidebook, 51st Annual Field Conference of Pennsylvania Geologists, Huntingdon, PA, p. 21-26.

Thompson, A.M., and Sevon, W.D., 1982, Excursion 19B: Comparative sedimentology of Paleozoic clastic wedges in the central Appalachians. International Association of Sedimentologists, Field Excursion Guide Book, Eleventh International Congress on Sedimentology, Hamilton, Ontario, 136 p.

Thompson, R.R., 1963, Lithostratigraphy of the Middle Ordovician Salona and Coburn formations in central Pennsylvania. Pennsylvania Geological Survey, 4th ser., General Geology Report 38, 154 p.

Tucker, M.E., 1981, Sedimentary Petrology: An Introduction. Halstead Press, New York, 252 p.

Wagner, W.R., 1963, Cambro-Ordovician stratigraphy of central and south-central Pennsylvania, *in* Cate, A.S., ed., Tectonics and Cambrian-Ordovician stratigraphy, central Appalachians of Pennsylvania. Pittsburgh Geological Society and Appalachian Geological Society, Field Trip Guidebook, p. 3-11.

Wagner, W.R., 1966, Stratigraphy of the Cambrian to Middle Ordovician rocks of central and western Pennsylvania. Pennsylvania Geological Survey, 4th ser., General Geology Report 49, 156 p.

Wheeler, R.L., 1980, Cross-strike structural discontinuities: Possible exploration tool for natural gas in Appalachian overthrust belt. American Association of Petroleum Geologists Bulletin, v. 64, p. 2166-2178.

Wilde, P., 1991, Oceanography in the Ordovician, *in* Barnes, C. R., and Williams, S.H., eds., Advances in Ordovician geology. Geological Survey of Canada, Paper 90-9, p. 283-298.

Wilson, J.L., 1952, Upper Cambrian stratigraphy in the central Appalachians. Geological Society of America Bulletin, v. 63, p. 275-322.

Wilson, J.L., 1983, Middle shelf environment, *in* Scholle, P.A. and others, eds, Carbonate epositional environments. American Association of Petroleum Geologists Memoir 33 p. 297-345.

Woodward, H.P., 1964, Central Appalachian tectonics and the deep basin. American Association of Petroleum Geologists Bulletin, v. 48, p. 338-356.

# Field Guide to the Birmingham Window and the Union Furnace Quarry, Huntingdon County, Pennsylvania

Prepared for
**The Pittsburgh Geological Society**

By
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May 4, 1996

# APPENDIX 2
# THE BIRMINGHAM WINDOW
by
David P. Gold

The Birmingham "thrust" zone is composed of a number of planar and lensoid fault planes in both the hanging wall (Cambrian dolomites and sandstones of the Gatesburg Formation) and footwall strata (Middle and Upper Ordovician limestones and shales and Lower Silurian sandstones) at these localities. A discrete thrust plane is well exposed in the abandoned quarry, 250 feet east of the turn-off to Birmingham, where massive beds of Gatesburg dolomites overlie black carbonaceous shales of the Antes Member of the Reedsville Formation (Figure 2 , stations 4 and 5), and in the railroad cut at Stop # 3, where cherty dolomites and calcareous sandstones of the Gatesburg Formation overlie middle Ordovician limestones (Figure 5, station # 11).

The simple anticlinal form shown in Figure 6b (section CC') of the southern end of Sinking Valley is complicated here by faults, some of which are inferred from drill cores. An interpretation of these by Moebs and Hoy (1959) is reproduced here in Figure 6b. The Sinking Valley fault and its splays are arched over an axis plunging southwest, which is nearly coincident with the axis of the Sinking Valley Anticline. Although the northwest limb is displaced approximately 2 miles, the surface expression of the fault is limited to the two windows (W on Figure 4) near Birmingham, where Ordovician and Silurian rocks are exposed beneath Cambrian dolomites and sandstones. The Sinking Valley Fault (see cross-sections A-A', B-B', in Figure 6b) dips northwestward from the "windows" at Birmingham under Brush Mountain, and presumably continues under the Allegheny Plateau.

The Honest Hollow and Birmingham faults are interpreted as splays off the Sinking Valley thrust fault. They dip southeast and represent the bounding faults of the Birmingham "window" slices (see cross-sections A-A', B-B', in Figure 6b). More drill holes are needed to determine the relationship of the Shoenberger Fault to the Sinking Valley fault system.

In the railroad cut at Stop # 3, numerous intraformational antithetic and synthetic thrust faults of unknown displacement, and several extensional faults of small displacement are exposed in the hanging wall rocks (Ore Hill and Sandy members of the Gatesburg Formation. A number of small (1 to 5 m) "healed" faults apparent in the wall reflect an early (possibly Acadian) deformation event. "Horst" blocks meters to tens of meters in size in the footwall exhibit a complex relationship to the main thrust fault. Although most of the larger faults are synthetic, small antithetic faults are present. Extension faults of small displacement are common: the early "healed" faults are rare.

One of the most complex structures in the footwall units is located 240 feet (about 75 m) along the railroad cut (Station # 14, in Figure 5). This structure is a totally isolated block, bounded by a folded fault. The beds within the block exhibit a nearly 180 clockwise rotation.

**Figure 5. Detailed Cross-Section of the Birmingham Fault Along the Railroad Embankment (Stop # 3).** (After D.P. Gold, 1984).

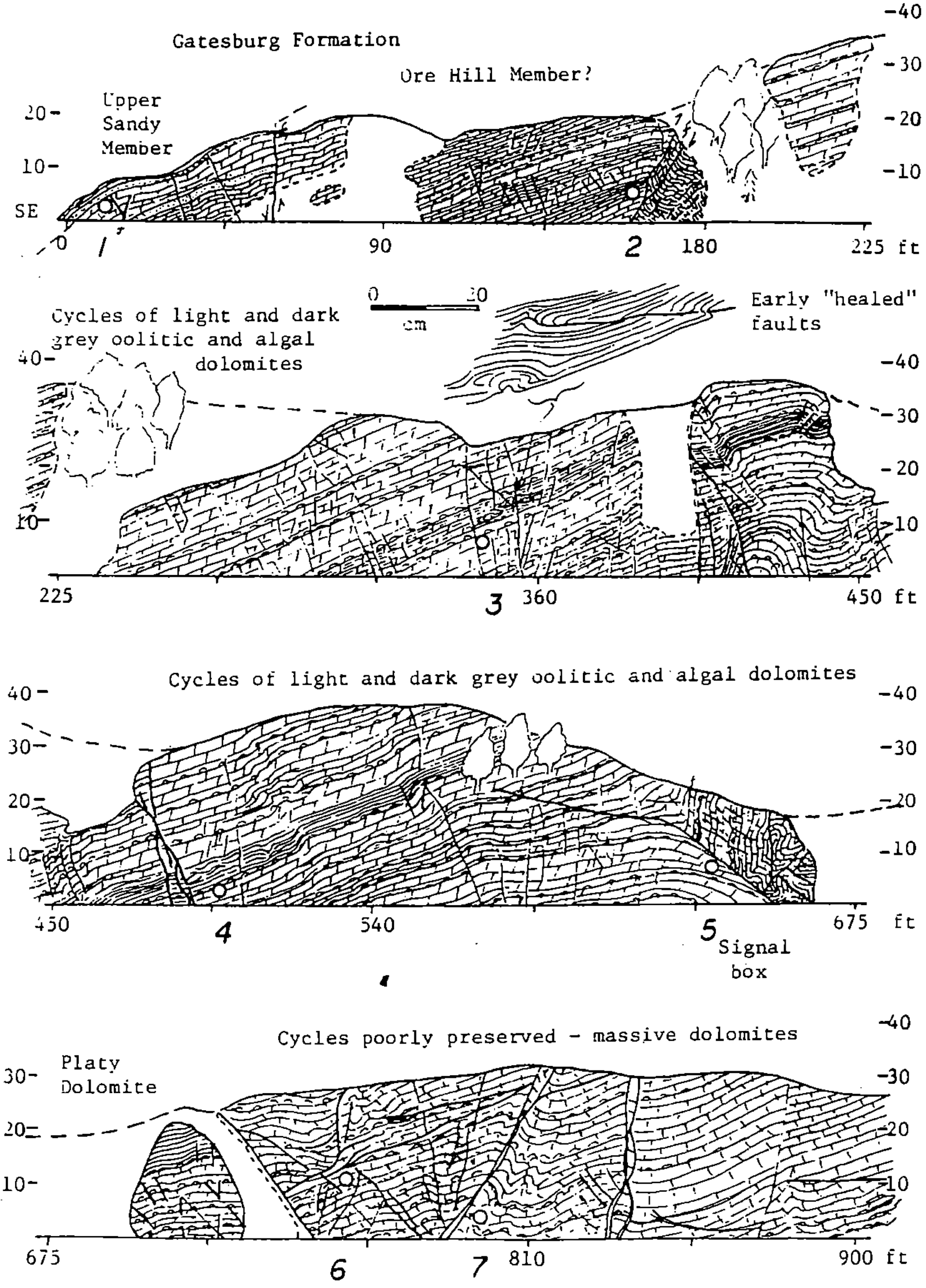
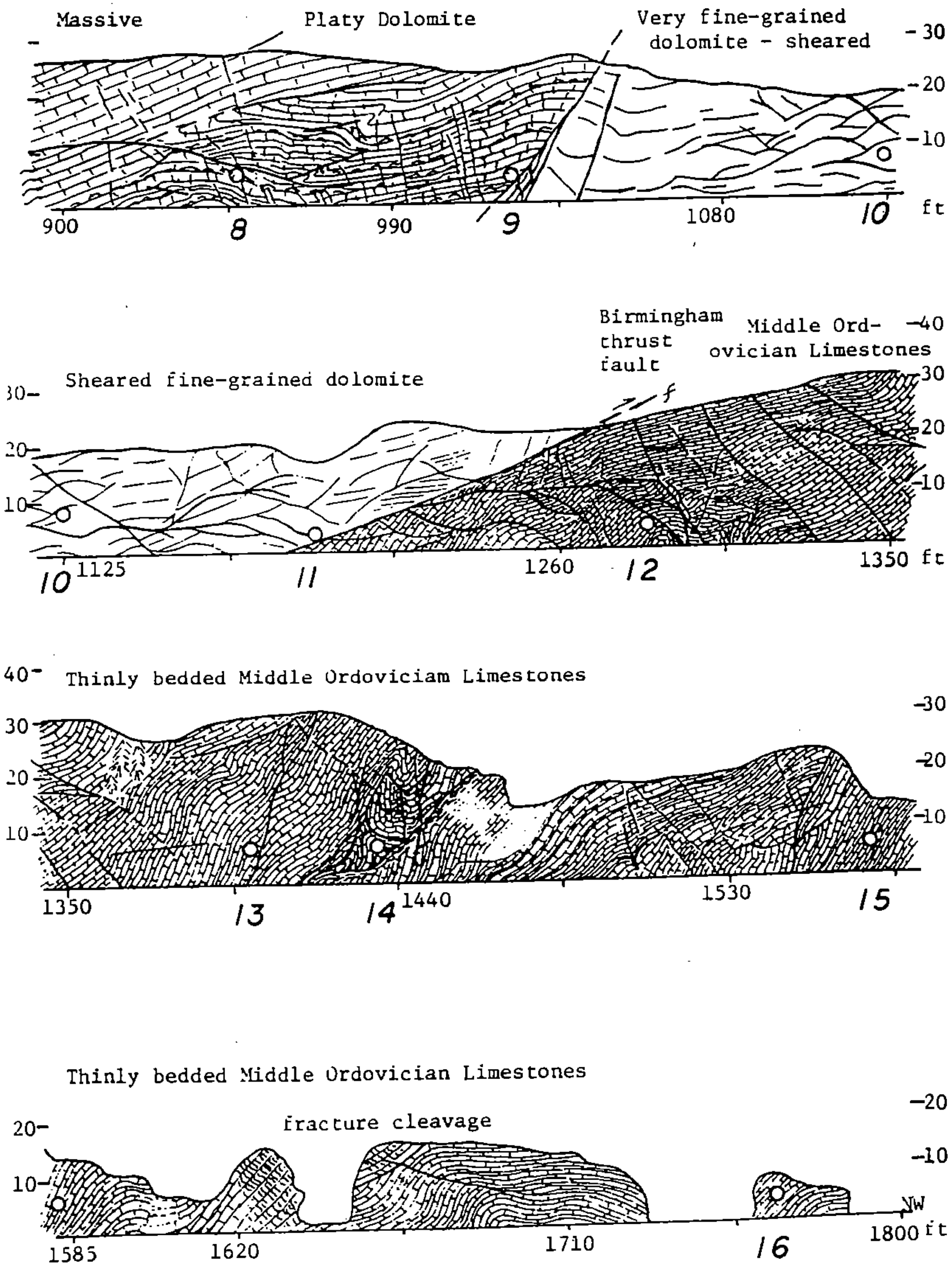


**Figure 5. (continued)**



STOP # 6. Birmingham Window (North side of lineament).

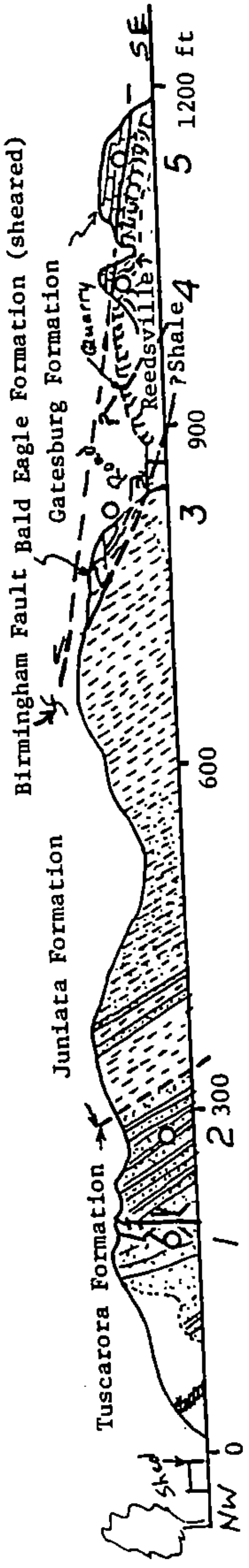


Figure 11. Schematic cross-section of the road-cut near the turn-off to Birmingham.

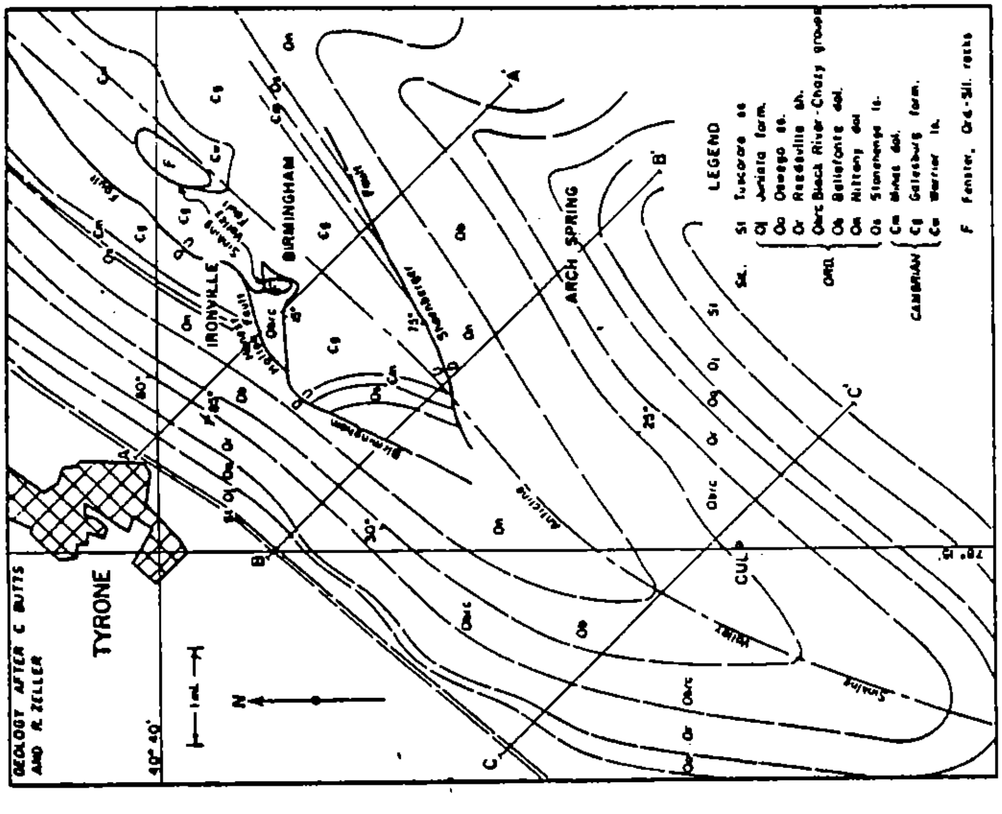


FIG 6a. Geological Map of Sinking Valley
(from Moebs and Hoy, 1959)

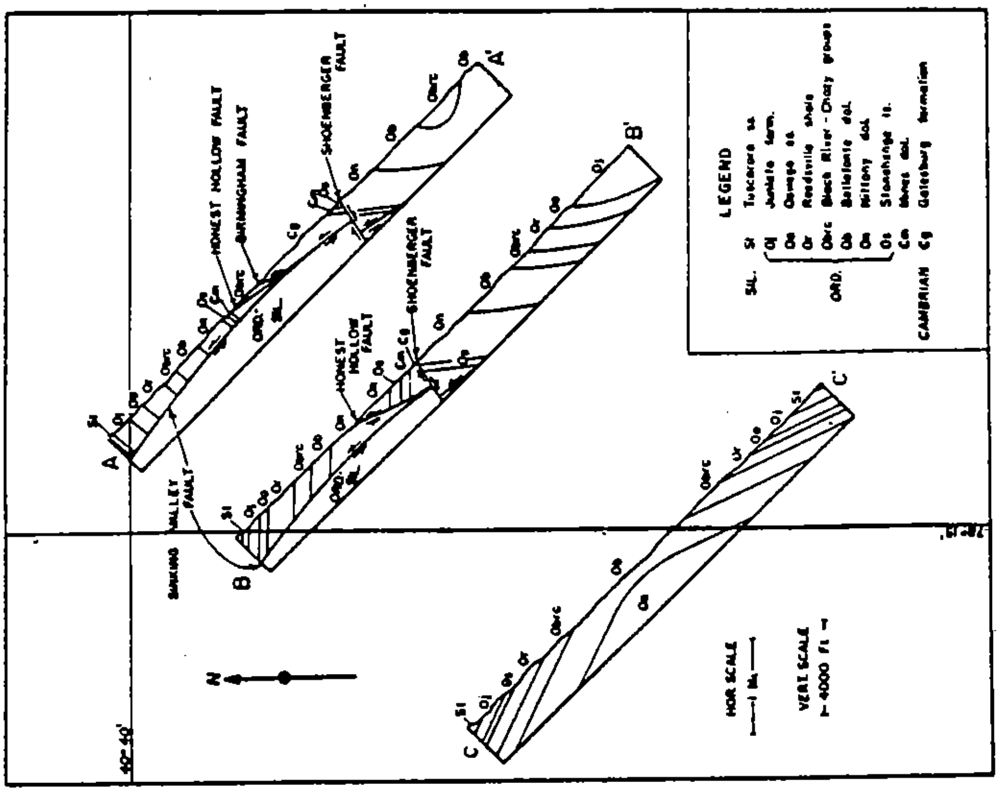


FIG 6b. Structural Cross Sections
(from Moebs and Hoy, 1959)

Figure 3. Legend for Geologic Maps of the Scotia and Birmingham areas.

| STRATIGRAPHIC UNITS | | |
|---|---|---|
| RECENT | Alluvium | Qal |
| ORDOVICIAN | Nittany Formation | On |
| | Stonehenge Formation | Os |
| CAMBRIAN | Gatesburg Formation – Mines Member | €gm |
| | Upper Sandy Member | €gus |
| | Ore Hill Member | €goh |
| | Lower Sandy Member | €gls |
| | Warrior Formation | €w |
| | Pleasant Hill Formation | €ph |
| | "Window" – Carlim Fm. to Tuscarora Fm. (Ordovician to Silurian) | W |
| | | |
| | | |
| | | |

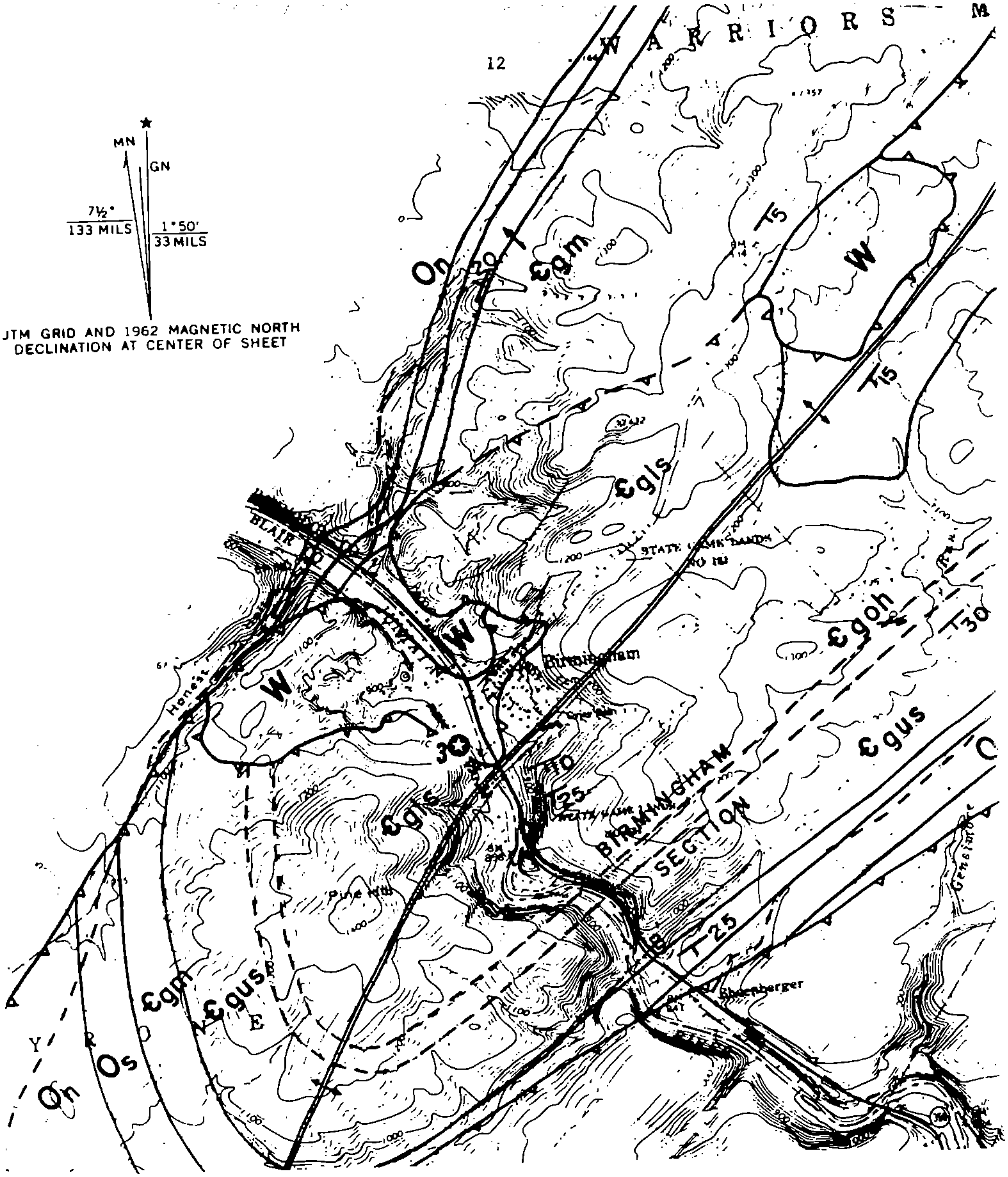


Figure 4. **Geologic Map of the Birmingham Area, with Thrust Fault and Window.** (Courtesy of Roger Pollok).

# THE UNION FURNACE QUARRY

by

Blair Tormey

## INTRODUCTION

Subdivision of the Middle Ordovician carbonate strata of central and south central Pennsylvania has challenged geologists for more than a century. The criteria for subdivision and nomenclature established by Collie (1903), have been modified and re-defined over the years, resulting in the present scheme of five formation and ten members used by Faill (1989) (figure 1). The combination of units at certain localities and splitting at others, suggests that the section represents a number of facies rather than contiguous layers (beds) of wide lateral extent and well defined contacts.

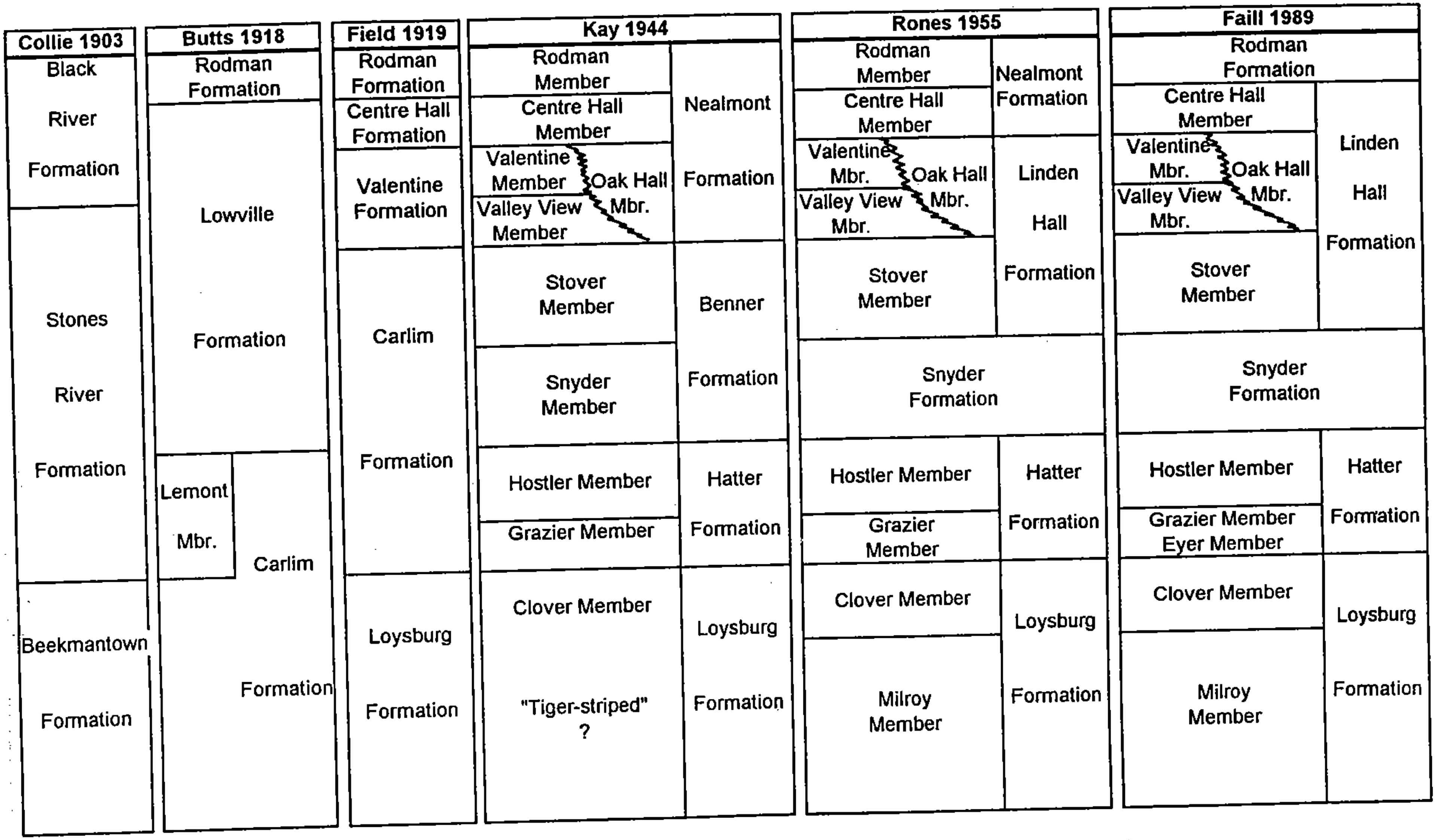
The Union Furnace Quarry is located nine miles southeast of Tyrone on Route 453 in Huntingdon County. Owned and operated by the New Enterprise Stone and Lime Company, the quarry exposes approximately 850 feet (stratigraphic) of the Middle Ordovician section. These strata can be subdivided into the Loysburg, Hatter, Snyder, Linden Hall, Rodman, and Salona formations. At least 12 bentonite layers have been found in this section and they, as well as other distinct beds, serve as marker horizons which are essential in correlating units in other locales.

The description which was conducted at Union Furnace detailed the Loysburg, Hatter, Snyder, Linden Hall and Rodman formations. The description begins in the Loysburg Formation at the lowest bed exposed in the hanging wall of the thrust fault exposed in the highwall. The thrust fault is responsible for the thickening of the unit at this locality due to the stratigraphic repetition across the fault plane. The datum for horizontal measurement is set at the base of the Hatter Formation.

## LOYSBURG FORMATION

The Loysburg Formation is the oldest unit studied in the section at Union Furnace. The lowermost Milroy Member with its characteristic "tiger-striped" lithologies is not exposed at Union Furnace Quarry. The Clover Member consists mainly of medium to dark-gray lime mudstone and wackestone interbedded with light-gray dolomite mudstone and wackestone. Beds range in thickness from several inches to two feet. Crypt-algal laminations can be found, and bedding parallel styolites are common throughout the unit. The upper 20 feet of the Clover Member consists of laminated dark-gray lime mudstone in beds one to two feet thick. A possible bentonite layer occurs at the top of the Clover Member. It is approximately four inches thick and marks the datum line for the measured section, as well as the base of the Hatter Formation.

The Loysburg Formation is thicker than usual at Union Furnace due to the stratigraphic repetition induced by the thrust fault. An overall thickness is not available as the lower contact with the Bellefonte Formation is not exposed in the highwall. The upper contact is well defined by the suspected bentonite layer at the base of the overlying Hatter Formation.


Collie 1903
Black River Formation
Stones River Formation
Beekmantown Formation
Butts 1918
Rodman Formation
Lowville Formation
Lemont Mbr.
Carlim Formation
Field 1919
Rodman Formation
Centre Hall Formation
Valentine Formation
Carlim Formation
Loysburg Formation
Kay 1944
Rodman Member
Centre Hall Member
Valentine Member
Oak Hall Mbr.
Valley View Member
Nealmont Formation
Stover Member
Snyder Member
Benner Formation
Hostler Member
Grazier Member
Hatter Formation
Clover Member
"Tiger-striped" ?
Loysburg Formation
Rones 1955
Rodman Member
Centre Hall Member
Nealmont Formation
Valentine Mbr.
Oak Hall Mbr.
Valley View Mbr.
Stover Member
Linden Hall Formation
Snyder Formation
Hostler Member
Grazier Member
Hatter Formation
Clover Member
Milroy Member
Loysburg Formation
Faill 1989
Rodman Formation
Centre Hall Member
Valentine Mbr.
Oak Hall Mbr.
Valley View Mbr.
Stover Member
Linden Hall Formation
Snyder Formation
Hostler Member
Grazier Member
Eyer Member
Hatter Formation
Clover Member
Milroy Member
Loysburg Formation

## HATTER FORMATION

The lower eight feet of Hatter Formation is comprised of medium-gray lime wackestone which is designated as the Eyer Member. It is separated by a large styolite from the overlying Grazier Member which comprises the lower half of the Hatter Formation at Union Furnace (approximately sixty feet) and consists of the fining upward medium to dark-gray lime wackestone and mudstone. The Grazier Member also displays a fucoidal texture in places, especially where weathered. The term fucoidal refers to the wormy appearance of the strata due to differential weathering of the rock because of worm burrows which filled with coarser sediment prior to lithification. A possible bentonite layer can be found in this member roughly fifty feet above the base of the Hatter.

The upper Hostler Member of the Hatter Formation is gradational between the Grazier Member below and the overlying Snyder Formation. The Hostler Member is approximately seventy-five feet thick, and is comprised of cycles of medium to dark-gray lime mudstone and light-gray lime wackestone with dense fucoidal structures. Shell hashes of randomly emplaced brachiopods are found within six feet of the base of the member. Beds in both members range from six inches to several feet in thickness.

The lower contact of the Hatter formation is taken at the bentonite layer at the top of the Loysburg Formation. The upper contact of the Hatter Formation is somewhat gradational with the overlying Snyder Formation and is accurate in Union Furnace to four or five feet. Faill (1989) places the boundary at the base of the first oolite bed in the Snyder Formation, however the oolite cannot be recognized in unweathered exposures. The Hatter Formation is approximately 135 feet thick at Union Furnace.

## SNYDER FORMATION

The Snyder Formation comprises a range of limestone types. The lower five feet is a massive bed of medium to dark-gray lime mudstone with faint laminations. The next unit is another five foot thick bed of light-gray, fine-grained lime wackestone. The middle of the Snyder Formation is characterized by forty five feet of massive beds of medium to dark-gray lime wackestone which cyclically fines upward into mudstone. Shale partings are common at the tops of these sequences, and laminations are prevalent throughout. The upper portion of the formation is comprised of medium-gray lime wackestone with fossil hash layers, conglomerate beds, and rip-up layers with little visible laminations. Two possible bentonite layers occur within six feet of each other in the formation, ten feet below the Linden Hall contact.

The basal contact of the Snyder Formation is taken at the oolite beds by most workers, however in this study, due to fresh surfaces, the lower contact was placed less accurately. The upper contact of the Snyder Formation at Union Furnace was defined at the top of the conglomeratic units and at the beginning of the fucoidal beds of the Stover Member of the Linden Hall Formation. The overall thickness of the Snyder strata at Union Furnace is approximately eighty feet.

## LINDEN HALL FORMATION

The Linden Hall Formation at Union Furnace can be divided into the Stover, Oak Hall, and Centre Hall members. The basal Stover Member is comprised of dark-gray, fine, lime wackestone in beds of one to three feet in thickness. This sixty foot thick member displays the most readily visible and dense fucoids in the section at Union Furnace, and is the primary characteristic used to identify the Linden Hall Formation. Fossil hashes of brachiopods and rip-up clast layers can be found throuhout the member.

The medial Oak Hall Member is comprised of approximately fifteen feet of dark-gray lime mudstone and fine wackestone in beds ranging from one to four feet in thickness. Fucoids are common in the unit, however not as dense as the underlying Stover Member. Burrow casts can be found on the bottom of certain beds. The Oak Hall Member is separated from the Stover Member below by a possible bentonite layer.

The sixty foot thick Centre Hall Member of the Linden Hall Formation consists of medium to dark-gray lime wackestone which also has fucoidal structure, but a not as dense as in the Stover Member. Beds in this unit are slightly thinner, ranging from six inches to 2 feet in thickness. Possible bentonite layers are most densely concentrated in this member of the Linden Hall Formation, with a total of five, three of which are in the upper ten feet of the formation.

The lower contact of the Linden Hall Formation is taken at the beginning of the dense fucoidal sequence of the Stover Member and the top of the conglomerate beds of the Snyder Formation below. The upper contact with the Rodman Formation is sharply defined at the last of the series of three bentonites in the upper ten feet of the formation. Overall, the Linden Hall Formation is approximately 135 feet thick at Union Furnace.

## RODMAN FORMATION

The Rodman Formation is the youngest formation described at Union Furnace. It is characterized by one to three foot thick beds of very dark-gray to black lime mudstone with no fucoidal structures and faint laminations. Shale interbeds are common, and several beds display a concoidal fracture due to the fine size of the grains. Bentonite layers are exposed in throughout the unit, however, they were not described due to the steepness of the slope at this exposure. Berkheiser and Cullin-Lollis (1986) describes four bentonite layers exposed in the Rodman Formation along State Route 453 less than a quarter of a mile to the southwest of the quarry. He also describes the Rodman Formation as being bounded both above and below by bentonite layers (Berkheiser and Cullin-Lollis, 1986).

The lower contact for the Rodman Formation at Union Furnace is taken at the third bentonite layer in the upper ten feet of the Linden Hall Formation. A transition from medium-gray wackestone in the upper Linden Hall Formation to darker mudstone lithologies in the Rodman Formation helps to define the contact. The upper contact of the Rodman Formation with the Salona Formation is not defined in this study due to lack of exposure. However, as mentioned previously, Berkheiser and Cullin-Lollis (1986) defines

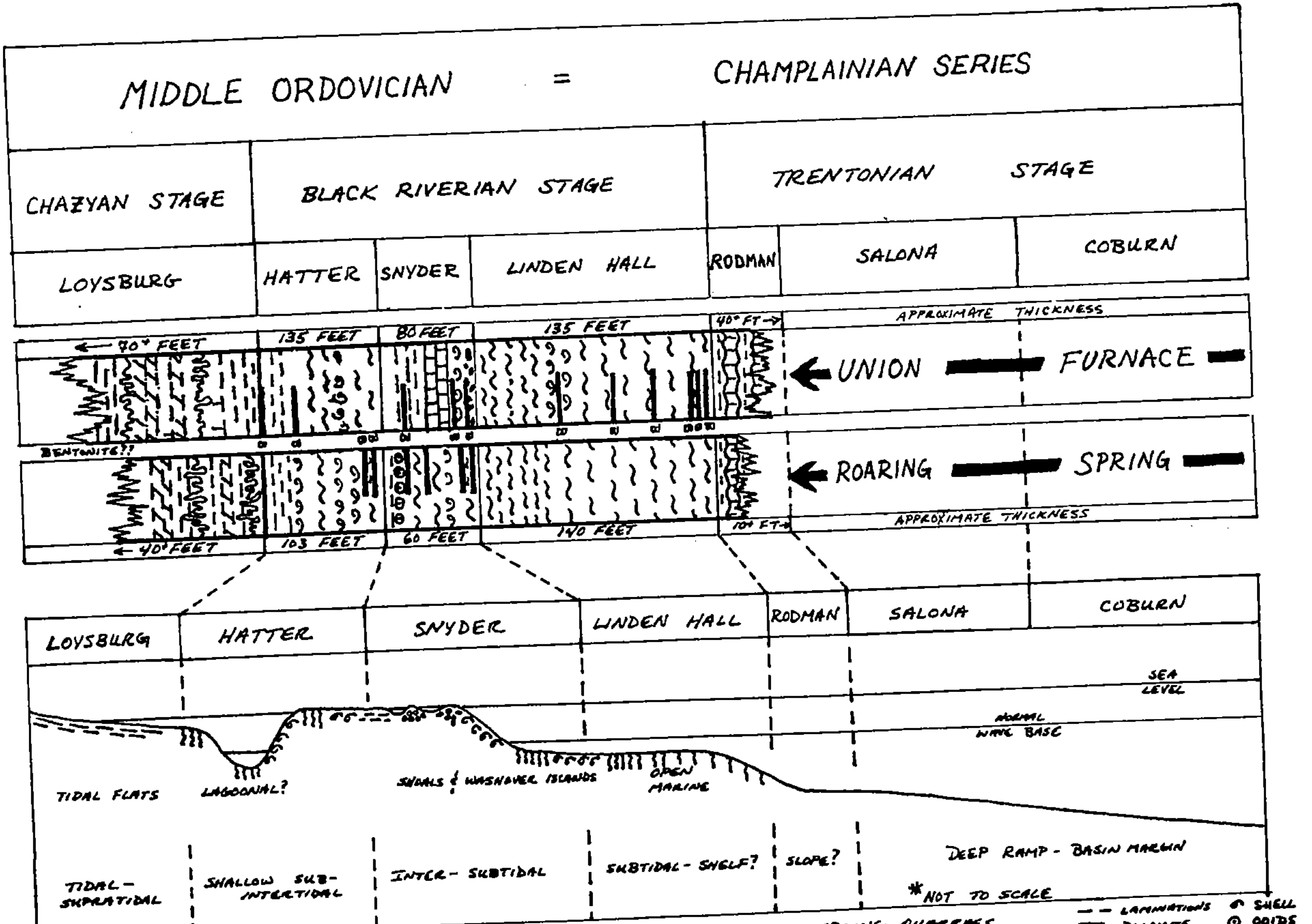


FIGURE 2: PALEO-ENVIRONMENT BASED ON UNION FURNACE AND ROARING SPRING QUARRIES.
(DEPOSITIONAL ENVIRONMENT SKETCH (AFTER BERKHEISER AND CULLIN-LOLLIS, 1986)
COLUMNS FROM TORMEY, 1996.)

the upper contact at a bentonite layer (specifically B11) exposed along State Route 453 near the quarry.

## CHEMICAL ANALYSIS AND ECONOMIC POTENTIAL

Carbonate rocks are quarried at the New Enterprise operations at both the Union Furnace and Roaring Spring Quarries for use as an aggregate and/or co-generation limestone. If the calcium carbonate content exceeds 85%, and the silica and insoluble residue content is relatively low, the rock qualifies as feed-stock for co-generation plants (Van Horn, pers. comm.). The Pennsylvania Department of Transportation rates coarse aggregate based on its skid resistance level (SRL), with designations, from best to worst, of E, H, G, M, and L (Berkheiser and Cullin-Lollis, 1986). All of the carbonate units studied qualify for this type of usage.

The formations which were deposited in the supratidal and intertidal zones are found to be less chemically pure and better suited for aggregate production. The Loysburg Formation according to Berkheiser and Cullin-Lollis (1986) on average contains approximately 79% $CaCO_3$, 11% $MgCO_3$, and 5% insoluble residue, and has a SRL rating of L. The Hatter Formation is on average comprised of 81% $CaCO_3$, 5% $MgCO_3$, and 12% insolubles with a SRL rating of L (Berkheiser and Cullin-Lollis, 1986). However it should be noted that the silica content is found to be considerably lower elsewhere in central Pennsylvania where the limestone more pure (Rones, 1955). The Snyder Formation on average consists of 84% $CaCO_3$, 7% $MgCO_3$, and 6% insoluble residue with a SRL rating of L (Berkheiser and Cullin-Lollis, 1986). This is largely the result of the multiple depositonal environments. However, the upper portion of the formation is more chemically pure due to deposition in deeper water environments (Rones, 1955), and has potential in co-generation uses. The Rodman Formation is comprised of 85% CaCO3, 2.9% MgCO3, and 8.1% insoluble residue with a SRL of L (Berkheiser and Cullin-Lollis, 1986).

The deeper water environments of the subtidal zones near the platform shelf of the Middle Ordovician have higher $CaCO_3$ purity, and thus better potential for co-generation. The only two units which meet the 85% standard are the upper beds of the Snyder Formation, and the entire Linden Hall Formation. The upper half of the Snyder Formation averages 89% CaCO3, 4% MgCO3, and 5% insolubles, and the Linden Hall Formation averages 90% CaCO3, 2.8% MgCO3, and 4% insoluble residues (Berkheiser and Cullin-Lollis, 1986). The Oak Hall Member of the Linden Hall Formation is laterally equivalent with the pure Valentine and Valley View members, which are recognized for their great economic value (Kay, 1944). However, the lower grade limestone of the upper Snyder and Linden Hall formations at Union Furnace and Roaring Spring have potential as a source for co-generation use and/or aggregate.

The formations deposited off of the shelf as peri-platform oozes tend to be less useful to the quarry operations due to the abundance of calcareous shale (Gold, pers. comm.). These facies include the Trentonian Stage strata of the Salona and Coburn formations. Generally these units are not mined by New Enterprise due to the low profitability (Van Horn, pers. comm.).

## LITERATURE REFERENCED AND CITED

Berkheiser and Cullin-Lollis (1986), Field Trip Guidebook, Pennsylvania Conference of Field Geologists.

Collie, G.L. (1903), *Ordovician Section Near Bellefonte, Pennsylvania,* Geological Society of America Bulletin, v. 14, p. 407-420.

Faill, R.T., Glover, A.D., and Way, F.H. (1989), *Geology and Mineral Resources of the Blanburg, Tipton, Altoona, and Bellwood Quadrangles, Blair, Cambria, Clearfield, and Centre Counties, Pennsylvania.* Pennsylvania Geological Survey, Atlas 86, 209p.

Field, R. M. (1919, *The Middle Ordovician of Central and South Central Pennsylvania,* American Journal of Science, 4th ser., v. 48, p. 403-428.

Gold, D. P. and Lowrey, T. A. (1993), Field Trip Guidebook, Friends of Mineralogy Fall 1993 Symposium, p 16-20.

Gold, D. P. (personal communications), Professor of Geosciences, Pennsylvania State University.

Kay, G.M. (1944), *Middle Ordovician of Central Pennsylvania,* Journal of Geology, v. 52, p. 1-23.

Lowrey, T.A. (1993), *Lithology, Stratigraphy, and Structure of Roaring Spring, Pennsylvania,* University Park, Pennsylvania State University, B.S. Thesis, 34p.

Rones, M. (1955), *A Litho-stratigraphic, Petrographic, and Chemical Investigation of the Lower Middle Ordovician Carbonate Rocks in Central Pennsylvania,* University Park, Pennsylvania State University, Ph.D. Thesis, 186p.

Rosenkrans, R.R. (1934), *Correlation Studies of the Central and South Central Pennsylvania Bentonite Occurrences,* American Journal of Science, 5th ser., v. 27, p. 113-134.

Tormey, B.R. (1996), *Subdivision and Correlation of Middle Ordovician Carbonates; Union Furnace and Roaring Spring Quarries, Huntingdon and Blair Counties, Pennsylvania,* University Park, Pennsylvania State University, B.S. Thesis 35p.

Van Horn, K. (personal communication), Mine Geologist, New Enterprise Stone and Lime Company.